Design Strategies for Whole Body Interactive Performance Systems

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Abstract

This practice-led research investigates a design framework within an artistic context for the implementation of Whole Body Interactive (WBI) performance systems that employ real-time motion capture technology. Following an Interaction Design perspective I engage in exploring the requirements for composers, dancers, musicians and performers and their expectations, within a series of transdisciplinary collaborative artistic projects. Integral to this investigation is a comprehensive review and analysis of the progression of interactivity in fine art, music, dance and performance practices, presented in this thesis. As I am particularly concerned with the seamless transfer of the tacit skills and the implicit knowledge of non-digital artists and practitioners to a WBI performance setting, my practical explorations emerged in the contexts of music improvisation - <i>Untitled#1</i>, contemporary dance - <i>Untitled#2</i>, contemporary music composition - <i>Hiroshima</i>, and traditional dance - <i>Duende</i>. Adopting a Holistic Design approach, the experience and knowledge gained from my first practical explorations led to the design and implementation of a WBI prototyping software environment called EnActor, used in tandem with the Orient wireless inertial motion capture system, developed by the Research Consortium in Speckled Computing, at the University of Edinburgh. EnActor provides a simple and effective solution to the problem of linking physical actions to rich digital media responses and can serve as a blueprint for the development of other WBI design software, since it has operated successfully as a prototype, addressing a wide range of WBI design briefs in various contexts. In this thesis I introduce the role of the WBI designer as a specialist interaction designer able to conceptualise WBI scenarios and implement complete systems that operate within various levels of body sensing and control. I also propose the development of WBI systems that are autonomous and unsupervised, and I explore various compositional concepts and mappings that are implemented as automatic, semi-automatic or manual modules and ultimately arranged into layers and to series of blocks that represent complete compositions. Following the understanding of interactivity as a property between systems, I identify the design of three basic types of WBI performance systems that differ in how a user engages with them: methodical, empirical and dialectic. Overall this research aims to facilitate designers and artists interested in the use of real-time motion capture systems in dance, music, theatre and performance art applications.
Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

Note: All videos that appear in chapters two and seven in this interactive version of the document belong to the original authors.

(Evangelos Lympouridis)
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1 Introduction

During the past decades, choreographers, musicians, composers and performers, in collaboration with technologists, engaged in exploring the utilisation of new digital technologies for extending traditional and contemporary artistic practices and examining new forms of expression on the performance stage. These early explorations were evolving in parallel with the advances of motion sensing technologies, and although they primarily shaped our understanding of interactivity in the performance art context, they imposed numerous unnecessary restrictions and new alienated processes on the development of such work.

In most cases this was a consequence of the interfaces that are commonly employed in interactive performances, as cameras and sensors only capture and present abstract data from the body, not the human body itself. This data is linked more to the nature of the sensing mechanism than the user’s physical body and offers limited control and occasionally chaotic responses to the intentions of the performer and the collaborating artists. As more advanced technological solutions are developed in the field of motion capture (mocap), the ability to digitally represent the whole body in time and space has improved, resulting in advancements in the design of Whole Body Interactions (WBI).

Instead of developing a new interface or an intelligent interactive software system for live performance, I propose to work with the actual digital representation of the body and ask the following questions: What is the future of interactive performances when we can precisely transcribe the physical body in its digital replica in real-time? What are the requirements of performers, musicians, choreographers and composers in this context and how can we design simple tools, to directly and creatively assist them?

The main observation that set my initial perspective for the investigation of the above questions concerns an absence, so far, of a design approach to the existing technology-based performance explorations. This has left the artists to directly try to relate their artistic concepts with various technologies without an interpreter, a specialist interaction designer, whose expertise can offer important insight and a design perspective to the development process of interactive art performances and systems. As the artistic processes are more and more occupied by algorithmic and technological interventions, non-technological practitioners are often excluded from participating in these exciting explorations. Additionally, when traditional artists attempt to transfer their skills to a digital interactive platform, their knowledge and tacit skills become isolated as they are required to operate within a new technological framework that has not been designed to meet their particular requirements.

Therefore, I began this practice-led research from an interaction design perspective with the intention to involve non-digital performance art practitioners throughout my explorations and practical work. My early design studies were in the context
of improvisation and contemporary dance and then I moved on to explore the design of WBI systems in the context of contemporary music and traditional dance. Towards the end of my practical work I have applied the design of these systems in the exploration of new hybrid forms of performance art that include notions of music composition, theatre and improvisation. With the outcomes of my research projects I aim to facilitate designers and artists interested in the use of interactive systems that employ real-time motion capture techniques in dance, music, theatre and performance art contexts.

Sound was the unifying force in all of my projects, serving as the primary feedback medium. When I first started designing WBI experiences, I developed systems by following two central metaphors: designing a virtual musician for a dancer or a virtual instrument for a musician. These two approaches differ in the amount of control the performer has over the system’s responses. Musicians expect an interactive system to provide immediate and relatively predictable sound on demand, in order to compose particular sonic experiences. In contrast, dancers are primarily focused on the body, its presence and movement dynamics in time and space, as they are traditionally dancing to the sound.

I was fortunate to employ in my practical explorations one of the most advanced wireless motion capture systems to date, developed at the Research Consortium in Speckled Computing, at the University of Edinburgh. This innovative technological motion capture solution, discussed further in Chapter two, is a promising technical innovation for tracking body movement on the performance stage with reliability, transparency and mobility. Because the novelty factor of any new technology is temporary, especially in our rapidly developing digital era, my aim throughout the discussion and presentation of this thesis is to go beyond the technical means that assisted these explorations and extract meaningful, fundamental design concepts that can be applied irrespective of the motion capture technology utilised. My objective is to demystify the underlying complexity and share the extracted findings from my endeavours with respect to the related theories and in reference to wider existing practise.

This thesis adopts a holistic approach for the investigation of WBI design and aims to lay out a theoretical and technical framework for the development of a diverse range of artistic works in the context of body-driven interactive performances. The holistic design framework as proposed by Woo (2007) describes three main phases in the design process: research, design and innovation, that are further described in the third chapter. The introduction of this model in my practical work enabled a fruitful collaborative environment for exploring the complexities of this transdisciplinary research area. It encouraged the investigation of multiple perspectives and a mutual exchange of expertise through established collaborations with fellow researchers in performance arts, choreography, music composition and informatics.

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1Three prototype versions of the Orient wireless inertial motion capture system have been developed at the University of Edinburgh between 2007-2010 by the Research Consortium in Speckled Computing. For more information please check the attached paper in the Appendix: Lympouridis et al. (2009)
During the first stage, the research phase, I worked in the context of improvisation, contemporary dance and composition. Three practical studies in the form of residencies and workshops, assisted my explorations to define the key notions for designing interactive performances and the practical requirements of choreographers, dancers, musicians and composers. These collaborative projects took place between September 2007 and September 2009 and are presented and discussed in the fourth chapter.

These first practical studies raised valuable questions and elicited knowledge that informed the design phase of my research, which took place between September 2009 and January 2010. My efforts concerned the realisation of a prototype WBI interaction design system, called EnActor, that I will extensively discuss in the fifth chapter.

Finally, the innovation phase of this research proved EnActor’s ability to assist the exploration of diverse interactive performance concepts and raised questions about the future of WBI performances. From rapid prototyping to extensive explorations in composition, these last practical studies indicated the system’s potential and usability. These key projects were developed between January 2010 to April 2010, and were linked to completely diverse performance disciplines. The findings and the development process of these projects are discussed in the fifth chapter, which presents the prototype interactive dance system Duende, that emerged from the traditional dance context of Flamenco; and Hiroshima, an experimental, hybrid performance piece that incorporates notions of play, music composition and theatre. An additional project in the context of Yoga can be found in the Appendix.

Developed for musical performances, dance, theatre or any other body-driven interactive application, the aim of EnActor is to facilitate the use of the whole body and the dynamics of movement to realise complete artistic interactive media scenarios and fast prototypes seen as WBI sketches. In order to achieve these goals, I developed technical skills and expertise in the use of inertial sensor motion capture systems, interaction design, programming, mathematics, wireless sensor networks and ubiquitous computing. However, it is my intention to metabolise and encapsulate this knowledge in abstractions, metaphors and formalities that aim to provide and communicate the power of these new tools in a more accessible way. During the discussion of my thesis, I will try to keep a balance between the basic technical knowledge needed for the appreciation of the proposed technologies and the inspiring notions of body, space and time that form the essence of performance arts.

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2 I define a WBI sketch as a prototype of a body-based interaction design concept
The context of this research stands at the crossroad of fine art, dance, performance art, and music composition with systems design and technology. Theoretical discussions and practical explorations in these areas have enabled the development of a diverse and highly valuable body of artistic work, where interactivity is seen as yet another property of experiencing art. In this first chapter, I intend to present a broad overview of the notion of interactivity as seen across these interlaced artistic practices. Moreover, I intend to cultivate a holistic appreciation for the term and discuss the work of pioneers who envisioned digital technology as an exciting new way to expand the boundaries of their artistic practice.

Contemporary explorations of interactivity in these artistic contexts have evolved with the development of specific technologies that are capable of transcribing the human body into digital data. This has allowed artists and technologists to capture and analyse meaningful data concerning the time, space and dynamics of the body’s movement, in order to synthesise audio-visual interactive responses.

After reviewing notable explorations in interactivity, I will provide an overview and assess various interaction design tools and technologies that have been utilised. These include camera-based (Optical) and sensor-based (Inertial) motion capture systems, as well as tools for mapping movement to digital interactions through various software design platforms.

In addition to providing an overview of the ideas, performances, and technologies that informed my own work, this chapter can offer guidance to those who are entering this emerging and exciting area of research and artistic practice.
2.1 Interactivity and Technology in the Artistic context

2.1.1 Views of Interactivity in Fine Art

The notion of interactivity, especially as a property of an experience, was first discussed in the fine art context, as a non-technological exchange of actions and information between the work and the viewers. In this context the viewers are commonly seen as participants and they are encouraged to interact with each other or the environment, through an artistic conception that is commonly defined as a happening, an installation or a public art project.

McLuhan (1964) incorporated the essence of experience in the arts with his comment: “Art, like games, is a translator of experience. What we have already felt or seen in one situation we are suddenly given in a new kind of material.” Experience is introduced here as the vehicle to both create and perceive a work of art. Interactivity in the art context in general, can be considered as an optional property for the communication of the art experience.

Cornock and Edmonds (1973) envisage several situations that characterise the relationship between the artwork, artist, viewer and environment, which are applicable in a range of contexts from traditional art exhibits to current examples of interactive artworks.

They defined as static, the condition where the art object does not change and is just viewed by a person. There is no interaction between the two that can be observed by someone else, although the viewer may be experiencing personal psychological or emotional reactions; the artwork itself does not respond to its context. For example, a painting on a wall may trigger a response from a viewer however, the response is a function of introspection by the person. The painting does not alter its properties in any way depending upon the viewer.

A dynamic-passive artwork, is an art object that changes with time by the artist’s program or by environmental factors, while the participant has no control and cannot alter anything. A Dynamic-interactive artwork though, enlarges the dynamic-passive paradigm, to include an output from the participant to the work and thus develop a feedback loop.

While pre-modern traditional painting is mainly perceived as a visual representation of history through portraits and landscapes, often having cultural or religious references, modern art pioneered visual styles (such as Impressionism, Cubism, Surrealism, etc.) that depicted the world in different ways, changed the purpose as well as the user experience of art from being an historical archive to a challenge of the viewer’s perception of the world. Mark Rothko (1951) connected his artistic practice with the audience by placing them within the experience of his work:

I paint very large pictures. I realised that historically the function of painting large pictures is painting something very grandiose and pompous. The reason I paint them, however - I think it applies to other artists I know
is precisely because I want to be very intimate and human. To paint a small picture is to place yourself outside your experience, to look upon an experience as a stereopticon view with a reducing glass. However you paint the large pictures, you are in it. It isn’t something you command. (in Stiles and Selz (1996))

Bourriaud (1998) confirms that as art and artists were increasingly more concerned about the experience of the work of art by the viewers, the audience transforms from observers to participants. Spectator participation, Fluxus group performances and happenings, became a regular feature of artistic practice. Kaprow (1958), the inventor of the art form of Happenings where audience participation was prevalent and encouraged, proposed that in such events there was no difference between performers and audience. In his essay The Legacy of Jackson Pollock he describes a happening as "a game, an adventure, a number of activities engaged in by participants for the sake of playing" and introduces the concept of creating art with everyday objects that engage the audience with the work. While Kaprow did not use technology to explore interactivity, his projects redefined the roles of performers and the audience by encouraging physical and interpersonal interactions.

Audience participation through technology became a popular concept for artists and art theorists in the 1960s and 1970s. Ascott (1966) a pioneer in art, technology and cybernetics, developed a theoretical position in which participation and interaction between the audience and the artwork were central, while Burnham (1969) argued for the importance of understanding artworks in their environmental context and contended that all things “which processes art data, . . . are components of the work of art”.

For Reichardt (1968), the director of one of the first art and technology exhibitions, the introduction of the computer is a defining a point for the merging of art and science. It challenged previous assumptions made by engineers, scientist and mathematicians that "art is magic", while also altering the perception by artists, composers and poets that "technology is a mystery". Media art reflects this idea in practice, since artworks can be proposed from research institutions, scientific labs and transdisciplinary collaborations between artists and scientists.

An example of how this integration can be practically realised is the Topological Media Lab (TML). This collective of artists and technologists, led by Sha Xin Wei, has explored interactivity through a variety of public experiments, installations and performances. Central to their research is studying the phenomenology, or conscious experience, of interactive performances.

The TGarden (2000), was one of the first complete responsive media environments, “a computational and media architecture”, in which visitors wearing specifically designed uniforms could generate and continuously shape the environment
though the manipulation of sound and digital images with their movement. The design of the different uniforms and the way these affected or informed the participant’s movement and behaviour, added the important aspect of theatre and play to audience participation. The work was the result of a collaboration between the Sponge\textsuperscript{5} and the FoAM art and technology groups, and a consortium of twenty-six artists and engineers, indicating that within these collaborative environments, traditional roles and practices seem to fuse. According to Sha (2006) the process revealed the different perspectives and priorities that designers and engineers have while solving a problem. For example, it was found that what engineers thought was an adequate disambiguation of human bodies moving in a room was quite different from what costume, fashion designers thought was acceptable as individual costumes. Therefore the understanding of the role and the vocabulary of each member in a transdisciplinary collaboration between artists and technologists is of high importance.

Video: The TGarden interactive Installation, presented at Ars Electronica, 2001

Digital technology as a tool, has expanded possibilities for experiencing content and increased the level of sophistication

\textsuperscript{5}Sponge is an art research group founded by Sha, Shalter and Farabough
for interactive, concept-based artistic works. In the context of interactive public installations, the audience is encouraged to develop communication links with other participants and generate interactive audio-visual content with their actions and through social interaction.

Dixon (2007) defines four categories in order to classify interactive art installations in relation to the openness of the system and the consequent level and depth of user interaction. These categories include: Navigation, Participation, Conversation and Collaboration. Navigation is the simplest form of interaction where the audience navigates through simple interfaces unfolding or moving through a narrative. Participation is the most commonly used aspect of interaction, where the user brings the environment’s sensory features to life and generates content through actions. Conversation refers to the idea of engagement based on some kind of dialectics with the content of the artwork, and collaboration emerges where actions are created collectively or significantly alter the artwork or interactive space itself. Although these were proposed in the interactive installation context, the sophistication of an interactive system results in the formation of different experiences in all other interactive art contexts.

Following the tradition of interactivity on the performance stage as it has emerged at the crossroads of fine art, dance, music, performance arts, and electrical/electronic engineering, one can identify David Rauschenberg and Billy Klüver (1966) as two pioneers of the first interactive performance works. They jointly organised meetings for artists and engineers to devise large-scale collaborative performance works, entitled 9 Evenings: Theatre and Engineering, in New York City. These events initiated the establishment of Experiments in Art and Technology, an organisation directed by Klüver, to foster research collaborations between scientists and artists. During a performance collaboration with the composer John Cage and the choreographer Merce Cunningham, called Variations V, Klüver built a system with photoelectric sensors detecting movement, and an array of microphones that detected sounds. The system created a reactive sound-scape that acted as an audio score for the dancers. This performance was an important precursor to computer-controlled interactive artwork, in the context of performance art, which was concerned with the seamless translation of body movement into sound.

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6 These innovative and artistically captivating works involved many of the Judson Dance Theatre artists, including Rainer, Paxton, Deborah and Hay, Childs, as well as Cage and Tudor.
While interactive installations position the audience as the end users of an interactive system, dance and performance arts, as discussed in the following section, sees the user as a virtuoso; an expert performer of an interactive system.

2.1.2 Views of Interactivity in Dance and Performance Arts

Cunningham was interested in using the computer as both a memory device and a creative tool that could extend his explorations on how movement is captured through film and video cameras. He created *Trackers* (1991), a live dance work that utilised Life forms, one of the first computer software programs designed for choreographers. Known today as Dance Forms, this software enables users to visualise choreography with a fully articulated human figure that can be manipulated into any shape. On a time-line it generates the movement pathways between each particular shape in the sequence, to create an animation. It is thus possible to build highly detailed, realistic and complex movement phrases involving multiple figures, danced from virtual characters.
His later work *Hand-drawn Spaces* (1998) in collaboration with Kaiser, Eshkar, and the Open Ended Group, was a landmark in the use of motion capture for dance performances. To create this performance, Cunningham choreographed and motion captured 71 short dance phrases that were used to create animation with a hand-drawn quality. The selection of the sequence of recorded phrases was done with the help of a new piece of animation software called the Motion Flow editor, developed specifically for the project.

Video: *Hand-drawn Spaces, 1998*

The concept of this work was further extended with *Ghostcatching* (1999), a collaboration of the Open Ended Group with choreographer Bill T. Jones, which demonstrated a virtual choreography based on full-body motion capture. *After Ghostcatching* (2010), was Jones' tribute to this monumental piece, and elements from the original work were reformed and refined with the use of new advanced technologies.
Bill T. Jones continued the thread initiated by Cunningham through his investigations of the development of interactive dance works with real-time optical motion capture. Downie (2005) who is now affiliated with the Open Ended Group has extensively explored the use of artificial intelligence (A.I.)\textsuperscript{7} to develop digital agents able to generate interactive visuals to accompany dancers in real-time. For the development of his collaborative works with the choreographers Bill Jones, and Trisha Brown, called 22 and How Long Does The Subject Linger On The Edge Of The Volume ..., respectively, he developed interactive systems that utilised optical motion capture capable of capturing the entire performance stage in real-time.

\textsuperscript{7}In his PhD thesis, Choreographing the extended agent performance graphics for dance theatre, 2005 at the MIT
It is interesting here to observe the continuation of Cunningham’s early ideas, evolving in parallel with advances in technology of motion capture and computing. From the static use of Life Forms, to the off-line use of motion capture for animating *Ghostcatching*, to Bill.T Johnes and Trisha Brown’s choreographies for real-time motion capture, there is evidence of the artistic value and aesthetic potential of these explorations in dance performance.

I would argue though that in these examples, the use of motion capture to digitise movement and create dancing animated forms and other visual elements to accompany the performance, exhibit a very weak interaction scenario. The choreography dictates the process, and the responsive system responds to the actions of the dancers, but the dance does not seem able to alter or be altered based on the responses of the system.

One of the most comprehensive early works that exhibited this understanding of sensing in dance performance is *The Secret Project* (1999) produced as a collaboration between the dancer and writer Jools Gilson-Ellis, music composer Richard Povall, and the dance team Half/Angel.

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The performance explores the interaction of choreography, poetry and the interaction with live vocals with sonic soundscapes. The performance was first presented at the 1999 International Dance and Technology Conference (IDAT). For Povall (1999) the idea of interactive performances relates to the development of an interactive space that is “physically and emotionally intelligent”. The key notion in this approach is the understanding the emotional intentionality of a movement, in an attempt to map the actual physical movement into reactive media. Birringer (2002) described The Secret Project as subtle and moving: “Ellis literally danced with her arms and voice as extended musical instruments that can layer and caress the textscapes/soundscapes she triggered in space through her interaction with the camera-sensor”. Following the understanding of sensing as a complete new dimension for the extension of movement in a multidimensional space, Birringer (2008) proposes interactive environments based on sensors and real-time processing as “a dynamically evolving dialectic between an artificial ecosystem and human agents”.

These were programmed by Povall using the EyeCon software system
Moreover in this work, I consider the integration of the performer’s voice into the interactive narrative to be important because it merges the physical and the digital interactions that are controlled by the performer. The interaction paradigm in this case is particularly strong, as the system requires both movement and vocal cues as input, in order to respond. The responses of the system affects the performer and the interaction loop is established. My personal interest and design perspective relates more to performance works that do not have a dominant choreographic element that dictates the interactions but acknowledge it as an equally important substance of the whole experience.

Two of the most influential groups exploring interactivity in the dance context who keep a balance between choreography and the interactive processes, are Palindrome and Troika Ranch. Palindrome has produced numerous works with its camera-based software system EyeCon, while Troika Ranch commonly use its custom-built motion-sensing system MidiDancer, which uses flex sensors to capture the performer’s body posture.

Wechsler and Weiss (2004) from the Palindrome group use the term *motion sensing* instead of *tracking*, in order to describe EyeCon and other similar camera-based software systems. They argue that this is a better descriptor since it is a system designed to give a sense of the motion, rather than exact data on position and motion.

Interaction, for Wechsler (2006), should be primarily approached as a psychological phenomenon, rather than a technical one: “Sometimes the subtlest of dance movements play crucial roles in our how we feel about what we are seeing, while at the same time large movements may be ignored - essentially rendered invisible to us”.

Palindrome has also measured physiological data, such as brain waves (EKG), the rhythm of the heart (ECG), skeletal muscle contractions (EMG) and skin-to-skin contact between performers, using a custom touching electrode system in an attempt to make a visual or acoustic representation of what is happening inside or around the performer’s body.\textsuperscript{10} I find this last element in their work to be particularly fascinating, as it reveals an interpretation of interactivity as a non-continuous digital information exchange, that extends the physical interplay. Tension that physically builds up gets released through the digital enhancement of touch as highly charged interactive moments.

\textsuperscript{10}www.palindrome.de - technology (last accessed August 2012)
Troika Ranch, is a collective of dancers, artists and engineers co-founded by Mark Coniglio in 1993. Their first production using live camera tracking was *In Plane* (1994), a duet with a dancer and her projected image. Coniglio (2004) compares the investigations of direct interactive relations between gesture, and sound, as “an attempt to release the performer from the synchronisation to external musical structures and define the whole composition as driven by rhythmical and internal movement structures”. He comments about the use of pre-recorded music on stage:

When the performers attempt to nuance a gesture or phrase in response to the aforementioned relationships, an unrelenting and unaware companion—the digitally recorded music with which they perform—thwarts them. In this situation, they cannot hold a spectacular balance because if they did, the music would race on ahead of them and a subsequent phrase of the dance would suffer as they attempt to catch up.
In his personal approach, Coniglio thinks of dancers as musicians performing a new musical instrument that they learn how to play. For him, the movement of the dancer needs to be in service of the sound, therefore affecting drastically the way the dancers perform and limiting the use of MidiDancer to work choreographically.
Video: Interview with Troika Ranch founders Mark Coniglio and Dawn Stoppiello

In parallel with their body sensor system MidiDancer, Coniglio developed Isadora, a modular software that became very popular within the digital dance and performance community, mainly because of its ability to assist the process of motion analysis and interactive control of digital video in real-time. From their early work, such as *In Plane* (1994) and *Vera’s Body* (1999), to their more sophisticated and theatrical pieces including *Future of Memory* (2003), *The Need Surfacing* (2004), *16(R)evolutions* (2006) and *Loopdive* (2009), there is a progression from experimental, improvisational sonic abstractions, to more coherent compositional works.

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Palindrome uses video cameras to define interactive areas around the stage and consequently the performer’s actions seem to explore the space. Knowing how the EyeCon software works, one can imagine the predefine lines and shapes around the stage. Occasionally, these interactions with the virtual space can create an anticipation effect for the viewer as he starts to recognise the moments of interaction and predict the response.
On the other hand, Troika Ranch which uses on-body sensor technology to capture the dynamics of the body seem more concerned about the dynamics of the movement and its relation to the generated audiovisual content. Although it is unclear if the differences between the technological mediums employed by these two groups informed their perspective in choreography and interactivity, or the opposite, these two groups have certainly established a solid foundation for the exploration of interactive technologies in the dance context. It is also particularly interesting to acknowledge the transition over time, in the work of both groups, from exploratory improvisational projects to more coherent performance pieces related to music composition and theatre.

The commonly addressed notions of time, space and dynamics in performance art are equally important in the explorations of not only these groups, but of most artists interested in interactive performances. Because sound has been central to generating interactive responses, both in my research and the works of others, I will further examine the notion of interactivity in contemporary and computer music traditions in the following section.
Bencina et al. (2008) define gesture-to-sound experiments as those that extend the body with sound to mesh gestural and sonic composition. He explains: “The aim is for them to support a kind of kinaesthetic-auditory synchresis, where the motion of the human body is mapped into sound in such a way that sound production becomes an inherent and unavoidable consequence of moving the body”.

The concept of translating movement into sound became broadly popular in the 1920s, thanks to Lev Termen, the inventor of the theremin, an early electronic musical instrument controlled by gestures without any direct contact. When playing the theremin, which typically consists of two antennas, movement of the left hand controls amplitude while the right hand controls pitch. Although the device informed and inspired the development of musical instruments that didn’t require any physical touch, this paradigm is simply responsive, rather than interactive, since the morphology of the instrument (the relationship between pitch, timbre and time), always remains fixed.

Video: Lev Termen performing the Theremin, 1920’s
As music composition was already fundamentally connected to mathematics and algorithmic logic long before the development of digital computational systems, computer music was one of the first practices that directly integrated digital technology and explored its potential in the production of artistic work.

In interactive music systems, Rowe (1993) defines an interactive computer music system as the “one whose behaviour changes in response to musical inputs”, while Paine (2002) expands this definition with the suggestion that the prefix of the word interaction, inter is defined as something between, among or mutual. This extension implies that the two parties exchange something; they act upon each-other in a way that is reciprocal. An expanded appreciation of the musical input, at Rowe’s definition, can include additional structural data forms, captured by bodily actions that reflect temporal and spatial characteristics as related to the performance of traditional music instruments.

Thus, the two main tendencies in interactive computer music emerge as digital compositional systems with interactive music algorithms, and as gestural control of interactive musical interfaces. The latter can been seen as an extension of the traditional musical instrument from a performer’s point of view, while interactive compositional systems frame the process of translation of traditional music composition to algorithmic logic and interactive digital programming.

For Garnett (2001) interaction in the context of computer music has two aspects: “either the performer’s actions affect the computer’s output, or the computer’s actions affect the performer’s output”. Although close to the music tradition that sees the computer as an instrument or in some cases as a performer, his proposition fails to describe the mutual exchange of information that the interactive setting enables.

Lippe (2002) offers a much more descriptive appreciation of interactivity in the musical context stating:

A composer can assign a variety of roles to a computer in an interactive music environment. The computer can be given the role of instrument, performer, conductor, and/or composer. These roles can exist simultaneously and/or change continually, and it is not necessary to conceive of this continuum horizontally.

This position is far more descriptive and accurate as it escapes a horizontal, linear formality and introduces the multidimensionality of musical exchange between all elements that are engaged in an interactive musical work.

For visionaries seeing the computer as a digital musical instrument able to generate sound through gestural control several ideas have been introduced. Mulder (1994) proposed the term virtual instrument, defining one as “ideally capable of capturing any gesture from the universe of all possible human movements and use them to produce any audible sound”. Wanderley (2001) in an attempt to highlight the tangible nature of these instruments, proposed the term digital instrument which more appropriately describes musical systems that contain a separate gestural interface from a sound generation unit, because these instruments are “much more real or tangible and less virtual”.

A more universal term, *interactive instrument*, was introduced by Chadabe (2002). The key point Chadabe makes while defining this term is the dynamic relation between the performer and the instrument rather than the physical identification of the system or the conceptual approach of its design. I find this term to be much more accurate to describe the complexity and the interesting relations that occur in interactive musical systems with gestural control interfaces.

These descriptions offer insight to the initial design approach of interactive sound systems by musicians, where an interface is used as a musical instrument controlled by the body. While Mudler seems to define a broad context of computer-based musical instruments, in which all different approaches in the future could apply, Wanderley is more concerned about the content of these attempts by identifying the interface and creating a metaphor to analogue instruments and their characteristics. Finally, Chadabe concentrates on a description of the core concept, as interactivity reveals the actual aim of these instruments which is its dynamic relation with the medium.

In the musical context therefore, interactivity has been investigated following the traditional paradigm of the musical instrument, where gesture is connected to sound via an interface. The design of new digital interfaces that are approached and performed as musical instruments, is the focus of the annual NIME conference (New Interfaces for Musical Expression). Extending this perspective one can think of the performer’s body itself as an interactive instrument, where gestures, movement dynamics and the body’s shape can generate expressive interactive sound responses.

The idea that the gesture itself contains expressive notions that can be directly translated into musical structures, became more popular with the pervasive use of digital cameras, a broadly accessible, unencumbered interface able to transpose human movement into data in real-time. David Rokeby, a well-known interactive art practitioner and theoretician, became highly popular exploring this idea with his software system, *Very Nervous System* (VNS) (1982-1991), which is able to translate physical gestures into real-time interactive sound environments, controlled directly with the body. In his early work, a simple camera was used by the VNS to gather data and visually analyse the physical gestures of a person and use them to generate interactive sound processes. These “impressions of actions” as described by Rokeby (1995) were “immediately translated into sounds or music, reflecting and accompanying the gestures, thereby transforming the interactor’s awareness of his or her body”.

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12 The NIME conference began as a workshop at the ACM Conference on Human Factors in Computing Systems (CHI) in 2001 and since then became an independent conference.
The transformation of movement, based on the idea of reflection, was further discussed by Rokeby through an interesting metaphor related to the myth of Echo and Narcissus. Interactive video can function as an immediate feedback of exact mirroring that produces a system of self-absorption, referring to Narcissus, while Echo relates to the transformed reflections that form a dialogue between the self and the world beyond, realised through sound.

Rokeby (1998) gradually began to focus more on the production of interactive installations that were generating audio-visual reflections upon the audience’s presence and actions. He describes his artistic practice as such: “I am an interactive artist, I create experiences, but what is crucial to the aesthetic and social construction of the work is that the audience is fully participant in it; they become the performers”. Rokeby’s contribution is of high importance for both his theoretical framework and the VNS software that inspired many new media artists and musicians to develop further work especially in the contexts of interactive performances and music.

Winkler, extensively used Rokeby’s VNS to create audio-visual interactive work and study the ability of the body to directly control digital media. There is a unique fusion of theatre, dance and music in his work, interlaced through an interactive
narrative that is unfolded by the performer. Regarding his findings for the synthesis and performance of interactive compositions, from a musical perspective, Winkler (1998) suggests that interactive musical systems present differing levels of interaction and describes four models of musical interactivity:

- **The Conductor Model**, exemplified by a symphony orchestra, where everyone is controlled from a single source.
- **The Chamber Music Model**, exemplified by the string quartet, where control may be passed from player to player at different moments within a performance.
- **The Improvisation Model**, exemplified by the jazz combo, where the musicians operate within a defined framework, frequently pass control, and vary the musical score with improvised interjections, interplay and improvised solos passages.
- And finally, the **Free Improvisation** Model, where a broad range of often chaotic interchanges are governed by a common musical understanding.

These models are directly linked to the Western music tradition and although they succeed in describing a wide range of interaction themes, they appeal to a particular "musical understanding" that stands within in a specific cultural and historical context. These contexts according to Winkler are made up of a "huge number of shared assumptions and imply rules based on years of collective experience".

I consider two of his interactive performances to be notably influential to my work: *Dark Around the edges* (1997) and *Songs for the Body Electric* (1998). In *Dark around the edges*, the performer uses repetition and rhythmical patterns to illustrate the idea of control over the musical synthesis. In order to orchestrate these rhythmical patterns, the body itself becomes a musical instrument and the choreography is defined by sets of repetitive actions similar to those of a machine. A particularly important element of this piece is the appreciation of the whole space as a theatrical stage. In various moments particular interactions are triggered based on the position of the performer around the space and the sounds seem to illustrate metaphors and actions as if they were performed within a theatrical play.
In *Songs for the body electric*, the theatrical element is even more dominant. The whole performance consists of six different scenes and the system is defined in such way that the performers share the parameters for the production of sound, as the interactive sound compositional mechanism follows the dynamics of the movement. The simple relation between the intensity of the movement to the produced sound creates a rich responsive environment.
Winkler (1995) has generally approached the body as a musical instrument and described successful techniques for musical interaction regarding metaphors from music composition. He proposed that as musical instruments have physical constrains that produce unique timbral characteristics, similarly, each part of the body can be interpreted as a unique musical instrument, with its properties defined by limitations in terms of weight, range of motion, speed and force that can be achieved.

Following a different approach Bahn, Hahn and Trueman (1998-2000) have created works that illustrates the functions of interactive musical performance and transcend the idea of the body as a musical instrument. Bahn and Trueman (2001) identified a problematic condition in the creation and performance of electronic music, “where the luck of a somatic involvement made it difficult to integrate electronic sound and interactivity into instrumental ensembles and dance performances”.

They address their work Streams (1999) as a process of composing for the body through analysis and synthesis algorithms. The sensor interface allows the performer to tap into her personal embodied knowledge, in this case, traditional Japanese
dance. In all of their collaborations, the form and musical texture are designed to be under the complete control of the dancer, while the technological interface promotes the integration of the individual’s vocabulary. Bahn and Trueman (2001) analysed the design process in their work as a parallel development of four layers:

- a social/cultural layer, for the construction of contexts for chamber music and dance
- a development layer of gestural interfaces and interactive tactile musical instruments
- a mapping layer, as the in-between sophisticated layer, linking gesture and sonic responses
- a layer for macro-scale operations of music composition, choreography and aesthetics

This perspective indicates an expansion in the understanding of interactivity within the musical context, since the use of the body has become central as an expressive medium that can explore and establish an interactive relationship with a digital musical system.

Video: Bahn, Hahn and Trueman, “Streams”
Hahn and Bahn (2002) further extend the concept of interactive music with the body in their work *Pikapika* (2001). The performer uses an extended interface, the Sensor-Speaker Performer (SSpeaPer), that transforms her into a musical entity, as the speakers are placed on her body and the sound is produced by her movement. Despite the aesthetic and conceptual layers of the work that is aesthetically related into a stereotypical interpretation of the *cyborg*, a compact on-body system that includes both sensing mechanisms and speakers that emit sound, “restores the ‘voice’ of the performer and supplies the character with an aural identity that she can shape through her movements”.

Video: Bahn, Hahn and Trueman, “Pikapika”

Ten years later, using an advanced inertial motion capture technology similar to the one used in my research, Skogstad and Quay (2011) were working within the context of interactive music to produce an advanced framework for the exploration of various music paradigms called *Dance Jockey*, including a complete, on-body, sound production system similar to the one proposed in *Pikapika*. 
To summarize, interactivity in a musical context was initially approached as an extended algorithmic composition, that required the establishment of various communication channels from the environment to a computer system in the form of audio or data. The later development of digital interfaces for gestural control of algorithmic compositions were designed analogously to traditional musical instruments and were performed accordingly. Following this tradition the body was seen as a musical instrument and was used to generate compositional processes with very interesting results.

Questions about the musical content of a gesture, became more popular with the use of digital cameras as an unencumbered interface, able to turn the body itself into a musical interface. This technological innovation enabled an extended discussion for the understanding of interactivity beyond the musical tradition that incorporated ideas from dance, theatre and performance. In the following chapter, I will discuss different technologies that are designed to sense the body and track its movement in space and the idea of mapping, which are central to the explorations of interactivity in live performances.
2.2 Interaction design tools and technologies

Interactivity and the use of computers on stage extended the dialogue in dance and performance theory and enabled new practices, but hardly changed its nature. Several authors, scholars and practitioners have introduced questions from a traditional perspective focusing on the implications of using digital technology on stage. Under these lines, Parrott (2004) stated: “technology redefines the principles of space and time that we’ve always looked at as choreographers, and we will continue to look at, but it helps us redefine them and redevelop those ideas.” (in Grove et al. (2004))

The analysis of notions of space and time has been influenced by the use of digital technology, which has introduced ideas of virtuality and interactivity and dissolved the boundaries of the physical stage, creating a more dynamic space with different properties, behaviours and limitations. The processes that I have defined for developing sophisticated interactions, follow a basic structure divided in four parts: sensing, analysis, mapping and synthesis.

Sensing refers to the ability of a computational system to capture data from the body and its movement in space. This process requires a digital interface, a sensing device that is implemented as a hardware system connected to a computer. Analysis is the arrangement and filtering of the captured data, in order to extract meaningful information that relates to specific physical or physiological changes that are considered key properties at each artistic project. Mapping stands at the core of the interaction design, as it connects physical actions with digital responses through artistic and conceptual lenses. Finally, Synthesis defines the way that the content and the aesthetics of each interaction are delivered back to the physical world, in order to serve the artistic intentions.

Except sensing, all other processes are mostly implemented in software that can follow basic algorithmic processes or more advanced computational concepts like artificial intelligence (A.I.). A.I. can be used to define the behaviour of an interactive digital agent, or to develop a sophisticated data correction mechanism in order to increase the reliability of the overall system. As mentioned before, the use of A.I. is far from the scope of this research, which is primarily concerned with the development of essential, simple tools that can be used creatively by an intelligent user.

2.2.1 Technologies in Motion Capture

Motion capture technologies are the most appropriate for dancers and choreographers to study interactivity, since they can provide fundamental data about the body’s shape, movement dynamics and position in space over time. While optical motion capture systems have been most frequently used in early explorations, there are a number of limitations for the performance stage and new technologies are required to define a solid framework for further studies in this field. Current
advances in wireless inertial motion capture solutions are very promising for delivering a coherent framework and enabling a creative exploration of interactivity in real-time dance performances.

More specifically, motion capture technology utilised on a performance stage, must fulfil some basic requirements for:

- Reliability
- Transparency
- Mobility

In regard to reliability, the system must be able to measure the performer’s position and movement in space with both speed and accuracy. Optical motion capture systems are more precise in reporting positions in space due to the direct tracking of visible markers, but they calculate the rotations of the body joints with an approximation. Additionally, as any optical system, they suffer from occlusion and line-of-sight restrictions. Conversely, inertial systems are designed to directly measure body rotations and further calculate the position of the joints in space with an approximation.

Another difference in the way these systems operate involves the reported tracking area. Inertial systems track the body within a virtual cube that moves with the performer, so that they always stay within the tracking area. Optical systems on the other hand are only able to track the performer within a rather limited space, defined by the intersection of all camera fields of view. If the performer moves outside of this defined space a camera-based motion capture stops reporting efficient data.

The limitations and problems of real-time optical motion capture for dance and performances are extensively addressed and discussed by Downie (2005) who states in his work: “Unfortunately, during the complexities of modern dance, over the size of a proscenium stage and with a number of other, similar bodies also visible, these data are of surprisingly little use.”

And he continues:

Due to the constraints of occlusion and the large capture volume, dancers wore a reduced marker set indicating their arms, head and back, making the kinematic fit harder. Both systems tested during the development of the work could take up to tens of seconds to register the entrance of a dancer into the motion-capture volume, and when material became close and complex, the kinematic data would simply disappear.
Since most performances that take place on stage involve various theatrical lighting arrangements, inertial systems can operate completely independently of these. In contrast, the accuracy of optical motion capture systems is related to the environmental lighting conditions, even when they operate at the IR spectrum. Moreover, the body of the performer must always be visible by the cameras, or occlusion problems occur if a required camera path is blocked, something that is not required for inertial systems.

Transparency is also very important when using motion capture technology in a live performance context, so it does not interfere with its concept and aesthetics. This is one of the main reasons why optical systems have not been broadly employed in this area. While inertial motion capture can be transparent, and placed under the performer’s garments providing a seamless technological solution for tracking movement, optical motion capture systems require that the performer wears either reflective or flashing LED markers on top of their garments, which can significantly alter the aesthetics of the performance. Markerless, optical motion capture is a technology that aims to improve body tracking with cameras without the need of any additional reflectors or tags on the body of the performer, but it is still in the early stages of development and it requires the performer to be dressed in dark uniforms while moving around a white painted space.

Mobility is yet another reason why inertial systems are far more appropriate for artistic applications. Optical systems are cumbersome, with a demanding infrastructure that is difficult and time consuming to install and operate. In addition, they require a long calibration process in order to operate efficiently. Inertial systems are highly portable; they require minimum infrastructure and have a relatively instant calibration process where the performer stands in an initial position for a few seconds. In addition, these systems can operate both indoors and outdoors with the same efficiency.

While both optical and wireless sensor-based systems are considered unencumbered, since they do not directly restrict the body from moving around the space like any wired sensing systems do, wireless sensor systems are directly derived from the concept of motion, since the sensors are attached to the body, in contrast with optical systems that emerge from the concept of vision, where a set of cameras are observing the moving body. Wearing a sensor system seems to directly extend the performer’s abilities to actively interact with the system, while optical systems act as an observer. Therefore, instead of performing or dancing with the system, the performer is forced to act for the system as if they were in front of a passive observer.

Despite the fact that these technological innovations are still imperfect for delivering both accurate positions and rotations of the body in space, they still operate within a reasonable and acceptable error for a wide range of applications. Especially in an artistic context where scientific accuracy is not essential, both types of systems can be used for various explorations and complete artistic works. However, I consider inertial systems to be far superior because they fulfil the requirements

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13 For more information please visit http://www.organicmotion.com (last accessed August 2012)
Case Studies Using Optical Motion Capture

DeLahunta (2002) confirms that choreographers have been especially reticent to use live performance technologies, like optical motion capture systems, because of their technical complexity and demanding infrastructure. Despite their limitations, since the mid-1990s, researchers, choreographers, musicians and technologists, have explored the artistic potential of these systems in real-time operation and set a number of important precedents. Because of the demanding infrastructure there are very few places with a dedicated optical motion capture facility for the research of interactive dance and performances.

A high volume of related artistic work and research into the use of real-time motion capture on the performance stage, especially in the dance context, has been carried out at the Herberger Institute at Arizona State University. In a dedicated motion capture lab called Motion-e, dancers and choreographers have explored and evaluated different digital interaction paradigms. These projects included the previously mentioned works of Bill Jones, and Trisha Brown, 22 and How Long Does The Subject Linger On The Edge Of The Volume ... that were realised in collaboration with Downie, as discussed earlier. The Motion-e lab employed an optical motion capture system and developed various technologies to increase its reliability and bypass the additional challenges of its real-time use on the performance stage as it is extensively described by James et al. (2006).
Similarly, Bevilacqua and Dobrian (2001-2003) performed a series of experiments at the REALab (Real-time Experimental Audio Laboratory), at the University of California, Irvine, exploring the use of a optical motion tracking system\textsuperscript{14} for the synthesis of interactive sound directly from a dancer’s movement. Although their findings were limited due to the technological restrictions of the employed motion capture system, their approach initiated researching the use on the use of the body as a medium, in order to explore the sonification of motion and the notion of virtuality (in Bevilacqua et al. (2001)).

These early explorations were centred on the dynamics of movement, such as the velocity and acceleration of the body’s limbs. They also associated spatial arrangements, such as absolute distance measurements relative to a fixed reference in the room or between various points of the body. These features were proposed as interesting concepts for the synthesis of real-time interactive music directly from dancers, and some basic examples were presented as an outcome of their research.

\textsuperscript{14}A Vicon, optical motion capture system
In a later work, Bevilacqua (2003) expressed that he was most interested in researching the immanent musicality of the human form, instead of “a proof of concept of yet another alternative controller”. He proposed that under this perspective “the technology is set aside and the body reveals its musical potential as both the musical instrument and the musician in a kine-sonic synergy”. However, this pursuit requires that the performer is skilled in both musical improvisation and movement, without being tied to traditional dance or music vocabularies.

Inertial Motion Capture and Wireless Sensing Technologies

Before I proceed to discuss inertial motion capture systems in more depth, I would like to briefly present some other wireless sensor-based technological systems that have been primarily designed for explorations on the performance stage. In such cases, the performer wears a sensing mechanism not to enhance his or her own abilities, as in a traditional cyborg
scenario, but to enhance the sensing abilities of the digital system. This enables the performer to achieve a higher level of communication and to establish an advanced interaction link with the digital medium.

Park et al. (2006) at the University of California, Irvine have been developing ATLS, a general wireless sensor platform, specifically designed for interactive dance applications. Figure 1. The system is not a complete motion capture solution, but exhibits a much broader perspective for sensing, as it captures “multiple levels of physical and physiological data from a performer”. The integration of body and motion data with the sensing of additional environmental conditions, offers a highly scalable, multimodal sensing system that can be creatively used by choreographers and performers.

Figure 1: The ATLS framework and sensors

From a music technology perspective, the Institut de Recherche et Coordination Acoustique/Musique (IRCAM), has been
working on a similar wireless sensor network platform, *WiSe Box*, with an emphasis on the resolution of the captured data, its high connectivity and the simultaneous use of the system by many performers. Figure 2. Its digital interface, designed by Fléty (2005), was created primarily for applications in music pedagogy, as well as interactive music and dance performance explorations.

![WiSe Box diagram](image)

**Figure 2: WiSe Box (IRCAM): A wireless sensor platform for interactive music**

Aylward and Paradiso (2006) from the Responsive Environments group at MIT Lab have developed Sensemble, a wireless, compact, multi-user sensor system for interactive dance, where wireless nodes are placed on the performer’s wrists and ankles to transmit motion data. Figure 3. The system can deliver some dynamic forms directly from the movement of the performer but it is very limited in the information it can provide about the surrounding performance space or the detailed posture of the performer.
In addition, research by Buckley et al. (2009) at the University of Cork has been mainly concerned with the miniaturisation of wireless inertial sensor units using a novel 3D flexible circuit. Figure 4. The design of the system makes it suitable for wearable applications in which small size and lightweight sensors are required, such as on body wireless sensor networks for medical, sports and entertainment applications. Because transparency of technology on the performance stage is very often a priority, the highly miniaturised nature of these sensors make them appealing for their use on stage.
Research institutions and private companies have made great advances in recent years towards the development of a robust solution in wireless sensor systems for full body motion capture in real-time. Animazoo and Xsens are the two leading companies that offer complete solutions for wireless inertial motion capture. Figure 5 shows the two most advanced wireless motion capture bodysuits based on inertial sensors: Xsens MVN Biomech (Left) and Animazoo IGS-190 (Right). These systems have been designed mainly for film, animation and video game industries, but they are also extensively used in movement science, and virtual reality (VR) applications. Recently, the Xsens MVN full body inertial motion capture system was evaluated by Damgrave and Lutters (2009) for its use in a scientific context, and it has been employed for interactive music and dance research by Skogstad et al. (2011) and their Dance Jockey system, mentioned earlier. Both of these inertial motion capture systems require the user to wear a uniform with embedded wired sensors and a wireless transmitter, as opposed to the Orient system that was employed in this research.

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15 At the end of 2010, Xsens announced a wireless sensor node with similar properties to the Orient system sensor node, called Mtw. As of Aug 2012, this sensor prototype is still not compatible with the company’s motion capture software.
Figure 5: Wireless motion capture bodysuits from Xsens and Animazoo [used with permission]
Video: Xsens promo video
As it was mentioned earlier, the Orient inertial motion capture system was developed by the Research Consortium in Speckled Computing\textsuperscript{16} at the University of Edinburgh. The system offers the first fully wireless, full-body, 3-D motion capture solution for real-time operation, using an on-body network of sixteen Orient inertial sensor devices. It does not require any infrastructure other than a computer and since every node transmits data wirelessly to the receiver, no special suits like those used by Xsens and Animazoo’s inertial sensor systems are necessary. Figure 6. This innovative technology creates a very flexible motion capture framework that can be easily set up to capture the whole body or only the required parts of it, such as the hands, legs or upper body, using completely independent wireless sensors.

\textsuperscript{16}Research Consortium in Speckled Computing, The University of Edinburgh : www.specknet.org (last accessed August 2012)
The system’s Motion Viewer software translates the orientation data gathered by the network of Orient devices to a real-time, three-dimensional (3D) model. The model consists of a number of joints connected by rigid rods to form a simplistic representation of the performer’s skeleton. Rotation data from each Orient device is mapped uniquely to a joint, and after each frame of data the full state of the model is updated using a forward-kinematic method (in Lympouridis et al. (2009)).
The Orient motion capture system can capture and playback multiple instances of rehearsal data that can be used for developing and debugging particular interaction algorithms, while it can be connected in real-time with a wide range of software as for instance Autodesk’s Motionbuilder for animation of virtual characters or to MaxMsp, Processing and Isadora for the realisation of interactive audio-visual scenarios.
The Orient system has been developed in parallel with this research, in three small-scale manufacture stages. Findings from my practical work that took place in the form of workshops and interactive performances and are presented in the following chapters also helped to inform the design of various components of the Orient system. In the following chapters, I will convey the design perspectives enabled with this technological innovation, through a discussion and presentation of my practical explorations. More technical information on the Orient motion capture system can be found in the Appendix.

2.2.2 Mapping Strategies and Interaction Design Software Platforms

Of major importance along with the development of hardware technologies for sensing the body, are software design platforms that have been developed by a wide range of artists and technologies for the realisation of interactive performances. Through the use of custom algorithms or complete software platforms, artists have explored the interconnections between
body actions and responsive audio-visual media. As DeLahunta (2002) has pointed out, we cannot avoid paying more attention to software development for artists by artists:

The process of computation is invisible in the simplest sense that the labour of the software programmer or engineer is largely taken up in the writing of an instruction that tells the computer hardware and connected peripherals how to execute an operation.

The idea of mapping is central in all these explorations and concerns the realisation of various arrangements between different sets of data. Mapping has been extensively discussed as a key element, in both theory and practice, for the exploration of the interactive and conceptual links of actions with audio-visual digital media, in dance, performance and music applications. For Birringer (2003) mapping is at the heart of the creative process for interactive live performance systems. DeLahunta (1998) notes that it is the manifestation of mapping that enters the field of perception of the viewer or listener and not the mapping itself: “Once completed, the instructions that comprise the mapping itself are relegated to the invisibility of computation. How this invisible mapping works is of interest primarily to those who are engaged in its construction.”

Despite its significance, there is no universal or specific methodology that can be applied to a wide range of artistic applications; instead mapping is the result of a rather idiomatic process that is tied to each specific project or art group. However, to offer some insight to this process, I will discuss four different key strategies that have been proposed for the mapping of the body as actions to sound and other digital media.

**Mapping Movement Data to Responsive Media Parameters**

Winkler (2002) notes that algorithmic processes create infinite variations that contain specific parameters open to influence by movement data.

Specific locations on stage may be used to start or stop various musical functions, trigger specific sounds or cue video events. Continuous data, representing speed, is used in the audio realm for such things as timbre shaping via filters, sample playback speed or delay.

This approach refers to the idea of direct control which relates physical to media parameters. As a process it is primarily concerned with the notion of movement and is related to the music tradition that examines the body as a musical instrument. Under this perspective mapping can include for Winkler: “linking weight to density, register tension to dissonance,
or physical space to simulated acoustical space, based on the composer’s creative instructions in order to produce desired associations and effects.”

The mechanics of interactions link the parameters of two or more different sets of data structures to the following three main mapping strategies:

- **one-to-one**, where a parameter from the movement is directly linked to a parameter of the sound
- **one-to-many**, where a parameter from the movement controls multiple parameters of the sound
- **many-to-one**, where many parameters from the movement control a basic parameter of the sound

Isadora, a software program mentioned earlier, developed by Troika Ranch, was designed to be simple enough for non-programmers to work creatively with. It uses a modular node-based structure for visual programming and has been widely used by Troika Ranch and many other artists, performers and choreographers for the realisation of interactive installations and performances with mixed media, with an emphasis on visual elements and digital video.

Along with Isadora, another example under this mapping perspective, is the EyeCon software platform developed by the dance group, Palindrome. Figure 8. The program can be used to define visual elements such as lines and fields on top of a live video image that is used for the tracking of the dancers. These graphical elements are mapped to predefined media events and structures. For example, when a body part touches or crosses a line, a sound, video or image is triggered.

Other program factors can detect movement dynamics and direction of motion, or other qualities such as an object’s size, symmetry, or form, and associate them with the control of continuous media variables, such as sound volume, a video clip playback speed, and other audio and video digital effect parameters (in Wechsler and Weiss (2004) and Wechsler et al. (2004)).
In regards to the mapping of sound to the dynamics of movement in their work with EyeCon, Wechsler et al. (2004) define two main strategies; timbral mimesis and syntactic mimesis. Timbral mimesis is the direct imitation of the timbre of a sound, whereas syntactic mimesis is the imitation of relationships between natural events. We can extend these strategies by introducing the notion of rhythmic mimesis, which concerns the analysis of movement into rhythmical patterns and their creative mapping to interactive responses with perceivable rhythmical structures.

**Mapping of Rhythmical Structures**

This approach in mapping is based on a mathematical analysis of movement in order to extract patterns that can be associated with primarily musical structures; therefore, it is more related to the tradition of algorithmic and interactive music composition. Guedes (2005) has analysed and produced theories and implemented algorithms for this demanding task.
The key component of his system was based on the adaptation of a score’s tempo in response to a dancer’s movement, so that rhythmic musical structures are generated from the rhythm of the dancer’s movement: “thereby enabling the dancer to slightly accelerate or slow down the music being played” (in Guedes (2007)). Despite the use of the term movement, this approach is concerned with the idea of motion, as it primarily analyses movement to extract motion patterns.

Mapping with Emotional Agents

Camurri, at the University of Genova’s InfoMus Lab, discusses mapping through the concept of emotional agents and the Kansei information processing framework. Emotional agents are connected to a state-based computational system that is able to classify and respond to the emotional states of the user. The concept of Kansei relates to the abilities that humans have for resolving problems and processing information in a rapid and personal way, an instant reaction mechanism.
This type of information processing is not a synonym for emotion, but instead it refers to the human ability to process information in ways that are not just logical.

The *emotional* mapping between gesture and music, proposed by InfoMus Lab was based on a study of affect semantics in music and in performance arts. By identifying different emotional characteristics in music and movement phrases they developed a system with the potential to relate the emotional characteristics of a movement (by examining its kinetic properties) to a particular sound that carries additional emotional qualities. In order to increase the efficiency of the system Camurri (2005) suggests the application of this approach on three different time scales:

- low-level features, calculated on a time interval of a few milliseconds
- mid-level features, calculated on a movement stroke, or motion phase, on time durations of a few seconds
- high-level features that relate to the conveyed expressive content (but also to cognitive aspects) and refer to sequences of movement strokes or motion (and pause) phases
Although this methodology has potential, it can be restrictive for artistic freedom, because affection assumptions may differ greatly depending on a given performance context. Even if there is an agreement that gestures or actions elicit certain emotions, the overall emotional expressiveness that dictates a performance narrative is shaped through complex additions by the performer, such as facial expressions and subtle nuances that cannot be captured. Since this mapping is concerned with the extraction and matching of emotions, it is linked to an explicit analysis of the gesture. As mentioned earlier, a gesture is an expressive movement that carries meaning found within a particular cultural context, and so I find this to be closely related to the philosophical tradition of Semiotics.

**Topological mapping**

A completely different approach has been taken by the Topological Media Lab (TML) in the development of Ozone, an interaction design software system that relies on a state-based engine. The software is described by Sha et al. (2010) as: “a media choreography system which statistically interprets sensor data generated by body gestures and uses the reduced data to steer a dynamical system to hint the real-time synthesis of video and sound”.

The states of the engine are predefined based on the properties of each interaction scenario and the software defines a topological mapping between these states in order to produce continuous responses of dense and rich media to the user’s multidimensional input. As the movement of the body is continuous, a topological understanding of interactive media does not rely on (grammatical) language or other explicit formal representations.” (in Sha et al. (2010)) The content which the artists provide to the system, encapsulate the aesthetics and conceptual framework for the application which are reflected back when the engine generates interactions within the responsive environment.

Following this approach, the users are set free to experience interactions by physically exploring their gestures and nuances without being restricted to discrete interaction syntax. The notion of experience is central to the explorations of the TML, which investigates questions and conducts research related to the phenomenological tradition and new interactive media technologies.

2.3 Final Thoughts and Conclusion

Although valuable explorations and intriguing artistic works examining the relationship between the physical body and digital media do exist in all related areas of artistic expression, information about the practice, methodology and know-
knowledge obtained is often fragmented and incomplete. Frequently, the initiatives behind these explorations are linked to specific artistic intentions or technological interventions and rarely contribute to the question of how a body-driven interactive media experience is designed. Therefore, this research is set to investigate a design framework for the study of the interconnections between body actions and interactive responses, using the synthesis of real-time sound as a medium. This framework should be able to function within a wide range of performance art contexts and communicate a selection of different scenarios, concepts and techniques that are linked to the idea of using the body as the vehicle for experiencing and controlling digital interactions.

In order to explore this design framework there is a need for a robust technology for motion capture that fulfils the central requirements for reliability, transparency and mobility that are necessary for its successful use on the performance stage. Additionally, we need to design innovative, simple and robust software tools that will enable the exploration of new paradigms in body driven performances. These tools should aim to liberate artists from the demanding engineering tasks often associated with the development of interactive work. As Sha et al. (2010) suggests, it is important to liberate the composer and the choreographer from having to configure the physical devices or computational units, enabling them to focus their energy on structuring the interactive events and the aesthetics of the performance.

Under my personal design perspective, I approached music composition as a structural, conceptual or aesthetic organisation of sound, and choreography as a composition of movement in time and space. The idea of the structural organization refers to the techniques that are employed in an artistic work, while conceptual and aesthetic organizations refer to the way that these can communicate energy and information. All interactive performances, including those that will be presented in the following chapters, are built on a cultural and conceptual foundation that defines their aesthetics and a technological layer that sets their limitations. The range between these, forms the creative space for the design of new interactive experiences.

Therefore, in parallel to my investigation of what new body sensing technologies can offer to performance arts and how, I propose the importance of the interaction designer as an essential figure not only in the development of coherent software tools and processes, but as an important member of a transdisciplinary collaborative framework that can lead to exciting body-based interactive art performances.

As techniques, concepts and aesthetics are not universal but exclusive to each artistic project, a framework for the collaboration and the exchange of knowledge and expertise between the interaction designer and the artists needs to be introduced. Hence, I explored all my practical work within transdisciplinary collaboration schemes, where individual expertise were mutually contributed. In the following chapter, I will discuss the design framework of whole body interaction and introduce the idea of experiential design through an analysis of a holistic design paradigm.
3 A Holistic Design approach in Whole Body Interaction

In this chapter, I will discuss the notion of interactivity from a design perspective and introduce the term Whole Body Interaction (WBI) in the performance arts context. WBI is a new, technologically-driven framework in Human Computer Interaction (HCI) that incorporates a body-based and user-centred interaction design with a holistic approach.

Following a basic analysis of Human Computer Interaction (HCI) through its historical evolution, there are three main design perspectives that influenced the understanding of the topic. The importance of the following analysis is not to simply identify the fundamental design perspectives in HCI as a transition from a lower sophisticated understanding of the problem to a higher one, but to acknowledge them as equally important elements for understanding design in the context of HCI.

A holistic design approach in problem solving requires the appreciation of a problem through multiple perspectives and within various levels of complexity. Although the term seems to be often introduced with a generic meaning, I have tried to embrace holistic design within the WBI context as related to the experiential design approach and the ideas of Woo (2007) that first introduced holistic design as a methodological process, in the context of industrial design. In this research framework, I introduce this perspective as an effective methodological foundation for collaborative design and development of WBI systems and performances.

Using this framework as a platform for design explorations, I engaged in this practice-led research in order to study the requirements of artists and performers from a design perspective and gain additional practical knowledge and experience through a series of creative, transdisciplinary collaborative projects.
3.1 The (I) in HCI

Using simple metaphors, Beaudouin-Lafon (2004) described three primary types of interaction for the use of a computer system:

- as tool
- as partner
- and as medium

The computer-as-tool extends human capabilities, while the computer-as-partner embodies anthropomorphic means of communication. Finally, the computer-as-medium sees the computer as an apparatus by which humans communicate with each other. I have focused in this research on understanding of the computer as a tool and as a partner, following the traditional HCI perspective.

Through an extensive analysis on the historical traces and scientific perspectives of HCI, Harrison et al. (2007) identified the major intellectual waves that shaped the field, referring to them as “the three paradigms in HCI”. According to Harrison, these have not developed in parallel, but in a linear time sequence, as computer technology expanded from the military to the industry and then to a broader audience of consumers.

The first paradigm was a fusion of engineering and ergonomics that saw interaction as a form of man-machine coupling. The focus of this perspective was on identifying problems and developing pragmatic solutions for them. This was the initial understanding in the field of HCI that naturally arose from the engineering perspective following the typical question: “How can we fix specific problems that arise in interaction with the machines?” (in Harrison et al. (2007)). Engineers were often approaching solutions following a trial and error methodology and other practical engineering and problem-solving scientific methodologies, without considering the perspective of the final user interacting with their design.

The second paradigm, which is still dominant in HCI, was built around the idea that human information processing is deeply analogous to computational signal processing and that the primary computer-human interaction task is to enable communication between the machine and a person.

Towards a broader understanding of interactivity, that crosses the boundaries between the first and the second paradigm, Kress and Leeuwen (2001) stated that “there is no communication without interaction”, which places communication as a property of interaction. Following these discussions, one can see how investigations surrounding HCI began to expand.
from its initial focus on engineering and ergonomics, to the areas of communication, cognitive science, psychology, sociology, design and analytical philosophy.

Harrison et al. (2007) proposed a third paradigm that defines interaction “not as a form of information processing but as a form of meaning making in which the artifact and its context are mutually defining and subject to multiple interpretations”. With this definition there was an attempt to frame tendencies and theories in HCI, referred to as the **phenomenological matrix**. Under this new perspective the focus shifts to embodied interaction, inspired by the philosophical theories of phenomenology. As said by Harrison et al. (2007): “the way in which we come to understand the world, ourselves, and interaction derives crucially from our location in a physical and social world as embodied actors”.

Embodied interaction was extensively analysed by Dourish (2004) in *Where the Action Is*. For Dourish taking a view from the phenomenological tradition can lead to a model that supports both analysis and design of interactive systems based on embodiment. Embodiment was approached in his work from a design and a philosophical perspective, that indicated the shift from a Cartesian model of cognition as information processing, towards a phenomenological perception of experience.

Within my practical explorations, I have approached the problem of designing interactions with the body through the three paradigms of HCI; therefore from an engineering, a design and a philosophical perspective. Considering the interconnections of these different paradigms in a non-hierarchical way, I was able to equally appreciate their contributions to the analysis and understanding of the core design problem in a broader sense and explore various methodologies for designing body-based interactions.

For example, while designing interactive systems for the performance stage, one might initially take an engineering perspective developing an efficient technological foundation that can be used to conceptualise and reflect on particular artistic questions and study the metaphors of their operations. To further optimize these operations one can look through a cognitive, perceptual or functional (ergonomic) perspective as indicated by the second paradigm. Finally, an analysis of an interactive performance setting from a philosophical perspective can offer insight on how these interactions are being experienced and interpreted by both the performer and the audience. Any other possible arrangements of these perspectives during a design process can offer additional, variant solutions to the problem.

### 3.2 Types of interactive systems

Interactive performance systems in general can be categorised based on their abilities to simply respond or interact with the environment following either a deterministic or a dynamic design paradigm. An interaction designer is required to provide the most efficient solution with the least computational expenses that can solve a particular problem.
Dubberly et al. (2009) extensively discussed and described extended variations of interactive systems able to interpret feedback based on ideas that were originally proposed in:

- Cybernetics, introduced by Wiener (1948)
- Autonomous interactive systems as designed and discussed by Pask (1976)
- General systems theory, a fundamental analysis on systems organisation and behaviour proposed by Bertalanffy (1950) and Boulding (1956)

Haque (2009) observed that “designers often use the word ‘interactive’ to describe systems that simply react to input” (in Dubberly et al. (2009)). Building a basic understanding of systems, these can be described as either static, meaning those that cannot act and thus have little or no effect on their environment; or dynamic, meaning those that can and do act and therefore change their relationship to the environment. Dynamic systems can be further categorised into those that react and those that interact. Some of the systems that interact have specific goals and are self regulating in order to achieve these goals. The goal of these systems, which are called first order systems, can only be adjusted by something outside the system. Second order systems have a built in learning or feedback interpreting mechanism, which can measure the effect of the first system on the environment and adjust the system’s goal according to how well its own second order goal is being met. Figure 9.
Instead of understanding interactivity as a property of a system, Dubberly et al. (2009) propose that it is better to study interactive relations between systems. Based on their description of dynamic systems as: reactive or linear (0 order), self-regulating (first order), and learning systems (second order), they worked out all possible combinations in six pairs. Reducing them to those that can describe the relations between a human user, which is always considered a learning system, and an interactive digital system, there are three pairs left:

A Learning System: The output of a linear system provides input for a learning system. If the learning system also supplies input to the linear system, closing the loop, then the learning system may gauge the effect of its actions and learn. Figure 10.
A Managing and Entertaining System: The output of a self-regulating system becomes input for a learning system...Often the application’s goal is to keep users engaged, for example, increasing difficulty as player skill increases or introducing surprises as activity falls, provoking renewed activity. Figure 11.

Conversing System: The output of one learning system becomes input for another...This type of interaction is like peer-to-peer conversation...and the systems learn from each other. Figure 12
Transferring the understanding of these in-pair combinations within the interactive performance context, I have identified three types of systems that can characterise the interactive nature of the relationship between the performer and an interaction mechanism as *methodical*, *empirical* and *dialectic*.

A *methodical* system, falls into the *learning system* category, and the performer’s actions are linked to a digital responsive mechanism that only operates with predefined and fixed properties. The design approach for these performance systems can follow f.i. metaphors of acoustic musical instruments and use simple or complex mapping techniques to instruct specific actions to generate specific responses. The performer can be trained to operate the system in a similar way to learning a traditional musical instrument. In this case, the sensing mechanism\(^\text{17}\) that is employed must function very consistently and efficiently, because a failure at that level will otherwise lead to unpredictable responses and a lack of control that will challenge the relation of the performer with the system.

An *empirical* system, falls into the *managing and entertaining system* category and uses an alternative design approach for the interactive mechanism that shares its processes and controls to establish a dynamic relation with the user. However simple or complex, these processes are pre-determined, even for systems that can evolve or change their behaviour over time, and are described to the interactive system as a set of rules\(^\text{18}\). The performer is required to either master these rules or operate within the complexity of the system in an improvised way through observation, adaptation and experience. The interaction design for this type of systems can follow various paradigms that relate to metaphors such as the interpretation of a narrative, the design of a responsive architectural space or the performance of a score.

\(^{17}\text{Sensors, cameras, motion capture systems etc.}\)

\(^{18}\text{Rules rely on a predefined syntax that describes specific conditions that lead to various predetermined states of the interactive system}\)
Finally, a dialectic system, falls into the conversing system category, and relates to the digital agent (A.I.) design paradigm, where the interactive system can interpret the responses of the user as feedback and respond accordingly. These performance systems can translate and interpret information, prior to their actions, based on the design of their artificial neural network. Their design approach can relate to metaphors of biological systems with behavioural properties that contain a dynamic learning potential. Dialectic systems can enable the exploration of mechanisms that establish a particular, idiosyncratic, relation with the performer.

These three types of interactive performance systems should not be seen or addressed in a hierarchical way, based on their complexity or the sophistication of their design, but as equally-powerful strategies for designing systems that can be interlaced to create interaction scenarios. Since learning algorithms and computational agents were beyond the scope of this research, my explorations were formed around the design of methodical and empirical systems.

3.3 Whole Body Interaction

In this research, I follow a basic idea about the notion of the body that I defined according to three discrete levels: the inner body, the outer body and the body’s surface. These are not related to the shape of the body itself but aim to represent metaphors for the discussion of the body through various perspectives.

The inner body operates around the notion of self and contains all biological processes that are linked to measurable physical data from the body. The body’s surface is a metaphor of a partially permeable membrane that enables the exchange of energy and information between the inner body and the environment. It should not be confused with the body’s skin as it is a metaphor that includes all senses and devices that are involved in experiencing the world. Finally, the outer body is the result of the exchange of energy and information with the world that informs the way that body movement occurs.

The appreciation of the body as a medium for exploring interactivity with digital media emerged with advances of technology that enabled the capture, analysis and communication of physical and physiological data from a user to a computer system. Whole Body Interaction (WBI) is a technologically-driven experience that engages the whole body to a reciprocal relation with digital systems and has to be analysed and further understood through the development of new experiences and additional knowledge.

As a term, WBI was first introduced at the 24th International Conference on Computer Graphics, (Siggraph, 1997) in order to describe the design approach taken by Fels (1997) for the installation Lamascope: an interactive kaleidoscope. The audience was invited to interact with a digital kaleidoscope via voice and gestures, exploring the idea of using the whole body as a means for interaction with a digital, responsive audio-visual system. Figure 13.
In recent years, the term has been broadly discussed in the context of HCI, as the basis for the formation of a new framework in interaction design. Most notable in this discussion are the contributions of David England who organised a series of workshops in WBI as part of the ACM International Computer Human Interaction conference (CHI). In the paper *Towards an Advanced Framework for Whole Body Interaction* England *et al.* (2009) propose an updated definition for WBI: “The integrated capture and processing of human signals from physical, physiological, cognitive and emotional sources to generate feedback to those sources for interaction in a digital environment.”

The foundations of WBI as proposed by England *et al.* (2009) incorporate a holistic perspective which can be traced back to Buxton (1987) and his proposal that “systems must begin to be designed in an integrated and holistic way”. Buxton (1991) was one of the first to understand and discuss digital technology in its wholeness and argued that we should consider technology in terms of the fidelity with which it reflects human capabilities on three levels:

- physical: how we are built and what motor/sensory skills we possess;
• cognitive: how we think, learn, solve problems and what cognitive skills we possess;
• social: how we relate to our social milieu, including group structure and dynamics, power, politics, and what social
  skills we possess.

The initial perspective in the design and implementation of WBI systems by England et al. (2009) was mainly technological
and it was proposed within the computational framework of Autonomic Computing.\textsuperscript{19} I would like to introduce the term of
whole body interaction in this research context, with the original intention to emphasise to the use of the whole body when
designing interactions for artistic performances and applications in music, dance, theatre and performing arts.

A WBI scheme in a performance arts context, could operate through the sensing of either the physical or physiological
data of the body or both, but primarily based on the artistic conception of each performance. The use of biosensors to
capture physiological signals (biofeedback) from the body includes devices able to capture brain waves (EKG), the rhythm
of the heart (ECG) skeletal muscle contractions (EMG) and mechanomyographic signals (MMG). To offer an example of
biosensing in an artistic context, Donnarumma (2012) is using an innovative methodology to sense and analyse the low
frequency sound, produced by the muscle tissue contraction of the performer’s body (MMG) in order to create a series of
artistic performances. His system, the Xth Sense,\textsuperscript{20} offers a particularly interesting perspective on the design of biophysical
musical systems that can fall within the WBI paradigm. In this research my primary focus on sensing was to measure the
body’s physical dimensions and the dynamics of its movement in space. Except from the creative use of voice, no other
data from the inner body was ever monitored in my WBI projects.

Performance art is primarily based upon an exchange, an osmosis between the social and personal layers of existence, of
both the performer and the audience. Except the “physical, physiological, cognitive, emotional and social sources” that are
identified by Buxton and England for the design of generic WBI systems, the interaction design in the proposed context of
WBI performances incorporates additional strong cultural and artistic sources.

Since the design of interactions with the body needs to address questions that expand into multiple fields of knowledge
and artistic practices, the designer often needs to obtain additional expertise through experience. Therefore, it is necessary
for the design of WBI systems to emerge within a collaborative transdisciplinary environment.

I propose that in order to fully explore the potential of mapping body actions to interactive media, following specific
artistic concepts, it is necessary to develop collaborative artistic environments and introduce the role of the WBI designer

\textsuperscript{19}Autonomic Computing is a systemic view of computing modelled after a self-regulating biological system; largely self-managing, self-diagnostic.
Source: www.research.ibm.com/autonomic/ (last accessed August 2012)
\textsuperscript{20}The Xth Sense is an opensource platform developed by the artist and can be downloaded from here:
as a specialist interaction designer. Ideally, a WBI designer should be able to design interactions that involve all notions of the body, the inner body, the outer body and the body surface as well as to operate within various levels of body sensing and be able to develop both methodical, empirical and dialectic systems. In order to conceptualise a framework for transdisciplinary artistic collaborations that include WBI design, I approached design from an experiential, holistic perspective.

3.4 A Holistic Approach in Interaction Design

Design is a creative methodology for problem solving, which includes developing concepts in separate stages and through different processes. Knowledge is broadly accepted to be the key element of problem solving. Kolb (1983) defines learning as “the process whereby knowledge is created through the transformation of experience”. Although the processes of learning and the nature of knowledge are not completely understood, there is wide agreement that knowledge requires experience. Knowledge and experience have a close relationship and a holistic design approach carries these convictions into both research and practice.

3.4.1 Holistic and Experiential Design

There are several propositions for the use of a holistic perspective in HCI. Dourish (2004) defines holistic design as the “one that sees interaction within a larger frame, often a cultural frame, and recognises that an interactive artifact must be designed as a part of this larger system”. Forlizzi and Battarbee (2004) define the term as processes that incorporate holistic factors of a user experience that go beyond or extend the “science of usability”. Dourish’s definition is concerned with a wider perspective in design while Forlizzi and Battarbee’s is about a broader understanding or the experiences that it enables.

Woo (2007) was the first to describe a holistic design approach as a methodological process that includes the designer. This perspective is concerned with the understanding of the design process itself, rather than with the proposition of a new design methodology. Therefore, I believe that it is more universal and can be discussed within a wide range of applications and many different design fields.

21 Woo originally proposed the holistic design framework in the context of industrial design.
There are three main phases at the core of his holistic model: the research phase, the design phase and the innovation phase. Woo (2007) describes how knowledge, that is formed during the research phase, is then used for the design and the innovation phases which produce new experiences that finally become an object for further research and additional knowledge.

The holistic design process is based on the Experiential Design paradigm; which we have to differentiate from Experience Design. Experience design is a particular methodology where the designer is focused on the overall experience of the end-user, while Experiential Design is the understanding of the whole process of design as an experience. The Experiential design paradigm can be visualised as a circular process that involves the two elements of cognition: experience and knowledge; and the three creative stages of the holistic model: research, design and innovation. Figure 14. (in Woo (2007))

This paradigm can be applied to a macroscopic overview of the design process, or to describe smaller parts of it that function through iterative constant loops. Influenced by this particular holistic design approach, I have developed an understanding, and worked within a collaborative design framework, where all processes were seen in a circular rather than a linear form.

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22 In “Digital Experience Design” Leung (2009) talks about the the ‘art’ of experience design and considers holistic factors of a user experience that go beyond or extend the ‘science’ of usability.
3.4.2 Holistic Collaborative Design Models

The introduction of the holistic design in this research has a dual function. One is to support the broader understanding of the design process as one system that includes the designer. The other purpose is to introduce a flexible collaborative framework in the artistic context, where the design is seen as a circular organic process rather than a methodological linear one. The main benefit of this understanding is to maximise the exchange of information, knowledge and experience between the collaborators and operate within a transdisciplinary environment that is established in a discrete, but non-hierarchical form.

Woo (2007) further describes an Experiential Design Knowledge System (EDKS), as an organic entity that is defined by a core that consists of experience and knowledge, and is surrounded by sets of sensory modalities, thinking modes and creative abilities. This model represents the dynamic interactions among the thinking abilities, sensory stimuli, and creativity of an
individual as they relate to the development of a design cognition, which evolves based on the formations of experience and knowledge during the design process. Figure 15.

Figure 15: An Experiential Design Knowledge System (EDKS) [Woo (2007) used with permission]

Each of the collaborators carry particular expertise and can be represented as an open EDKS model with distinctive characteristics. For example a choreographer can have amplified kinaesthetic and proprioceptive sensory perception while a composer can be more sensitive to the auditory and chronoceptive perception. Various creative abilities and thinking modes can be prioritised by each collaborator during the different phases of the design process. The WBI designer is required to additionally operate within this model as the coordinator, identifying and orchestrating processes that can lead to the development of the necessary knowledge that can lead to the design of new experiences.
Therefore it is necessary for the designer to operate in a more balanced economy of senses and promote the creative abilities of synergy, connectivity, divergent thinking and originality. The sensory modalities, creative abilities and thinking modes are not predetermined or fixed in any way, but they should be discussed and understood by the participants at an early stage at each specific collaboration. Figure 16.

Figure 16: An example of a collaborative system in the WBI performance context using the EDKS model [altered with permission]

Also important is Woo’s description of the trajectory of the overall design procedure as a spiral curve that moves through the areas of implicit (or tacit) and explicit knowledge as the progression passes from the different phases of research, design and innovation. Figure 17
In his words:

Revolving sensory modalities, creative abilities, and thinking modes around design cognition through the three stages of design innovation, design concepts ripen and mature through a process of externalisation. It turns as a curve, creating a base of new experience, and repeats its rotation between conceptualisation and externalisation. (in Woo (2007))

Dummett (1993) defines explicit knowledge as one that the knower can make explicit by means of a verbal statement: “Someone has explicit knowledge of something if a statement of it can be elicited from him by suitable enquiry or prompting”.

Implicit knowledge can be also defined as tacit knowing, what Polanyi (1967) explains as “we can know more than we can tell”. The understanding of these types of knowledge can bring valuable input to the design process and it is important for the collaborators to differentiate between them in order to effectively communicate their concepts with the rest of the group.

Figure 17: Holistic Approach: Cognitive Design Process based on the ExD model [Woo (2007) used with permission]
3.5 Conclusion

Following the observation that a design perspective is broadly excluded from the development of interactive art performances, I propose the introduction of the Whole Body Interaction Designer, as an expert who is able to design and implement interaction scenarios that link the human body to experiencing a direct control of audio-visual media. The WBI designer is expected to act as an interpreter of particular artistic concepts and make use of appropriate technologies that sense the body in various levels, in order to design interactive systems that can communicate specific artistic concepts to the performer and the audience. Although I initially propose the notion of the whole body interaction designer within an artistic context, the abilities of such design specialist can be easily expanded to a broader context and include other research and development areas as for example in health and rehabilitation, video game design and sports training.

The design of interactive performance systems can follow three main types: methodical, empirical and dialectic, which are defined by the relations that are established with their users. The designer can choose to work with a variety of body sensing technologies that concern the capture of physical or physiological data. Although physiological data of the body can be also seen as physical, this distinction is made to contextualise the focus of the sensing media that refer to either the inner or the outer functions of the body.

The conception of a WBI design framework has originally emerged as an effort to study the design of body driven applications in a wide area of practice. Within the WBI design framework the idea of composing interactions based on the whole body is central and connected to a holistic appreciation of design. From various definitions of holistic design I consider the one proposed by Woo (2007) to be most appropriate for applying the concept to a wider range of design practices. His model is founded on the experiential design framework that places the designer’s experience as central to the process of design. Woo introduces three stages for the design process: research, design and innovation. These stages do not follow a linear form; instead they illustrate design as an iterative, circular process.

I believe that this proposed framework can be a fertile foundation for the establishment of artistic, transdisciplinary collaborations between choreographers, composers, musicians, performers and WBI designers. Following this perspective, I have adapted the three phases of the holistic design model and used them as a foundation for carrying out my research on design strategies for WBI performance systems as well as all my practical explorations.

During the research phase of this thesis, three practical collaborative projects in the form of workshops produced important knowledge that informed the design phase that led to the development of EnActor, a prototype system for designing WBI performances. During the innovation phase, the knowledge that was acquired was practically applied with the use of the EnActor system for the development of three additional WBI projects that were set in completely different performative contexts.
Following a fusion of artistic and design practices, for example practical design sessions and performance rehearsals as well as theoretical and reflective discussions, the process for the development of each of these projects was considered idiomatic as it emerged within the ecology of each collaboration and aligned with the holistic design approach. Rehearsals became the main tool for studying and validating the design of proposed interaction scenarios and understanding the potential of WBI design within an artistic context often through trial and error. These studies, along with the findings from the projects and the design and development of EnActor, will be presented and discussed in the following three chapters.
4  Investigations in Motion and Sound

During the first phase of my research, I established links with other researchers in the areas of music composition and contemporary dance that led to the realisation of three collaborative projects. These projects offered me the ability to practically observe and study the requirements of WBI performances in a transdisciplinary platform and extract the core elements needed for the design of EnActor, a modular software system for assisting the realisation of a wide range of WBI experiences, that I will discuss in the following chapter.

Through experimentation and practical testing, these projects proved extremely informative and fruitful for all participants. They raised numerous questions concerning the nature of WBI performances and confirmed the equal importance of dance, music and interaction design expertise that are fundamentally required for the development of such multi-dimensional artistic work.

The explorations that took place in these projects were divided into two main thematic areas: those concerning the process of transcribing various conceptual and compositional elements into a technological driven WBI performance scenario and those focusing on the technical and technological aspects of this transcription. Therefore, they addressed the following fundamental questions:

• What do we aim to design?

and

• How can we design it?

In order to design body-driven interactions, my intention was to capture, analyse and sonify motion, movement and gesture. Motion is a scientific term that relates to the study of the physical and mechanical properties of movement. I define movement in this context to be the displacement of parts of the body in space that take place through the use of an applied force. Gesture can be seen as an expressive movement that carries meaning, which can be decoded and understood within a particular cultural context. (as in Iazzetta (2000)). Meaning in general is dependent on whether the context is cultural, individual, physical or experiential and as the perception of gesture indicates, it has multiplicity and even contradictory contexts in which it can be perceived with various different interpretations. In order to communicate all of these levels of the human activity with one term, I will address them as actions.

As I described in the second chapter, the technological link between body actions and sound is defined at each interactive performance project, on a particular cultural and aesthetic foundation. The technological limitations that were known or
discovered during the process, defined the actual range of our creative potential. I consider the design of each interactive mechanism that I have implemented a summary of interaction sketches that helped me to realise the requirements, tools and strategies to follow when designing WBI performance systems.

The first two projects, *Untitled#1* and *Untitled#2* were developed in collaboration with Beatrice Cantinho, a PhD candidate in the areas of contemporary dance and philosophy at Edinburgh College of Art. *Untitled#1* took place during a residency at Dance Base, National Centre for Dance, in Edinburgh, and *Untitled#2* was realised during a residency at Casa Municipal da Juventude in Lisbon, Portugal. The third project, although it never reached the stage of a complete performance, was a workshop in collaboration with Shiori Usui, a PhD candidate in contemporary music composition at the University of Edinburgh who also participated in *Untitled#2*.

*Untitled#1* was an exploration around the central concept of an improvisational dialogue between the performative and the musical gestures as created by acoustic instruments. The team included two musicians, Nuno Torres (Saxophone) and Ricardo Jacinto (Cello). The proposed interactive dialogue in *Untitled#1* was structured within an improvisational context and was investigated in three stages, that I will further present and analyse.

The second phase of this collaboration, *Untitled#2* concerned ideas of composition seen as a broader term to describe the arrangements of all interconnected elements in a complex WBI performance scenario. It was an attempt to investigate the design process of WBI in a contemporary performance context, where improvisation is structured along with choreography and music composition under a mutually derived compositional score. This score aimed to describe and communicate particular conditions and qualities to all members of the group, establishing compositional boundaries for improvisation. Part of this study was to investigate the ability of a digital interactive system to follow a compositional, time-based linear structure, through posture recognition processes.

The final project in the research phase was a workshop in *Digital Surfaces*. I examined ideas for self-contained, modular compositional structures for the realisation of a dynamic rather than a linear, time-based, composition. The core concept was focused on the idea of interaction with digital surfaces, a representational or virtual form of physical surfaces, and aimed to enhance the interaction metaphors and explore more tactile theatrical associations between the performative gesture, the physical space and the sound.

Through the perspective of a designer in these projects, I will summarise the key outcomes from my experience and discuss my observations and findings in relation to other proposed ideas in this context.
4.1 Untitled#1

Video: Untitled #1 : Video documentation with notes

Part One

Untitled#1 can be divided into three distinct parts or interactive scenarios. In Part One, the central artistic objective was to allow the performer to engage in a dialogue with the surrounding space and the audience, by creating interesting relations between direct eye contact and the generation of sound. In order to investigate this interaction concept, the space around the performer was divided into several virtual areas. Figure 18 The area behind her was associated with a long drone sound that was triggered when she turned her back to the audience. The detection of where the performer was facing in the space was made possible with the use of the orientation of the performer’s body as provided by the motion capture system.
The space in front of her was also divided into five equal areas. For each of these areas the musicians composed an improvised short musical phrase that was played-back each time the performer stood and looked in that direction. Following the musicians’ suggestions, an additional layer was added to manipulate the produced sound, using reverberation and sound granulation techniques, directly controlled with her body.

![Diagram of the space divided into five equal areas.]

Figure 18: Drawing for Part One, Untitled#1 Project

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23 The process where digitised sound is decomposed in small fragments and recomposed in abstract forms.
The associations between particular gestures and the generated sound processes were found to work particularly well when they followed simple metaphors. The reverberation of the generated sound, for example, was linked to a circular movement of the spine, creating a metaphor for the circular expansion of sound waves as the performer rotated around her vertical axis. This link was considered to be successful by the whole group, since connecting the effect to the performed gesture was easy to perceive and control.
Another interaction sketch that worked particularly well was to create an association between the granularity of the produced sound and the relative position of the performer’s hands. Standing with her hands at her side, the higher she raised them toward the ceiling, the smaller the sound grains became. This increased the perceived intensity of the produced sound and created an association between the extension of the body and increased fragmentation.
Generally speaking, two extreme positions of the body\textsuperscript{24} can be linked to two extreme conditions that are defined for a sound manipulation effect\textsuperscript{25}. These can be simply connected through a linear, exponential or any other fixed one-to-one mathematical relation. This design perspective is typical of a methodical system as the parameters of the interaction remain fixed and follow a particular function that links the action data to the required qualities of the produced sound.

Composing spatial interactions that rely on orientation data, as initially explored in this first part, was rather limiting since the performer was required to stand at a fixed position on the stage. Any displacement, led her pointing to another direction in the physical space. This happens because what it was actually designed was the space within the motion capture cube, which was then scaled to represent interactions around the physical space. If the performer deviated from the pre-defined initial position, the association between her orientation and the physical space was distorted, because the system was unable to adjust to her new position accordingly. This problem is illustrated in Figure 19.

\textsuperscript{24}In the previous example the position of the hands at the lowest or highest point possible
\textsuperscript{25}It can also be linked to one parameter or many, through the interpolation between two defined states of multiple processes
With the use of simple additional technology that is able to report the performer’s updated position and correct her orientation to accurately correspond to the whole physical space, the displacement error would be corrected and would make it possible to design a fully interactive theatrical stage.

Figure 19: Displacement of the performer leads to inaccuracy of her orientation in the physical space

Part Two

The main concept for the second part of *Untitled #1* was initially introduced from a choreographic perspective and was related to the exploration of primal movements of the body.

Cantinho (2008) explains:

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26 This can be easily done for example with the use of simple camera tracking from the ceiling or a step tracking algorithm
Repetition, allows a very minimal idea of effort use, and the production of an image that can be described as hypnotic, magnetic, and dormant. This enables an intensification of the concentration, both by the dancer and the viewer, that can be enhanced with the exploration of various kinetic alterations using various velocities, dynamics, and transitions.

Thus the design process for the interactive scenario in the second part incorporated self-contained, dynamic and kinetic measurements taken directly from the performed gestures. For example, data was taken from the position of the performer’s hands, the velocity of the gestures, and the angles of the elbow and the armpit. These were used to control a set of sound effects, each connected to a dedicated audio input for each musical instrument. As in the first part, the input data were mapped directly to the sound processing parameters. In this example, there was the addition of a dynamic relation, enabled by a mechanism that was able to constantly adjust its relationship to the increase or decrease activity of the performer’s actions over time. The WBI system in this case constantly adapts its behaviour and therefore this design approach belongs to an empirical system.

By primarily using measurements taken directly from her movements to generate the interactive response, the performer was able to focus more on the exploration of her choreographic ideas and to engage in a playful improvisational dialogue with the musicians.

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27 Using simple low-pass filtering for example, this relationship can obtain dynamic characteristics by involving the elements of time and expressivity.
I additionally explored the potential for using orientation data, in this instance from the hands, to control the balance of the sound emitted from the stereo speaker setup. I experimented with designing an interactive scenario where the performer could direct how the sound travelled through the speakers with the movement of her hands. Figure 20  The effectiveness of this interaction, however, was again dependent on the performer standing at a fixed position on the stage.
Another spatial interaction designed for this part of *Untitled #1*, involved creating a way for the performer to intentionally end a constant interaction link. In order to accomplish this, I used orientation data to create a scenario where the performer could stop all interactive processes by turning her back to the musicians. This enabled her to escape from the interaction loop and therefore control when her movements would have a direct affect on the sound. This design element, which was requested by the performer, was found by all members of the group to be of high importance and worked particularly well within this interaction design paradigm.
Part Three

During the third and final part of *Untitled #1*, the designed interactive elements were based on ideas relating to time and memory. The objective of this stage was to enable the performer to manipulate the instrumental sound produced by the two musicians in real-time, by physically interacting with them. In order to accomplish this I followed a hybrid interaction paradigm. With a combination of spatial and kinetic data, I created a playful theatrical illusion by enabling the performer to *grab* and interact with the performed live music with her hands. When the performer faced a musician and raised her hands, the last musical phrase that they played was digitally captured. The performer could then play this phrase back in small fragments, by performing a gesture akin to scanning the recorded sound with her hands. Figure 21.

Video: *Untitled #1* : Part Three
In this example, metaphors were created by incorporating culture-specific signs into the choreography and build associations with the interaction. For instance, the raising of the hands that triggers the mechanism to grab a musical phrase, can be associated with the stop sign. Moving the hands from right to left, which effects how the phrase is recalled, suggests an exploration of the space that in this case becomes audible. The distance between the palms of the performer’s hands is directly related to the duration of the produced sound phrase fragments, which creates a strong visual link between space and time. These associations show that metaphors can be created through many different ways; they can relate f.i. to cultural signs, a defined semiotic syntax relative to the artistic concept or refer to physical shapes and dimensions. In my research, I have concentrated primarily on the use of metaphors within the individual context of each project in order to develop an abstract vocabulary that communicates core ideas conceptualised by the artists and collaborators.
The exploration of spatial-based interactions in parallel with body-centred kinetic processes can provide a wealth of different design strategies for creative WBI design. Depending on the conceptual approach and the particular requirements of each performance piece, these techniques can be employed and extensively explored as fundamental design paradigms for synthesising a wide range of audiovisual interactive scenarios.

The design of the *Untitled#1* project occasionally introduced implications for the performer and the choreography, since the body was mainly approached and designed as a controller following the methodical system design approach. The performer found herself in a rather unfamiliar role performing subconsciously as a musician or a conductor, something that had a direct impact on her movement sequences. This was interpreted by the collaborators as a shift in the main focus of the system application from experiential to structural, as the design strategy that followed the controller metaphor influenced the artistic concept.

The holistic design framework operated well within the whole development process and was welcomed by the collaborators. The three phases of the holistic model – research, design, and innovation – were introduced to each of the three scenarios in an iterative way. The research phase for each part of *Untitled#1* was based on the innovation outcomes of the previous phase, while the design phase utilised concepts and algorithms that were also related to the study of the abilities and limitations of the motion capture system that was used. At this time, the Orient sensors were only at an early prototype stage and technical difficulties often interfered with the design process. As the designer, I had a strong interest in understanding the artistic process and specific requirements of the musicians and the performer. Because of our different perspectives and areas of expertise, the communication of concepts and ideas was sometimes challenging, but much was gained through this collaboration.
To create *Untitled#2*, the team of *Untitled#1* was expanded to include two more dancers and a music composer. The work was conceptualised with the primarily objective being to create a dialogue between the digital and the physical notions of presence, time and memory. Through this project we worked towards a more specific arrangement, a semi-improvisational piece, that could associate all elements involved in our process with compositional ideas, to construct a narrative. Elements from choreography, music composition and interaction design were interlaced in a single score that was primarily used to communicate our initial ideas, but eventually became a central component of the piece. The score was further realised in software that described the mappings between the dynamics of the dancer’s movements and sound throughout the performance. The design perspective of this WBI software was based on the idea of writing interactive virtual scores, co-performed by an unsupervised, autonomous system during a live performance.

A virtual score, in Manoury’s terms, is a musical organisation in which we know the nature of the parameters that will be processed, but not their exact outcome at run-time, and it therefore enables the notions of improvisation and play. Manoury (1998) suggests that “we should come up with means of composing electronic music in which, as analogy to instrumental music, some components are determined beforehand, and others variant under what is meant to be expressed.” (in Cont (2008))

Manoury’s perspective can also be applied when performing interactive compositions with the body, as explored in this work. Following a conceptual narrative derived mainly from the choreography, the interactive compositional system that was implemented, progressed over nine phases in a time-based sequence. Some of these compositional phases, that were controlled by one of the dancers, were designed to have a specific sonic character, while others to exhibit a more dynamic sound similar to improvisation. As in *Untitled#1*, which had a defined space to unlink the performer from the interaction loop, in this project she could switch the system on and off based on predefined rules; such as the recognition of certain sequences of postures. These rules were considered central to the composition and were extracted either from the choreography, the music or the interaction design. As discussed earlier interactive systems that rely on the description of rules belong to the empirical performance system category.

The choreography brief for the dancers instructed each of them to produce a movement sequence, comprised of a series of postures. The work begins with the dancers walking around the performance space, and then each introduces their individual choreography with different intensities and pace.

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28 There was a fixed duration of the performance; 30’ minutes
Each performer gradually begins to break their movement phrase into fragments, define new sequences and borrow elements from the other dancers’ choreography in order to compose a new common phrase. Figure 22.
Video: *Untitled #2* : Choreographical phrases
This led to the idea that each of the dancer’s movement sequences could be associated with a specific sonic character, defined by the composer. Every time the performer wearing the motion capture system copied a posture from a predetermined sequence, the interactive system adopted the distinct sonic characteristics that were originally set for that particular movement phrase.
In order to implement this, a training session for the system was arranged, where each performer demonstrated their postures wearing the motion capture system. A digital database was then created that contained all postures within the choreography.
Video: *Untitled #2*: Training of the posture recognition system
Figure 23: Example of posture recognition training of one of the three choreographies

Posture recognition can be used to provide important elements for composing a narrative or define rules that switch between the interactive parts of a composition and assist the choreographer, composer and WBI designer with defining key structural elements in their arrangements. An extensive analysis of the use of postures in interactive dance Bill. T Joenes work 22.
Challenges and Lessons Learned

One problem that had to be addressed early on during these collaborations was related to letting go of the traditional roles and re-envisioning the development process for this unique type of work. In the beginning of the Untitled#2 project for example one of the collaborators came with a strong artistic concept already formalised. It did not, however, take into account the full potential or limitations of the employed technology. After lengthy discussions, we reached a mutual understanding that the artistic concept must be developed concurrently with the interaction design, following extensive explorations with the technological part. A transdisciplinary collaboration can more effectively operate within a non-hierarchical framework, where the artistic concept engages in a synergistic relationship with the WBI design and any other involved disciplines.

The holistic design approach clarifies this process and sets the research phase as an ideal platform for collaborators to exchange information and build a common language. Starting with simple keywords of interest and general statements, collaborators can gradually build a mutual understanding and begin to gain experience through small trials and prototypes of ideas. The coherence of a WBI performance piece is a reflection of its development process.

The design phase of these projects suffered from extensive technological challenges. These are an important part of technology-based practical research, as they are often strong indicators of most requirements needed for an effective and reliable design. In pure artistic explorations though, technological challenges can be very frustrating and restrictive to the creative process and discourage artists from engaging with a new practice.

At this point, since many operations were becoming standardised, I started designing a software toolbox to assist the WBI design, optimise the prototyping process and bypass challenges, while I was studying the limitations of the technology.
As a result of these experiences, the importance of a reliable motion capture technological solution became apparent to everyone in our team. In the final days of the *Untitled#2* project, the Orient system proved unstable for full-body motion capture, so the WBI software system was re-designed to use data from only the upper-body. My observation was that the developers of the Orient system were more concerned at the time about the accuracy of the motion capture rather than its reliability, which is highly important for the performance stage.²⁹

Participant feedback from *Untitled#1* indicated that the sound of the interactive system was too dominant, which set the aim for *Untitled#2* to design a system that performs as another musician and is integrated within the compositional structure. In order to achieve this, I implemented a mechanism that was able to operate a database of pre-recorded musical phrases provided by the other musicians and the composer, which could be driven by a compositional arrangement.

²⁹The developers of the Orient system had a particular interest at the time (November 2008) for achieving the highest motion data capture rate possible (over 128Hz).
In the design of the interactive system for *Untitled#2*, the body of the performer was approached as a musical instrument, and a set of rules along with the mapping was described at the compositional layer. Three profiles with distinct sonic characteristics were then designed to relate to each performer’s personalised sequence of choreography. These individual profiles included mechanical sounds, internal body sounds, and a selection of short pre-recorded sounds and phrases preformed by the musicians.

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The linear time-based compositional system proved to be flexible in terms of its organisation but problematic regarding the communication of its progression to the musicians and the dancers. Specific key-sounds were therefore introduced throughout the composition, acting as milestones, so that the digital system could inform the group about its progression. The synthesis of the sound produced through the interactive system and the live musicians was only moderately successful. On several occasions, it was unclear when and how the system was participating in the overall composition, because its sonic characteristics were at times very similar, even identical, to the music that was performed in real-time. In line with our intentions, the sound engine produced material that often seemed to mimic the way the musicians were performing. This created tension and conflict as it was described by saxophonist, Nuno Torres: “As the production of these sets of sounds acoustically with my saxophone need a rhythmical breathing and deep concentration, the reproduction of similar sounds suddenly by the interactive system were completely destroying my process.” Although mimicking the musicians was a conceptual decision, we concluded that it would be more interesting and effective to have a distinct sonic character for the system, so that it would be more obvious when the dancers’ movements triggered an interactive response.
4.3 Digital Surfaces workshop

During the Digital Surfaces workshop, I primarily explored the design of spatial interactions using virtual 3D objects and their surfaces and used volumetric and geometrical calculations for measuring self-referential distances and shapes between various parts of the body. In parallel, I examined the idea of developing dynamic compositional systems that were not restricted to a linear time-based progression like the one implemented for, *Untitled#2*. This perspective signifies the importance of short interactive scenarios, seen as complete WBI sketches, where all motion and spatial interactions are designed as self-contained compositional objects. These can then be introduced and performed on demand via the description of rules for their activation, and can be used in a performance setting to introduce explicit key-moments or build a complete dynamic non-linear narrative. At the end of the workshop the performer was able to activate each compositional block on demand based on which surface of the body or space was touching, as related to the original artistic concept that we explored.

Following the experience gained from *Untitled#1* in the development of spatial interactions, these new scenarios were not designed to activate the entire physical performance space, but only used within the virtual motion capture area that was fixed around the performer. Following this approach, the described assignments remain more reliable and accurate as they are independent from the performer’s position on the stage. The design questions at this phase involved developing methods for defining and implementing a virtual responsive environment with interactive properties, and investigating how easily the performer is able to adapt to it without having any visual feedback.

The artistic concept for the project was related to the human urge to scratch, and led to the development of a system able to recognise when the performer was scratching parts of her body or external virtual surfaces. Using basic collision detection algorithms, it was possible to compute the distance and the dynamics of the performer’s interactions with several virtual areas and design sonic responses.

The Digital Surfaces workshop led me to consider the close relationship between WBI performances and first person 3D computer games or virtual reality (VR) applications. In these types of games and experiences, interactivity largely relies on collision detection; therefore, I subsequently used collision detection algorithms to recognise spatial interactions between the hands of the performer and virtual surfaces. The final system was designed to detect when the performer was touching or approaching the head, arms, chest, stomach and legs, as well as other virtual planes, points and geometrical shapes that were arranged around the interactive space.

One of the first scenarios to be attempted, failed to work because the motion capture system lacked the required precision. The objective was to detect how and when the hands of the performer were moving around her head and link these actions to a compositional module able to synthesise mumbled voices; referring to the notion of memory. Although the system
could detect when the performer was touching her head, the precise location of where the hands actually were in relation to her head proved challenging to such degree that she had almost no control over the synthesised sounds.

Video: Digital Surfaces : Head voices

In this case, the limited resolution of the technology set a boundary for the creative exploration of such detailed and subtle interactions; as a result, all of the following examples implemented during the workshop were based on gross body movements. Moreover, it revealed a major challenge for integrating arts and technology, as artists usually think in physical or conceptual terms and then are forced to alter them because of the technological limitations. Although this seems like a never-ending battle, the creation of a reliable system, able to digitally represent the body in space with high accuracy and in real-time, will set the first landmark for a wider range of detailed artistic explorations in WBI performances.

On an attempt to design interactive areas around the performer, the digital cubic space defined by the motion capture system was divided into twelve virtual planes and the interaction was based on a collision detection algorithm that was able...
to detect when the performer was touching each virtual surface and then measure the depth of the performer’s penetration inside it and the velocity of her scratching gestures. Figure 25

Figure 25: Reaching a virtual surface through the kinetic space (red sphere)
Two key questions, regarding the synthesis of interactive sound, that were discussed during the research phase of the workshop were:

- When and how should the interactive system respond?

and

- How is that response interpreted, by the performer and the audience?

The composer conceptually defined the qualities of the sounds for each of the twelve virtual areas, with pre-recorded sounds of stretching, scraping and hitting the strings of a piano.
The sound was initiated when the performer first touched a surface, while the velocity of her action and the depth of her reach into each surface altered its sonic characteristics. The depth in which the performer reached inside each surface was linked to a real-time frequency filtering algorithm that added additional expressiveness to the original sound. This provided a connection to the physical struggle of the performer trying to scratch or break through the virtual surface. The link between the velocity of the scratching movement and the playback speed of the sound led to sharp, high pitched qualities with fast gestures and deep, ominous sounds with slower movements.

Video: Digital Surfaces: Slow and fast scratches

An interesting observation here is that although the interaction design with the virtual surfaces concerns the spatial domain, it actually corresponds to the kinetic domain. Therefore, the design of spatial interactions must take into account the actions that are required to trigger these events and relate to the physical presence of the performer. There should be a high synergy between all elements involved in the design of these paradigms that enable a wide range of possibilities.
The produced sounds generated from the virtual surfaces were space directional and were reproduced in a surround speaker setup, adding to the immersion of the performed actions. The design of the virtual areas had a fixed orientation aligned with the surround speaker setup so that the sound of was always projected from the direction of the performed gesture. Figure 26.

Figure 26: Interactive Digital Surfaces arranged around the performer in a fixed cube
Usui, the collaborating composer had a strong interest in working with body-generated sounds, so we investigated two different scenarios to externalise internal sounds of the body. In the first scenario, stomach sounds were generated when she touched her abdomen. This direct association between the physical body and the produced sound was found interesting, although it illustrated the concept and produced a highly exaggerated effect. The produced sounds were additionally disseminated around the room, through the surround speaker setup, following the circular movement of the performer’s hand around her belly. This association was particularly strong to the idea of control, which was demonstrated with the use of the surround sound in relation to the circular gesture itself; as opposed to the orientation of the gesture in space as approached in previous examples.

In the second scenario, scratching sounds made with different materials were assigned and generated as she scratched her legs.

Video: Digital Surfaces : Inner body

In the second scenario, scratching sounds made with different materials were assigned and generated as she scratched her legs.

30 As seen in Untitled#1 and at the previous interaction scenario with the 12 virtual planes
The orientation of the performer was used again in the last scenario of the project, where the sound was projected from a secondary quadrephonic system situated above the performance space. In order to amplify the concept of this act, which was related to anxiety, the projection of the sound always came from the back of the performer. While exploring the space, the performer generated sounds moving her shoulders, which were merged with her own produced vocals. This integration between the physical and the pre-recorded vocals worked particularly well and we both agreed that additional work is required to explore the full potential of this interaction mechanism.
Video: Digital Surfaces : Hunting Voices
4.4 WBI Design outcomes

While working on these first three practical projects, I realised and explored various concepts and strategies that assisted the design of the WBI systems that I developed. These observations differed in their nature and their contexts, as I was aiming to explore a rounded appreciation of the WBI design process. I will now discuss various of these ideas and the possibilities that these enable.

Cognitive Interactions

Woo (2007) examines the concept of cognitive interaction, which is a model for describing the role of experience and the mental process of acquiring and understanding information in design. Cognitive interaction is built around four main components: senses, intelligence, knowledge, and experience. He represented their relations in a Cognitive Design Map (CDM), which represents the interconnections of these four components during the process of cognitive interaction. The system moves from the real world of experience to the conceptual world of knowledge; therefore from conceptualisation to externalisation and experience. The senses connect the real with the conceptual worlds, and intelligence externalises knowledge to artifacts and experiences. Figure 27.

This model offers a very interesting illustration of the synergistic nature of a human’s ability to perceive, communicate, design and offer new experiences. It is noticeable that all holistic models described by Woo, as well as those that are broadly observed in nature, such as the natural cycle of water, are loop systems that are open to external input.

I consider these first three practical explorations as part of my research phase that enabled the realisation of new experiences. Through these, I acquired the necessary knowledge to proceed to the design phase of my work and propose a software prototype system for the realisation of WBI performances and applications. Woo’s model of cognitive interactions was an interesting visualisation for conceptualising the design process as an experience and relating to its synergistic nature with the senses, knowledge and intelligence of the individual.
An Objective View on Virtuality

There is an interesting analogy between the technology of the movie camera and the technology used for motion capture. The movie camera is a device that captures information from the world and represents motion as a sequence of images. This technology operates in three-dimensions: a two-dimensional flat projection of the surroundings, plus time. In contrast, motion capture technology isolates the subject from its environment, only capturing its actual movement, and it operates in four dimensions: the three-dimensional space plus time.

While recent advances in 3D movie cameras led to devices that operate in four dimensions, the movie camera is only able to capture and playback sequences of movement from a subjective, personal point of view. Motion capture on the other hand is able to capture a movement from an objective view, a “god’s perspective”. An objective form of representation, although it can be conceived and theorised by intelligent beings, is not fundamentally built into our perception. Developing an objective appreciation of movement in space can be fruitful for understanding the body in space when designing digital interactions. Therefore working with motion capture can help practitioners to think and address the body from multiple
perspectives, cultivating a holistic, objective understanding of its movement around the space.

The Transcription of the Body to the Data-Body

As discussed previously, Troika Ranch’s MidiDancer is a sensor system that can measure the flexion and extension of the major joints of the body but it provides no information regarding the space where the movement is taken place. On the other hand Palindrome’s EyeCon system is built around the idea of the representation and analysis of space through cameras, and focuses primarily on the design of spatial interactions. The advantage of using motion capture in this framework is that it brings these two general interaction design domains in one platform and reveals their synergistic nature.

Therefore, of major importance in WBI performances is the process of transcribing the physical presence of the body in its digital replica, the *data-body*. This term was introduced by Krämer (2001), to address the virtual body as the physical body in a manipulable data form. The data-body, as realised through motion capture in this research, is a mathematical abstraction that aims to represent body posture and movement within a digital, virtual space. The efficiency of this computational transcription is subject to an error factor that characterises the accuracy of the representation of the physical body in the virtual space and has a direct impact on the efficacy of the interaction design.

The closer the digital representation is to the actual physical dimensions of the body, the easier it is to design interactions as they are originally conceptualised. If the error factor of the body-space representation is increased, the potential of the interaction mechanism to operate as intended can vary significantly, delivering more abstract, less predictable or undetermined responses that directly affect the structure and meaning making of a performance.

In all the described projects, participants imagined various scenarios that although conceptually interesting, implied highly challenging interactions to compute in an emerging WBI system. Although the digital, interactive transcriptions of these scenarios could potentially be designed as algorithms and implemented in software, the level of their efficacy would be impacted by the data-body representational system presenting an extensive error. In various cases during the development of these first three projects, ideas that seemed interesting proved impossible to implement as discussed. In most cases this was related to spatial interactions; such as the exploration of an interaction scenario during the Digital Surfaces workshop, based on the position of the hands around the head.

Understanding the mechanics of the body to data transcription process helps to identify and isolate or incorporate the error factor into the design process. If the error is measurable, and it is either linear or consistent, then it can be corrected or excluded from the interaction design and improve the predictability of the interaction loop. If the error is not linear and rather complex, then it cannot be corrected or excluded and the system suffers from a fundamental deficiency, leading to its
inability to perform as it was originally designed. In this case, the one should focus more on how to incorporate the error as a creative element in the design or isolate the use of its most unpredictable elements. In an ideal scenario if the error factor is close to zero, the WBI design can be directly assigned precisely to the physical environment and the described physical interactions.

Energy Transformations

Following an analysis of energy transformations, there are interesting observations concerning the dynamics of the transcription of energy from one form to another as a circular process. We can follow the path of energy transformation starting from the performer’s body that initially transforms chemical energy to kinetic. Part of this kinetic energy is captured by the sensors and is transformed to electrical energy that is then encoded and transmitted as electromagnetic energy; radio signals. The receiver of the motion capture system connected to a computer, decodes these radio signals back to electrical energy that is then measured and visualised under a defined dynamic range on the computer. Based on this dynamic range of data, digital sound can be generated and shaped. The digitised sound signals become again electric energy that enables actuation, through amplification that excites the speakers to produce the actual sound back to the physical environment. The speakers provide the necessary energy for the production of acoustic waves that are then picked up by both the performer and the audience. The performer reacts to the produced sound by feeding back kinetic energy to the interactive mechanism, while the audience that observes a part of these transformations engage in the process of meaning making. Fig28 If interactive visuals are added as feedback, then the same process is performed with additional actuation in the form of controlled light emission (such as video projections or the control of theatrical lighting).
This exciting repetitive, circular process is based on a series of energy transformations that can be adjusted in three ways: either by increasing, equalising or decreasing the energy exchange. In each of the above described transformations, we can choose either to amplify, reduce or sustain the energy exchange. This process defines the final action-to-reaction dynamic relation, which practically defines the energy of the produced sound to the performed gesture. A simple example is the
drastically different perception one may have if there is a significant increase or decrease of the energy of just the final sound amplification of the speakers. Suddenly, the same movement can trigger a reaction that can be perceived as having a major or a minor responsive affect to the physical environment.

**Time-Based and Space-Based Interaction Design**

Mazé and Redström (2005) discuss the structure of computational artifacts through the concept of temporal and spatial forms. The spatial form concerns shapes created in 2D or 3D space, while the temporal deals with structures related to time.\(^{31}\) The sensing of the body and its representation as data-body via motion capture technology offers the ability to capture information from the physical world and represent it in two main digital forms: as position data in the virtual space, which is an analogous representation of the physical space; and as kinetic data in a bio-mechanical, temporal domain that offers a sequential body-motion mathematical model for further analysis of movement and motion. Complete and efficient tracking of the body in space should provide the designer with the following information:

- **Position** - Relative or absolute position update of each part of the body\(^{32}\) (in polar or Cartesian coordinates)
- **Rotations** - Information about the rotations of each of the body limbs (as Euler angles, rotation matrices or quaternions)

Aspects of the kinetic domain, such as velocity, acceleration, angular velocity as well as various angles and relative distances from the joints of the body, can then be easily calculated if these primary requirements are provided. As mentioned earlier, optical motion capture systems measure the positions of the joints in order to further extract their rotations, while inertial solutions measure rotations in order to calculate their positions.

**Types of Space in WBI Performances**

Regarding the understanding of space, Barrault (1980) suggested that in theatre “a human being struggles in space” and that “theatre is the art of the human being in space”. The idea of space in his statement though relates to the conventions of three-dimensional physical space. As the notion of space has been approached in this research context and discussed

\(^{31}\) Representation of movement is time-based (frames of data)

\(^{32}\) An extension for tracking the position of the performer around the physical space creates an ideal interactive, theatrical stage
during the collaborative projects beyond its traditional understanding, I have identified five interconnected concepts for the use of the term *space* in the WBI performance context:

- **Physical space**, which contains all information related to the physical dimensions as they are perceived by the performer and the audience.
- **Kinetic space**, that defines the limitations of the performer’s movement abilities in the physical space.
- **Virtual or Data space**, as a digital transcription of the physical and the kinetic space.
- **Conceptual space**, that contains all the ideas and concepts within a WBI performance.
- **Interaction space**, which contains the syntax that is used to describe the synergies between the conceptual space and all the others.
- **Sonic space**, that reveals the interaction space and communicates it back to the performer and the audience in the form of sound.

The most abstract of the above structures is the conceptual space, as it is simply unconstrained, imaginary and infinite. Therefore, it requires external constraints in order to be defined under a specific artistic conception. All other notions of space contain particular constraints that are either physical, mathematical or computational, and are used to communicate ideas and define the relations between the concept and the final realisation of an WBI performance. Following this analysis one can add other conceptual definitions of space such as a haptic space where the sense of touch is dominant or a rhythm space where various patterns emerge and transcend. The definition of space was used here in an abstract form that aimed to assist the communication of ideas between the collaborators rather than defining a coherent model for the analysis of space within the complexity of WBI design.

**The Virtual Motion Capture Cube**

Inertial motion capture technology is able to represent the position of the body in space in real-time. The captured virtual space can be visualised as a cube that is fixed around the performer as they move along the boundaries of their physical environment. Figure 29 The performer never goes outside their personal virtual cube, but carries it around like a shell.
around the physical space. However, as discussed, there is a level of uncertainty in the transcription of the physical dimensions of the body to its digital representation.\(^{33}\)

**Figure 29: Interaction space within the (transparent) boundaries of the physical world**

Spatial interactions within the motion capture cube, can be defined in two main ways: One can either choose to design them based on a static cube having the virtual body rotating around it, as the performer rotates around herself in the physical space; or design them based on a personal cube that rotates accordingly with the performer, so that she always faces the same plane. Figure 30

\(^{33}\)Represented by an error factor
In order to design virtual musical instruments that are based on virtual surfaces such as a virtual drum, a personal rotating cube needs to be used, as it has a fixed spatial relation to the performer. Arrangements of interactive elements, such as geometric shapes and topologies within a personal cube result in a more controlled interaction by the performer, as all elements remain at the same relative positions to the performer as she moves around in space.

Designing interactions around a static cube can offer the perception to both the performer and the audience, of a digital enhanced physical space, because the arranged interactive properties correspond to particular physical dimensions and orientations. Through these spatial arrangements, the performer can generate sound by interacting with virtual surfaces, just by suggesting their presence in mid-air.

Various scenarios of spatial interactions can be designed depending on the requirements of each project. We can use simple two or three dimensional primal geometrical elements, such as planes, cycles, spheres, cylinders, etc. and describe their.

Figure 30: The two modes of the interaction cube (Dynamic and Fixed)
properties and interactions with them by the performer. Additionally we can create interactions at the floor level which the performer can engage with using their hands. By determining the projection points of the position of the hands onto the virtual floor plane, and calculating the distance between the palms from that level, we have an accurate model for designing interactions with the physical floor level. Figure 31.

Figure 31: Floor level interactions

While supervising an MSc project in Digital Media, I encouraged students to explore a series of audiovisual-based WBI scenarios using this idea, including a Jackson Pollock style painting application.

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34 A Digital Studio Media project, with students from MSc Sound Design and MSc in Digital Media, The University of Edinburgh, 2009. For more information please visit www.sonotonia.land/Audisee_web (last accessed August 2012)
Near Space - Far Space, and the Kinesphere

Berti and Frassinetti (2000) who study the human understanding of space in the field of neuroscience, define two distinct notions of space in the human brain: the *far space* is the space beyond reaching distance and the *near space* is the space within reaching distance. The virtual space that the Orient motion capture system is able to represent is restricted to the near space. As I mentioned earlier, using additional technology for position tracking, it is possible to extend the system to represent both the near and the far space and therefore create a fully interactive performance stage. This would enable the tracking of performers “at multiple temporal and spatial levels”, as proposed by Sundaram *et al.* (2006).

The definition of the kinetic space can be seen in direct correspondence with the analytical models that were proposed by Laban and Kirstein, who use the term kinesphere to describe “the sphere around the body that a dancer can easily reach

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35F.i. ceiling cameras, step tracking algorithms, RF tagging, ultrasonic sensors etc.
while standing still and that moves with the person’s trace-form in space”. Figure 32.
Laban (1963) suggests:

Whenever the body moves or stands, it is surrounded by space. Around the body is the sphere of movement, or Kinesphere, the circumference of which can be reached by normally extended limbs without changing one’s stance. Outside this immediate sphere lies the “general” space, in which the human can enter only by moving away from his/her original stance. In a way, he transfers what might be called his “personal” sphere to another place in the general space.

Laban’s kinesphere is included in a cube and the model can describe all possible movements of the human body inside it. In a similar way the virtual (or data) space, that is enabled through the motion capture technology, defines a motion capture cube that contains the kinetic and the interaction space which are also spheres that can be directly associated with the definition of Laban’s kinesphere and the near-space described by Berti and Frassinetti (2000).
The interaction space within the motion capture cube is defined as a subdivision of the kinetic, spherical space. As discussed earlier at the Digital Surfaces workshop, where twelve distinct areas were defined as equal parts at the four sides of the virtual motion capture cube., The actual interaction space was defined from the intersections of the described virtual surfaces with the kinetic space that defines the limits of the performer’s ability to reach, as represented in Figure 33.

Figure 33: The Kinetic and the Interaction space within the motion capture cube

Although the designed interactions primarily take place within the virtual motion capture cube, the effect of the interaction commonly occurs in the far space. For example, in *Untitled#1* the performer was able to direct the sound from speaker to speaker, or interact with the sound generated by the musicians playing in real-time. Interactive performance systems that
encapsulate actions and interactions within the near space can be specifically designed; as for instance in Bahn and Hahn’s *Pikapika*, where speakers are embedded on the performer’s body, or at Skogtad and Quay’s demo where the performer holds the speakers.

**Temporal and kinetic interactions**

In order to design body-driven interactions, the main intention is to capture, analyse and sonify motion, movement or gestures from the performer. This analysis is related to the kinetic space, which is a digital representation of the body movement and its posture at any given time. For every updated motion capture frame, several kinetic properties of the body can be extracted. For example, the velocity and acceleration of each limb and any body angle between limbs, can be computed and used to dynamically compose body-driven interactions. These types of interactions exclude any orientation error or any other spatial dependencies from their design and therefore liberate the performer from complex instructions, as they only refer to qualities that are particular to their own body.

36 These are considered more reliable as they isolate a highest error factor of the employed motion capture technology, which is to calculate positions in space.
Video: Early days video demonstrating the calculation of an elbow angle

Figure 34: Left elbow angle measurement

Another consideration when designing WBI scenarios is that the digital machine shows no understanding other than the computational, geometric structures of the body’s virtual representation. There is no way, so far, for a digital system to be
able to distinguish an intentional from an unintentional movement, interpret the nuance of a gesture and define its cultural meaning in order to provide relative feedback.

Hahn (1996) discusses movement as mapped into our bodies through varied training, which differs from culture to culture. These differences can drastically alter the aesthetics or understanding of a performance. Thus, the responsive effect to the dynamics of an action and its subtle nuances have to rely on a syntax of transformations that needs to be predefined and specifically implemented as a compositional layer within the given cultural and aesthetic context of each WBI performance. With these projects, a continuous stream of data from the body was used to determine the sonic responses, but the knowledge from that experience indicated that it is necessary to have an activator, or a particular event that triggers a sound or a complete new scenario. How does a responsive event get triggered? How is it shaped? And when and how does it end? These questions were investigated during the next phase of the research, the design phase, where I proceed towards the development of a generic, modular, WBI design system.

This became progressively clear after the development of these first three projects where basic design approaches were taken and explored. Most interactions in Untitled#2 were based on how to extract the intensity of a movement from the kinetic data and match it to the intensity of the produced sound. During the development of this project I found velocity to be the most accurately represented data for determining the intensity of the performed gesture. So velocity was used as the main way to drive the energy of the generated sound and build a specific character for it in conjunction with all the other measured kinetic features, such as body angles and various distances between the joints.

The Use of Metaphors

One of the first strategies I identified for composing body-driven digital interactions is to generate illusions or magic. This can be found at the third phase of Untitled#1 where the performer could capture a musical phrase by just looking at the musician and raise her hands. In general, a movement that produces a sound other than its physical one can be perceived as an illusion. Accepting and understanding technology as a medium able to create illusions is necessary to create magic, but also to perceive and enjoy it. Tognazzini (1993) couples magic with showmanship, entertainment and performance and relates it to digital interface design. Stage magic is the act between magicians and audience and the purpose of a magic act is to entertain and excite an audience.

The magical element in the WBI performance context is currently amplified because these new experiences have not yet been presented to a broader audience. Of course, once the technology becomes widely used, the innovation factor will eventually decrease and even disappear over time. We can support this observation by looking at the progression of other
technologies for entertainment, such as the movie camera. A primarily magical effect that the moving image offered to audiences in the beginning, which was further amplified by the explorations of visual illusions from early silent cinema pioneers like Georges Mellies and Segundo de Chomon, progressively disappeared.

Video: Georges Mellies “The Vanishing Lady”

Fels et al. (2002a) describes the use of metaphor as a way to refer to elements that are common knowledge. Through metaphors, transparency increases making interactions more expressive and transparent to all parties. The use of metaphors benefits both the user, the designer and the audience but also the communication of ideas during the design process. This observation was the starting point for understanding and proposing a foundation of basic metaphors for the design of WBI systems. For instance, in a dance performance context, I found that an interactive system is most effective if it is designed and operated as a digital musician, while in a music performance context, it should be primarily designed and operated as a musical instrument. The practical distinction between these two basic approaches is the development of a compositional layer between movement and sound, able to assist the organisation of the produced sound in a dance
The resulting interactive sound is associated, or directly affected by the body and various design paradigms can be explored as metaphors between the body and the production of sound. The paradigms that I explored during the first three collaborative projects were:

- The Body as a controller.
- The Body as a musical instrument.
- The Body as a medium.

The body as a controller was the main design paradigm that was explored in *Untitled#1*. The sound was initially produced by acoustic instruments and not directly by the body. The aim therefore was to explore creative mapping techniques in order to control the digital manipulation of the acoustic sound in real-time through the performed gestures. The body in that case was relying on the external sound to become audible and the interaction followed the metaphor of a conductor or an operator. Under this paradigm I found that the manipulation of the sound with the hands is better understood by both the audience and performer because there is an obvious connection between the actions and the sonic result. WBI systems that are designed to create sonic qualities akin to a sound processor though, could arguably be more effectively operated by a musician or a composer rather than a dancer.

*Untitled#2* was based on the idea of the body seen as a musical instrument, which generates sound relative to the effort of the movement, primarily represented by the acceleration of the limbs. Dancers do not commonly have musical training and their main concern is the articulation and expression of a movement and the control of its dynamics. The body as a musical instrument design paradigm led me to realise that for dance applications there has to be an additional compositional layer that leads the WBI system to operate, designed under the metaphor of a composer or a musician, rather than directly as a musical instrument. The body therefore can be seen as a musical instrument, but the set of rules that need to be defined as a compositional layer, leads the WBI system to operate under the metaphor of a musician.

At the Digital Surfaces workshop, I investigated the use of the body seen as a medium for personifying theatrical characters and reveal interaction scenarios through play within a sonic-theatrical environment. The performer enables and controls particular sound arrangements, while exploring interactions with predefined spatial and kinetic characteristics. There is a
strong relation between these scenarios and VR applications or first-person 3-D video game experiences and the addition of visual feedback would benefit their extensive exploration.

My conclusion is that a WBI system should be able to provide a wide range of responses starting from having an absolute control of the synchronisation of sound to a movement, as found in a methodical systems, all the way to complete abstraction. Absolute control can refer to the design metaphor of a musical instrument and is more appropriate for music performance applications. More abstract responses are closer to the dialectic system paradigm, where the responsive sound can be interpreted not only as a direct cause of the movement, but as an actual reply from the interactive system to the performer. Compositional elements that rely on rules create additional dynamic conditions that correspond to the notion of empirical systems.

Compositional arrangements

In relation to the ideas about mapping that were described in the first chapter, these projects identified the importance of compositional arrangements as another dimension of mapping. From the music perspective, Risset (1999) says about real-time music systems that:

Not only does the use of real time systems bring limitations and difficulties for the durability of the music, but one may even argue that the concept of real time concerns primarily performance and may be of little relevance to musical composition.

Although concerns as these about the notion of composition may be raised by the music composition tradition, I approached composition as a multidimensional organisation of events, dynamics and interactions that define an WBI experience. The organisational structure that reveals to the audience the playful, interactive act of the performer as an experience, is similar to a broader sense of composition, that includes all the involved parameters that exist in music composition, choreography and interaction design.

During the first phase of the research, I progressively explored compositional structures under a broader understanding of the term. These explorations lead to the definition of three types of compositional paradigms for WBI performances:

- Pattern-based: A composition that refers to a static or evolving mapping, always defined as an interaction pattern
- Linear time-based : A composition for WBI performances with multiple states and a linear time progression through those.
Modular / state-based: A composition for WBI performances with dynamic arrangements of self-contained compositional modules

Compositional elements include creative mapping that often requires several trial and error tests that aim to reveal unidentified relationships between sound, gesture and meaning from multiple perspectives, such as of the performer, the WBI designer, the composer and the audience.

Hahn and Bahn (2002) offers insight to the mapping process for Pikapika as follows:

Individually, each mapping was designed with the greatest simplicity and obvious relationship. The short punctuating sounds were tuned to articulate Hahn’s movement as she raised her wrists above a certain angle. The sounds continue looping as her hands are raised, allowing her to detune and transform the sounds until her wrists lower beneath the threshold angle. These basic sounds are cast into her body-mounted speakers; right arm mapped to right speaker, left to left, allowing her to walk throughout the performance space in sonic character.

I believe that this description defines a new compositional paradigm that can stand between the traditional understanding of music composition and choreography; that of a WBI mapping organisation.

From the dance and performance perspective, Birringer (2008) clearly defines the essence of the transcription of a gesture to sound beyond simple cause and effect:

I should think that the system only becomes challenging and valuable to the performer once she can play it and modulate the sonic space and musical parameters around her to allow herself and the audience to perceive the real-time conversions of movement into sound.

Matching the energy from a performed action to the sonic energy of its response, was found to be the basic formula in my design approach. Except loudness, which can be directly associated with the representation of the energy of the performed action, the overall process can contain control over various other characteristics of sound. Depending on the method followed to synthesise the responsive sound, one can associate qualities such as its pitch, timbre and duration to changes of the intensity of the movement, but also control spatial and sound effects parameters, such as its reverberation or delay.

The WBI systems for these projects were not approached and designed as intelligent agents, able to interpret feedback. Consequently, the question of how an interactive performance system should respond to body actions, was addressed only by aesthetic, compositional and conceptual answers, specific to each project following the development of methodical and the empirical system design paradigms.
The interactive mechanisms developed for the first three projects, were designed as rough sketches and were independently implemented, since the projects explored different scenarios and varied in their artistic briefs. The knowledge that was gained from that experience, provided me with a strong foundation to continue my design investigation and begin thinking of a software prototype that could offer a solid platform for the realisation of a wide range of WBI scenarios.

EnActor’s design structure consists of eight basic layers:

- The motion tracking and the motion analysis
- The core modules
- The whole body control panel
- The preset manager
- The extension modules
- The sound composition
- The digital musical instruments
- The speakers setup

The following illustration provides a blueprint of the proposed components of my software system, EnActor. Figure 35. This design layout illustrates the interconnections of the main modules and a few extensions, which I have determined through my research to be necessary for the WBI modular system prototype.
5.1 EnActor’s Design Layout

5.1.1 Motion tracking and Motion Analysis Layers

The motion tracking layer of the system consists of the motion capture technology utilised and software that captures and distributes the body’s data. As previously mentioned, throughout my research I employed the Orient sensor-based wireless motion capture system prototype, developed by Young (2010) and the Research Consortium in Speckled Computing at the University of Edinburgh. The system is able to capture orientation and rotation data directly from the user’s body and transmit it to a base-station connected to a computer that runs MotionViewer, the dedicated motion capture software. The software provides a rapid real-time pre-visualisation of the data-body using a simple 3D rigid model and can additionally record and playback raw motion-captured data.\footnote{This was proved extremely helpful as the testing of the algorithms could be performed with recorded data during the development of each project.}

In order to enhance the reliability of the transcription of the physical body to its digital data replica, an extension of MotionViewer assists the design of an accurate 3D body model that is analogous to the actual physical body of the performer. Figure (36). Without this addition, all measurements of the relative positions of the body parts in the virtual space will suffer from an initial error. Spatial interactions in particular require that the virtual body model is an exact replica of the performer’s physical body or else their actions will not match the described interactions. To offer a simple example, if the defined length of the hands of the virtual character is not exactly analogous to the physical body of performer, and they touch their palms the virtual character will not. A future upgrade to the MotionViewer software should be the use of a biomechanical model for filtering the motion capture data through the restrictions of the human body architecture.
The motion analysis modules that I have implemented in MaxMsp extract useful data for each part of the body including:

- the position in Cartesian or polar coordinates,\(^{38}\)
- the rotations in the form of quaternions or Euler angles

\(^{38}\)Available in both the static and the personal interaction cube scenario that I described in the previous chapter
• the velocity vector and its magnitude
• the angles between the limbs

This data can be easily accessed on demand by the interaction designer using a drop-down menu and distributed to all the other modules of the system. Figure 37.

Figure 37: Motion analysis drop-down menu

5.1.2 The Core Modules

My approach for dealing with complex problems, is to invent simple mechanisms at a fundamental level that can provide efficient solutions. Therefore I begun to investigate the design of a simple mechanism that could solve the basic problem of generating sound from an action, which could be easily customized, controlled, transformed and reproduced. The benefit of this approach is that it drastically decreases complexity, as the same module can then be used for all parts of the body. The overall responsiveness of the WBI system is then constructed through the operation of many simple layers and is fully appreciated when they all correspond in parallel.

39 The drop-down menu and the send/receive module was acquired from Martin Parker’s MaxMsp mp-send library
At the core of my design there are two basic modules, one for kinetic and one for spatial interactions, which enables the mapping of the body’s activity around the space to a resulting sound. An instance of these basic modules is attached to each part of the body and through specific adjustments, they define the engagement that the movement of each limb has to the overall composition.

For transmitting data from the motion capture system to all various modules of EnActor as well as other third party applications running either on the same computer or remotely I have implemented a streaming data structure based on the standard OSC protocol.

5.1.3 Kinetic Interactions: The Fundamental Mechanism

The hit-frame is a metaphor I used to describe a trigger that follows the detection of the conclusion of a gesture performed by a body part. This concept is associated with the performance of a wide range of traditional musical instruments, mainly string and percussive, where a hit or a pluck is needed in order to generate the sound. Although a hit can be instantly understood when performed with the hand, the movement of any part of the body can be analysed in a series of hits. Rotating or moving the wrist for example can cause additional hits, detected from the elbow and the shoulder. A direct response to a hit-frame can be seamlessly perceived as an immersive act in the digital setting. The main functions of the fundamental mechanism are based on the velocity vector analysis of each part of the body. I used velocity as a representation of the intensity of a movement and therefore as the key for building interactions with controlled intensity of the sonic response. Below I will analyse the layout of the main elements of this process and the metaphorical and functional rationale for each step of the algorithm. A graphical interface acting as a control panel of the fundamental mechanism, in MaxMsp, can be seen in Figure (38). I will proceed with a more technical analysis of the design of the module through the steps of its functions.

![Figure 38: An instance of the fundamental mechanism in MaxMsp](image-url)
Velocity Magnitude Normalization

Birringer (2008) suggests that: “What is crucial about the interaction is the range of the responsiveness of the controller with regard to the dynamic range of expression of the performer.”

I consider this observation central to my approach, as it clearly relates the range of expressiveness of the performer to the responsiveness range of the interactive system. This component is designed to have two different modes for performing this: static or dynamic. When set in static mode, the mapping of intensity between input and output is set as a fixed ratio that can be set to a preference or defined during a calibration process, in which the maxima of the performer’s actions is recorded and used to define the maximum response in sound. Therefore, this setting is used in the design of methodical systems. In dynamic mode, the algorithm periodically measures the performer’s mean velocity, and the sensitivity of the system is dynamically re-adjusted as found in an empirical system. A static system requires the performer to adjust to the system’s fixed configuration while a dynamic system is constantly trying to adapt to the performer’s temporal activity.

Activity Threshold

Equally important to the sensitivity adjustment is establishing the minimum amount of movement required to trigger a response from the system. This activity threshold is necessary to identify a range of low-motion, as stasis, where the system is put on hold. This component affects the sensitivity of the system, determining whether or not it responds to very subtle movements. The activity threshold can be manually adjusted or linked to the previously described normalization process, as a percentage of the whole intensity measurement range. Additionally, the detection of activity below this threshold can be assumed as stillness and used for example to activate the posture recognition algorithm, which is an extension module described in greater detail later in this chapter.

Filtering and Shaping Motion Data

Filtering is necessary to create a smoother data input and shape, for example, the character of an empirical system’s responses. Using a simple low pass filter we can adjust the system’s responsiveness independently to the increasing or decreasing of velocity of an action. A fast responsive setting to these changes can be used when the sound must instantly match the actions of the performer while a less responsive setting can be useful to produce layers of sound that match the intensity of the performance over longer periods. Alternatively, these settings can be defined to produce a system that is
sensitive to an increase in the body’s velocity but unresponsive to a reduction in velocity, and visa-versa. Other filtering techniques can also be applied in order to adjust the data to a particular, desired form. Remapping the velocity data to a mathematical function provides a method for defining a new distribution of intensity that leads to a desired effect. This can be done by selecting one of the predefined functions in the system, such as an exponential one, or through defining a particular mathematical function. Figure (39) shows how the incoming data are shaped to produce much higher accents with the use of an exponential distribution. This process can drastically alter the character of an action or be used to fine-tune the resulting sound. Taken to the extreme, we can even inverse the incoming data so that, for example, gross movements create subtle responses while fine movements have intense responses.

Figure 39: Motion data shaping (here through an exponential distribution)

Body movements relating to the use of the large muscles of the human body
Hit Detection

The hit detection algorithm is at the heart of the kinetic interaction module. The velocity of any movement always follows the same cycle: starting from zero it raises to a peak and then falls, either to zero or to a point where the velocity rises again. The last step, when velocity is close to zero or before it rises again to continue to another part of the gesture, is where the system detects the hit-frame mentioned earlier, while the reported peak describes the intensity of the movement. Often a second hit occurs following the initial one, due to a recoil effect, as the limb tends to slightly move backwards in response to a sudden stop in mid-air. The designer can optionally select to either accept or reject the second hit. Figure (40) illustrates an example of the hit detection algorithm. By transforming the velocity vector to a digital signal one can alternately use audio DSP techniques to detect the produced hits.

Figure 40: An intensity-time graph indicating the detection of a series of hits over time.
Every detected hit generates a sonic response with an intensity relative to its peak velocity measurement. Thinking of a musician hitting a drum or plucking a guitar, the sound emerges at the end of the performed action. Similarly with EnActor, when using a percussive or string metaphor to sonify an action, the sound should begin as the movement ends. In contrast, this association is weaker with responses that reference a wind instrument or a drone effect, where the sound should begin from the beginning of the movement and sustain, following the dynamics of the movement during the whole action. In this case the system can be set to initiate the sound at the beginning of an action.

Just as force, when hitting a drum or blowing into a wind instrument, is directly associated with the energy of the produced sound, the increase of velocity of an action should produce sound with greater energy. For example a hit can correspond to a specific event or a note on a virtual instrument, or it can trigger a sound on a sampler having its sounds organised under a particular concept.\footnote{Such as its perceived intensity, high or low pitch etc.}
Meta Data From a Hit

Monitoring the velocity vector of a limb can provide additional information regarding the orientation of the movement and further classify a hit. Detecting whether a hand created a hit while moving up, down, left, right, back or forth, we can relate each event to particular sounds with different qualities. In addition, constant orientation and velocity measurements, reported for each part of the body, can be used to control continuous features of the sound. This dynamically and persistently shape its sonic character by creating a richer and more precise response to the movement. These can affect, for example, the playback speed of a sound and control its reverberation or filtering.
Pattern Following and Tempo

By coding a mathematical formula\(^\text{42}\) or simply providing the structure of a musical phrase or tune, in midi notes or numerical sequences, the detected hits can follow a musical pattern, while optionally syncing with a master clock that provides the tempo. These functions can play back a musical arrangement with variable speed and can be linked to the central pattern compositional layer or be independent. If this option is excluded, the intensity of the perceived hit will correspond to an arrangement of associated sounds as discussed earlier.

![Ruby code and midi pattern editor](image)

Figure 42: Ruby code and midi pattern editor

The pattern following approach can be illustrated using the barrel organ as a metaphor. Similar to how a barrel organ plays a predetermined musical score, encoded on a cylinder, that can vary in speed according to how fast the organ’s crank is turned, the detected hits from the body can relate to a predetermined musical structure and the performer can control its playback speed, amplitude and other characteristics of the produced sound through movement. As discussed earlier, Guedes has been working on pattern recognition techniques which are more demanding than pattern generation. Pattern following, instead of recognizing, based on the body’s movement, is a direct way for an interactive system to unfold specific patterns and respond within a predetermined artistic structure.

\(^{42}\)Ruby scripting was selected as part of the ajm extension for MaxMsp
www.composition.com/web/software/maxmsp/ajm-objects (last accessed August 2012)
Pattern-Based Compositional Engine

Within the fundamental mechanism I have incorporated a pattern-based compositional engine that involves a master clock which provides the basic tempo. The master clock can drive other compositional subroutines, each one linked to a particular instrument under the same tempo, or a subdivision of it. Each pattern-based compositional engine has two main features:

- a rhythmical pattern generator, and
- a time adjustment algorithm

The time adjustment and the pattern based synthesis algorithms offer the coherence of the rhythm and the perception of its measure. While a professionally trained dancer can produce hits, in a rather accurate sequence, often a slight variation of the sequence seems to destroy the perception of a resulting rhythmical pattern. The time correction, is an internal mechanism, able to assist the dancer by either leaving a produced hit to pass directly, or delay it, resulting to a coherent rhythmical structure where events are always required to be synced on-beat. This process ensures that each of the body’s produced hits can be accurately registered within the defined rhythmical pattern and its time signature. The accuracy of the algorithm could be additionally adjusted to create a humanising effect and avoid a quantised mechanical feeling. Figure 43.

Figure 43: The pattern matching and time correction mechanism as implemented in MaxMsp

Following this method, the extraction of the rhythm of a dance from the generated hits is able to match a predefined musical structure and sustain a rhythmical accurate pattern. This engine can work in conjunction with the pattern algorithm that
describes a musical phrase, in terms of notation for example, which can then get accurately reproduced by the body. Urs Enke (2006), the developer of DanSense, an extension library for MaxMsp, has taken a more sophisticated approach for the rhythmical analysis of dance and the synthesis of musical patterns.

**Recording and Playback Hit Detection Data**

Another component of the kinetic interaction design module is its ability to record the hit data so that it can be played back at a later time. When used, a series of hits will be played back only after the completion of a gesture sequence, as opposed to when the hits were actually created. This option can offer the impression of a dialogue, as the system does not respond while the performer moves but only when she stops, by mimicking the dynamics of the last performed action sequence.

5.1.4 Spatial Interactions

**Scene Designer**

For developing the module for the design spatial interactions I have followed a similar architecture to a simple video game engine. A scene designer is used to create areas of interactions using 2D or 3D shapes that are either fixed or they can change their position, shape and other of their properties over time. Since EnActor, in its current state, has no graphical interface for designing these virtual areas, I used simple geometrical and mathematical formulas to describe shapes and volumes as simple elements or instruments in a scene. In the future, I would like to update the module to have a 3D graphical design interface, able to fully assist this task. The interactions with the objects in a scene can then be defined as self referential or dynamic, as described in section 4.4 and can be extended from appearing in the mocap cube to actually relate to the whole physical space.

To demonstrate the above concept, I have used basic algorithms to create and arrange virtual surfaces, shapes and volumes around the mocap space and monitor their interactions with the performer. A practical example is the AreaPhone, a virtual instrument that was designed for a collaborative project with composer Shiori Usui that I will discuss in the next chapter.

The main idea of the AreaPhone refers to the distribution of sound samples around the performer that can be metaphorically seen as a virtual Xylophone. The instrument can form an area of up to 360 degrees around the performer with two

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43 A very promising platform for the design and realization of spatial interactions is a 3D-game engine (f.i. Unity3D).
orientation options. It can be *EnBodied*, so that the performer can *carry* it around and the instrument always remains in the same position relative to the performer, or it can be *EnSpaced* which means that the instrument is fixed in the virtual space and the performer freely rotates around it. Figure 44. These two configurations are based on the design within a static or a personal cube as described earlier in chapter Four.

The divisions of the instrument can be equal or individually defined and can be designed on a single plane, for example parallel to the ground level, or as a fully 3-Dimensional volumetric shape. The configuration and design of these spatial interactive instruments can be made easier and more meaningful if visible to the designer through a graphical interface. The extension of a physics engine into the algorithm could result in graphical instruments with physical properties able to be extended, stretched, vibrate etc.
Collision Detection Module

The Scene Designer module receives the body movement analysis meta-data as input that is related to spatial navigation such as the position, the orientation, the angles and the distances between any of the performer’s limbs. This data is monitored through collision detection algorithms that can inform the system of interactions between the moving body and the designed elements of a virtual scene similar to virtual reality (VR) and video game applications. Upon proximity or contact, the module informs the system about various parameters of the movement that can be used for generating interesting dynamic responses. As discussed earlier at the Digital Surfaces workshop the system that was designed was capable to proximately detect when the performer was touching parts of her body such as the head, the torso, the abdomen, the hands and the legs. This functions are embedded at the collision detection module.

Orientation and Spatial Interactions

The orientation of the performer in space is a rather abstract idea, since every part of the body has its own orientation. In my research, I found the following body parts that were able to provide useful data on their orientation and relate to various interaction scenarios:

- The orientation of the hand, where the performer is pointing at
- The orientation of the head, where the performer is looking at
- The orientation of the hips, where the performer is standing towards
- The orientation of the chest, where the performer is facing

The Orient motion capture technology that was used could have been greatly enhanced with additional technology such as ceiling cameras, step tracking algorithms, RF tagging, ultrasonic sensors etc. in order to enable its full potential for designing accurate spatial interactions across the whole physical space. One can use this module creatively to demonstrate interactions that are based on the orientation of the performer around the stage and within the motion capture cube.
5.1.5 Whole Body Mapping

Each part of the body can be assigned to a uniquely programmed instance of the core modules that corresponds to a layer of the interactive sound triggered through activity detection. The whole body mapping control panel is used to access all parameters of the core modules and configure them independently. Figure 45. The gray blocks are responsive to mouse clicks and open a control panel associated to each part of the body.

Based on the previously described components with optional adjustments, a wide variety of responsive scenarios can be programmed independently for each limb. The overall system is extremely versatile and depending on the application and the design approach taken, it can lead to a methodical or an empirical system. Building and layering additional sets of mappings can lead to dynamic presets that correspond to a specific character for the interaction mechanism, or interpolate them directly from the preset manager.

Figure 45: Whole Body control panel
5.1.6 The Preset Manager

The *preset manager* is as analogous to a page of a compositional score or a sketch. All of the programmed settings, for mapping activity data to the desired responses, including the syntax and the configurations, are contained in the preset manager. The presets that are designed for a specific application can be recalled automatically or manually during a performance. When recalled automatically, it can be linear, based on the time progression of the performance, or dynamic, based on the description of rules and conditions that can be met during the performance. Figure (46). The control panel for each instance of the core module has its own preset manager that can assist the designer to create more complex layers of presets easily.

![Figure 46: Preset Manager](image)

5.2 The Extension Modules

EnActor’s basic structure, comprised of the components of the core module and the included processes described above, can be used to explore a wide variety of interaction paradigms. The simple yet versatile modular structure provides a solid platform for the design and realization of a diverse range of WBI sketches and scenarios. Nevertheless, I have also conceptualised and implemented a series of extension algorithms in order to expand EnActor’s mapping abilities and explore more complex interaction strategies. EnActor was designed as a modular system so that more extensions can be added, e.g. tools related to particular performance theories such as the Labanotation or Forsythe’s technique of “isometries”. These can be easily added to and communicate with all other modules using the OSC standard communication protocol.

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44 Video demonstration of isometries technique: [http://www.youtube.com/watch?v=9-32m8LE5Xg](http://www.youtube.com/watch?v=9-32m8LE5Xg) (last accessed August 2012)
I consider the implementation of extension modules for biosensing and biofeedback as very important at the next version of EnActor.

**Posture Recognition**

In general, I consider body postures to be very important elements for designing digital interactions. A posture can function as a distinct compositional moment for the choreographer, composer and performer and can be easily recognised by both the audience and the digital interactive system. Through data analysis and the implementation of simple recognition algorithms, a body posture can be learned, identified and recalled by the WBI system. It can then be used to trigger a specific event or change the settings and mappings of the interactive system to a desired arrangement. Because each posture contains a unique set of geometrical relations between the limbs, it can provide useful data for the generation of corresponding interactive audio-visual content. In order to design a robust posture recognition algorithm, I worked on a simple idea that follows these steps:

- Measure the velocity magnitude of the whole body.
- If it is below an established threshold, the body is approaching a posture, as it almost stands still.
- XYZ Data or angles from the body are collected at an adjustable frame rate and duration in order to calculate the mean values of the posture.
- A string of numbers that identify each posture is then stored in a database.

Every time the algorithm detects that a person is holding a position, the values of the posture is compared to all the others stored in the database. It is either matched with the signature of an existing pose if the difference is below a threshold, or classified as a new pose. A performance can either begin with a predefined set of postures, or with no training data so that the database is empty and starts collecting and comparing the postures during the action. The algorithm has also the option to readjust the stored postures to to fit the performer’s posture adjustments over time. The use of posture recognition as a strategy for WBI design was first introduced for the project *Untitled#2*, as discussed in chapter four, but the algorithm was further refined and explicitly used for a later project, entitled EnYoga. More information about this project can be found in the Appendix. Figure 47.
Posture Classification

Another extension for EnActor was implemented during the research phase of EnYoga, where I engaged in discussions with a professional Yoga instructor about the practice and the role of the body alignments. Together, we analysed and categorised a large amount of Yoga poses (Asanas) based on the axis of the spine. While observing the body in different sets of postures, useful information was extracted and used for the implementation of a posture classification algorithm. Figure 48 illustrates some of the categorised postures.
The final algorithm was able to instantly categorise the body’s posture, into the following categories, based primarily on the position of the spine:

- **Deep Bend**: a deep bend of the spine which is defined by an angle of less than 30°
- **Gamma**: a range of postures with the spine positioned around 90°
- **Standing**: a pose performed with a straight spine
- **Leaning Forward**: a pose with the feet horizontal, and the spine bent forward from horizontal to an almost vertical position
- **Back-bend**: a challenging range of standing poses with the spine curved back
- **Arch**: a specific type of back-bend where the body forms an semi-circular curve
- **Twisted**: the spine is twisted rotating the upper body to the left of right
- **Lying Down**: a setting used to differentiate postures with a straight spine to those performed with the body lying down vs. standing up
- **Balance Challenging Postures**: This extended algorithm specifically designed for the EnYoga project, was able to classify postures into three main categories that were challenging in terms of the body’s balance. From left to right, the first case is the one in which the hips are the lowest part of the body touching the ground, followed by balancing on one leg, and finally a position in which the lowest points of the hands are lower relative to the lowest points of the two feet. Figure 49.
These posture classification algorithms proved to work with optimal efficiency organising a large set of postures, even without a learning process. This module can be used in various scenarios to inform the system of the performer’s posture.

Video: EnYoga data collection
Gesture Recognition

Although gesture recognition was never practically applied to any of the projects with live performances, the main concept can be helpful for various WBI interaction scenarios. For example, detected gestures can be associated with the progression of a composition, the activation of an event or the recall of a preset of mapping arrangement. For a proof of concept, I tested an algorithm implemented by the Institut de Recherche et Coordination Acoustique/Musique (IRCAM) and distributed under the FTM extension library for MaxMsp. Figure 50. The Gesture Follower module is a learning and analysis algorithm based on a Hidden Markov model, that provides detection of an action from a pool of stored examples given during a training session. The algorithm recognises the most likely performed gesture and uses time warping for further analysis of the quality of its execution.

Figure 50: IRCAM’s Gesture Follower v.3
Surround Sound Control

Surround sound control with the body is often an interesting addition to strengthen the link between gesture and sound. Indicating that the performer is in control of the projection sound source creates an additional layer of interactivity that can be immersive and also easily perceived by the audience. Depending on the speaker setting, the sound panning can be done through simple faders or more complicated algorithms for surround control of sound such as for example ambisonics. The graph that is included in the algorithm, is used to define the shape of the transition as the sound travels across the speakers.

Figure 51: Surround control faders patch in MaxMsp

45 An ambisonics Library for MaxMsp is developed by the Institute for computer music and sound technology, ICST, Zurich.
A condition that was found problematic, concerned the communication of the experience of moving the sound around the space as it emerges from the performer’s perspective. In a typical setting, where the performer is on the stage, these interactions can be communicated to a degree using a duplicate surround system. One for the performer and one for the audience. Alternative performance settings can offer a various degree of engagement as I explored at the Untitled#2 and the Digital Surfaces projects where the performer was at the centre of the surround sound setup and the audience all around it so that could share the perception of control of the sound.

5.2.1 Composition Modules

State and Time-Based Compositional Modules

Compositional modules can be particularly useful for designing WBI systems, f.e. in the dance context, where the dancer is more naturally inclined to focus on the dynamics of her own movement rather than with the production of a particular sound-scape (at least when compared to a trained musician). Compositional modules can be categorised as:

- Automatic where the performer has no control over,
- Semi-automatic where the performer influence the synthesised sound and
- Manual, where the performer is directly controlling the sound.

Automatic modules contain pre-composed sound and provide a sonic foundation, over which other events can be constructed and conducted. These layers can offer aesthetic and structural support to the interactive sonic events, which are getting interlaced with the background sound. Additionally, they may also include sounds that act as signs for the performer, for example, a sound that informs them about the progression of the composition to the next segment.
Semi-automatic modules are compositional objects that connect to a dynamic input. These modules are designed to operate according to certain syntactical rules, which define their sound character and directly connect with an on-body mapping arrangement. For example, when a semi-automatic module is operating it can continuously generate sound, which the performer interacts with, altering its sound characteristics and shaping its loudness with the intensity of their movement. These modules can be very rich because of their enclosed syntax and can operate with both the rhythmical detected “hits” and any other continuous data captured from the body.
Manual modules are the basic elements of methodical systems, which can be designed following a musical instrument paradigm. These modules need to be particularly robust and predictable within the range of their operation. The performer has direct and absolute control over the synthesis of their produced sound which is generated on demand.

5.2.2 Compositional Blocks

As seen at Figure (52) these modules can be further organized in layers and these layers can form complete compositional blocks. A compositional block is therefore a collection of modules that operate simultaneously. After defining several compositional blocks a WBI system can operate them based on their progression and activation mechanisms as:

- Linear time-based
- State-based
- Pattern-based

In a linear time-based interactive composition these blocks are engaged to perform in a series following a linear time (timecode) progression through multiple states of the composition. While this may limit the potential for a system to exhibit a dynamic compositional character, it can offer a solid structure for the performer to explore and master the composition through training, gaining virtuosity over the performance. A state-based dynamic structure on the other hand liberates the performer from the connection with linear time and creates a dynamic, improvisational relationship with the performer, who engages in a dialogue with the system. Finally, pattern-based arrangements can emerge through a static or evolving pattern that defines the progression of the composition.

By defining the content, dynamic range, and mapping of each compositional module, a designer can produce unique aesthetic and interactive characters for the WBI system as well as complete narratives. As a general note, I realised that simple mappings can be more effective and fruitful than complex arrangements, especially when many compositional modules are performing at once. Instead of building complex layers that are difficult to operate it is generally better to build simple interactions that can be well understood and easily executed by the performer. Ultimately, complexity is perceived from many simple layers operating collectively.
5.2.3 Digital musical instruments

The aesthetics of the performance are also shaped by the method chosen for the production of the interactive sound. Basic methods that can be used for synthesis of interactive sound are:

- Digital manipulation of live sound
- Physical modelling
- Digital instruments
- Sound sampling techniques

Live sound can include the manipulation of physical instruments as in _Untitled#1_ or using the performer’s voice as seen at the _Secret Project_, the interactive performance described in the second chapter. The real-time manipulation of live sound provides the benefit to the performer of having physical control over the original sonic material that is fed into the interactive system, which is a playful physical act on its own. In the case of live musicians, an immediate relation is established between them, the performer and the interactive system.

Physical modelling algorithms have not been used in any of my projects but further research aims to explore ways on how to map physical properties of sound directly to physical characteristics of movement.

Digital instruments for composing electronic sound, using both software or hardware, can be employed for the exploration of various methods in electronic synthesis, such as additive or subtractive, that carry characteristics related to the electronic and electroacoustic music tradition. None of the projects in this research aimed to examine this approach and relate to their distinct aesthetics, but future collaborations with electronic music composers could reveal interesting associations between movement and the synthesis of electronic sound.

I consider working with sampling techniques a highly flexible method for exploring interactive sound with the body in the performance art context, because the sound can keep references from its original source while it can also be digitally manipulated to produce more abstract electronic qualities. Sampled sound material can be collected and organised based on their original physical characteristics and then by their perceived intensity. This process helps preserve the coherence of the resulting sound, since digitally altering a sound to increase or decrease its intensity can often create unwanted digital artifacts. Professional sound sample libraries from acoustic musical instruments often use the same technique, where
multiple recordings of the same notes are organised based on their intensity. The sounds in my last three projects were organised in a similar way on a virtual sampler\textsuperscript{46}. Figure 53

![Diagram of Kontakt software sampler](image)

Figure 53: The arrangement of sound samples in the software sampler Kontakt

5.2.4 Speakers Setup

The setup for the speakers within the physical performance space is the last layer in the design of the proposed layout of a WBI prototype system. Although there are no algorithms involved in this process, it is equally as important as all other design layers of the system. Since the final sound source of a WBI system is represented by the speakers, their arrangement around the performance space can drastically alter the experience for both the performer and the audience. More details about different setup concepts can be found in the Appendix.

\textsuperscript{46}In these projects I have used Native Instrument’s digital sampler Kontakt. www.native-instruments.com/#/en/products/producer/kontakt-5 (last accessed August 2012)
“Human endeavors called creative - man’s poiesis, the bringing forth of objects which would not have come to existence without composition, without art, without desire - entail a hidden orientation towards discarding the technical code inscribed into available tools. In short: art is made by inventing the techniques of its making, which is to say by questioning established, inherited techniques and methods. Artifacts are as traces of poiesis, tangible products testifying at invented ways of acting in a medium.” AGOSTINO DI SCIPIO

6 Final Projects

In the final phase of research, Enactor’s effectiveness in designing WBI sketches and complete performances was tested through the development of three additional projects, Hiroshima, Duende, and a workshop in the context of Yoga. These projects were defined as pilot studies and were set to examine a broad context of WBI applications. With the exception of Hiroshima, the other two projects are not considered to be complete performance pieces but preliminary studies that led to the development of prototypes for the study of WBI applications in the context of traditional dance practice and Yoga.

Hiroshima is a complete, sonic-theatrical, interactive performance piece. Through an exciting collaborative and methodical process, with composer Shiori Usui, I aimed to investigate the direct use of the body to orchestrate and perform an interactive, time-based music composition. As part of the project we realised a detailed score based on the development of various compositional elements and objects. Through this project, I studied and applied various design strategies and compositional ideas that enabled a sense of acting and play at the core of an interactive sonic-theatrical musical performance.

Duende is a WBI system developed within the traditional dance context of Flamenco. Dancer and instructor Mariza Dima, described during the project the essence of this traditional dance practice and proposed possible scenarios that led to the development of the first WBI performance system in a traditional dance context. Duende is a prototype designed for a playful Flamenco dance style called Buleria. Its components though, can be adjusted, expanded and used in various other styles and traditional dance forms. It requires further testing of its value as a training system and has not yet been utilised for the development of a complete artistic performance piece. The aim of this project is not to render traditional musicians as obsolete, but to illustrate that systems can be designed to operate accurately and creatively within a traditional dance context.

The EnYoga system was developed for the sonification of Yoga, during a workshop with instructor Gesa Piper. This was a

\[47\text{In Scipio (1997)}\]
\[48\text{Based on a choreography that is realised along with detailed compositional structures}\]
brief study of the interactive relations between a WBI system and its user, away from the traditional performance context. My aim was to work within a context that escapes central performance requirements; for example, the presence of audience. The objective of the study was to create a personalised system that operates at an intimate level with the user. In addition to the information provided in chapter five, in relation to EnActor’s posture recognition extension, more details about the project can be found in the Appendix.
6.1 Hiroshima - Exploring Composition in WBI with EnActor

6.1.1 Introduction

*Hiroshima* is a performance, in collaboration with composer Shiori Usui, that can be described as a combination of music composition, storytelling and interactive theatre. Because of its unique qualities, I consider this to be a new form of performance, which I refer to as interactive sonic theatre. A three dimensional digital reproduction of the performance setting can be seen in Figure 54.

*Figure 54: Hiroshima 3D space plan*

*Hiroshima* draws inspiration from 6 August 1945, a day of international remembrance of humanity’s catastrophic nature. The abstract narrative unfolds with the performer’s embodiment of virtual characters depicting the morning of this infam-
ous day at a family’s house in Hiroshima. By means of acting and interacting with sound, the performer communicates emotions through an unfolding narrative. She engages in a constant transformation, expressing the diversity between the present reality and the one of the play, as realised in a conceptual-based interactive composition. Because of the nature of the storytelling element, which extensively uses hands and facial expressions, I focused only on the upper body of the performer to design the interactive mechanism for this performance.

To explore the storytelling element of *Hiroshima*, I related the role of the performer to a *rhapsode*, an ancient Greek performer of epic poetry. In this pre-theatrical practice, the narrative was communicated through language, gesture and sometimes music, but it did not include the actual re-enacting of roles, as was common later in traditional Greek theatre. In this modern interpretation of the practice, the performer in *Hiroshima* adapts the role of a rhapsode and narrates a non-verbal story with means of expressive gestures and interactive sonic responses. She undergoes a constant transformation while using the interactive system and embodies several characters as she communicates the narrative of the piece to the audience.

The idea of the performer as a virtuoso of the interactive system, the composition, and the performance as a complete interactive environment, was an integral part of our approach. Through intense training and rehearsing, the performer embodied the composition which was then enacted through an immersive momentum.

6.1.2 Compositional Elements

Having worked before with Usui with Digital Surfaces and Untitled#2, there were already common elements in our understanding of the WBI framework. The knowledge and experience obtained from all previous projects, as well as the design of EnActor, informed new ideas for using the body to compose sound. In this piece, Usui has a dual role of both performer and composer.

The main idea for the development of the piece was to use various compositional blocks arranged in a linear time-line. As illustrated in the previous chapter, each block contains layers of compositional modules, which include all mappings and syntax that connect actions with sound. A primary aim of this collaboration was to realise a performance piece, presented in front of a live audience, which would test the experience of orchestrating and performing a complete music composition.
A complete score was produced for the final performance that included details of the musical structure, the interactive compositional blocks, detailed mapping to the body and acting instructions. This score became an integral part of the development of the work and was used as a blueprint for the design of the performance mechanism. At the end of the project, all elements were re-analysed and informed a final version of the score that can now be used for documentation and also future re-enactments of the piece. Figure56. The complete score and various stages of its design can be found in the Appendix.
INTRODUCTION

TYPE OF SOUND: speakers

PARTS OF BODY USED
body movement
resultant sound

Notes for performance practice

Notes for performance

COOKING A speakers 3 & 4

LEFT AND RIGHT FOREARMS
Intensity of the hitting movement corresponds with the triggering of different samples

AREA-PHONE
Samples distributed 180 degree of space in front of the performer.
Area divided into 18 spaces with 54 samples distributed.

EXAMPLE SEQUENCE 1

WIND speaker 3 (L.H.), speaker 4 (R.H.)

LEFT AND RIGHT FOREARMS
movement of arm
playback of audio ON
no movement of arm
playback of audio OFF

velocity of movement
correspond to the intensity of sound
e.g. when the velocity of movement is strong, the volume of the sound increases.

CONTROL (approx. 30 sec.)
Imagine that you are "conducting" an orchestra or playing an instruments with different sound colours and pitches.

YOKO'S VOICE speaker 1 (L.S.), speaker 2 (R.S.)

LEFT AND RIGHT SHOULDERS
movement of shoulder
playback of audio ON
no movement of shoulder
playback of audio OFF

Note that the right and left shoulders share the same audio samples.
Note that the audio samples are arranged from phonemes to small phrases.

Eyes open when the sound of voice is heard (from unconsciousness to consciousness). As if hearing or reacting to someone's voice.

CLOCK A speaker 7

PARTS OF BODY USED
body movement
resultant sound

Notes for performance practice

Notes for performance

SPINE
sitting still
normal playback of audio
bending backwards
lower pitch
slower ticking sound
e.g. The clock sound when the body is bent extremely backwards.

bending forwards
higher pitch
faster ticking sound
e.g. The clock sound when the body is bent extremely forwards.

AUTOMATED PRE-SET
repetition of the same pitch.

AUTOMATED FADE-OUT
transition to lower pitch
less frequent occurrence of the sound.

Be aware of the axis (i.e. spine) and feel the weight of your body.
In quest for balance of your body.
Explore the subtle changes of the speed and pitches of the clock sound.

Move the body slowly most of the time. A few sudden changes of speed and pitch of the sound in between.
Do not move your feet.
Eyes closed.
Imagine that you are travelling through the time.

Move the forearms after playing with the clock sound.
Eyes closed.
Create rhythmic interplay with the clock sound.

D. W. A. S. M. E. N.
Usui, as a performer, was able to conduct the sound production in real-time by operating multiple sets of digital sound instruments, which mainly correlated to notions and metaphors of intensity, time and space. During the design phase, in order to create a bridge between the perception of a movement’s intensity and its reflection to the sound in terms of traditional composition, a common eight-level scale was used to describe the dynamics of a performed sound to the responses of the interactive system.

<table>
<thead>
<tr>
<th>Dynamic</th>
<th>Velocity</th>
<th>Voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppp</td>
<td>16</td>
<td>Whispering</td>
</tr>
<tr>
<td>pp</td>
<td>33</td>
<td>Almost at a whisper</td>
</tr>
<tr>
<td>p</td>
<td>49</td>
<td>Softer than speaking voice</td>
</tr>
<tr>
<td>mp</td>
<td>64</td>
<td>Speaking voice</td>
</tr>
<tr>
<td>mf</td>
<td>80</td>
<td>Louder than speaking</td>
</tr>
<tr>
<td>f</td>
<td>96</td>
<td>Speaking loud</td>
</tr>
<tr>
<td>ff</td>
<td>112</td>
<td>Yelling</td>
</tr>
<tr>
<td>fff</td>
<td>126</td>
<td></td>
</tr>
</tbody>
</table>

This dynamic scale was considered especially useful when testing and utilizing the AreaPhone component of EnActor.

![Figure 57: Dynamic range used for intensity measurement in Hiroshima](image)

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50 The AreaPhone was introduced and described in the previous chapter.
Based on the original concept we created a first version of an abstract performance narrative which was analysed in terms of its dynamics and divided into sections, to be implemented in the WBI system as compositional blocks. The overall appreciation of the performance system was considered as empirical, since the performer was able to engage to a continuously progressing and adapting interaction mechanism, but various parts of the design concerned methodical systems, as for example the use of the AreaPhone. Its use in *Hiroshima* was based on a 180 degree area, divided into a number smaller regions, depending on the requirements of the composition during the performance.

Figure 58: Equal and unequal arrangements on the instrument

Through the process, several observations emerged regarding the use of compositional modules and the design of various instruments and interactive processes. I will summarise these through some basic examples of the use of the three different types of compositional modules. I advise the reader at this point to watch the full play of *Hiroshima* and study the score of the performance before continue reading the following analysis.
Video: Hiroshima: The complete performance
6.1.3 Automatic Compositional Modules

Automatic compositional modules are pre-composed modules that can automatically recall or play back a sound track, or begin their automatic sound synthesis processes which are driven only by a timer. These are close systems, not connected to any layer of the performer’s actions and can be used to:

- inform the performer of the progression of the narrative

(video H1) The loud sounds of the engine indicate a threat and the performer hides under her desk. When the engine fades out, the progression of the interactive system directly associates stomach grumbling sounds to her hands and she moves back to the desk illustrating this particular change. The automated sound is used here as a signal to the performer to hide, knowing that she is now detached from the interactive system. Therefore, the performer is able to identify certain parts of a pre-composed sound layer with specific changes to the mapping of the interactive system and relate to the progression of the narrative. These associations can then be objectified as special key moments and assist the performer to enact the narrative.

[Video H1: Hiroshima: Engine/ Stomach grumbling]
• provide a foundation of sound

(video H2) A layer of pre-composed sound begins, consisting of hissing noises and radio signals, and the performer constructs her sonic structures on top of this layer. This can be used by the performer creatively as a sonic foundation over which other sounds can be interlaced to create a dialogue or a rhythmical structure.

• take over of a semi-automatic module and lead its progression

(video H3) Just before the first vocal sound appears the clock module is switched into an automatic mode from its previous manual one and fades out. At this point the performer can control vowels and the synthesis of short abstract phrases
moving her shoulders. The clock continues to tick but its rate and pitch is not longer controlled by the performer. They are driven instead by an automatic algorithmic process that it is programmed to drive the clock sound engine to generate exactly the same result as it gets reduced and finally disappears from the synthesis.

Video H3: Hiroshima: Clock Automation

- adapt and serve a conceptual role in the performance

Following a conceptual decision, all automated modules in Hiroshima represent elements that the performer’s character is not in control of. For example, various sirens and the sound of engines represent an external threat, and the radio signal sound composition layer is used as a historical reference. Elements such as these are externalised and used to shape the dynamics and create key-points in the narrative of the performance. In order to differentiate those from the sounds that the performer controls, these external automated sounds are played-back through dedicated sets of speakers. Sounds that referred to external elements of the environment were emitted from the set of speakers positioned behind the performer,
and the radio by a smaller speaker in her front-left area. Figure 59. More information on various speaker setup concepts can be found in the Appendix.

6.1.4 Semi-Automatic Compositional Modules

The semi-automatic modules share the production of the sound with the performer. These are empirical systems that require a dynamic input to operate or to shape their produced sound. I consider them very important in order to:

- disengage the performer from an absolute link with the production of the sound
Following a direct movement to sound interaction paradigm, such as when directly operating a digital instrument with the body, can create a feeling of predictability and lead to the perception of repetitive and unexciting reactions by the WBI system. This effect is commonly addressed as the *mickey mouse effect*, drawing a reference to the one-to-one sound relation between movement and sound often found in the popular cartoons. Using a semi-automatic compositional module the performer’s movement only controls some parameters of the sound synthesis, minimising this effect. The performer is controlling the rate and pitch of the clock sound with her spine, without any intensity matching between her movement and the response.

/video H4: Clock Intro

• encourage specific requirements that shape the qualities of the actions

In an attempt to provide a theatrical experience, the designer often needs to address techniques that can instruct or even shape the qualities of the performer’s actions. When a wind sound is introduced, each hand’s movement...
controls the volume envelop of a dedicated wind instrument while the sound is constantly playing. Additional filtering of the sound produces a sharper sound at a higher intensity, offering more variation and a dynamic character. This particular design leads to a smoother movement and a stronger association with the sound of the wind, since the performer does not need to register a hit to initiate the sound and therefore her movements become steady and continuous.

Video H5: Hiroshima: Wind Control

- enrich the sound composition with additional sound layers that relate to secondary control mechanisms

(video H6) For some layers of interactive sound, the connection between the actions and the resulting sound is not explicit, but is designed to primarily serve the sound composition and build a rich sonic environment. A semi-automatic layer operates an instrument that produces sound inversely analogous to the activity of the performer. The result is a sound that increases as the performer’s activity decreases and comes closer to stillness. This reversed mapping logic was partly used to avoid absolute silence when the performer is not moving, but also to add a dramatic sense to the performance. This
specific low frequency sound layer automatically increases its sensitivity over time and reaches a climax at the end of the performance.

Video H6: Hiroshima: Subsonic Vibrations and Reversed Activity

6.1.5 Manual Compositional Modules

Manual modules are those in which all parameters are controlled by the body and the movement of the performer in time and space. Therefore, these are approached and designed as methodical systems. These modules can relate to:

- an instrument, where the main focus is to relate to motion-sound qualities

(video H7) The sound synthesis in this case is instructed through an absolute association between the dynamics and rhythm of the performed actions. The performer can amplify this relation by mimicking physical actions related to the performance
of musical instruments as hits or other gross palindromic movements. The performer is using the virtual AreaPhone as a musical instrument, and registers her actions clearly as hits.

Video H7: Hiroshima: AreaPhone as Instrument

- an illustration, where the main focus is to reveal gesture-content qualities

(video H8) The gesture to sound relation is built here through actions that illustrate a link or a representation of the sound source. The performer can engage in a more theatrical role and amplify this relation with a broader communication of emotions; for example, facial expressions and short movement sequences. The performer is using exactly the same setup as in the previous example but she is now engaged to perform along with the associations of the produced sounds, and what these can physically represent, by illustrating related actions. This approach is associated with a theatrical tradition.
Video H8: Hiroshima: AreaPhone as Acting

- a metaphor, where the primary focus is on representing movement-concept qualities

(video H9) In this case actions are used to communicate an emotional or a metaphorical state of being. The intense shattering glass sounds emphasise at the emotional state of the performer, as her whole body seems to break down and movement becomes rapid and asynchronous. Alternatively, the interactive sound can be used to provide a context for the performed gestures or relate to concepts within the environment of the play. This approach amplifies the performance or dance element, primarily connecting the movement to a specific concept.
(video H10) A performance with a manual compositional module operated by secondary body movements and their dynamics can be seen in the following two videos where vowels and short phrases from additional virtual characters appear in the play. In both cases the construction of the sound is controlled by the performer’s shoulders and the synthesis is based on a collection of short phrases and vowels. These are either produced in real-time or recorded and played back at the end of the performer’s cycle of actions,(video H11) a paradigm that relates to a more theatrical idea and mimics a dialectic system.
Video H10: Hiroshima: Talking Vowels I
(video H12) During various stages of the performance, Usui uses her physical voice to create additional sonic material that is then manipulated in real-time with her body. A similar approach was explored in *Untitled#1*,\(^{51}\) with the direct manipulation of live, acoustic sound with the body. This intense and engaging interaction provided an additional level of expressivity and control for the performer, since she could produce specific qualities with her voice that were further manipulated and interlaced with the other compositional layers in the performance.

\(^{51}\) As described in subchapter 4.2
6.1.6 Adaptation of the Composition and the Notion of Play

The design approach and the various strategies that were followed in Hiroshima, allowed the performer to gain virtuosity over the composition. The time-based progression of the compositional blocks and their fixed duration formed a concrete foundation over which the performer was able to structure a reproducible performance piece, while constantly exploring the interactive system in a playful way. During the rehearsals, several explorations of the body movement in the spatial-temporal domain helped the performer find a balance between a well-defined choreography and improvisation.

Birringer (2008) offers insight into this fine balance with the following statement:

When interactive performance is presented to a viewing public, the interactor engages a real-time system and environment of feedback that require specific subtle techniques to generate processes. While the software
and hardware design for the environment may be deployed for specific purposes, and thus have a compositional or conceptual dimension, the performance application focuses on a reflexive and adaptive (often quasi-improvisatory) role of experience in the embodiment and articulation of the system’s virtualities.

Detailed compositional and choreographic elements are of high importance as they offer the performer the ability to orchestrate and reproduce a recognizable performance piece. The fine balance between these and the adaptive and reflexive elements, as described by Birringer, is what enables the performer to extensively explore and master the WBI system. The reflexive element was emphasised with the design of immediate and expressive interaction mechanisms, such as the AreaPhone, that facilitate the exploration of micro-tonal and micro-temporal modifications of the sound. Since the performer was also the composer of the piece, her understanding of the composition was very strong. In this project the WBI system was tailored around this particular relation and a future attempt to replicate the performance with an actor or a dancer is worth investigating.

During the conceptualization and the technical realization of the piece, there was a constant quest for elements that could enable a sense of **play**. The importance of a playful interaction encourages engagement with the system and offers a counterbalance to the element of control that is also required. A fundamental conception on how to create an environment that promotes the notion of play, was inspired by the work of Botz - Bornstein (2004), where he states about play: “One has the impression that in play the lack of individual and subjective consciousness of the player has the precise effect of augmenting the intensity of the play’s consciousness.”

What Bornstein describes as the lack of “individual and subjective consciousness of the player” was explored in *Hiroshima* through a constant transformation of consciousness, a continuous metamorphosis of the performer. This metamorphosis was described in the narrative and was implemented through the interactive system following the composition. The effect of “augmenting the intensity of the play’s consciousness” was considered of high importance for communicating the narrative. Regardless of which limbs were mapped to each compositional block that produced sound, the performer was encouraged to explore the movement of her whole body and define expressive ways, such as the use of facial expressions and live vocals, to synthesise and deliver the sound and the narrative of the performance.

Kinetic patterns and particular sonic responses quickly started to emerge at various parts in the composition as the performer let go of her subjective consciousness and personified the diverse roles of the narrative. We observed that the performer gradually became more open to directly embodying different entities and roles and relate to them through specific kinetic patterns or sounds. These were recognised as, “objective elements of consciousness”, that according to Botz - Bornstein (2004):
Games renounce objective elements of consciousness that have been objectified by a subject beforehand, in order to find its own consciousness directly. And that is what permits play to overcome that mechanic stage and to become playful in the proper sense.

During the final stages of our rehearsals, interest shifted toward identifying how to amplify this effect by constantly breaking and challenging these defined objective elements. Our goal was to find a new balance between the more solid elements of composition and choreography and of improvisation.

A way to break these objective elements was explored through the use of real-time vocals, and their real-time manipulation by the performer as described earlier. The performer created an abstract vocabulary for expressing and externalizing emotions vocally, while rules for their manipulation were described with the compositional objects that were created. This additional layer of expression became an important tool for the performer to define a variety of new playful responses and engage in new patterns with sometimes symbolic or representational functions.
6.2 Duende - Exploring the transfer of traditional dancers to a WBI setting

6.2.1 Research phase

Studies in the research context of interactive music and dance related to traditional dance forms are rarely found. The reason behind this can be traced to the resistance that traditional practitioners often present against working with new digital technologies, as well as the observed dominant preference for electronic sound and contemporary dance styles, found in most interactive music and dance research and artistic explorations to day.

The aim of explorations of interactivity in the traditional dance context, is not to create a digital system that could replace musicians but only mimic to a degree, their virtuosity and playfulness when performing within a traditional framework. Moreover, is an attempt to link the emerging technologies with the direct transfer of tacit skills of traditional performers and create a bridge between technology and the playfulness of traditional dance.

This study was a proof of concept for the ability of EnActor to be programmed to operate with a specific traditional, rhythmical, dance framework and provide a digital setting for the dancer to engage in meaningful interactions with the system, using only her tacit skills with minimal instructions.

This project was also realised around a holistic design model approach, where during an extended research phase, discussions with the traditional dancer served to communicate, understand and appreciate the broader cultural elements that form the basis of Flamenco music and dance. A prominent characteristic of dancing Flamenco is the fast interplay between the performer and the musicians, and the continuous succession of hits, both on-beat and off-beat, that drives the intensity of the dance. Dima and I agreed that this physical interaction was the key element that needed to be transferred to the digital setting. Dima emphasised the significance of the accentuation of each rhythmical structure as the pivot that assists both the performer and the musicians in knowing at all times on which step of the meter they are. A deep understanding of each particular rhythmic structure (compás) is fundamental for all the participants in Flamenco, since it forms the foundation upon which the physical interplay between them unfolds. This knowledge and particular Flamenco patterns informed the development of the compositional layers through EnActor. My focus was on how to realise a system able to operate within a solid structure but also offer enough space for improvisation.

Dima described in detail the ways in which the performance of the different instruments including the voice of the singer, and the dancer’s actions, drive the performance from low intensity to a crescendo. During a traditional performance, the overall intensity of the group is most often driven by the dancer. The musicians respond to her dynamics either by recognizing certain gestures which form part of a patterned step, or by observing the overall dance in relation to the compás (rhythm) and to the succession of traditionally formed structures. These aspects of Flamenco were perfectly aligned with
the basic design framework of EnActor and its core module. Figure 60 shows a traditional setting of Flamenco dance.

In addition to the overall intensity, there is the significance of shifting the hits between “on- and off-beat” during the performance. This practice by both the musicians and the dancers not only enriches the sonic space but also transfers the interplay to a higher level of communication where the precision, speed and creative tacit skills of every participant, play a major role in the formation of a momentary excitement; a crescendo reached in a collaborative manner. In the language of Flamenco this is referred to as Duende and was chosen as the name of the interactive system.

The research phase concluded with a design brief for the development of a compositional algorithm based on the characteristics of a selected traditional dance form, which could be driven by the intensity and the rhythmical patterns produced
by the dance. The challenge was to achieve a fast and playful interaction with the whole body within the selected Flamenco style and encourage the emergence of sonic vocabularies directly understandable and usable by the performer. The basic patterns of a particular Flamenco dance were described to EnActor’s pattern matching algorithm to ensure their structure, while the time signature of the traditional rhythm was secured by the time adjustment algorithm.

6.2.2 Design and implementation

The design phase began with the development of the rhythm-based compositional block and was followed by its mapping to the body. There were three sound layers integrated in the composition imitating the musical instruments of the cajon, the castanets and palmas (clapping), broadly used in Flamenco. Each of these instruments and its compositional layer was connected to the body in an iterative process passing through continuous refinements. Through practical observations and several trials with different arrangements, we ultimately defined the mapping scheme according to what felt most natural to the dancer. The cajon was mapped to the legs, while the palmas were mapped to the hands. Castanets, the playful percussion instrument used traditionally by Flamenco dancers, were associated with the movement of the chest and hips. The body mapping process revealed some interesting observations regarding the embodied metaphors that were used. While palmas are traditionally created by a skilled “palmero”, the clapping sound emerged as an obvious link to the dancer’s own hands in Duende. The pace and volume of the clapping was associated to the intensity of the movement of the dancer’s hands, which provided a strong connection that was perceived as matching.

The sound of the cajon, was assigned to the legs, again leading to another interesting observation. Although the cajon is a percussive instrument performed by the hands, in the traditional setting the dancer carries out choreographed or improvised steps over the beat of the cajon. This creates a strong association between the movement of the legs and the rhythmical percussive patterns. In addition, the footwork in the traditional setting serves as a percussion instrument itself, accompanying and interplaying with the cajon, while performing on the off-beat.

The mechanism of Duende was completed over three stages while it was explored through a series of practice sessions after the development of each stage. In the beginning of each session, some rehearsal time was spent on refining and reconfiguring the adjustable presets based on the temporal, desired body movements of the performer. This proved to work particularly well, since the performer was registering and associating the intensity of her movements to the sounds with a desired effect which best matched her temporal preferences. Figure 61.
Part of this process was to carefully refine the mapping of the velocity data to the character of the sound. By adjusting the motion data shaping and filtering module, the sound instruments can develop various characteristics related to the sensitivity of their response and the sharpness of the resulting sound. As an example, the exponential distribution used for the castanets, resulted in highly responsive sound and developed a sharp, playful character.
After the thresholds had been readjusted to accommodate the movement set, the performer sought to identify patterns in the way the system responded best to her movements. The dancer first experimented with each instrument by moving each part of her body, and then she proceeded to explore the ways in which all the instruments could be combined through dance. Practising is essential in order to embody the responses and start building a sonic vocabulary. I consider this process to be the most crucial for building engagement with the system, gaining expertise and virtuosity. With time, the performer mastered the system and transformed it into an interactive compositional tool which assisted her to create a series of improvised performance trials.
With minimal practice the performer started creating musical phrases associated with particular movements and performed them on demand. Appealing to ideas of control and memory, the ability to recall musical phrases through repetition provided strong associations for both the performer and the viewer, creating a mutually engaging experience.
This progression of the dancer from the exploratory use of the system to virtuosity and the mastering of particular techniques within the interaction loop, manifested the abilities of the system to ease the transfer of her tacit skills gained from the traditional Flamenco dance into the new interactive setting. The system is not only the mediator of a dancer’s tacit skills but also a distinctive new medium on its own. Figure 62.
Figure 62: Rehearsal setting for Duende
6.2.3 Agency and Responsiveness

The interaction mechanism of the Duende system was designed and operated through the metaphor of the virtual musician. An important element of systems that are designed to operate under this metaphor is the connection between stillness and silence that offers a critical perception of control. This was confirmed as valid particularly for dance systems such as Duende, where the perception of the rhythm controlled by the body, can only be maintained through this basic rule. For example, even if a short sound of the cajon, associated with the foot steps of the performer, is produced after the performer stands still, it is enough to challenge the whole application and be clearly interpreted as a mistake.
Another element to maintain the central metaphor of the musician is responsiveness. Musicians that operate instruments expect an immediate sound response to their gestures and so do dancers, at least in the traditional context. Therefore the response time of the interactive system needs to be as low as possible. If the response occurs within the range of some milliseconds the system can be considered responsive, following the metaphor of a musical instrument. If the response time is longer than that, or comes after the completion of a gesture, it can operate as a musician engaging in a dialogue with the performer in an improvised setting. Siegel and Jacobsen (1998) make some valuable observations about system responsiveness:

If a dance interface is sluggish in tracking movement, there will be an inherent and perhaps unpredictable delay between action and reaction. The amount of lag that can be tolerated will depend on the type of gesture and the desired type of correspondence between gesture and sound. For example, if a slow, sweeping movement is used to evoke a crescendo, a lag time of over 1 sec might be imperceptible. However, if a sudden and precise
gesture like the striking of a fist on a table is to evoke a sound with a sharp attack, a delay of 50 msec would be entirely unacceptable.

Although responsiveness is tied to the abilities of the technological system, the perception of it is subject to various other parameters that are defined by the concept, content and context of each application and guided through the design of all engaging parameters that link the sound and movement in both physical and digital domains.

Further development

Traditional dance imposes very specific rules for the choreography and the music composition that can guide the transcription of various compositional layers effectively. Thus the study of these relations, naturally became the core element of the research phase for the design and realisation of the interactive mechanism of Duende.

While utilizing their training and in-depth knowledge of movement and the body, skilled dancers can collaborate with WBI designers, choreographers and composers to further investigate the realisation of traditional dance-based WBI performances. Additional styles of Flamenco as well as various other types of traditional dance and music can be explored and transcribed to EnActor. Acquiring expertise in this new interactive design process opens up new opportunities for the fusion of traditional and technological elements into interactive dance and performances.
7 Summary & Future developments

7.1 Introduction

The main objective of this practice-led research was to investigate a design framework for developing interactive performance systems that enable the experience of direct control of digital media with the body through the use of advanced technology for real-time motion capture.

My investigation was carried out in parallel to the coordination of a series of workshops and collaborative artistic projects with musicians, composers, dancers and performers. In this final chapter, I will summarise my results and discuss the aims and findings of my thesis while taking into account current research, new artistic explorations and recent technological advancements. Finally, I will raise questions about the future of dance, music, performance art and theatre that utilise real-time motion capture in their practices.

7.2 Statement of the Problem

As discussed in the second chapter, there is a wide area of research and practice that explores interactivity in the contexts of fine art, music, dance and performance art. Since these explorations evolved in parallel with the development of software platforms and various sensing technologies, such as cameras, wireless sensors and complete motion capture systems, they often addressed challenges that were more related to engineering and programming rather than to traditional and contemporary artistic practices. Unlike traditional tools that are solid and simple to use, digital tools are often characterised by fluidity, complexity and a rapidly evolving nature that can impose additional obstacles.

Calibrating sensors, adjusting cameras and other challenging and often unreliable electronic devices, along with programming and debugging custom software, progressively became an integral part of the new explorations in digital performances. At the same time, performers were often restricted with additional rules and constraints, that were neither conceptually nor aesthetically driven but purely technologically based. As a result, the technical and engineering skills required for the development of such demanding work, along with the frustration of using abstract and unreliable technologies discouraged or even excluded the majority of traditionally trained artists and performers from an thorough participation in these explorations. Therefore there is a necessity for a non-pervasive technology able to inform a digital machine of human presence, condition and actions in space and time with reliability. Towards this technological innovation the specific
requirements of the performance stage should inform the development of a real-time motion capture solution that can be specifically used as a robust tool for further explorations of this proposal in a broader artistic context.

I believe that non-digital performance practitioners carry important knowledge that should be able to be seamlessly transferred to emerging interactive digital platforms. Moreover, their participation in the actual design and development processes towards these innovative platforms is necessary. Therefore, my practical explorations included collaborations with dancers, performers, musicians and composers that were not part of the digital and interactive art communities.

The observation that initially mobilised my research was that in most cases there is an absence of an interaction design perspective regarding the strategies and collaborating methodologies that can be followed for exploring interactivity in the performance art context. Therefore, I have found it important to propose the development of a coherent interactive performance design framework and introduce specialists in body-based interaction design that could work closely with artists and performers within a collaborative, transdisciplinary platform.

Often through trial and error, mappings and assignments were thought to be most successful when they were related to metaphors that were unique to the project, suggesting a particular idiomatic relation for their use rather than a universal one. More general metaphors that were explored related to associating the body with a controller, a musical instrument, a musician or a medium for personifying theatrical characters and engaging with interactive environments.

7.3 Holistic Design

As discussed in chapter Three, the Holistic Design Model, proposed by Woo (2007) is based on understanding of the entire design process as an experience that includes the designer, and describes it not as a linear, methodological progression towards a specific goal, but as a circular continuum that leads to the aggregation of experience and knowledge, which leads to innovation. This analysis describes three phases in the design process: research, design and innovation. Within the research phase there is an exchange of information from previous experience that enables the formation of knowledge. This knowledge is then used in the design phase, which can contain various processes and methodologies and leads to the realisation of new experiences that occur in the innovation phase. These new experiences raise questions that reflect upon the design aims and processes and become elements for further research, and the model continues infinitely.

In addition to the Holistic Design Model, a transdisciplinary collaborative approach was followed on all of my practical projects and explorations, that were integral to the progression of this research. Within the transdisciplinary collaborative

52Similar to the Experiential Design approach
environment, this design model offered an interesting platform for the integration of the diverse knowledge and expertise of my collaborators. Moreover, it did not impose a specific design methodology, but instead provided a framework where many methodologies were applied. An extensive study of these collaborations was not part of the central aims of this research, but I would like to stress the importance of:

- The co-evolution of a technique within a non-hierarchical framework, where the artistic concept engages in a synergistic relationship with the WBI design and any other involved disciplines, and
- The co-evolution of language as one should not assume that common terms imply common understandings.

Therefore, the concepts, the expectations and the technical solutions that are found, need to be constantly communicated with the whole team through an understanding that is built around a common language that is formed within the ecology of each collaboration. As the holistic design approach attempts to clarify this process it establishes the research phase as an ideal platform for collaborators to exchange information and build this common language. Starting with simple keywords of interest and general statements, collaborators can gradually build a mutual understanding and begin to gain experience through small trials and prototypes of ideas. The coherence of a WBI performance piece is a reflection of its development process. Since the model is circular, there is no specific beginning and end in this process and can still operate when started from any of its phases.

7.4 Motion Capture Systems

Motion capture is a powerful technique able to digitize and record a movement from an objective view, a "god's perspective". An objective form of representation, although it can be conceived and theorised by intelligent beings, is not fundamentally built into our perception. Exploring and understanding this new form of representation can become beneficial to both artists and designers interested in the development of WBI performance systems.

The research continues for a sophisticated technological apparatus that can enable a seamless and in-depth exploration of various body-based interaction design paradigms, based on traditional artistic notions such as composition, dynamics, space and time. Towards these efforts, wireless, inertial motion capture systems are leading to a robust technological solution that is ideal for the performance stage. Although not yet perfect, this particular technology, as opposed to optical motion capture systems, fulfils all the requirements set for a successful integration on the performance stage to a satisfactory degree, exhibiting a high level of reliability, transparency and mobility. Moreover, the agency of a sensor-based system is
fundamentally different from an optical one, which can be seen as a passive observer, so that when for example a dancer is using it, they dance with the system rather than for the system.

My investigations on the potential of wireless sensor-based mocap systems was made possible due to the first fully wireless, full-body inertial motion capture solution, that was developed by Young (2010) and the Research Consortium in Speckled Computing at the University of Edinburgh. More information about the system can be found at the Appendix.

Towards the end of my research, the technological advantage that this prototype wireless inertial motion capture system has offered was reduced, as commercial solutions following a similar design are now entering the market as commercial products. A strong indication that inertial sensor technology in motion capture is evolving quickly toward the direction of the Orient prototype design, is the first generation of fully wireless inertial sensor from Xsens, called Mtw. Although these sensors are not yet fully integrated with their complete motion capture software environment, they are sold as wireless inertial sensor units.

![Figure 63: Xsens, Mtw wireless inertial sensors](image)

In addition, the recent focus of Human Computer Interaction towards a physical computing paradigm in general, has...
greatly influenced the video game industry and offered the necessary background for the development of a wide range of simplified body and motion sensing devices, such as the low fidelity and low cost Microsoft Kinect and the Nintendo Wii controller. These interfaces are downgraded consumer devices from the expensive full body motion tracking systems that follow the optical or inertial sensor-based paradigms.

Nintendo’s Wii is an interface that uses motion sensors to capture data related to the dynamics of the user’s actions and can only approximately track the position of the sensor in space with the use of an infrared camera. Kinect on the other hand, is an interface that uses 3D depth imaging technology to scan the environment for human presence and calculate the estimated position of the user’s body joints using advanced algorithms. Kinect reached the market after I completed my practical explorations. As a widely accessible product, it has broadly delivered the message of the possibilities of body-controlled interactions, not only to the video game community but to a wide area of research and practice. Although these technologies can and have been used creatively in a performance art context, the performers and the artistic intentions in this case are subject to major constraints and limitations, since they can not represent the body in space with accuracy. Therefore, in contrast with a complete motion capture solution, interaction and game designers that use Kinect for developing body-based applications, often follow a design approach that is more linked to the sensor itself and what it can deliver, rather than to the user’s body and experience. Future developments in this area can potentially offer a low cost solution for tracking the whole body of the user in space with much higher accuracy and deliver the WBI design paradigm to a much broader audience.

7.5 Whole Body Interaction

In order to identify the range of expertise that is required for an interaction designer to design body-based interactions in the performance art context, I have introduced the notion of Whole Body Interaction (WBI) as a subset of Interaction Design. As a technologically driven framework, WBI examines ways in which designers can develop computational systems that incorporate physical, physiological, cognitive and emotional data from the user’s body into their design. Since the nature of the artistic process differs significantly from the scientific, the notion of WBI was not introduced here as a coherent methodological framework, but as a central notion that aims to emphasise the particular role of the interaction designer and indicate the centre of the interaction design process, which is the whole body.

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54 The device combines data from an infrared (IR) camera analysing a laser generated pattern, and a colour (RGB) camera
55 As f.e OpenNI and NITE software frameworks. www.openi.org
56 At the end of 2010, six months after I finished my last practical work
Since each performance has unique requirements that are related to its concept, content and context, my understanding is that there is no standard methodology that can be broadly applied in a wide range of artistic projects. The role of the designer in a WBI performance collaboration is to become an interpreter of the specific artistic intentions, as they emerge within the ecology of each project, and design interactions that promote these concepts. Every WBI performance should emerge in a technologically reliable and playful interactive environment that allows a rounded appreciation of the experience for both the performer and the audience. The role of a WBI designer in these collaborations is to introduce various concepts, techniques and limitations of the WBI framework and engage in mutual understanding of what the artist’s expectations, intentions, concepts, experience and knowledge are in order to design a corresponding autonomous system.

7.6 WBI Systems, Sketches and Scenarios

Following the understanding of interactivity as a property between systems, proposed by Dubberly et al. (2009), I identified three basic types of WBI performance systems: methodical, empirical and dialectic. The interactive mechanism of a methodical system has fixed properties and the performer can be trained to operate and learn it, similarly to a musical instrument. Empirical interactive systems adjusts their goals and share the control of their synthesis processes with the performer, who is trained to perform the system through experience, similarly to navigating within an interactive space, performing a musical score or dancing to a choreography. Finally, dialectic systems employ artificial intelligent processes, able to interpret the performer’s actions as feedback and adjust their goals accordingly, prior to responding.

While related terms have been discussed in other HCI contexts, I believe that these descriptions better correspond with the concept of performance and its artistic requirements. During this research, my aim was to design and build simple tools that can be directly understood and creatively used by a wide range of practitioners, artists and performers, instead of designing digital intelligent agents that engage in a dialogue with the performers.

Regardless of the nature of a WBI system, in general they should be able to provide a wide range of responses starting from an absolute control and synchronisation to the movement all the way to complete abstractions. Absolute control directly refers to methodical systems and to the design metaphor of a musical instrument, which can be more appropriate for music performance applications. Abstract responses are closer to the dialectic system paradigm, where the system’s processes can be interpreted not only as a direct cause of the movement, but as an actual reply to the performer. Empirical systems mainly stand at the range between these two extremes and share their processes with the human user.

In an attempt to simplify the development of a complete system, I introduced the notion of WBI sketches and scenarios.
The rapid prototyping of a simple body-based interaction concept is a WBI sketch and it is used for testing and validating ideas before adding more value and content. Information gained from these assessments along with a coherent design brief based on an artistic concept is a complete WBI performance scenario. Finally, a WBI system is a collection of mechanisms that can offer complete experiences that are based on sketches, scenarios and compositional arrangements that operate within the concept and the duration of a performance work.

7.7 Compositional Modules, Layers and Blocks

Since not all performers have sufficient music training or particular expertise on the control of digital interactive processes, a compositional structure is often required to ensure the formation of particular qualities and an orchestration of the produced responses. Therefore an integral part of my design was the analysis and development of various mapping and compositional concepts that I ultimately arranged in modules, layers and blocks. A compositional module can be automatic, semi-automatic or manual. Automatic modules contain pre-composed processes with no other interactions, aside from initiating, interrupting, or completing their content. Semi-automatic modules share their real-time digital processes with the performer, while manual modules are solely controlled by the performer.

Several of these modules can be further organised in layers that form complete compositional blocks. A compositional block is therefore a collection of modules that operate simultaneously. After defining several compositional blocks a WBI system can operate them either through a static or an evolving pattern, a linear time progression, or the introduction of a set of predefined rules that trigger them.

7.8 EnActor

During the first phase of my work, I established collaborations with other researchers in the areas of music composition and contemporary dance. Through the emergence of two projects and a workshop described in chapter four, I extracted useful knowledge regarding the design of body-based interactive processes and developed an understanding of the particular artistic requirements for their application in the performance art context.

Motion capture technology offers data related to the position and rotations of the body limbs in space. The Orient inertial motion capture system used in my research provides a virtual data-space that can be visualised as a cube, which contains a sphere that encloses all possible movements within the area of reach of the performer. This sphere can be seen in direct association with Laban’s kinesphere and used in the design of spatial and kinetic interactions.
With this system, scenarios for spatial interactions can be designed either dynamically, from the perspective of a personal motion capture cube that rotates along with the performer or a static one that has a fixed alignment with the orientation of the performance stage. Although it is common for both approaches to be interlaced within a WBI system, they result from two completely different design paradigms. Interactions based on kinetic properties of the body of the performer exclude any spatial dependencies and focus on the dynamics of the performed actions to generate their processes. These were found to be more reliable in my explorations, as inertial motion capture systems primarily sense the rotations, and then calculate the position of the limbs in space, leading to less efficiency for the design of spatial interactions.

EnActor is a prototype software for WBI design capable to address the development of a wide range of body-based interaction systems and scenarios. My approach for designing EnActor was to invent a simple mechanism at its core, that could be easily controlled, transformed and reproduced, and was able to solve at a fundamental level the basic problem of generating digital processes as the result of an action. The benefit of this approach is that it drastically decreases the design complexity, since the same module can be used for all parts of the body while having the ability to store particular configurations independently. The software prototype was implemented in MaxMsp as a collection of modules and it is easily expandable.

The core module of EnActor is able to accommodate all basic functions of the two identified central paradigms in WBI scenarios: kinetic and spatial interactions. Kinetic interactions provide the essence for adjusting the dynamics of the performer’s actions and extracting valuable triggers for the initiation of certain digital processes based on the detected hit frame. These triggers can create single events, organised as coherent rhythmical structures or be used for the playback of predetermined media arrangements following the barrel organ metaphor.

For the design of the core mechanism of EnActor assigned to implementing kinetic interactions, I followed the basic premise that every hit creates a sound and I started thinking of movement as a series of hits. Every time a limb stops and reaches a new position it generates a hit. The momentum of a hit characterises the intensity of the action that created it and affects the dynamics and qualities of its response, similar to when an object hits a physical surface. Inspired by this logic, I developed a mechanism, the fundamental mechanism, that was able to analyse the dynamics of movement in real-time and break it down into a series of events that can be used as triggers for various digital processes.

Using this mechanism one can choose to place the trigger at the end of an action, following a percussive or string plucking metaphor, where the sound initiates as the movement ends or at the beginning of it. The latter can be used for responses that are required to have a continuous reference such as a long drone sound or a wind instrument, where the sound begins with the movement and is continuously shaped following the dynamics of the whole action.

Monitoring the velocity of the performer’s actions, the core module of EnActor registers the hits produced by the body and
associates their dynamics according to the rules established by the designer. Just as force, when hitting a drum or blowing into a wind instrument, is directly associated with the energy of the produced sound, the increase in velocity of an action should produce sound with greater energy. Any reversed logic or alternative scenario to this, given by a specific artistic concept, can be addressed. Using an instance of the core module of EnActor assigned to a particular limb of the performer, the designer is able to sculpt the dynamics of the incoming energy from a gesture to match the desired dynamics of the synthesised response. The main methods that were followed to shape the data prior to sending them to their mapping associations included defining an activity threshold, performing velocity magnitude normalisation, and using techniques for filtering and reshaping the data, as described in more detail in chapter five.

To summarise the basic points, an activity threshold is set in order to distinguish movement from stillness; although it can introduce artifacts such as rare unintended responses by the system these can be bypassed with training. The velocity magnitude normalization can be either static or dynamic. If a system is static, the performer must adjust to the system’s fixed configuration, while a dynamic system constantly adapts to the performer’s temporal activity. Finally, filtering motion data can produce among other functions smoother responses that are sensitive to an increase in the body’s velocity but unresponsive to a reduction in velocity, and visa-versa. Reshaping the velocity data to a mathematical function provides a method for defining a new description of energy transformation between action and response.

The other part of the core system of EnActor was designed to address spatial interaction concepts. These are particularly close to Virtual Reality (VR) and video game applications and similar algorithms for designing 2D and 3D shapes were used along with collision detection and orientation algorithms. Collision detection can report when and how the performer touches or approaches a virtual object or any parts of their body, while orientation algorithms can be used to design interactions related to where the performer is pointing or looking at, and where they are facing or standing towards. Using a graphical environment for designing a scene is a necessary addition at the future development of the spatial interaction part of the software.

In addition to the abilities of the core module, the capacity of EnActor was expanded with the use of extensions such as the posture and gesture recognition, posture classification and surround sound control modules. Additional processes assigned to a common interaction scenario can be designed and added to the system using the OSC standard communication protocol.

57 A new function or distribution, f.e exponential, reversed linear, Gaussian etc.
7.9 General WBI System Design Notes

All practical explorations, presented in the previous chapters, were built on the understanding that there is a cultural and conceptual foundation that dictates the aesthetics and artistic intentions and a technological layer that sets limitations. The range between these defines the creative potential for the design of new interactive experiences.

Throughout my research I have identified particular strategies for designing WBI systems within artistic performances that can deliver specific interactions linked to specific concepts. Although I chose to work within the performance art context, there are valuable findings that can benefit the general understanding of WBI.

Overall, the WBI systems that I designed and implemented, were autonomous, operating in real-time during the performances with no external supervision. I believe this is an important factor for the design of such systems, as we have to offer autonomy to both the performer and the interactive system in order to form an engaging relationship.

Fine adjustments to the energy exchange between every step of the interaction cycle, described in chapter four as energy transformations, define the dynamics and the overall character of the media responses to the intensity of the performed actions. Regardless of the sophistication of the mapping that is used to describe an interaction, only the control of the energy transformation within a step of the interaction cycle can significantly alter or even overcome all other mapping arrangements.

Shaping motion data, in general, through a particular mathematical function or distribution can become an integral part of fine-tuning the dynamics of the interactions. In addition, one can associate two extreme conditions of the body such as the contraction and extension of its limbs\(^{58}\), the position of the hands, the velocity of the body’s limbs and their in-between distances, to two extreme conditions that are described in an interaction scenario. The mapping between those can then follow a linear, exponential or any other mathematical formula and can be further filtered to assign a particular character to the responsiveness of the system.

In general, I observed that an important way to demonstrate the performer’s control over the interactions is to pause or minimise the digital processes when the performer suddenly stops. In addition, recognising a specific body pose can be used as a trigger for various processes such as the progression of the composition or the formation of special moments of intensity associated with particular keypoints in the choreography and the composition of sound.

In an attempt to transfer the skills of artists and performers in a WBI platform, it is necessary to place the performer at the centre of the development process rather than an end-user of an interactive system. In *Hiroshima*, I investigated the extensive use of various compositional modules, blocks and layers, to define sophisticated structures that can be mastered.

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\(^{58}\)This concept was further addressed at the EnYoga project. See Appendix
and performed with the body in a linear time sequence. The development of such work requires the use of compositional blocks that can be easily re-arranged in a linear time. I consider the transition between two compositional blocks of high importance and various solutions can be found for informing the performer for the progression of the composition or for creating specific events that either mask or intensify these transitions. An important indication that the development of Hiroshima is adding to the exploration of new artistic expressions, is that the system was mastered by the performer to a virtuoso level, through a series of rehearsals.

Similarly, when I used the pattern-based compositional modules of EnActor to explore the idea of transferring the skills of a traditional dancer in a WBI setting the system was successfully upgraded and mastered through iterative design studies and rehearsals. As presented earlier in the discussion about Duende, I explored the hypothesis that real-time motion capture based systems can be used to design playful interactive experiences in traditional dance contexts such as of Flamenco. Although the performance system was configured to a particular style of Flamenco, any other traditional dance genre could be described and implemented with EnActor as a training or rehearsing WBI system. After defining a WBI system that functions within this context, further work can be carried out for the development of more complex compositional structures. These can explore various traditional dance forms and fuse with theatrical and musical ideas to structure new artistic experiences. Finally, additional studies should be carried out for the development of advanced WBI training systems that can be used in various contexts including dance and sports training.

7.10 Final Thoughts and Future Developments

While body controlled interactions are becoming increasingly popular, the ability to design interactions purely based on the physical body and space remains limited, but I think promising developments are on the horizon. Motion capture requires a much higher reliability in the contexts of cinema, and virtual reality while systems operating in real-time are primarily used in video game development, rehabilitation and the pre-visualisation process in animation and cinema.

For the performance art context, a reliable real-time inertial motion capture solution will offer a creative design platform to WBI designers and help them to further investigate their conceptions and interconnections with a wide range of disciplines. As the reliability of these systems progress, WBI design software environments with greater usability, flexibility and interconnectivity should be developed. EnActor can serve as a blueprint for their design, since it has operated successfully as a prototype, in addressing a wide range of WBI design briefs.

Although my work primarily concerned the transcription of actions to sound, I am aware of the immense potential of adding interactive visual media. Gotsis (2003) has used stereoscopic cameras to track the limbs and position of dancers.
and explore notions of interactive music and choreography in immersive virtual reality environments. In her work, virtual entities that contained sounds responded to the detection of the performers while they were navigating through an immersive audiovisual VR environment.

Within the performance context Tsakos (2011) envisions a merge of new media with theatre, music, cinema and performance arts in an attempt to generate experiences that can enable a sense of magic and inspire the audience. Tsakos’ work, which typically involves impeccably synced multi-media and dance performances without the use of any sensing devices, is now shifting to whole body interaction. At the same time that I was working on Hiroshima using the AreaPhone and the Orient motion capture system, she was exploring the potential of a markerless motion capture system for the design of similar spatial interactions for a theatrical performance.\(^{59}\)

\(^{59}\)Tsakos used Organic Motion, a markerless motion capture system that does not need passive or active markers but requires the performer to be dressed in black around a white space in order to perform reliable motion tracking. http://www.organicmotion.com/ (last accessed August 2012)
In a similar way to Tsakos, Matreyek (2010) creates theatrical performances where an actor is synchronised with pre-rendered animation, physical objects and sound. In both these artists’ work the ability of the performer to synchronise with external media is exploited to such a degree that they seem to control or interact in real-time with digital animation and sound.
Video: Matreyek, synchronised performance to animation

These projects indicate that there is a movement towards fully audiovisual interactive settings, creating highly immersive environments where magic and dance meets storytelling and composition. Similarly, the addition of real-time interactive graphics to the experiences that were described in this thesis can significantly impact the way these are perceived and add another expressive dimension to the work. The gestural controlled instruments of Duende or the imaginary theatrical space of Hiroshima, if visualised, can create immersive dream-like experiences.

I strongly believe that we are moving towards an interactive performance media holism, and with a reliable motion capture technology, disciplines such as dance, theatre, music, performance art, animation, cinema, virtual reality and video game design will meet on a common ground. In that case, we should begin to investigate what the future of storytelling will be, and explore how to communicate these emerging immersive experiences with a broader audience.
Appendix

List of Conferences, presentations and publications

Papers and Publications

• “Whole Body Interaction Design in the artistic context using Motion Capture technologies” book chapter, pending for publishing by Cambridge Scholars Publishing, UK

• “EnActor: A Blueprint for a Whole Body Interaction Design Software Platform”, paper and poster, NIME 2012

• “Fully Wireless, Full Body 3-D Motion Capture for Improvisational Performances”, paper and workshop, CHI2009 Boston 2009

• “Exploration of digital manipulation of acoustic sound with the body, using a sensor based motion capture system”, paper, Audio Mostly, Glasgow 2009


Conferences and workshops

• NIME-2012 Ann Arbor, MI, USA, 2012

• CHI-2009 Boston, MA, USA, 2009

• Audio Mostly, Glasgow, 2009

• 8 th workshop on Speckled Computing, Edinburgh, 2009

• 7 th workshop on Speckled Computing, Edinburgh, 2008
- SMC07 International Conference, Lefkada, Greece, 2007
- 6th workshop on Speckled Computing, Edinburgh, 2007

Presentation of practical work

- “Hiroshima”, Video documentation of the performance, Sonorities Festival, Queen’s University, Belfast, March 2012
- “Hiroshima”, Whole Body Interactive Performance, Inspace gallery, The University of Edinburgh, April 2010
- “Digital Surfaces”, Workshop, Inspace gallery, The University of Edinburgh, June 2009
- “Duende”, Workshop and rehearsal, Inspace gallery, The University of Edinburgh, February 2010
- “Digital Surfaces”, Workshop, School of Music, The University of Edinburgh, June 2009
- “Untitled #1”, Interactive Performance, Residency, The DanceBase, Edinburgh, June, 2008

Academic employment related to this research

- MSc Project Supervisor for “Audisee Project”, The Edinburgh University, Jan 2009 – March 2009
- MSc Project Supervisor for “Through the Wireless Interface” project, The Edinburgh University, Jan 2008 – March 2008
- “Ensemble Project”, Sound and Interaction Designer, December 2006 - March 2007, AHRC, Napier University, Edinburgh
- MSc Project Supervisor for “Wireless Gestures” project, The Edinburgh University, Jan 2007 – March 2007
- Interaction and Sound Designer for the “Ensemble” project, Napier University, Jan 2007 – April 2007
EnYoga

Introduction

This workshop in the use of a WBI system in Yoga practice was carried out in parallel to my last projects and although it is not directly related to the performance art context it provided me with valuable insight over the intimate relations between the user and a WBI system and demonstrated the use of the posture recognition and classification algorithms.

Although Yoga can be an intense exercise for some it is also a relaxing meditative body-mind practice. There are many Yoga training applications based on new media in the format of interactive DVD’s and computer software but also hardware, like the Wii balance board and Wii Yoga Mat which can be used along with the software wiiSports and wiiYoga with Nintendo’s Wii console. (in Graves et al. (2010)).

An early research project by Fels et al. (2002b) called The Therapeutic Interactive Yoga System, although it was quite a premature experiment, indicated the benefits and greater potential for the development of WBI applications in this context. Described as the “first step” by the authors, they used three Polhemus magnetic sensor-based motion capture, in order to recognise four different Yoga postures and respond with audio-visual and olfactory feedback.

The one-week workshop with Yoga instructor Gesa Piper was based on the holistic design model approach and the main questions that were discussed and analysed during the research phase were related to the nature of the application we intended to explore.

- What type of interactive experiences can be created in the context of Yoga?
- What are their requirements and how can we develop and test them?
- How would these affect the experience of the Yoga practice?

According to Piper there is often music accompanying the practice of Yoga, sometimes with cultural references, for example traditional Indian music, or ambient, easy-listening, instrumental music. The music provides an esoteric link that is not connected with the body’s motor control processes, in contrast to dance where the dancer often moves according to the music. In the context of Yoga, music aims to relax practitioners and enable a particular mindset that encourages the connection with their inner self. During the early stages of Yoga training, it is also common to receive instructions from the teacher that aim to build an awareness of the whole body, adjust the alignments of the limbs and highlight the importance of breathing within a posture and throughout a movement.
Based on these observations we identified two types of interactive experiences that would be useful to design and prototype:

- a teaching system for training purposes

and

- a system to sonically accompany the practice and extend the experience of the user.

In the first case, the success of an instruction based training system would primarily relate to the reliability of the motion capture. Since the necessary reliability wasn’t met by the Orient motion capture, the focus of this early application was the design of a prototype system that could augment the practice and create an extended and intimate experience for the user.

As Yoga is not typically performed on a stage or in front of an audience, an esoteric relation between the interactor and the system was expected to be created. While a system designed through the metaphor of a musician engages in a dialog with the performer, a Yoga practitioner follows a predetermined set of postures, which can be seen as a fixed choreography that should not be influenced or altered by the interactive responses. The design metaphor that I adopted for this system was that of the composer, where data from the body are linked to compositional ideas that produce the sound-scape.

The EnYoga system

Enactor’s posture recognition module was primarily used to alter the sound composition algorithm through different presets, and inform the way data from the body were mapped to the sound. Based on different categories of postures, the system mapped elements of the interactive composition to parameters derived from the body of the performer. For instance, if a posture was based on standing on one foot, the distance between the feet was added to the sound composition, while the angle of the spine was used when the posture was based on the rotation of the hips.

The body measurements that were more often monitored and linked to the sound composition were: the distance between the hands and feet; the bending and twisting of the spine; and the overall flexion or extension of the whole body based on an average calculation of all its angles. Figure 64.

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60 Precise training systems for Yoga could be potentially designed as the reliability of the motion capture technology advances.
61 As seen for example in Untitled#2, subchapter 4.3
together with the body alignment meta data of EnActor, created a rich data collection mechanism that was mapped to the compositional algorithms driving the digital sound instruments.

In terms of aesthetics, the resulting sound was composed from a selection of environmental sound samples including: blowing of wind, associated with the back bend and extension of hands; fire crackling, associated with a deep bend or flexion; thunders, in response to balance demanding postures; running water, in response to a left twist; rain, in response to a right twist; and finally a low-pitch, constant hum in the background, based on the fundamental frequency of the Hindu’s sacred syllable of “Om” or “Aum”, produced various harmonics depending on the position of the spine.\footnote{This last addition was associated to the importance of breathing and relaxation, as explained by Piper.}
The subtle use of sound manipulation techniques such as time stretching, pitch shifting, filtering and reverberation, directly controlled by body measurements, offered each sequence of postures a variant sonic character that remained coherent to the composition of a unified ambient sound-scape.

Reflection

Despite the short duration of the workshop (five days) its main objective to study the potential of EnActor to create interactive sketches for more personalised applications was proved. The system was designed so it would be fairly easy to replace the sound layers in order to match another user’s personal preferences. While it was not my intention at this point in time to develop a highly sophisticated WBI system for Yoga, it is a starting point for more extensive analysis and the testing of different design approaches with various Yoga practitioners.
According to Piper, the experience was “truly immersive”. She reported that having direct control over the external stimuli of the sound, promoted her concentration on the practice rather disturbing it. Even small changes to the sound were reported as surprisingly informative, offering a complete new experience. These comments give partial evidence in support of the hypothesis that a WBI system can offer an extensive experience in this context, or at least demonstrates that it does not disturb or conflict with the practice. Further studies are required in order to design and create systems that can be considered valid for the intimate interactive relations between a user and a WBI system.
Speaker arrangements

In each of the three projects realised with EnActor, a different approach for the speakers setup was explored in an effort to:

- Represent a musician or an instrument
- Represent space
- Explore alternative physical feedback ideas

For project *Duende*, each of the three virtual instruments that were defined had their own dedicated speaker. The speakers were then arranged in a way that correlated to the traditional Flamenco setting, positioning them where the each of the musicians would be seated behind the performer.

The speakers for the Hiroshima project were strategically placed in an attempt to create a sonic-theatrical space. In more detail two speakers in front of the performer intended to represent the intimate space of her personal thoughts and verbal interactions. Two speakers at each side by the performer emanated sounds that belonged to the space of the house where the theatrical narrative was unfolding in. Two speakers at the back were projecting the external, environmental soundscape. Finally, a speaker at the left hand side of the performer represented a clock and a speaker at the front right side was linked to a synchronised pre-composed piece of various radio recordings and sonic elements collected from the chronological era of the narrative, providing a historical reference. (Japan, 1945)

Finally for the EnYoga project a subwoofer was placed on the floor and low frequency vibrations were produced and progressively amplified when the performer was in a posture that was challenging her balance. These vibrations had a direct physical impact on the performer, not only providing auditory cues but also additional tactile feedback, since she was able to sense the vibrations through the floor.
Fully Wireless, Full Body 3-D Motion Capture for Improvisational Performances

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ABSTRACT
This paper describes a framework for exploring the boundaries of interactive whole-body improvisational performances using the Orient-3 Wireless Motion Capture System in collaboration with composers and musicians. The requirements for improvisational performances are explored and the choice of the Orient-3 motion capture system is justified from among mechanical, acoustic, magnetic, optical and inertial motion capture methods.

Categories and Subject Descriptors
H.5 [Information Interfaces and Presentation]: Multimedia Information Systems – Animations; User Interfaces – Input Devices.
J.5 [Computer Applications]: Arts and Humanities – Performing arts (Dance and Music).

General Terms

Keywords
Wireless Motion Capture, Full-body Motion Capture.

1. INTRODUCTION
Motion capture is the recording of motion for either real-time or delayed analysis, and playback. Subsequent analysis of the data is used in a wide range of applications including clinical studies, i.e., gait analysis, sports science, i.e., biomechanical studies in skill acquisition, and computer animation. A number of classical motion capture methods ranging from mechanical, acoustic, magnetic, optical and inertial methods are described in Section 2. A full body, fully wireless, 3-D motion capture system is described in Section 3 and its choice for interactive improvisational performances is justified in Section 4, with early results and plans for future research described in the rest of the paper.

2. MOTION CAPTURE METHODS
Classical motion capture techniques [2] are distinguished by the location of the sensors - either external to, or on the subject, and the nature of the transducers employed – mechanical, acoustic, magnetic, optical or inertial.

Prosthetic or mechanical motion capture methods require the subject to wear an external structure or exoskeleton, and the posture is determined by detecting changes in the optical or electrical transducers at the joints. The main disadvantage is the cumbersome external structure, whereas the many advantages are the direct computation of rotation, simultaneous capture of multiple subjects without problems of occlusion, portability and relatively low cost.

In the acoustic motion capture method, audio transmitters are attached to the performer and the external receivers measure the time to receive the signal, and compute the position of the transmitters using triangulation. As in the previous method, the principal advantage is the lack of occlusion in the case of multiple performers, whereas the many disadvantages include unwieldy wires, limited size of the capture area, reflections of sound compromise accuracy, and the low rate of transmission only supports limited number of transmitters.

Magnetic motion capture method uses a large central magnetic transmitter to compute the position and orientation of the receivers attached to the person. The lack of occlusion is the principal advantage; disadvantages include the cabling which inhibits movements, interference from metal in the vicinity, and the limited capture volume.

Optical motion capture (Vicon [3], Qualisys [4], Motion Capture [5]) is probably the most widely used method in which either passive reflective markers or active markers are attached to a performer, and a system of fixed cameras record the position of these markers. This approach allows the performer greater freedom of movement, and achieves faster sampling at a high resolution than the previous methods, in a capture area which is normally larger in comparison to the acoustic and magnetic methods. This method is by far the most expensive and suffers from problems of occlusion. Extensive post processing is required in order to locate and identify the markers and account for any crossovers.

A typical optical motion capture session is both a time-consuming and expensive process with well-defined phases: planning, setting-up and calibration, capturing of performance, post-processing for the identification and location of markers,
and the final editing of the data. There are intrinsic problems in using markers, mainly the inconvenience of attaching them to the body and failures in tracking them, and the requirement for special lighting conditions. Techniques in software have been developed to understand the motion in the images from the cameras by extracting the silhouette of the subject [6][7], without using on-body markers. Commercial marker-less optical motion capture systems have appeared on the market recently [8].

Motion capture suits [9] using inertial sensors are aimed at alleviating some of the problems of the optical method. The sensor devices, each with a gyroscope and accelerometer, are embedded in the suit which also contains the wires connecting them together to a base unit. The advantage over the optical method is the lack of cameras and can therefore be used anywhere, and with no concern about lighting conditions and occlusion.

3. **Wireless Motion Capture**

3.1 **Orient Motion Capture System**

The Orient Motion Capture System [1] developed by the Research Consortium in Speckled Computing [11] at the University of Edinburgh demonstrated for the first time, fully wireless, full-body, 3-D motion capture in real time using on-body network of fifteen custom-designed Orient inertial sensor devices (Figure 1). The system is free of infrastructure such as cameras, magnets, or audio receivers, nor does it require special suits to be worn to contain the wires as in the case of Xsens’s Moven and Animazoo’s IGS-190.

The compact Orient device measuring 36x28x11mm and weighing 13gms contains 3-axes gyroscope, magnetometer and accelerometer. The sensors are sampled at up to 512 Hz, and a positional update rate of up to 64 Hz is achieved over the wireless network for full-body motion capture using a modest low-power 250 kbs radio. This is achieved thanks to an efficient local orientation estimation algorithm in the device firmware running on a 16-bit dsPIC, which reduces the communication data by 79% compared to existing methods [1].

The Orient-3 device captures full-body motion data at the maximum update rate of 64 Hz for around 150 minutes from a full charge. The whole device can be placed into a low-power, sleep mode for weeks at a time, whilst being ready for use within a couple of seconds of being woken by a radio signal. The 120mAh lithium polymer battery and charger are integrated into the device, with charging as simple as plugging in a lead, even when the device is held in a strap for use.

Figure 1: (Clockwise bottom-right) Orient-3 device; Mobile Phone; Orient Base-station.

Its onboard ADC is used to sample the inputs of the analog sensors: rate gyroscopes, magnetometers and accelerometers in each axis, plus temperature monitoring to allow compensation of the thermal response of the sensors. When multiple Orient devices are used together, their measurements are synchronised and their results transmitted across the radio channel in sequence, so that a complete frame’s data can be assembled at the base-station (Figure 1, top-right) within milliseconds. The base-station has USB, Bluetooth and WiFi interfaces which can bridge to a mobile phone (Figure 1, left).

The 3 x ADXRS300 Rate Gyroscopes

- 3-axis MMA7260 Accelerometer
- 3 x HMC1052 Magnetometers

Temperature Monitoring

Signal Conditioning

433MHz Radio CC1100

Power Management

Figure 2: The system block diagram of Orient-3

3.2 **MotionViewer Software**

The MotionViewer software provides a user-friendly interface (Figure 3) for the performer to interact with a network of Orient-3 devices. The software comprises of five main subsystems: Device Interface, Forward-kinematic rigid-body model, Project Management, Real-time visualisation, and a Plugin API.

The Device Interface is used to configure individual Orient-3 devices and set up a network to perform motion capture. The base-station with its USB, Bluetooth and WiFi interfaces acts as a bridge between the Orient-3 devices and the host which could be a PC, PDA or a mobile phone. The interface is designed to be usable as a library for stand-alone applications, in addition to its use in MotionViewer.

A simple calibration process requires the performer to hold briefly, just for a few seconds, a pre-determined stance which enables the alignments between the Orient-3 devices and the performer’s body segments to be automatically accounted for.

The Rigid-body Model provides the translation from the orientation data gathered by the network of Orient-3 devices to a real-time 3D model of the performer. The model consists of a number of joints connected by rigid rods to form a simplistic model of the performer’s skeleton. The proportion of the sizes of the rods in the model should correspond to the relative sizes of the limbs of the performer. Rotation data from each Orient-3 device is mapped uniquely to a joint, and after each frame of data the full state of the model is updated using a forward-kinematic method.

The Project Management feature in MotionViewer allows several takes of motion capture to be amalgamated as a project. Each take of the performance can have its own set of Orient devices, complete with their own calibration data and joint
mapping. Joint mappings can be changed after captures are completed allowing mistakes to easily be corrected.

A real-time Open-GL visualisation of the body-model is provided which enables the capture performances to be monitored. The full 3-D model is viewable with the performer able to move freely around the body to inspect it from different angles.

The Plugin API allows the MotionViewer application to be extended. Two types of Plugins are supported: Live and Export. Live Plugins run all the time, even during live motion capture, whereas Export Plugins allow for high-speed, off-line export of motion capture data for use in other applications. Plugins are given access to the body model and are free to manipulate it. A generalised annotation mechanism allows for Plugins to add data to the model without requiring sub-classing of the main software. Annotations can be used to pass data between Plugins. Examples include a Live Plugin for real-time data graphing, which allows sensor data such as acceleration to be monitored along with the 3D model, and a BVH Export Plugin, for integration with existing animation software, such as Motion Builder.

4. IMPROVISATIONAL PERFORMANCE

The sonification of gestures using wireless motion capture for interactive virtual instruments had been explored in a previous work [12] using on-body wireless network of Orient-2 devices, and interpreting the gestures as sounds in MaxMSP. The current research extends this further by exploring the transcription of whole body movements, such as in dance, into sound. The aim is to create a system for relating human movement with sound within a specific context, i.e., to explore the potential and limitations of whole-body improvisational performances using wireless motion capture systems by interfacing the output of Orient-3 with a set of sound modules and customizable algorithms for adapting to different cultural and artistic contexts.

The Orient-3 is eminently suited (as compared to the traditional motion capture methods outlined in Section 2) for the purpose of creating a framework for bringing together dancers, composers and musicians to explore the different creative processes and their interconnections. It is small, lightweight and unobtrusive and does not interfere with the dancers. It is easy to use with minimal calibration and does not require technical knowledge to operate it. The full-body motion capture data is available in real time which is a critical requirement for improvisational performances. There is no danger of problems due to occlusion when several performers dance in a limited space. The Plugin API in MotionViewer allows easy interfacing to software such as MaxMSP, which is favoured by composers and musicians for its graphical programming environment for algorithmic development. This is particularly important for the task at hand. For instance, within the context of dance, it functions as a virtual musician, whereas within the context of a musician’s requirements, it functions as a virtual instrument. These two aspects require the manipulation of different parameters, different algorithmic structures and different compositional techniques. The lack of physical resistance is counterbalanced by the audiovisual feedback.

The framework realises a virtual representation of the postures of the different parts of the body based on the sensor data. The movement of the performer is represented in the virtual space, which in turn powers the engines responsible for audio and visual outputs. Examples of movement data include the velocity of the body parts and the angles between the different limbs.

The framework was tested extensively at a workshop at Dance Base in Edinburgh in June 2008, where the limitations of interactive performances were explored when a dancer digitally manipulated the acoustic musical gestures from a cello and a saxophone [13]. A computational structure was defined in MaxMSP for different sound qualities. The next workshop in November 2008 in Lisbon, aimed to create a more dynamic virtual space and concentrated on the interaction between the physical and virtual elements with concepts such as time and memory were guidelines for the dialogue between the physical bodies and virtual performers, and between a digital composition system and the analogue musical instruments.

5. CONCLUSION

In the first instance, the research focuses on the sonic-compositional element; a future development will realise three-dimensional graphical content based on the interactive relationship between the performer with this virtual space. Initially, the virtual space is limited to a cube surrounding the
body. This will be extended to situate the performer in a more dynamic virtual world with translational movement derived from a camera or step tracking software which are provided as Plugins for MotionViewer. Another extension will be to integrate a pair of wireless datagloves in the Orient-3 Motion Capture System which will capture the expressions of the fingers in tandem with the actions of the hands to provide richer interactions in the virtual world.

Future research will explore the notions of posture and stillness in the context of yoga and meditation practices. Another area for experimentation and validation of research findings will be the application of this framework in a contemporary Japanese dance practice called Butoh which has influenced western dance in a new understanding of body and space.

In the proposed research the movement manifests itself through sonic and visual feedback. The area that has to be better understood and explored is the neutral ground where the exchange takes place between the physical and virtual worlds.

Such interactive system introduce a new reflexive relationship of the body with itself that is revealed through the virtual body: the body becomes both a subject and an object by affecting and being affected by its virtual environment.

6. ACKNOWLEDGMENTS

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7. REFERENCES


HIROSHIMA

Work for a whole body interactive performance

The work was world-premiered at Inspace, Edinburgh, U.K. on 27th April 2010.

Original Concept and Performance Score © Vangelis Lympouridis and Shiori Usui 2010
The work was created as a collaboration of two artists:

**Shiori Usui:**
Composition and Performance

**Vangelis Lympouridis:**
Whole Body Interaction and Sound Design

Special Thanks to:
- **Sean Williams**: sound recording and audio engineering of the première.
- **Michael Cullen**: assistance and contribution of sound source (high frequency signals and low bass)
- **D.K Arvind, Alex Young, Paul McEwan and Martin Ling**: assistance on the Orient motion capture system
- **Prof. Nigel Osborne and Prof. Peter Nelson**: supervision – Shiori Usui
- **Dr Martin Parker**: supervision – Vangelis Lympouridis
- **Mark Daniels**: Inspace (Edinburgh, U.K.)

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- Research consortium in Speckled Computing, The University of Edinburgh (http://www.specknet.org)
- Inspace, Edinburgh
- Arts and Humanities Research Council (AHRC)
- Overseas Research Student Award Scheme (ORSAS)
Technical Requirements

Real-Time Motion Capture: Orient -3 wireless sensor base system
visualisation software (with motion viewer application) for the Orient motion capture system
Max MSP patch
8 speakers
1 subwoofer
1 small microphone for live voice input (e.g. DPA mic./wireless mic.)
1 chair for a performer
1 medium size desk for a performer
1 large desk for a operating the systems
two laptops for operating the Orient motion capture system and Max MSP patch
external sound card
8 channel mixer
stage lighting as a single/multiple spot(s) is ideal

For more information on the Orient motion capture system, please visit;
http://www.specknet.org/
http://homepages.inf.ed.ac.uk/ayoung9/orient.html#Overview

Speck Sensors on Body

1 left forearm
1 right forearm
1 left upper arm
1 right upper arm
1 chest
Position of Speakers and Performer
Hiroshima: Whole body Interactive performance  3D sketch visualization
Hiroshima: Whole body Interactive performance  3D sketch visualization

Front View

3D Image by Vangelis Lympouridis
Hiroshima: Whole body Interactive performance  3D sketch visualization

Top View

3D Image by Vangelis Lympouridis
Notes for Musical Notation

NOTE-HEAD

\[ \times \]  
approximate pitch

\[ \downarrow \]  
low pitch

ACCIDENTALS

\[ \downarrow \]  
a little flatter (from already flattened pitch)

\[ \downarrow \]  
a little flatter (from the pitch without any normal sharp or flat accidental)
## INTRODUCTION

<table>
<thead>
<tr>
<th>TIMELINE</th>
<th>TYPE OF SOUND: speakers</th>
<th>PARTS OF BODY USED</th>
<th>body movement</th>
<th>resultant sound</th>
<th>Notes for performance practice</th>
<th>Notes for performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLOCK A, speaker 7</td>
<td>SPINE</td>
<td>sitting still</td>
<td>normal playback of audio</td>
<td>bending backwards</td>
<td>bending forwards</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>lower pitch</td>
<td>higher pitch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>slower ticking sound</td>
<td>faster ticking sound</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>e.g. The clock sound when the body is bent extremely backwards.</td>
<td>e.g. The clock sound when the body is bent extremely forwards.</td>
</tr>
</tbody>
</table>

### AUTOMATED FADE-OUT
- transposition to lower pitch
- less frequent occurrence of the sound.

### COOKING A, speakers 3 & 4
- LEFT AND RIGHT FOREARMS
  - Intensity of the hitting movement corresponds with the triggering of different samples
  - AREA-PHONE
    - Samples distributed 180 degree of space in front of the performer.
    - Area divided into 18 samples distributed.

### WIND, speaker 3 (L.H.), speaker 4 (R.H.)
- LEFT AND RIGHT FOREARMS
  - movement of arm
  - no movement of arm
  - playback of audio ON
  - playback of audio OFF
  - velocity of movement
  - correspond to the intensity of sound
  - e.g. when the velocity of movement is strong, the volume of the sound increases.
  - Practice by using different parts of hands, e.g. fingers, only arms, palm facing up/down.
  - CONTROL (approx. 30 sec.)
  - Imagine that you are "conducting" an orchestra or playing an instruments with different sound colors and pitches.

### YOKO'S VOICE, speaker 1 (L.S.), speaker 2 (R.S.)
- LEFT AND RIGHT SHOULDERS
  - movement of shoulder
  - no movement of shoulder
  - playback of audio ON
  - playback of audio OFF
  - Eyes open when the sound of voice is heard (from unconsciousness to consciousness). As if hearing or reacting to someone's voice.
**THE DIFFERENT SAMPLES ARE TRIGGERED ACCORDING TO THE INTENSITY OF THE HITTING MOVEMENT (SEE APPENDIX 1).**

- A: Sound of stacking saucers No.1, stacking saucers No.2
- B: Sound of saucers put away, saucers sliding
- C: Sound of grabbing bowl from cupboard, grabbing glass from cupboard
- D: Sound of plates removed No.1, plates removed No.2, stacking plates
- E: Sound of plates straightening up, plates put away No.4, glasses being stacked
- F: Sound of plastic roll No.1, plastic roll No.2, plastic plate No.3, plastic plate No.4
- G: Sound of plastic bowl No.1, plastic bowl No.2, plastic bowl No.2, plastic plate No.2
- H: Sound of chopping 4, 6, 8
- I: Sound of chopping 1, 2, 3
- J: Sound of wood No.7, wood No.8, wood No.9, wood No.10
- K: Sound of wood No.4, wood No.5, wood No.6
- L: Sound of wood No.4, wood No.5, wood No.6
- M: Sound of glass put down, slide, drawer closed
- N: Sound of desk drawer, closet drawer closed
- O: Sound of pots put away No.3, pots put away No.2, pots away No.1, pots away No.2, pots put away No.3, pots being put away No.1, pots being put away No.2
- P: Sound of pot lid 1, 2, 3, 4
- Q: Sound of hitting metallic object 1, 2, 3

**EXAMPLE: SEQUENCE 2**
- One hand closed, another hand open with palm down, leaning forward
- Hands closed, both hands
- Palm down, both hands, hands at different height, leaning forward

**EXAMPLE: SEQUENCE 3**
- Palm down, both hands
- Palm down, both hands
- Hands closed, both hands
- Palm down, both hands
- Palm down, both hands
- Palm down, both hands

**MIXTURE**
- Break the relationships between the image and sound that you created previously (i.e., the image and sound of cooking) by applying different gestures to similar types of sounds.
  - Example 1: Apply the gesture of "mixing some cooking ingredients in a metal bowl" to more "wooden" timbre such as chopping sound.
  - Example 2: Apply "cutting" gesture used for chopping sound to more "metallic" timbre.
- Also mix with the "conducting orchestra" or "playing instrument" approach.

**ENGINE**
- Speakers 5 & 6
- Ramping from speaker 5 to speaker 6
- Real-time voice input:
  - Unprocessed
  - Vowel based sound
  - Sound of exhaling air
- Radio signal
- White-noise, beating effect, radio tuning sound
- High frequency signals
- Speakers 5 & 6

**LEGAL WARNING**
- The different samples are triggered according to the intensity of the hitting movement (see Appendix 1).

- A: Sound of stacking saucers No.1, stacking saucers No.2
- B: Sound of saucers put away, saucers sliding
- C: Sound of grabbing bowl from cupboard, grabbing glass from cupboard
- D: Sound of plates removed No.1, plates removed No.2, stacking plates
- E: Sound of plates straightening up, plates put away No.4, glasses being stacked
- F: Sound of plastic roll No.1, plastic roll No.2, plastic plate No.3, plastic plate No.4
- G: Sound of plastic bowl No.1, plastic bowl No.2, plastic bowl No.2, plastic plate No.2
- H: Sound of chopping 4, 6, 8
- I: Sound of chopping 1, 2, 3
- J: Sound of wood No.7, wood No.8, wood No.9, wood No.10
- K: Sound of wood No.4, wood No.5, wood No.6
- L: Sound of wood No.4, wood No.5, wood No.6
- M: Sound of glass put down, slide, drawer closed
- N: Sound of desk drawer, closet drawer closed
- O: Sound of pots put away No.3, pots put away No.2, pots away No.1, pots away No.2, pots put away No.3, pots being put away No.1, pots being put away No.2
- P: Sound of pot lid 1, 2, 3, 4
- Q: Sound of hitting metallic object 1, 2, 3
- R: Sound of chopping 4, 6, 8
- S: Sound of chopping 1, 2, 3
- T: Sound of wood No.7, wood No.8, wood No.9, wood No.10
- U: Sound of wood No.4, wood No.5, wood No.6
- V: Sound of wood No.4, wood No.5, wood No.6
- W: Sound of glass put down, slide, drawer closed
- X: Sound of desk drawer, closet drawer closed
- Y: Sound of pots put away No.3, pots put away No.2, pots away No.1, pots away No.2, pots put away No.3, pots being put away No.1, pots being put away No.2
- Z: Sound of pot lid 1, 2, 3, 4
- AA: Sound of hitting metallic object 1, 2, 3

**COOKING**
- Speakers 3 & 4
- Left and right forearms
- Intensity of the hitting movement corresponds with the triggering of different samples.
- Space divided into 12 areas and 18 samples distributed in total.
- Right forearm - 4 areas with 10 samples
- Left forearm - 8 areas with 8 samples

**AREA-PHONE**
- Speakers 1 & 2
- Real-time voice input:
  - Unprocessed
  - Vowel based sound
  - Sound of exhaling air

**RADIO**
- Speaker 8
- Pre-composed
- White-noise, beating effect, radio tuning sound

**HIGH FREQUENCY SIGNALS**
- Speakers 5 & 6
- Pre-composed
(COOKING B) – "MASTER" – speakers 3 & 4

MASTER – SLAVE ALGORITHM
- The movement used for Cooking B is recorded, and used directly for triggering the rhythmic content of the 2 voices – "slave" – (see below).
- Imagine as if you are inside the stomach. Move like a small creature living in the stomach.

2 VOICES – "SLAVE" – speakers 1 & 2

MASTER – SLAVE ALGORITHM
- The movements of forearms used for Cooking B are recorded, and used directly for the rhythmic content of the 2 voices – "slave" – .
- The rhythmic content of "Male voice" is shaped according to the movement of right hand, and the "Female voice" is by left elbow.

REAL VOICE: speakers 1 & 2

REAL-TIME VOICE INPUT -
processed
SPINE
- The movement of bending forward and backward controls the granulation.
- The movement of bending right and left controls the delay effect.
- phoneme based sound
- "conversation" using phonemes with the "2 Voices" (i.e. "slave" voices) coming out from the speakers 1 & 2
- imitation, repetition, variation, retrograde of the sound of the "2 Voices" & fragments of laughter.

EXAMPLES:

EXAMPLE 1: VOWEL

EXAMPLE 2: CONSONANT & VOWEL

EXAMPLE 3

EXAMPLE 4

hints of man's voice in Japanese (Hirohito)
fragments of Japanese songs
fragments of man’s voice in Japanese (Hirohito)

LOW BASS: PRE-COMPOSED

volume: unnoticeable at the beginning. When there is less movement of body, the volume of the low bass increases.

(COOKING B) – "MASTER" – speakers 3 & 4

MASTER – SLAVE ALGORITHM
- The movement used for Cooking B is recorded, and used directly for triggering the rhythmic content of the 2 voices – "slave" – (see below).
- Imagine as if you are inside the stomach. Move like a small creature living in the stomach.

2 VOICES – "SLAVE" – speakers 1 & 2

MASTER – SLAVE ALGORITHM
- The movements of forearms used for Cooking B are recorded, and used directly for the rhythmic content of the 2 voices – "slave" – .
- The rhythmic content of "Male voice" is shaped according to the movement of right hand, and the "Female voice" is by left elbow.

REAL VOICE: speakers 1 & 2

REAL-TIME VOICE INPUT -
processed
SPINE
- The movement of bending forward and backward controls the granulation.
- The movement of bending right and left controls the delay effect.
- phoneme based sound
- "conversation" using phonemes with the “2 Voices” (i.e. “slave” voices) coming out from the speakers 1 & 2
- imitation, repetition, variation, retrograde of the sound of the “2 Voices” & fragments of laughter.

EXAMPLES:

EXAMPLE 1: VOWEL

EXAMPLE 2: CONSONANT & VOWEL

EXAMPLE 3

EXAMPLE 4

hints of man's voice in Japanese (Hirohito)
fragments of Japanese songs
fragments of man’s voice in Japanese (Hirohito)

LOW BASS: PRE-COMPOSED

volume: unnoticeable at the beginning. When there is less movement of body, the volume of the low bass increases.
### ALERT II

<table>
<thead>
<tr>
<th>1 min. 14 sec.</th>
<th>28 sec.</th>
<th>1 min. 52 sec.</th>
<th>45 sec.</th>
</tr>
</thead>
</table>

**BREAKING DISHES**: speakers 3 & 4

- Right Forearm
  - Movement of forearm
  - Playback of audio ON
  - More extreme movements
  - Playback of audio OFF

**ANGRY VOICE**: speakers 1 & 2

- Left and Right Shoulders
  - Movement of shoulder(s)
  - Playback of audio ON
  - Left shoulder movements triggering 2 different sound files in turn.
  - Right shoulder movements triggering 1 audio file.

**HIGH FREQUENCY SIGNALS**: speakers 5 & 6 > PRE-COMPOSED

**NORMAL II**

- Right Forearm
  - Movement of forearm
  - Playback of audio ON
  - Just 1 sound file triggered
  - No movement of forearm
  - Playback of audio OFF

**BREAKING DISHES - Reversed Sound**: speakers 3 & 4

- More extreme movements
  - Playback of audio OFF

**CLOCK A**: speaker 7

- Live-processing of samples.
- Same as before the Clock A before.
- Try to gain the balance with movements again.

**CLOCK B**: speaker 7

- Automated

**EXAMPLE 6: SOUND OF CLOCK B REPEATED UNTIL THE END**

- Distorted, harsh sound.
- Voice inhalation (to the extent of not damaging vocal cords).
- Phonemes
- Extreme pitches
- Short rhythmic values
- Loud dynamics (e.g. f, ff, fff)

**EXAMPLE 5: VOICE INHALATION**

- Sound of laughter

- CUE for performer
- Sound of glass
- Low vib.
"Hu hu hu"
## APPENDIX 1

### Area-phone A: approximate references of pitches for each sample

<table>
<thead>
<tr>
<th></th>
<th><strong>GENERAL TIMBRE</strong></th>
<th><strong>LOW VELOCITY OF MOVEMENT</strong></th>
<th><strong>HIGH VELOCITY OF MOVEMENT</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ceramic</td>
<td>![Staff A Low]</td>
<td>![Staff A High]</td>
</tr>
<tr>
<td>B</td>
<td>ceramic</td>
<td>![Staff B Low]</td>
<td>![Staff B High]</td>
</tr>
<tr>
<td>C</td>
<td>ceramic</td>
<td>![Staff C Low]</td>
<td>![Staff C High]</td>
</tr>
<tr>
<td>D</td>
<td>ceramic</td>
<td>![Staff D Low]</td>
<td>![Staff D High]</td>
</tr>
<tr>
<td>E</td>
<td>ceramic</td>
<td>![Staff E Low]</td>
<td>![Staff E High]</td>
</tr>
<tr>
<td>F</td>
<td>plastic</td>
<td>![Staff F Low]</td>
<td>![Staff F High]</td>
</tr>
<tr>
<td>G</td>
<td>plastic</td>
<td>![Staff G Low]</td>
<td>![Staff G High]</td>
</tr>
<tr>
<td>H</td>
<td>wood</td>
<td>![Staff H Low]</td>
<td>![Staff H High]</td>
</tr>
<tr>
<td>I</td>
<td>wood</td>
<td>![Staff I Low]</td>
<td>![Staff I High]</td>
</tr>
<tr>
<td>J</td>
<td>wood</td>
<td>![Staff J Low]</td>
<td>![Staff J High]</td>
</tr>
<tr>
<td>K</td>
<td>wood</td>
<td>![Staff K Low]</td>
<td>![Staff K High]</td>
</tr>
<tr>
<td>L</td>
<td>wood</td>
<td>![Staff L Low]</td>
<td>![Staff L High]</td>
</tr>
<tr>
<td>M</td>
<td>wood</td>
<td>![Staff M Low]</td>
<td>![Staff M High]</td>
</tr>
<tr>
<td>N</td>
<td>wood</td>
<td>![Staff N Low]</td>
<td>![Staff N High]</td>
</tr>
<tr>
<td>O</td>
<td>metallic</td>
<td>![Staff O Low]</td>
<td>![Staff O High]</td>
</tr>
<tr>
<td>P</td>
<td>metallic</td>
<td>![Staff P Low]</td>
<td>![Staff P High]</td>
</tr>
<tr>
<td>Q</td>
<td>metallic</td>
<td>![Staff Q Low]</td>
<td>![Staff Q High]</td>
</tr>
<tr>
<td>R</td>
<td>metallic</td>
<td>![Staff R Low]</td>
<td>![Staff R High]</td>
</tr>
</tbody>
</table>

---

**NOTE:** Defining the Velocity of Movement

The calibration procedure before the performance defines the threshold of the velocity with the lowest intensity (i.e., where there is no sound). The range between the lowest threshold value and the maximum pre-recorded intensity value was then equally divided by the numbers of samples that are used.
### APPENDIX 2

**Area-phone B: approximate references of pitches for each sample**

<table>
<thead>
<tr>
<th></th>
<th>GENERAL TIMBRE</th>
<th>LOW VELOCITY OF MOVEMENT</th>
<th>HIGH VELOCITY OF MOVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>fire</td>
<td>variable according to acoustic and the patch</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>water evaporation/ water boiling</td>
<td>white noise like sound</td>
<td>white noise like sound</td>
</tr>
</tbody>
</table>

---
APPENDIX 3

MaxMSP patch:

programmed by Vangelis Lympouridis
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