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Phase-Only Optical Information Processing

D. J. Potter

Abstract

Historically, much scientific work has been performed with two optical systems - the telescope and the microscope. Although Galileo was probably not the first to invent the refracting telescope, his rapid development of the instrument from 1609 results in his association as the father of the telescope today. Certainly he was the first human to view the giant moons of the planet Jupiter - Io, Ganymede, Callisto and Europa - and thus dare to venture our world was not the centre of the universe, and save our race from another thousand years of mysticism.

A year later, in 1610, Galileo invented the microscope and this led to the new field of science called 'microscopy' to open up the previously unsuspected world of the ultra small. Tiny life forms no larger than a pinhead were revealed, and with instrumental improvements by later scientists the existance of bacteria proven. This discovery prompted the sterilisation of surgical equipment taken for granted today, saving countless millions of lives since then through freedom from bacterial infection.

It is beyond doubt that the new world opened by the invention of the microscope inspired the scientists of that time to seek yet greater magnification and sharper images, to delve deeper into this tiny world. Yet technical improvement in the design of the microscope wase hampered by the lack of a proper theory of image formation. Not until the late nineteenth century, when ABBE and RAYLEIGH provided the foundations of the present day diffraction theory of imaging was the microcope properly understood.

The work of this thesis has its roots in the developments of the early twentieth century microscopists. For many years they had observed tiny, transparent organisms and sought ways to improve the visibility of these creatures so that their nature might better be understood. The problem was solved by F.Zernike in 1935 (1, 425 for ref.) when he considered the way the organisms altered the phase of the illuminating light field.

By the correct positioning of a thin phase-plate in the back focal plane of the microscope lens, Zernike demonstrated that optical thickness variations of the organism may be rendered visible as intensity variations.

In this thesis , the light distribution in the back focal plane of such a lens that results from a transparent object is analysed in detail. From the expression derived by Zernike to explain the operating principle of his invention, we evaluate alternative formulations of the problem and proceed to a full analytical expression for the light field . Though mathematically awkward, it is shown the expression is not unworkable and several useful results are derived.

In place of a microscope the study is based on imaging in a modern image processing bench, the physical principles involved being identical.

Zernike introduced the idea of image modification through the use of a basic form of phase filter. The second half of this thesis develops this idea to show the use of much more intricate phase filters, which may be used to 'recognise' particular objects. Filter design is followed by experimental results on a special type of phase object, the programmeable Spatial Light Modulator.
