Hyperspectral Interferometry for Single-Shot Profilometry and Depth-Resolved Displacement Field Measurement

by

Taufiq Widjanarko

A Doctoral Thesis submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University

April 2011

Abstract

A new approach to the absolute measurement of two-dimensional optical path differences is presented in this thesis. The method, which incorporates a white light interferometer and a hyperspectral imaging system, is referred to as Hyperspectral Interferometry. A prototype of the Hyperspectral Interferometry (HSI) system has been designed, constructed and tested for two types of measurement: for surface profilometry and for depth-resolved displacement measurement, both of which have been implemented so as to achieve single shot data acquisition.

The prototype has been shown to be capable of performing a single-shot 3-D shape measurement of an optically-flat step-height sample, with less than 5% difference from the result obtained by a standard optical (microscope) based method. The HSI prototype has been demonstrated to be able to perform single-shot measurement with an unambiguous 352 μm depth range and a rms measurement error of around 80 nm. The prototype has also been tested to perform measurements on optically rough surfaces. The rms error of these measurements was found to increase to around $4\times$ that of the smooth surface.

For the depth-resolved displacement field measurements, an experimental setup was designed and constructed in which a weakly-scattering sample underwent simple compression with a PZT actuator. Depth-resolved displacement fields were reconstructed from pairs of hyperspectral interferograms. However, the experimental results did not show the expected result of linear phase variation with depth. Analysis of several possible causes has been carried out with the most plausible reasons being excessive scattering particle density inside the sample and the possibility of insignificant deformation of the sample due to insufficient physical contact between the transducer and the sample.

Keywords:. Hyperspectral interferometry, Single-shot measurement, Profilometry, Depth-resolved displacement field measurement, Absolute distance measurement, Phase measurement, Low Coherence Interferometry,

Acknowledgment

everything turns more expensive when they are rare
except knowledge
which becomes more precious when they are abundant
(hazrat ali bin thalib r.a.)

I would like first to express my gratitude and thanks to Islamic Development Bank which has generously awarded me The Merit Scholarship Programme that has enabled me to pursue a research training in optical interferometry - my field of interest back since my final years of my undergraduate education which I once hoped to someday to be able to pursue research training in this field.

It is such a great honour and pleasure to be able to carry out my PhD study under the supervision of Prof. Jonathan Huntley. Not merely does he educate me to be able to perform independent research, but also on how to promote the research output to the industries. I would like to also express my thanks to my second supervisor Dr.Pablo Ruiz, from whom I learnt many things on the experimental works.

My thanks also go to Dr.Manuel De la Torre-Ibarra, a visiting researcher from CIO Mexico, who really taught me on the real technical issues on the optical table. I can't imagine without his kind helps, cheerful and outgoing character that I would be able to cope the pressure that sometimes mounted during the experiments, especially when the result came out unexpected and I need to struggle to find the problems... Also my thanks go to Dr. Russ Coggrave from Phase Vision Ltd who has assisted me a lot with his savvy and skilful knowledge in electronics and hardware programming.

Helps and stimulating discussions from my lab cohorts are greatly appreciated: then Dr. Adel El-Mahdy with his long experience in optical experiments and without his help the sample made from spin coating process would not be possible, then Dr. Nadeem Shaikh who has helped me in providing the template from which this thesis is constructed from, Bona Burlison-from whom I learnt organising things in the lab and the set-ups so it looks tidy and pleasant to work in, and indeed alleviating the stress by sharing jokes from British telly shows.. Also without the support from my family and friends in Indonesia and in the UK and mainly East Midlands this study will not be successful, to which I express my sincere thanks. My appreciation also to my teachers Dr. Hakim Malasan, Prof. Bambang Hidayat and particularly Prof.Andrianto Handojo from Institute of Technology Bandung (ITB) Indonesia who has taught me that optics is much more interesting than simply the knowledge about lens, mirrors and other transparent materials.

I wish not to thank my wife and daughter. For their constant love, support, patience and understanding they deserve more than gratitude. They deserve dedication, to which this work is I dedicated to.

Loughborough, May 2011