

**APPLICATIONS OF DIGITAL HOLOGRAPHY
IN OPTICAL METROLOGY
AND INFORMATION REDUCTION**

By

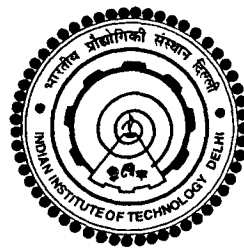
MD. MOSARRAF HOSSAIN

INSTRUMENT DESIGN DEVELOPMENT CENTRE

submitted in fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

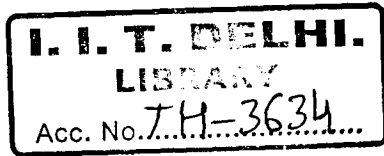
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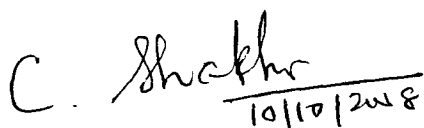
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MEMORY OF MY
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CERTIFICATE

This is to certify that the thesis entitled “APPLICATIONS OF DIGITAL HOLOGRAPHY IN OPTICAL METROLOGY AND INFORMATION REDUCTION” being submitted by Md. Mosarraf Hossain to the Indian Institute of Technology, Delhi for the award of the degree of “DOCTOR OF PHILOSOPHY”, is a record of the authentic research work carried out by him under our supervision and guidance. He has fulfilled all the requirements for submission of this thesis, which to the best of our knowledge has reached the required standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any other degree.



C. Shakher
10/10/2008

Dr. Chandra Shakher

Professor

Instrument Design Development Centre

Indian Institute of Technology, Delhi



Dr. D. S. Mehta

Associate Professor

Instrument Design Development Centre

Indian Institute of Technology, Delhi

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MMHossain
Md. Mosarraf Hossain

ABSTRACT

Optical interferometric techniques are more sensitive, accurate, precise and wholefield in comparison to other conventional measurement techniques. These techniques are non-contact type and non-invasive. Before the development of digital holography all the pioneers in optics in the past compared only two coherent waves and their phases. Therefore, the results were in the form of phase differences. Digital holography has made possible the quantitative measurement of phase from a single hologram. This has provided a very powerful tool for optical metrology. Freedom from processing of recording material and direct availability of phase from one digital hologram have made interferometric processes faster, robust and almost realtime. The measurement of contours of diffused objects, measurement of refractive index of transparent liquids, measurement of temperature in laminar free convection of water, and a method of information reduction using digital composite holography are presented in this thesis by using lensless Fourier transform digital holography (LFTDH).

The thesis is organized in five chapters-

Chapter I provides detailed description of digital holography including brief history of its development, mathematical background for recording and numerical reconstruction and brief description of few widely used digital holographic recording and reconstruction processes. Further, this chapter describes briefly the process of digital holographic interferometry and its applications in optical metrology. Also in this chapter a brief

description about holographic information reduction and possibility of its implementation by using digital holography is provided.

Chapter II describes a method of contouring for diffused objects using dual-index immersion method and digital holographic interferometry. In this method the required interference phase (phase difference corresponding to two different states of the object) map is generated from the two individual phases calculated from two different digital holograms. The first hologram is recorded using distilled water while the other is recorded with the solution of distilled water and ethyl alcohol. The fringe spacing of the interference phase map is calculated by plotting the 1-D phase of the interference phase map. The 1-D phase map is unwrapped to visualize the shape of the object. Depth contour interval is calculated using the values of two refractive indices used in the recording of two digital holograms and the associated experimental parameters. Information regarding depth of an object can be extracted from the value of fringe spacing of the interference phase together with the depth contour interval. The minimum depth contour interval achieved by this method is 120 μm .

Chapter III deals with a method for measurement of refractive index of transparent liquids using digital holographic interferometry. This method is based on the measurement of interference phase between the two wave fields reconstructed from two digital holograms. First hologram is recorded using distilled water of known refractive index. Water-ethanol solution of unknown refractive index is used in the second exposure. From the 1-D wrapped interference phase, fringe spacings are calculated at different slopes of the object. The calculated value of slopes of the object and the fringe spacings in the interference phase map

are used to calculate the unknown refractive index using the known refractive index of distilled water. The measured values of refractive index by this method was compared with that measured by Abbe refractometer (Abbe '60' refractometer, Bellingham and Stanley Ltd., London). The deviation of the $\sim 0.002 - 0.02 \%$ was noticed. The method can provide the accuracy of measurement up to 1 part in 10^6 or less depending on the type of instrumentation is used and slopes are measured more precisely.

In chapter IV a method for measurement of temperature in laminar free convection flow of water using digital holographic interferometry is investigated. Quantitative interference phase map is calculated from two digital holograms. First one is recorded in quiescent state of water, while the other is recorded in steady laminar free convection of water. The interference phase is unwrapped using standard unwrapping algorithm [69-71]. The equation of Tilton and Taylor is used to get a relationship between the temperature and refractive index of water. The quantitative unwrapped phase is used in calculations for determination of temperature from the known value of temperature in the quiescent state of water. The deviation in the measurement of temperature by digital holographic interferometry and that of thermocouple was found to be within 2%. The free turbulent convection flow was also visualized by using the method.

Hologram contains substantially more information than necessary for some specific applications. In chapter V, a method of information reduction, which aims at efficient storage and transmission of holographic information is investigated using digital composite holography using lensless Fourier transform configuration. Since most important cue for

perception of depth is stereopsis, in this method the smallest possible band of spatial frequencies in the vertical direction is sampled and recorded. The sampling of the spatial frequencies in the horizontal direction, which determines the visible depth of the reconstructed image, is done just enough to provide the minimum stereopsis and parallax in the horizontal direction. The area of an elementary lensless Fourier transform digital hologram (ELFTDH) obtained by combined sampling is so small that it contains only the minimum information necessary for an image with recognizable depth and resolution. An ELFTDH recorded in the present method reconstructs all parts of the image simultaneously as the experimental arrangement used in this method can be approximated close to an ideal Fourier transform holography configuration. The maximum information reduction factor 105 could be achieved by this method. In near future by the use of sensor having better specifications and more precise signal processing more information reduction factor can be achieved.

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