Shape and deformation measurement by adaptive methods in TV holography and digital holography

PhD dissertation

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Introduction

The recent successes in the automatization of various optical measuring methods can postulate creation of new knowledge based systems. Such a system continuously adapts itself to the change of measuring conditions and environment. That is why it is called 'adaptive system'.

Thanks to the fast evolution of the high resolution, computer controlled CCD and CMOS devices, new methods are developed for electronic processing of data in speckle metrology and in holography too. Although these methods produce lower quality results, they are also full-field methods with the same sensitivity as conventional holographic methods.

The electronic realization of speckle metrology is called TV holography and in holography the new method is the digital holography.

There are different realizations of adaptivity in modern optical measuring systems. On level is the level of adaptive optical elements (computer controlled light sources, beam splitters, mirrors, spatial light modulators) and adaptive software routines. This is the simplest level of adaptivity.

A higher level of adaptivity when the optical system can modify its parameters based on the measured signals. (E.g. the system can measure histogram of the detected image, and set the proper exposition time to use the detector in the linear range.)

In a more complicated case, more feature of the detected image is necessary. In this case the detected image is characterized by an image quality vector in which the histogram is only an element.

Maybe the highest level of the adaptivity is the adaptive optical measuring method, when the measurement of the shape or deformation is automatic process independently from its type and magnitude.

The synthesized reference beam TV holographic technique is such a method. In this method synthesized reference beams are used for compensating the deformation of the investigated object. The phase-fronts of the reference beams are built from phase shifted plane waves. The actual phase-front can be built after the measurement using recorded pictures in the computer memory.

Using this technique the sensitivity of the measurement can be changed after the recording. In this way the fringe density at highly deformed points can be decreased; different components of the complicated fringe pattern can be removed; and the evaluation of the fringe system can be done more easily.

The method can be applied in TV holography and holography too. Remote comparative measurement is also possible by this technique.

The principle of synthesized reference beam TV holographic can be adapted in projected fringe methods too.

Artificial neural network is an excellent example for adaptive system. It is an effective tool for identification and classification. Nowadays neural networks are used in coherent optical metrology too. Successful applications have been presented in defect detection and fringe pattern evaluation. Articles dealing with the data reduction, as an important step of the application of artificial neural networks are also can be found in the literature.

Digital holography is one of the most actively researched fields in coherent optical metrology. Based on the possibility of the calculation of the complex amplitude, different new methods appeared in this field, using phase manipulation methods.

Digital holograms of the different states of the investigated object are easily transferred to any place using the internet to perform remote comparative measurement.
Our department has been connected to the research in digital holography from the beginning.

Goals

My goal was to investigate the application possibilities of adaptive measuring methods in TV holography and digital holography, for shape and deformation measurement of diffuse surfaces.

I wanted to elaborate the comparative TV holography to use any kind of reference beam to increase the adaptability of the method.

My aim was to use artificial neural network for processing of interferograms performing classification and evaluation.

My goal was to develop new methods to record higher resolution digital holograms increasing the upper measuring range.

Methods and devices used in the thesis

The measurements were performed in the laboratories of the Optical Metrology Group at the Department of Physics.

Main applied devices: He-Ne laser with 35 mW output power, computer controlled diode laser with 10 mW output power, CCD camera using 1280 x 1024 pixels (pixel size 6.7 μm), spatial light modulator (resolution 800 x 600 pixels, pixel size 32 μm), computer controlled piezoelectric phase shifter.

Computer programs from other sources: Holovision 2.2 program for the evaluation of digital holograms, MATLAB program from Balázs Gombköto for reconstruction of digital holograms, preprocessing and simulation program in MATLAB for Kohonen neural networks from Gábor Vásárhelyi.

My own programs: simulation programs for speckle interferometry and digital holography, fringe compensation and phase calculation program, preprocessing units for neural networks, simulation program for Kohonen networks.

New scientific results

Thesis one

Adapive TV holographic interferometer for shape and deformation measurement [1-4.]

I have developed an active interferometer, based on the previously introduced comparative speckle interferometer. This new interferometer is capable for shape and deformation measurement of diffuse surfaces.

I have modified optical devices for computer controlling (mirror, beam splitter, pin-hole).

A computer controlled multi-wavelength light source has been developed, using the histeresis in the temperature-wavelength function of the highly stabilized diode laser for shape measurements.

Using the above optical elements in an interferometer it has been shown that adaptive measurements can be performed in speckle metrology and holography for shape and deformation measurement.

I have shown that adaptive preprocessing routines can be applied in the evaluation of interferograms. I have written adaptive equalizing procedures for non uniform illumination and for non uniform reflectivity of the object to equalize the visibility of the interferometric fringes on the whole surface.

Thesis two

Indirect synthesis of wave fronts [5-12.]

New method has been introduced for indirect synthesis of wave fronts in comparative and compensation measurements. The phase-fronts of the reference beam are built from phase shifted plane waves. The actual phase-front can be built after the measurement using recorded pictures in the computer memory.

The method can be applied in TV holography and holography too. Remote comparative measurement is also presented by this technique.

I have written an evaluation program, which can work with speckle interferograms and holographic interferograms too.

I have investigated the effect of the synthesized wave front on the accuracy of the measurement. The number of the necessary phase steps were also analyzed.

The principle of synthesized reference beam TV holographic method successfully adapted in projected fringe methods too. Shape measurements for diffuse and mirror surface were presented.

Thesis three
Development of simulation program package [13-21.]

I have shown that the existing simulation methods in speckle metrology can be improved by the simulation of the surface shape and roughness.

I have shown that the non uniform reflectivity and the phase front of the illumination can be useful parameters in the simulation. I have broadened the application field of the simulation by the simulation of shape measurement.

I have developed the method for changing the parameters of the simulation in multiple steps to generate movie files.

I have shown that the simulation program can complete by virtual reality elements.

Using 3D models of 120 devices in the optical laboratory of the department, the program can generate 3D files for the images of the optical arrangement.

The program can identify optical devices in real arrangements, to record geometrical features.

Thesis four

Application of neural networks in the evaluation of interferograms [22,23]

I have shown that multilayer neural networks are able to classify speckle interferograms. I have developed a DELPHI based program for simulation of multilayer neural networks. For this purpose, I have used and enhanced the previously developed MATLAB routines.

I performed classification tasks for speckle interferograms and holographic interferograms. Using the artificial neural network, fringe systems belonging to erroneous deformation can separate with 100% efficiency for holographic interferograms. The efficiency can reach 90% for speckle interferograms.

I have proven that the skeleton lines of the fringe system in speckle interferograms can be generated using Kohonen networks. I have developed a simulation program for Kohonen networks in MATLAB. The network can produce the skeleton lines for speckle interferograms and holographic interferograms too. I have developed a method to find the skeleton line of fringes containing arms.

Approximately 30000 simulated interferograms were produced, using the previously developed interferogram simulation program.

Thesis five

Application of digital holography for comparative and compensation measurement [24-27.]

I have investigated the applicability of direct and indirect synthesis of wave fronts in comparative measurement using digital holograms.

I have implemented the direct synthesis of wave fronts in digital holography and TV holography. I have compared the measuring ranges for direct and indirect synthesis in digital holography.

I have investigated the possibility of the increasing of the resolution and the upper measuring range of the digital holograms, not increasing the resolution of the recording devices.

I have proposed the application of the interline and the drizzle method to record high resolution digital hologram.

I have developed shape measurement methods, based on digital holography for measurement of running gears.

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