IMAGE PROCESSING AND ANALYSIS OF DIGITAL SPECKLE PATTERN INTERFEROMETRIC IMAGES FOR MONITORING / SURFACE VIBRATION / TILT

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1. Abstract
A digital speckle pattern interferometric system to monitor surface vibrations and out of plane tilt is presented. The resolution of the system to measure out of plane displacement is 1/2 per fringe.

2. Introduction
Monitoring of vibrations of surfaces is of great interest for many potential applications [1-6]. The importance of optical techniques for determination of vibration analysis of mechanical structures stem from the fact that they enable measurement of vibrational motion without mechanical contact. Optical techniques can be employed to measure the vibrations of objects such as aeroplanes, automobiles and other mechanical components etc. [5-14]. During the last twenty years literally hundreds of studies have been carried out in this field. These studies can be divided into three categories based on optical technique employed: Holography, Moire, Speckles and other optical techniques. Each of these methods can be applied in time averaged, pulsed and stroboscopic modes of operation. In all these methods the results obtained from an intensity map show that the area at rest during the exposure time appears brightest. From such maps the amplitude of the displacement of a vibrating object may be determined. None of these methods, however can be used to measure real-time non-periodic motion. Such non-periodic motions are of great importance in determination of transient effects and also characterisation of vibrational motions which have complex (i.e. multi-frequency) and time varying power spectrum (for example speakers responding to music). The sensitivity and accuracy provided by interferometric techniques have always been attractive [15]. In this paper we present digital speckle pattern interferometric system to monitor surface vibrations and out-of-plane tilt.

3. Working Principle
As with most interferometric devices, digital laser speckle pattern interferometry (DSPI) uses a single coherent optical source to produce described data. To create interference, the laser beam is split into two parts each beam passing through its path to the recording plane (Fig.1).

Fig.1. Schematic of DSPI system to measure vibration/out of plane tilt.

The object bCam is expanded and directed onto the object to be tested. The scattered light from the object is collected and imaged onto the CCD. The uniform reference beam is added directly onto the CCD. The most rapid spatial variations in this interference pattern have dimensions inversely proportional to the angle between the two waves. In conventional holography the angle may be arbitrarily large. It is much smaller for DSPI because the resolution of CCD / TV target is almost two decades less than that of high resolution film used for holography. The intensity of the interference pattern is transformed into a corresponding charge distribution by CCD target. As CCD target is scanned, the charge distribution is converted into a current variation-the video signal. The speckle data from the camera signal is sent to the processor in either analog or digital form (depending on camera).

When DSPI is applied for vibration analysis the video store is not needed. Assume that the object and reference waves on CCD target are described by...
\[ d(x) \]

\[ I(x) = U_0^2 + 2 U_0 U_1 \cos(d) + U_1^2 \]  

(\(d_{\alpha\beta}\) is vibration amplitude at a point of spatial co-ordinates \(x\) and \(w\) is the vibration frequency. The intensity distribution over the CCD camera target becomes

\[ I(t) = I_1 + U_1^2 \]

\[ = U_0^2 + 2 U_0 U_1 \cos(d) + U_1^2 \]  

(\(d_{\alpha\beta}\) modulates this speckle pattern)

4. DSPI System

Schematic of the developed DSPI is shown in Fig.1. Developed DSPI system as shown in Fig.2 which can be used as real time tool for monitoring vibrations, tilt and out-of-plane deformations. System displays real-time speckle correlation fringes with holographic sensitivity. System consists of:

- 25 mW Spectra-Physics He-Ne laser (Semiconductor laser can also be used), HTC-550, B/W CCD camera (7.95 nm * 6.45 nm, equivalent to 1/2 incli camera tube, minimum illumination of 0.5 lux, resolution of 600 lines horizontal), Image processor( PC AT 486, Main memory-SimB, Hard disk-540 MB, DT connect, DT 2851- frame grabber board, DT 2858 frame processor board).

The resolution of the system is:

1. Out-of-plane displacement: 1/2 per fringe.
2. About 25 clear fringes in case of out of plane tilt

Number of experiments were conducted using developed DSPI system in a well lit room to monitor vibrations and measure tilt using developed DSPI system. Fig.2 show typical vibration modes of a loud speaker captured and processed by the system. Fig 3 show the typical fringe pattern on a monitor, when the object is tilted between two exposures. The analysis of experimental results is done by using Wyko fringe analyser available at Mecanical Eneineering Laboratory. Agency of Industrial Science and Technology, Namiki, Japan. In the course of digitising video fringes, the program occasionally makes an error in locating or ordering fringe points, for example, it may miss fringes, digitise noisy fringes that are not on a fringe, or assign a wrong order number to a digitised point. To correct this situation fringe scan parameters has to be used judiciously. To let us correct these errors, the programs brings up the fringe editing display after the interferogram is digitised. If required, one can add, delete, or move digitised points. Fringe order numbers can also be changed. once this work is correctly accomplished, normal analysis can be initiated. Fringe scan parameters (line skipped, extra scans, low-pass filter, display, thresholds etc.) should be adjusted to take special care of DSPI fringes. If interferogram is having diagonal fringes, the program may not work properly. Due to speckled image it was difficult to analyse the DSPI fringes from the WISP-11 program if program is used in normal way. By making few changes in the execution of the program we could analyse the tilt contours shown in Fig. 3. Fig.4 show the optical path difference of tilted surface as shown in interferogram Fig.3.

5. Image Processor

The image processing system converts the analog signal of the CCD into a digital stream. The standard TV signal is sampled and converted to a 8 bit deep data word. Typically the images have a size 512 x 512 pixel. On board memory can store two full image frames and input LUTs allow hardware processing on board. For accelerated processing, the DT 2858 auxiliary frame processor is connected to DT 2851. The input signal is digitally integrated over several video frames before further processing. The system employed is a PC based image processor with 2 image memories. The raw image thus obtained is enhanced by a series of filters in sequence.

Image processing has wider applications in a variety of fields. This PC based system can accept input either from a radiographic imaging system or directly from the video camera. The processing system can then enhance the image by various means. The signal to noise ratio is improved by image summation or frame averaging. After summation all succeeding processing techniques serve only to improve the presentation of the information contained in the original image. Most techniques can be performed within a few seconds. A digital representation of the image is also provided for archiving. DT cards are from Data Translation Inc., USA. The software is MS-DOS compatible and is hardware dependent (Image processing cards) in order to optimise execution time. DT Connect is an interface specification based on external input/output data ports and software protocols, which permits the direct connection of stand alone data acquisition and grabber boards to processor boards for greatly accelerated signal and image processing. Hence the slowdowns associated with data transfer over micro-computer bus is eliminated. DT 2851 is a 512 X 512 X 8 bit frame grabber for a real time digital image processing on the IBM PC AT. The board digitise a video signal and stores an image in one of the two onboard memory buffers and displays at the rate of 30 image frames per second. DT 2851 can process images in real time. DT 2851 can take RS-170, RS-330, CCIR,
Fig. 2. Typical vibration mode of a loudspeaker.

Fig. 3. Typical DSPI fringe pattern when object is tilted with two exposures.

**Fig. 4.** Optical path difference in DSPI interferogram of tilted surface shown in Fig. 3.
PAL, NTSC video input from an ordinary video camera or solid state camera.

DT 2858 is a pipelined board designed for high speed 16-bit image processing with DT 2851 High Resolution Frame Grabber on PC AT. This board does arithmetic intensive operation on 512 X 512 image frames. DT 2858 receives 8 bit data from DT 2851 over one of two external ports. These ports (one for input, one for output) are completely independent of the PC bus and entire image frame transferred at much higher speeds.

6. Software
Several software programmes have been developed for image improvement and these can be categorised as either point transformations or two dimensional transformations. Point transformations such as grey-level manipulations are relatively simple operations. Two-dimensional transformations are mathematical procedures that transform an element of the original image into an element of the filtered image weighted with its environment.

A list of typical software developed is given below
- Display / save images and sub images
- Acquire images from DSPI set-up
- Histogram (Equalisation, Modification )
- Scaling
- Gradients ( Sobel, Laplace , Robert )
- Convolution
- Annotation
- Filters ( Lowpass, Highpass, Median, Laplacian, Mode, Gauss, Exponential, Logarithmic, Wallis )
- Image addition / subtraction
- ZOOL
- Binary
- Linear Intensity Mapping

Time taken to acquire and enhance the image varies from 20 seconds to two minutes, depending on the combination of software used.

7. Acknowledgement
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8. References