

IMAGE PROCESSING SYSTEM FOR ANALYZING HIGH SPEED PHENOMENON

--- HIGH SPEED VIDEO CAMERA AND IMAGE PROCESSING PROGRAM ON PERSONAL COMPUTER ---

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ABSTRACT

In order to study high speed deformation of materials, we develop a high speed digital video camera (maximum frame speed: 300,000 frames/sec) using a new MOS type solid state image sensor. The digital image taken by the high speed video camera is analyzed by an image processing program PIMPOM. It is a wide use and conversational program for a personal computer and the processing speed is very high. In order to analyze displacement distribution, we develop a new grid method using Fourier transform. By using this method, we analyze the displacement, velocity, strain and strain rate distributions in a rubber tube when an unloading wave propagate in it.

1. INTRODUCTION

Because the frame speed of a high speed camera is necessarily large, a very large amount of recording materials such as a film and a tape should be used when it is difficult to detect previously the start timing of the phenomena such as lightning, crack propagation etc. If we record cyclically the phenomenon on rewritable IC memories instead of a film or a tape and stop the recording when the phenomenon is just over and hold the phenomenal image on the IC memories, we can avoid the waste of recording materials. By this principle, we make a system of a high speed video camera with IC image memories. We utilize a new MOS type of area sensor¹ on the market as the image sensor of the camera. It is possible to change the area size for output into any size by a software. The smaller area is selected, the higher the frame speed is.

In order to analyze the image taken by the high speed video camera, a wide use program on a personal computer is developed². It has a lot of menus such as region set, disk access, value transform, one and two dimensional mask filtering, thinning, geometric transform, printer output, process repeat, graphics, image input by an image scanner, Fourier transform, Hadamard transform, histogram etc.

Furthermore, we make a program for analysis of the displacement, velocity, strain and strain rate distributions by using the Fourier transform of the image of the deformed grating on a material. Formerly, we have presented a new method to analyze the displacement and

strain distributions of a material³. In the method, when the first harmonic of the Fourier spectra of a grating is shifted, the image obtained by the inverse Fourier transform of the first harmonic shows moire fringes which are displacement contour lines. In the present study, we develop the method into velocity and strain rate analysis from time different continuous images. This new method is accurate. Automatic processing can be performed. We show an application to analysis of stress wave propagation in a rubber tube.

2. HIGH SPEED VIDEO CAMERA

Recently, CCD type solid state ICs are widely used as image sensors. In this study, we use a new type solid state image sensor HE98246¹ (made by Hitachi Ltd.). It is a MOS type image sensor. The circuitry diagram is shown in Fig. 1. It consists of two dimensional photodiode arrays which have 649x491 pixels (photodiodes). The pixel size is 13.5 μ m square with an optical aperture ratio as high as 54 percent.

There are a pair of vertical shift registers placed both sides of the image area (photodiode area) and a horizontal shift register placed on the upper side.

The vertical shift register generates vertical scanning pulses for selecting a row in which the signal is output. The pixels in the other row continue to charge electric signal. The shift register, placed on the left side, carries out prescanning to control the charge storage time. It works as an electric shutter. The right shift register controls three switches for each row and it leads the charged signal on the row to the vertical output line S.

The horizontal shift register provides the photodiode array with the scanning pulses of 16 MHz, which is a double of the clock pulse frequency (8MHz) supplied from the outside driver. When the horizontal switch on the row selected by the vertical shift register is closed by the horizontal shift register, the electric signal charged in the photodiode is output to the horizontal output line. Each horizontal switch is selected sequentially and the signal from each sequential photodiode in the row is led from the horizontal output line to the vertical output line.

Thus, the photodiodes are swept out by selecting the vertical switch and horizontal switch and by changing them sequentially.

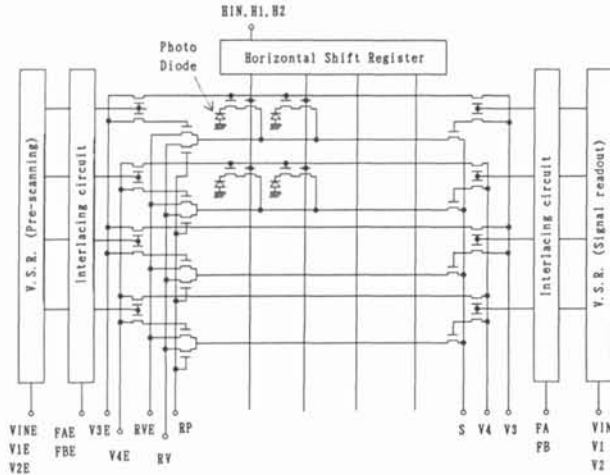


Fig. 1 Circuitry Diagram of MOS Type Image Sensor HE98246

After the last horizontal switch is selected, the next vertical switch is selected and the first horizontal switch is selected again. In this selection, if we change the scanning area as shown in Fig. 2, the scanning speed for one frame is changed. The smaller area is selected, the higher the frame speed is.

In other word, the scanning area is changed by selecting the horizontal switches and the vertical switches, that is, by sending a horizontal start pulse and a vertical start pulse. By changing the interval of the horizontal start pulses, the maximum horizontal scanning speed is 649 times as high as the scanning speed in ordinary use. In the same manner, by changing the interval of the vertical start pulses, the maximum vertical scanning speed is 525 times as high as the ordinary scanning speed. However, in this HE98246, there are 27 and 9 optical black reference pixels in the horizontal and vertical lines, respectively, where we can not get image signal. Therefore, by combining the changes of the intervals of the horizontal and vertical start pulses, the maximum frame speed is about 300,000 frames/sec. In this case, the frame size is only one pixel. If the optical black reference pixels are erased and the clock speed is double, the theoretical maximum frame speed is about 20,000,000 frames/sec though the image size is one pixel. The frame speed or image size of this video camera is controlled by a personal computer.

The signal from the vertical output line is stored in IC memories by using a A/D converter or stored on a video tape recorder. If we store the image signal by rewriting cyclically in the same IC memories, we can store the desired images by sending a trigger after occurring the phenomenon. This corresponds to the three dimensional (x,y,t) transient memory. It is possible to catch the phenomena such as lightning and crack propagation in which it is difficult to get a trigger beforehand.

3. PROGRAM OF IMAGE PROCESSING ON MICROCOMPUTER (PIMPOM)

Formerly image processing system was very expensive, because the computer for image

Horizontal Start Pulse

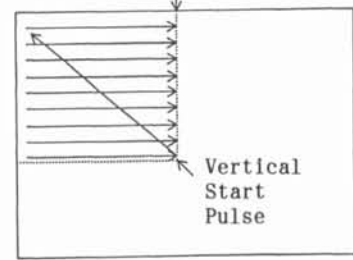


Fig. 2 Change of Scanning Area

processing requires a lot of memories and high speed performance. However, recently, personal computers have good cost performance

and the performance of memory size and calculation speed becomes better. Personal computers have many merits as follows:

- (1) Cost is low.
- (2) Size is small. It is easy to carry it to any place where we need it.
- (3) Many informations of the hardware and software are opened to the public.
- (4) Many softwares and hardwares for personal computers are put on the market.
- (5) Expandability and applicability of system are high.
- (6) It is easy to access the graphic RAM.

At these points of view, we use a personal computer for image processing. The computer is NEC PC-9801VX (CPU 80286). The image size is 640x400 pixels with 16 (4 bits) of 4096 colors.

The program of image processing is written using BASIC and assembly languages. It is easy to process an image by conversationally selecting a menu number. The data required for processing is asked by the computer so that we need not to remember the command statements and the order of the parameters. The menus of this program are shown in Table 1.

The characteristics of this program are the following:

- (1) Basic processing menus such as region set, disk access, value transform, image input by a scanner, image output to a printer, mask, geometric transform, Fourier transform and Hadamard transform are prepared.
- (2) Check menus such as histogram, palette change and value distribution on a line are prepared.
- (3) The image just before the present one is stored. If Undo function is selected, the present process is canceled and the image before the present processing comes back.
- (4) Automatic processing is performed by storing the menu numbers of a sequential process.
- (5) It is possible to return the menu when the processing is broken by any reason.
- (6) It is easy to connect any other application programs to these menus.

This program is useful for an ordinary personal computer. We can operate it by using only an ordinary computer except some menus

Table 1 Menus of Image Processing Program on Personal Computer (PIMPOM)

- (1) Initialize
- (2) Displayed Image
- (3) Demonstration
 - (f.1) Return to Main Menu at Break
 - (f.2) Undo
 - (f.3) Text Color Change
 - (f.4) Cursor Display
 - (f.7) Erase and Display Image
 - (f.8) Color Scale
 - (f.9) Histogram
- 1. Region Set (Full Area, Coordinate Numerals Input, Cursor Key Input, Mouse Input, Disk Region, Former Regions, Region Memory)
- 2. Disk Access (Load, Save, Montage etc.)
- 3. Value Transform (Erase, One Value, Reverse, Threshold, Contrast, Extract, Shift, Circulation, Free Transform, Palette Change)
- 4. Line Mask (Value Distribution, Average, Anti-shading, Free Mask, Thin Out)
- 5. Area Mask (Average, Medium, Differential, Laplacian, Free Mask, Edge, Skeleton, Expand, Shrink)
- 6. Geometric Transform (Move, Enlarge, Reduce, Rotate, Mirror, Magnify, Rotate, Affin Transform)
- 7. Print Out (Numerals, Hardcopy, Two Values, Moiregraphy, Color)
- 8. Process Repeat (Memory Start, Memory End, Repeat)
- 9. Chain (Graphics, Image Input, Line Chase, Fourier Transform, Hadamard Transform)
- 10. Option
- 99. End

such as image input and Fourier transform. We don't need any special hardware for image processing. The processing speed is very high, because each menu is written by a machine language. For example, mask and geometric transform is processed in about 6 sec. Value transform is processed in about 3 sec. This processing time is for the case that the image size is 640x400 pixels. The smaller the size is, the shorter the time is.

4. STRAIN RATE ANALYSIS BY FOURIER TRANSFORM

The moire method⁴ and grid method⁵ have been used as one of the noncontact measuring techniques of displacement and strain of materials. In the classical conventional moire method, moire fringe pattern is generated by the superposition of a model grating and a master grating. Moire fringes form contour lines of the equal displacement when the pitches and the directions of the grating lines of the two gratings coincide with each other before deformation. Displacement that is equal to an integer times half of the master grating pitch is related to the points of maximum and minimum brightness intensity of the fringes.

In order to improve the accuracy, we³ have formerly presented a new method of the moire analysis of strain using the Fourier transform. we develop the method into a mismatch method and a grid method. They use the

phase information of the moire fringe brightness or grating brightness. By shifting the Fourier spectrum of the image of a deformed grating, we obtain the "complex moire pattern," from which strain distribution is given as the derivatives of the phases of the complex moire fringes. The analysis is completely automated by digital image processing. All of the laborious and subjective procedures required in the conventional analysis such as fringe sign determination, fringe ordering and fringe interpolation are eliminated permitting objective, fast and accurate analysis.

In this study, we develop it to analysis of velocity and strain rate from high speed video images.

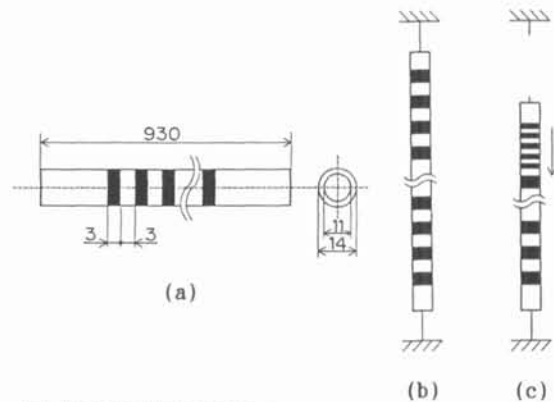
The basic procedures required in this analysis are as follows:

- (1) Sampling of a deformed grating by a TV camera.
- (2) Discrete Fourier transformation of the image.
- (3) Extraction and shift of the first harmonic of the spectra.
- (4) Inverse discrete Fourier transformation of the shifted first harmonic.
(Generation of the complex moire fringe pattern)
- (5) Computation of the arguments of the complex moire fringes.
- (6) Determination of the displacement distribution.
- (7) Determination of the velocity, strain and strain rate distributions by differentiating the displacement in consideration of the transform from the Euler coordinate to the Lagrange coordinate.

The two time differentiation of the data obtained from images by the conventional method is scatter. However, the scatter obtained by this Fourier transform method is very low because the interpolation is very natural and smooth.

5. APPLICATION TO UNLOADING WAVE PROPAGATING IN RUBBER TUBE

A rubber tube is painted a grating on its surface as shown in Fig. 3(a). The rubber tube is stretched at the upper and lower ends



- (a) Before Stretching
- (b) Before Unloading (Stretched)
- (c) In Unloading

Fig. 3 Schematics of Rubber Tube with Grating

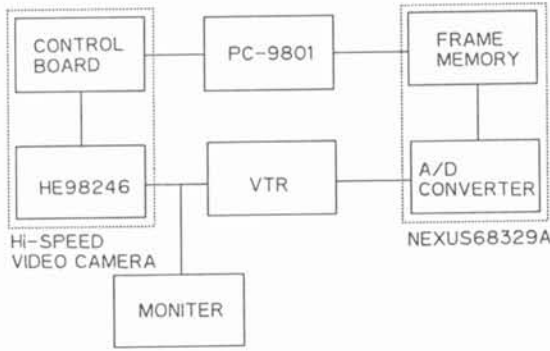
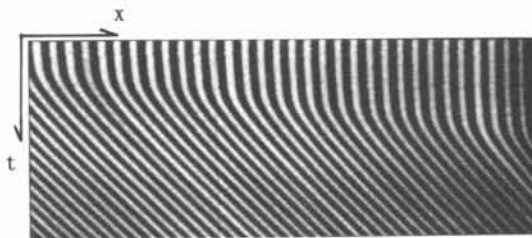
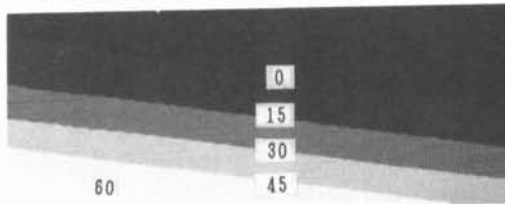


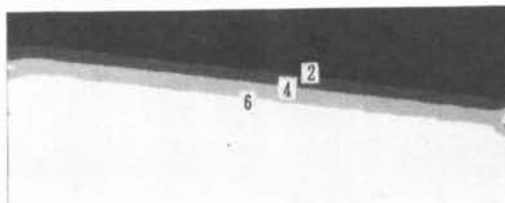
Fig. 4 Diagram of Analysis System



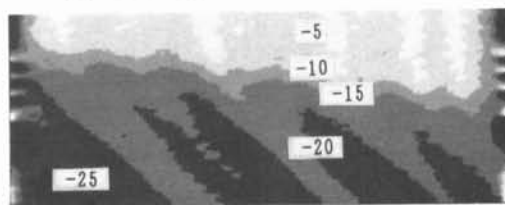
(a) Original Image by High Speed Camera



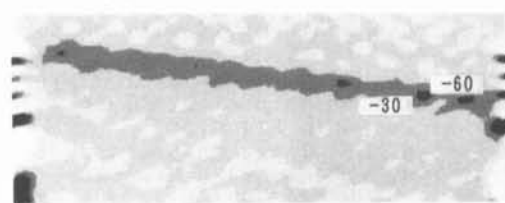
(b) Displacement Distribution (mm)



(c) Velocity Distribution (m/sec)



(d) Strain Distribution (%)



(e) Strain Rate Distribution (1/sec)

Fig. 5 Analysis of Unloading Wave Propagation in Rubber Tube

as shown in Fig. 3(b). When the upper end is cut, the unloading stress wave propagates in the tube as shown in Fig. 3(c). We take the propagation of the unloading wave by the high speed video camera and analyze the image to obtain displacement, velocity, strain and strain rate distributions. The diagram of analysis system is shown in Fig. 4.

In this experiment, we control the scanning area of the image sensor of the high speed video camera by the personal computer. We take a picture that the horizontal length is 512 pixels and the vertical length is 2 pixels. Now, we consider this deformation is one dimensional so that we can separate the vertical 2 pixels into two different time data. Thus, the frame rate in this case corresponds to 15,730 frames/sec.

The original image obtained by this camera is shown in Fig. 5(a). Because we rotate the camera 90 degrees, the left side of the image corresponds to the upper of the rubber tube. The right corresponds to the lower. The downward direction shows the time coordinate. Figures 5(b), (c), (d) and (e) show the distributions of the displacement, velocity, strain and strain rate, respectively, obtained by the grid method using Fourier transform.

6. CONCLUSION

We developed a new type of high speed video camera. It is easy to change the frame speed and frame size by inputting the data from a personal computer. Though we analyzed the unloading wave propagation in a rubber tube in this study, this high speed video camera and the image processing program PIMPOM are wide use so that they can be applied to various phenomena. The fringe analysis method using Fourier transform can be applied to various fringe analysis methods such as photoelasticity, holographic interferometry, speckle interferometry, moire interferometry and other interferometry.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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