DESIGN OF AN EDUCATIONAL SIMULATION PROGRAM USING DIGITAL VIDEO PROCESSING TO DETERMINE THE THERMAL EXPANSION OF MATERIALS

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ABSTRACT

The present report describes the realization of an educational simulation program to determine the amount of linear thermal expansion in experimental materials. An interferogram signal derived from an interferometric measurement system was modeled as a video signal in a computer environment. A simulation program was designed from the model signal in order to detect the amount of expansion in materials. The simulation program determined the amount of to heat by detecting the number of fringes in interferogram video signals of the material. This simulation program facilitated experimental studies

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in academic institutions which are deprived of interferometric measurement systems.

Keywords: Digital video processing, measurement, computer science engineering education, interferometry

1. Introduction

Precise and accurate measurement of minor displacement is an important industrial application, which is essential for accurate measurement of expansion and shrinkage. The precision and performance of measurement systems has increased in accordance with the demand for information on the dimensional stability and thermal expansion characteristics of advanced technological materials [1].

Interferometric measurement systems are widely used in precise displacement measurement because of their high performance [2]. The interference characteristic of light is used in such systems, and displacement is determined by analyzing the interference signal, called an interferogram. Electronic systems are widely used to analyze the displacement information derived from an interferogram signal. Demarest used an electronic interferometric measurement system in order to reduce the ambiguity in high resolution, high speed measurement of laser measurement systems [3].

Components of electronic circuits should be chosen carefully and certain tolerance intervals should be provided in order to achieve the required accuracy and reliability of the measurement system. Furthermore, improving the performance of the desired features increases the complexity of the circuit, thereby requiring a new design. Recent developments in hardware technologies and standard studies have made possible the projection, processing, storing and transmission of digital video signals. Rapid developments have also occurred in digital video technologies, digital video processing theory, algorithms and hardware, due to the abundance of application areas [4]

Effective use of video processing method in precise displacement measurement became possible with the increased performance of image detection sensors and the development of high-capacity data storage devices.

With the increased availability of such technologies, the present study reports on the realization of a simulation program, based on a method of digital video processing of interference fringes, which is designed to determine the thermal expansion of materials.

2. Modeling of Interferogram Video Signal

In this phase of the study, an interferogram video signal derived from an interferometric measurement system was analyzed in order to generate a true model interferogram signal in a computer environment. An Interferogram signal derived from a LETI-1 interferometric measurement system is shown in Figure 1.

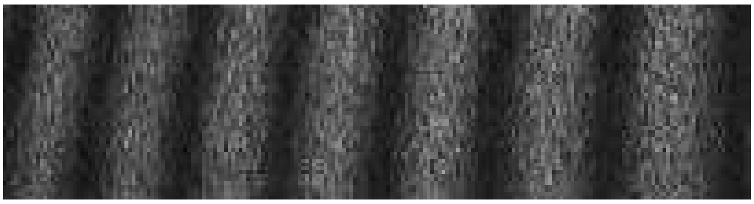

Figure 1-Interferogram Interference Signal

The signal structure of the interferogram signal was analyzed in MATLAB, using the program's signal-processing interface (SPTool). As can be seen from Figure 2, the signal is in sine form and includes noise components.

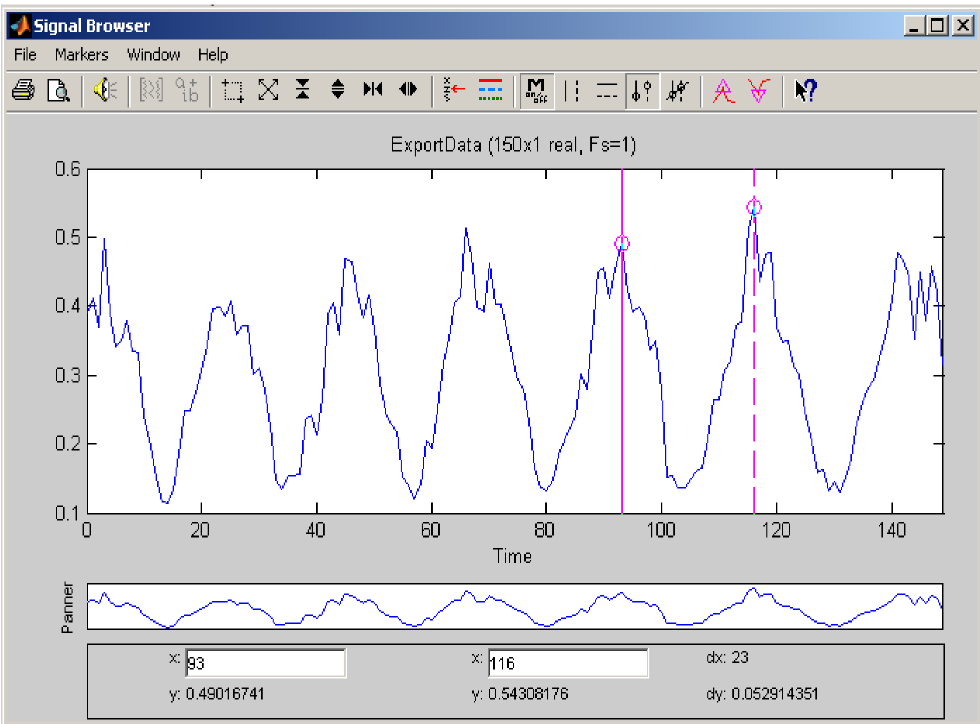

Figure 2- Signal Structure of Interferogram Interference Signal

The code line developed in the MATLAB environment in order to generate the model interferogram signal in sine form was:

I_sin(1,:)=.2*rand(1,100)+(.2*sin(2*pi*x+phase))+.1;

The sinus form of the interferogram function with noise component, [generated using the "rand" function] / [including the "rand" function], is shown in figure 3

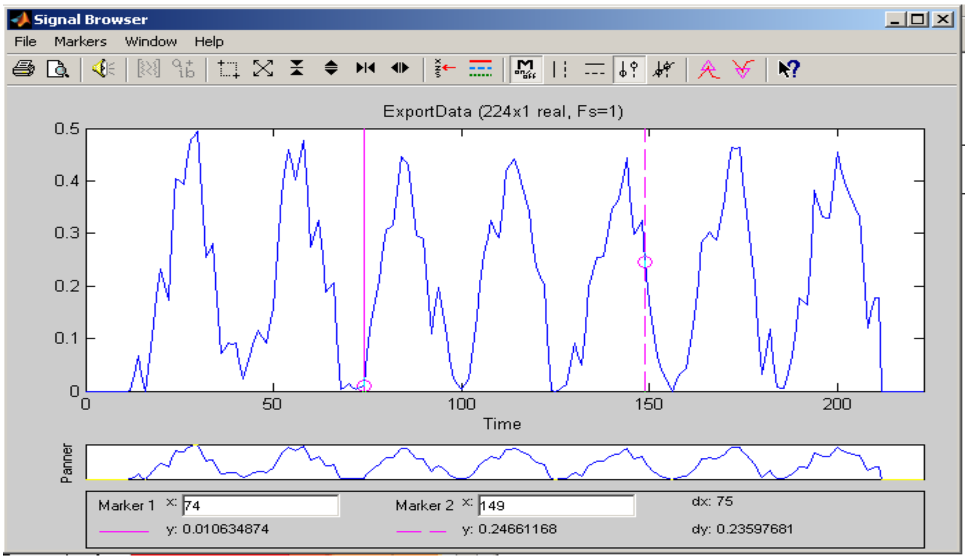

Figure 3- Modeled Interferogram Video Signal Structure

The interferogram video signal was acquired by combining image frames derived from different phases of the sine function. The image frames had a multi-frame structure and formed a sprite video signal when they were combined using the movie2avi instruction. A frame of the model interferogram video signal is shown in Figure 4.

Figure 4- Modeled Interferogram Interference Signal

3. Formation of Video Analysis Program

The video analysis program, represented in Figure 5 as block diagram, was developed in the Simulink software environment, in order to obtain the displacement information of the thermal expansion process via video signal. The simulation program is composed of the following sub-components: source video signal phase, thresholding, filtration, tagging, decision and result.

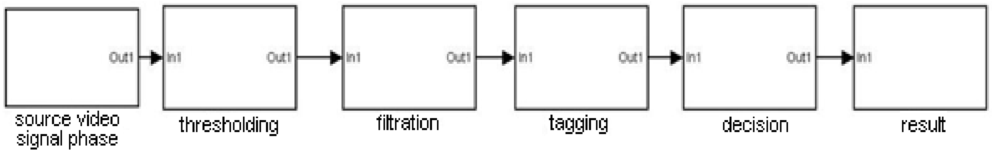

Figure 5-Block Diagram of Interferogram Video Signal Analysis Program

Video Signal Phase:

This phase transfers the interferogram signal, formed as an avi file in the MATLAB environment, into the Simulink environment for processing.

Thresholding:

The thresholding phase is used to convert the video signal from the former phase into dual images with automatic threshold values. Determination of threshold value is made by threshold phase, using the method developed by Otsu [ ]. The contrast of minimized pixel groups in the first image was separated in a histogram and a threshold value was determined. According to pixel brightness value (either below or above the threshold value), the image frame was formed as a dual image containing a binary number set, as shown in Figure 6.

Figure 6- Interference design thresholding phase output

Filtration: In this phase, "salt and pepper" noise in the dual form video signal was eliminated with median filtration. An image of the filtrated interference signal is shown in Figure 7.

Figure 7- Interference pattern filtration phase output

Tagging:

The block tags connected elements in the image frame of the video signal which was transformed into dual image form and the reference number of the elements were transferred to an output. A tagging matrix was developed, within which a pixel equal to 0 represents base, a pixel equal to 1 represents the first connected element and a pixel equal to 2 represents the second connected element. Respectively the connected element is shown, therefore, the number of objects departed from base of video frame as can be seen in Figure 8 with tagging block. Based on the example image frame shown in Figure 6, the tagging procedure gives a resulting value of 7.

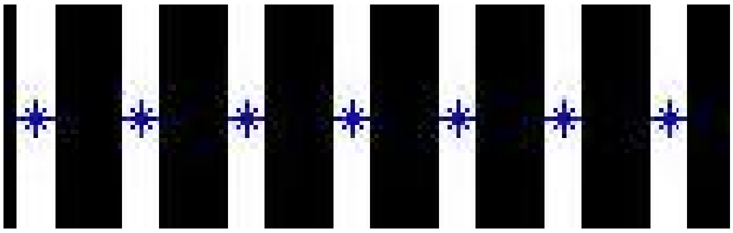

Figure 8- Tagged Model Interferogram Signal Image Frame

Decision:

The decision phase compares previous image frames in order to detect whether there is a position change in the interference fringes of the video signal, which represent the extent of thermal expansion. When there is a fringe slide because of extension in image frame, logic 1 information is transferred to the output of the phase. (Figure 9)

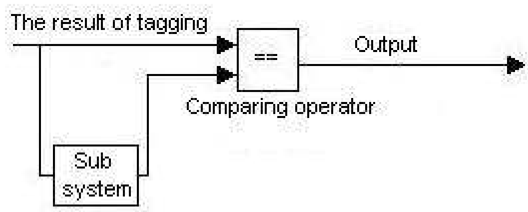

Figure 9- Decision Phase of Simulation Program

Result:

In this phase, 1 information is detected derived from slide of each interference fringe. For that purpose, a counter sub-system was designed in synchronous structure using j-k flip-flops. The binary number value was converted into the decimal system and transferred to result phase. After the number of sliding interference fringes due to displacement were detected, the amount of extension in the experimental material was calculated with equation 1.

$$\Delta L = \frac{\lambda}{2} N \tag{1}$$

In this equation, ΔL corresponds to the extension amount; λ; He-Ne corresponds to laser wavelength laser and N corresponds to the number of fringes. The sub-system of the result phase allows the amount of expansion to be calculated in units of µm. Figure 10 shows a block diagram of the result phase.

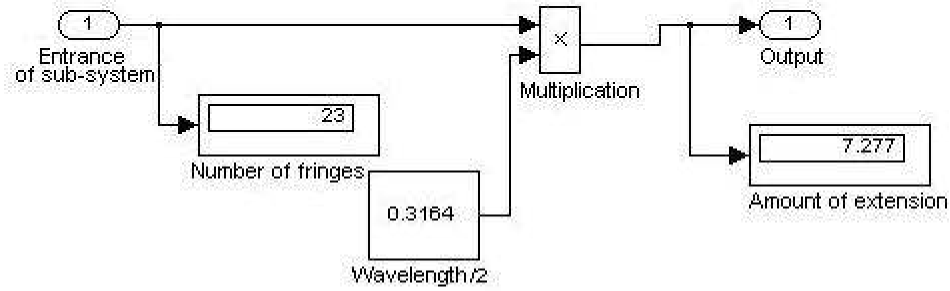

Figure 10-Result phase of Simulation Program

4. Results and Discussion

The simulation program was used to generate model interferogram video signals compatible with the thermal expansion periods of experimental materials, aluminum and copper. The heat interval for measurement of linear displacement was determined between 20 and 50^0C. `The laser beam wavelength was determined as 0.6328 µm, which is widely used in interferometric measurement systems. For the aluminum material, the simulation produced a fringe number of 322 and a displacement of 101.88 µm. The fringe number for copper material was 292 and the amount of displacement was 92.38 µm. The results were compatible with theoretical data.

5. Conclusion

Interferogram video signals derived from interferometric measurement systems were modeled precisely with the computer program and analyzed with the designed simulation program via a video processing method. According to these results, the amounts of expansion for the experimental materials in the determined heat intervals were compatible with theoretical results.

The present study demonstrates that either modeled interferogram video signals or interferogram video signals derived from interferometric measurement systems can be analyzed with the simulation program using features of MATLAB/Simulink software without using additional electronic systems. Furthermore, the program allows academic institutions which host lectures on optoelectronics and measurement instrumentation to conduct experimental studies without the need for an interferometric measurement system.

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