Reprinted from SPIE Vol. 370—Holographic Data Nondestructive Testing

Fault detection in non-destructive testing (NDT) by an opto-electronic hybrid processor

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Abstract

An opto-digital interferogram evaluation system for quality control applications is presented. The system allows the recognition of certain predefined fringe configurations in the input data. Thus the processor is well suited to detect defects of an interferometrically recorded object.

Introduction

Modern interferometric methods such as double exposure holography, time average holography etc. have proven their utility in research and prototype testing over more than 15 years[1]. But now due to the introduction of compact systems for non-destructive testing (NDT)[2,3] interferometry is entering the field of quality control in mass production of highly reliable parts, such as car tires etc. ...

Together with this change in application there is a change in the evaluation of interferometric data from interferogram interpretation to classification. Until now detailed information about object deformation or mechanical stress was evaluated from interferometric data which is a very time consuming procedure only possible for experimental purposes. In quality control however online computed "go" or "no go" decisions are desirable. Especially if NDT is used in production lines, computer-aided fault detection seems to be inevitable.

The proposed system allows fast, easy and artefact-free data acquisition from photographical transparencies due to its optical preprocessor while the digital section guarantees maximum flexibility which allows to classify according to any desired criterion.

Processing Philosophy

As for most pattern recognition tasks a large amount of data reduction has to be applied to the input signal in order to extract suitable features before the final decision can be computed.

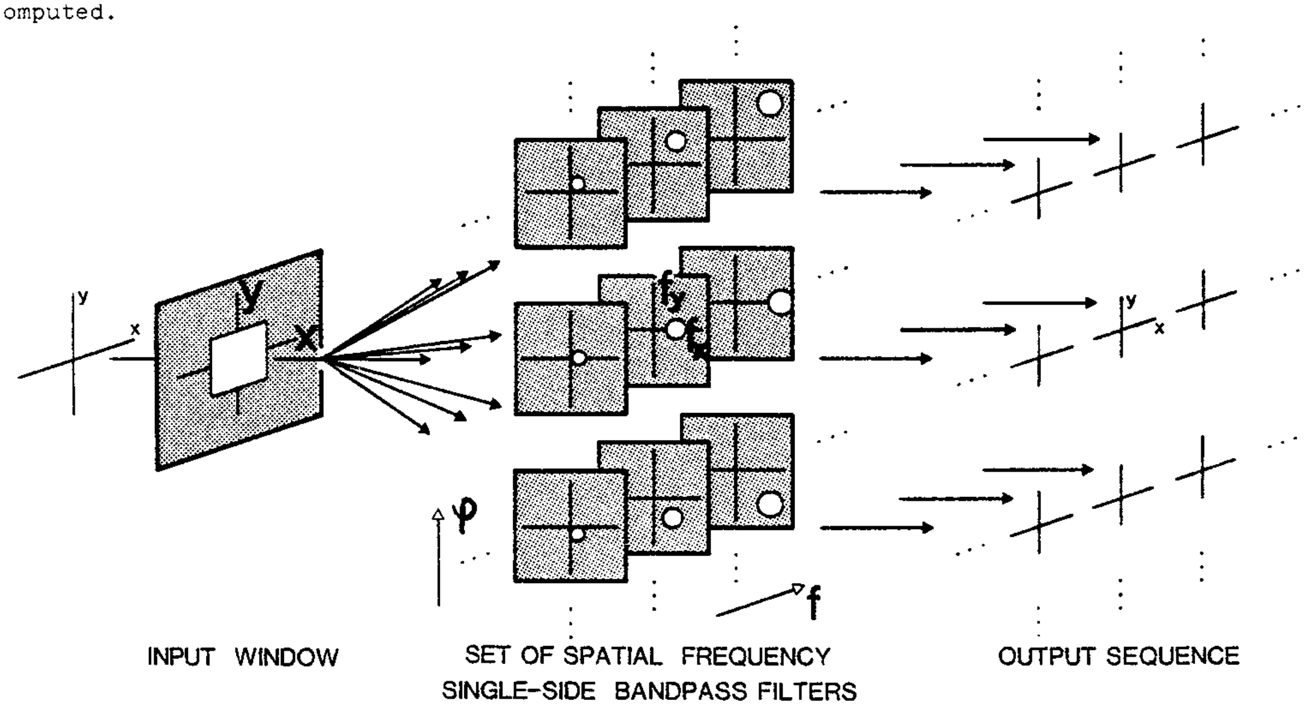

Figure 1. 2-D spectrum analyzer based on the filter-bank principle

Features

The locally grating-like structure of interferograms suggests a signal description by the local orientation and spacing of the fringes or correspondingly the local spatial frequency in polar frequency-coordinates (φ, f). These features extracted by a preprocessor unit serve as input for a digital computer programed with the decision criterion which uses local neighborhood comparison algorithms leading to the final classification.

Preprocessing

As the preprocessor acts on an enormous amount of data it is of utmost importance to operate it in a parallel mode for speeding up the whole system. Because furthermore the input data is recorded on photographic film an analog-optical device is well suited especially as flexibility is not necessary at that stage. As reported earlier[4,5] there exist several possibilities to realize such optical 2-D local spectrum analyzers. The chosen method is based on the filter-bank principle[6,7] : A set of single-side bandpass filters is successively applied to the input image leading to a sequence of output signals (Figure 1.). Each of those filter results contains informations about the location of fringes having frequencies according to the chosen filter's passband. The frequency-coordinates given by the center-frequencies of the filter functions are obviously already sampled. Further sampling has to be applied to the space-coordinates of the preprocessed output (which can be chosen rather coarse due to the signal properties of the interferograms) and to their corresponding signal values. The latter are no real features but they play an important role during the digital data-acquisition.

Digital data acquisition

In order to obtain a single, spatially organized data array in which each cell contains the frequency-coordinate of the corresponding fringe section of the input image the sequence of filtered output signals has to be compressed. This is achieved by using a maximum detection mechanism: For each array point (space-coordinate) only the frequency-coordinates that correspond to the highest signal value within the sequence are stored. After maximum detection the signal amplitude is no longer stored. The further digital processing highly depends on the desired classification task.

Experimental Realization

Figure 2. shows the experimental system. A coherent-optical Fourier-processor with two sandwiched diaphragms acting as time-varying filter function serves as spectrum analyzer. The output is monitored by an ordinary TV-camera feeding its video signal to a digitizer and furtheron to a microcomputer which also controls the succession of the filters in the Fourier-domain.

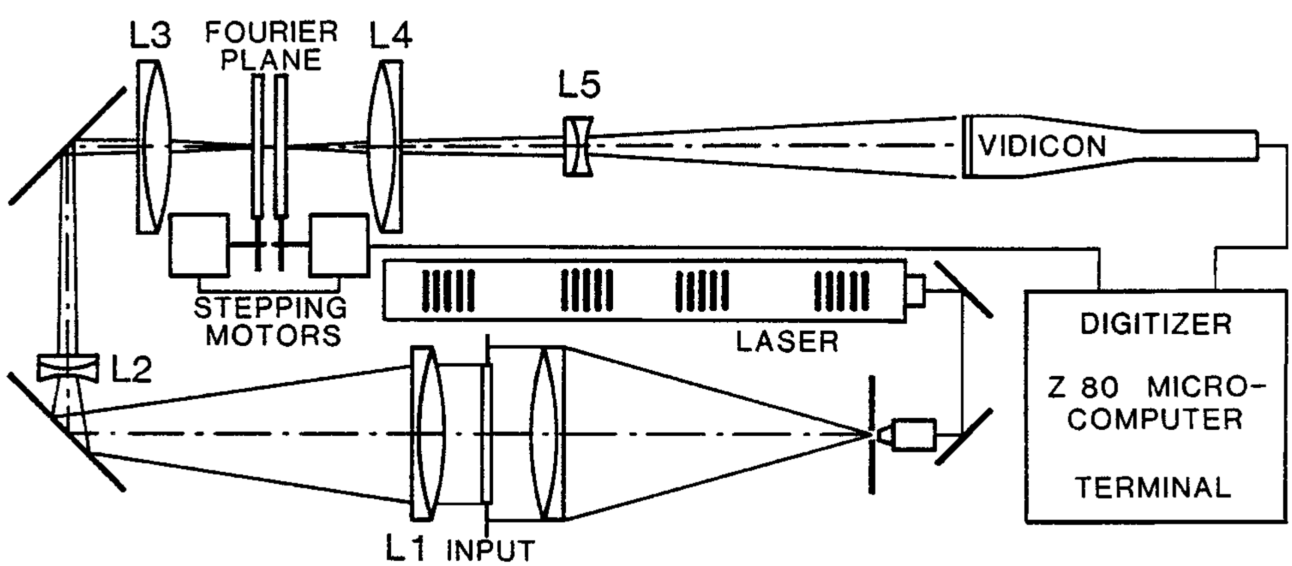

Figure 2. Experimental setup

Coherent-optical preprocessor

In the coherent-optical preprocessor unit the input image (up to 4,5 x 4,5 cm^2) is illuminated by parallel coherent light from an expanded LASER-beam. The lenses L1, L2 and L3 perform the Fourier transformation with a focal length of more than 6 meters leading to conveniently scaled spectra in the frequency plane.

The filter components are shown in Figure 3: A logarithmic spiral scanning the radial frequency f and a sector selecting the angular frequency φ . Each filter component is mounted in a stepping-motor driven ball bearing. Both are centered as a compound filter on the origin of the frequency plane.

Figure 3. Filter components

The geometry of the filter masks was chosen in order to obtain constant relative bandwidth operation (10%) and a radial scanning ratio of 20, determined by an upper and a lower frequency bound. This limited scanning range from 0.25 to 5 mm^{-1} eliminates low and high frequency noise such as illumination fluctuations and scratches in the input image and fits for a large variety of interferometric data. The rotational increment of both filter parts is 10 degrees which assures scanning without any gaps. As for real-valued inputs the complete information is contained in one frequency halfplane a whole scan consists of 36 (spiral) times 18 (sector) filter positions (M = 648) coded into a 10 bit word.

Lenses L4 and L5 serve for the Fourier-retransformation resulting in a focal length of about 2.2 meters in order to get the output scale reduced to the size of a 2/3" vidicon target.

The optical processing capacity is about 8 Mbit which is in the order of the information content of the input data including recording artefacts as mentioned above. This figure is given as the product of the space-bandwidth product (SBP) and the amplitude accuracy as follows:

$$C = SBP \times R = A \times B^2 \times R \; ;$$

A: input pupil defining the size of the input image
B: the system's maximum bandwidth defining the spatial resolution (usually given by the diameter of the effective lens aperture)
R: amplitude resolution.

The whole unit measures (1.15 x 0.45)m^2 with a height of 20 cm.

Opto-electronical conversion

The spatial sampling lattice mainly depends on the gradient of the fringe spacing variations and their curvature (signal properties), i.e. on the size of the light areas in each output frame. The effect of the filter point-response is of minor importance. For common input data N = 16 x 16 sampling points seem to be sufficient. A conventional TV-camera was used for the output detection as to avoid expensive CCD sensor arrays. The N samples are extracted from the video-signal in a special manner in order to allow digitizing and data storage in real time by an ordinary microcomputer. Figure 4. explains the temporal succession of the electric signals for a complete measuring cycle. The data acquisition time for the 256-element feature vector is M x 20 msec $\approx$ 13 sec. .

Digital computing

The final computing is done within about one second since the feature vector represents only 2.56 kbit of stored data (N x 10 bit). A typical algorithm is described by, first selecting array points containing radial frequencies within an appropriate range and then investigating the neighborhood relations of the angle component of these points. The decision-making process depends on the required task and can be individually programed.

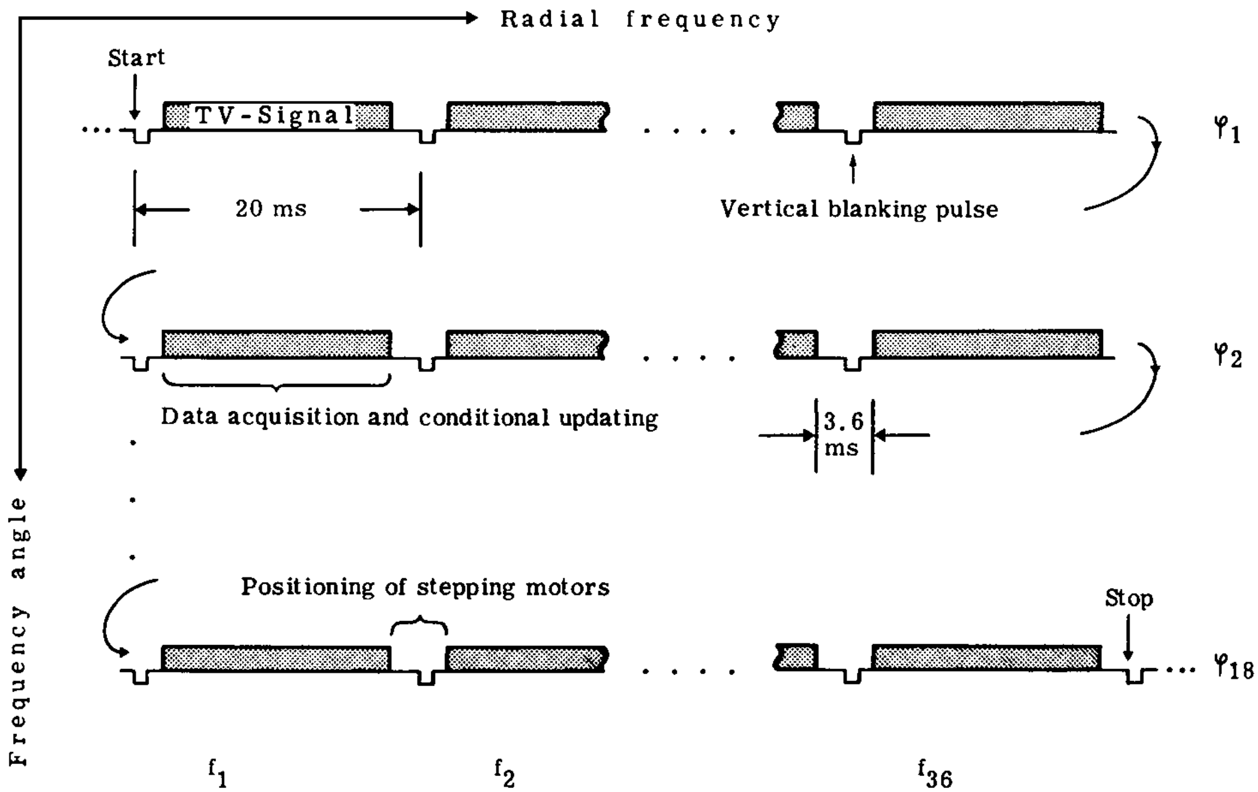

Figure 4. Temporal succession of the microcomputer controlled data acquisition and filter positioning (real time)

Experimental results

In order to illustrate the processor's working principle a testpattern (Figure 5.) consisting of 16 gratings, having four different frequencies, each in four directions is used as input image.

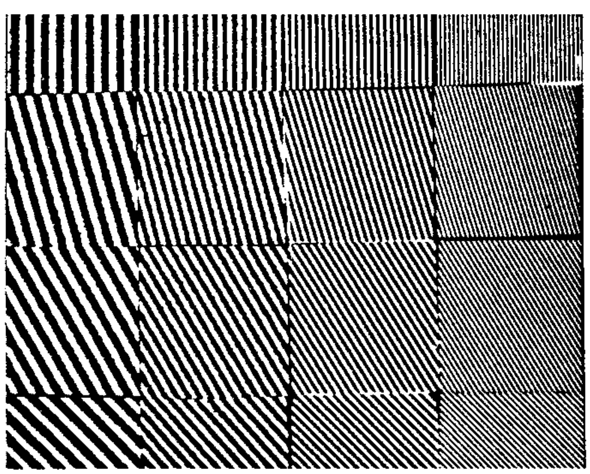

Figure 5. Testpattern

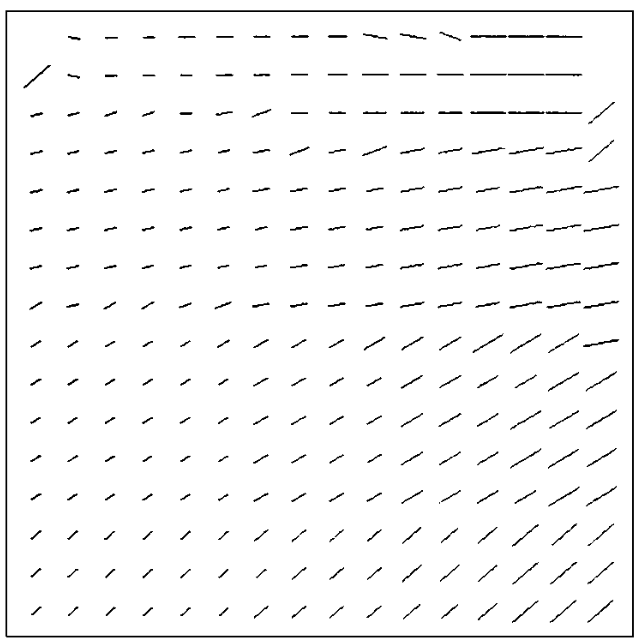

Figure 6. Gradient field (image deformation in the vertical direction is due to format restrictions)

Figure 6. shows a computer printout of the feature vector. The chosen representation may be called a gradient field. An actual interferogram of a metal plate having three welded joints on the other side is to be seen in Figure 7. As a hypothetical task these three areas shall be detected. Figure 8. shows the gradient field and Figure 9. a simplified computer plot of the interferogram with white marks inserted at the automatically detected areas that indicate faults in the object.

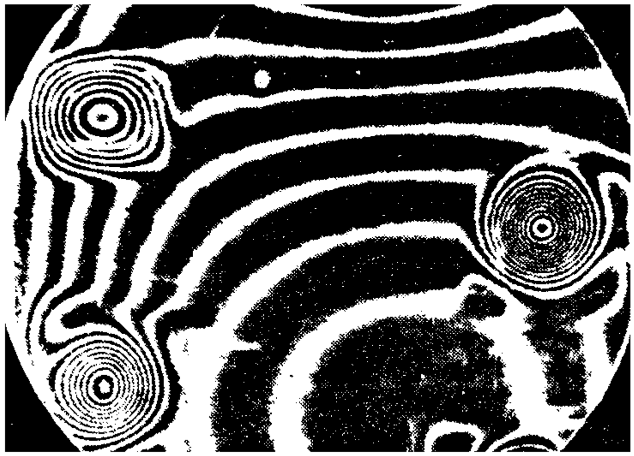

Figure 7. Interferogram of a metal plate showing irregularities on the surface

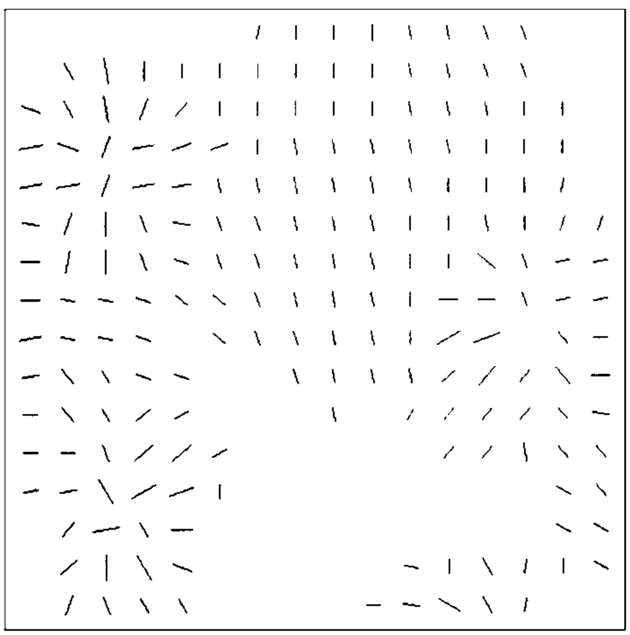

Figure 8. Corresponding gradient field (a lower frequency bound was set by the computer)

Figure 9. Automatically detected irregularities

Conclusion

The presented concept of a hybrid interferogram evaluation system offers highspeed processing and good flexibility as well. The optical preprocessor allows data reduction factors of up to 3000, from about 8 Mbit of the input data down to 2.56 kbit of the digitally stored feature vector. In spite of the high reduction there is virtually no loss of relevant information due to the chosen features that are reliably extracted from a great variety of input images without any alterations of the preprocessor's parameters. Analog optical computing is of great advantage for the opto-electronic conversion as it works without artefacts on photographically stored data. The digital computer adds the necessary flexibility to the system and allows easy computation of the final decision according to a desired criterion and ensures that alterations concerning the classification task can easily be met. The described processing is highly insensitive to noise and other artefacts commonly present in interferograms.

Acknowledgements

The authors like to thank Stefan Klauser for the construction of the video-digitizer.

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Please cite as:

Glünder H. and Lenz R. (1983) "Fault detection in non-destructive testing (NDT) by an opto-electronic hybrid processor". In: Vukicevic D. (ed.) "Holographic data, nondestructive testing" (Proc. of a Conference in Dubrovnik/Croatia, 04.-08.10.1982) SPIE Optical Engineering Press, Bellingham/WA, pp. 157-162.