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Image Processing [and Discussion]

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Image processing

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Ultrasonic recordings and radiographs contain in pictorial form information required for decision making. Many investigators are actively engaged in the interpretation of images, obtained by both aeroplanes and satellites, by automated techniques. The techniques employed to process these images are relevant to the needs of engineering and medical diagnosis from both ultrasonic and radiographic images. In particular, since the use of intensity as a feature for classification is frequently unsatisfactory in these monochromatic images, the importance of features based on texture is considered. In addition the development of automated processing of ultrasonic records of British Rail track is discussed.

1. Introduction

Until a few years ago, the presentation of radiographic and ultrasonic data depended mainly on analogue techniques, and the results obtained revolved around either the choice of radiographic film or the setting of threshold levels. These techniques are associated with a considerable loss of information either from superimposition or from the simplification of the display. Recently the processing of data by computer has enabled these deficiencies to be removed and has permitted the presentation of completely new pictures. A major advance has taken place in radiography where the introduction of computed axial tomography has fundamentally transformed investigation of the brain (Ambrose & Hounsfield 1973). The new information has been obtained by making full use of three dimensions instead of two, and by leaning heavily on data processing.

It is probably true to say that the major role, at present, of image processing is in enhancing images for better visual interpretation. Although attempts are being made to automate interpretation, and this paper will include examples, interpretation of complex images by computer remains a very difficult task. The reasons for this are many but essentially relate to a development time of 25 years for computers and millions of years for the eye–brain combination.

Image processing is now playing a role which complements that played by mechanical and electrical aids for man in improving signal:noise ratios. Thus while the telescope acquires more photons than the eye, image processing can, for example, optimize their spatial distribution in an image by correcting for dynamic changes during the acquisition time. Image processing can also be aimed at reducing the limitations imposed by the physiology of the eye, at the more effective extraction of information from multispectral sources or more simply for cosmetic purposes by using techniques such as filtering, edge enhancement and grey level stretching.

Image processing transforms data and should be designed to extract in an optimum way the desired information. It does not create information and therefore it should not be allowed to encourage the acquisition of low quality data.

2. IMAGE ANALYSIS

There are four basic stages in the analysis of images: data acquisition, pre-processing, feature extraction and interpretation. It cannot be stressed too strongly that every consideration should be given to the data acquisition stage since this sets the limits to significant interpretation. In radiography this necessitates the optimization of source and detector parameters to identify and locate an abnormality; in ultrasound it necessitates the optimization of source and coupling. These factors are considered in detail in other papers in this symposium.

In some problems, abnormalities produce signal intensities which exceed noise by several standard deviations or have features (e.g. size, shape or structure) that readily distinguish them from their environment. In such cases, threshold techniques are employed and the defect is readily rendered visible in a one-bit display showing only presence or absence. Further thresholds may be set in terms of spatial parameters and the recognition of a range of defect types can be achieved. In principle the detection of defects in rail by ultrasonic means (Krautkramer & Krautkramer 1977) belongs in this category.

3. INSPECTION OF RADIOGRAPHS FOR SINGLE DEFECTS

The use of thresholds (or level slicing) is at the heart of most image processing techniques and the initial application of ratioing, normalisation or fitting procedures permits a considerable extension of this simple processing tool. As an example, consider the detection of defects in a radiograph of a fuel element weld (Clements 1976). The simple use of a single threshold across the radiograph would be totally inadequate since normal changes of film density will frequently be greater than that associated with defects. A first useful step would appear to be to ratio a normal image with an abnormal one. Unfortunately in many applications this can lead to problems because the normal physical variation from weld to weld introduces significant artefacts other than defects, such as ripples in the weld surface. (This is unlike multispectral data from the same scene, where taking ratios is a very useful initial stage.) An alternative approach is to use a fitting approach in which the expected variations can be described by a mathematical approximation, i.e. a type of louvre fitting procedure. For a two-dimensional matrix of density values, surface fitting is involved and the computation can be simplified by fitting plane surfaces in a succession of overlapping areas. These are usually adequate for providing a base reference surface and this technique has been shown to be feasible for the automated inspection of fuel element end weld radiographs.

The detection and measurement of small defects in a radiograph depends on their contrast and the grain size of the film. The contrast is determined by the change in transmission of X-rays associated with the defect and the density of the film but is reduced by geometrical factors, scattering, energy spread of X-ray source, etc.; usually the grain size and speed of the film decrease simultaneously and a practical limit is therefore set by the allowed X-ray intensity and the time available. The background noise in the radiograph is due to random blackening of the grains and is usually termed quantum mottle. The associated film transmission change can be comparable with that associated with a defect and the spatial appearance of the noise is such that it leads to sharp gradient changes in a microdensitometer trace and white noise in a spatial frequency display.

The detection of low contrast, small defects is clearly very difficult since the associated density change is similar to the noise variation and the spatial frequency spectrum is similar to that of the grains. The eye–brain combination makes the best use of the physiology of the eye to produce remarkable detection results and the object of image processing is to attempt to approach this capability. Essentially the eye locates the defect by using a combination of contrast difference and frequency spectrum difference (the defect is associated with a higher amplitude at lower frequencies). The eye then measures it by maintaining the high frequencies associated with the edge of the defect but filtering out the high frequencies associated with the background noise.

Interactive image processing is used to determine a procedure which will give an equivalent capability. Visually it is convenient first to examine the data in detail by stretching the density values associated with the defect and investigating the consequences of various thresholds at the site of the defect and nearby. These procedures can be made more quantitative by curve-fitting in the region of the defect, determining the standard deviation, and applying thresholds at σ, 2σ, 3σ, etc., greater or less than the mean density, depending whether the defect is associated with a higher or lower density. If this procedure reveals the defect, and the associated pixel area is greater than that associated with the noise, then the problem has been solved, since it is then a simple operation to apply a further threshold based on area to remove the noise.

The above example illustrated that visual evaluation can be aided by image enhancement and in many cases the use of subtraction, filtering, grey level stretching, etc., makes decision-making simpler. However, implicit in these operations are that the only feature to be manipulated for interpreting images is the intensity, and that the eye performs the interpretation from the enhanced image. It is possible to aid the evaluator by displaying other features in the image; for example, perimeter, area and shape are features which can be evaluated in different regions of the image and used by the evaluator for interpretation.

4. FEATURE EXTRACTION IN SINGLE WAVEBAND IMAGES

In fact, when evaluating radiographs or ultrasonic signals it is customary to treat the data as if they were monochromatic and therefore to derive features that are based only on variations of the intensity. (This limits the processing significantly: when multispectral data are taken, provided dispersion is significant, more information can be derived from an image which may well permit an improved interpretation.) Intensity variations in an image are often referred to as texture, and their representation is based on the use of first- or second-order statistics over sub-images containing $P \times P$ pixels. By using first-order statistics, features are calculated that are independent of the location of an intensity value (i) but simply the frequency of occurrence which can be represented by the discrete density function $f(i)$ (Harlow *et al.* 1976). Customary features are the mean (or first moment about zero), given by

$$\mu = \sum_{i=0}^{n} i f(i);$$

the rth moment about zero, $m_r = \Sigma\, i^r f(i);$

the rth moment about the mean, $c_r = \Sigma\, (i-\mu)^r f(i);$

the variance, $V = \Sigma\, (i-\mu)^2 f(i) = C_2;$

the skewness, $$S = V^{-\frac{3}{2}} \Sigma \, (i-\mu)^3 f(i) = C_3/C_2^{\frac{3}{2}};$$

and the kurtosis, $$K = V^{-2} \Sigma \, (i-\mu)^4 f(i) = C_4/C_2^2.$$

By using second-order statistics, features are calculated which relate to the location of intensity values, or rather the spatial relations between intensity values. These can be represented (Haralick 1974; Evans & Custance 1977), by spatial frequencies, calculated by a Fourier transform, or by a range of pragmatic parameters such as the number of edges per unit area, the spatial regularity of shapes (such as pores) and spatial intensity co-occurrence probabilities. The latter approaches have been developed because they are computationally simpler or faster and heuristically advantageous.

5. Inspection of radiographs for multiple defects

We have examined the use of features based on second-order statistics to represent microporosity observed in radiographs. Fourier techniques rely on the presence of spatial frequencies associated with the pores that are not present in the grains. The limit of pore resolution is thus set by using fine grain film and long exposure times, pores being distinguished by their lower spatial frequencies. Difficulties were met, however, since the grains tend to produce a white spectrum. Co-occurrence probabilities have also been examined (Stanley 1977). This type of analysis has two advantages over Fourier methods: it is faster and it is unlikely to be affected so severely by the granularity of the image. In fact, the porosity should be distinguished since it is less random than the grains, associated with a clustering of *darker* grains and the neighbour distance in the co-occurrence matrix can be optimized to emphasize the pores. As in the use of the Fourier methods, the radiograph examined did not show clear results and further work is in progress.

This paper has been concerned with the general approaches to image processing and it has shown that it is difficult for a computer to incorporate the many factors that trained interpreters employ in evaluating images. These factors include intensity, texture, shape and context. It has been shown that image processing systems have achieved success by using intensity and limited success by using texture. Shape and context have received very little discussion. It is interesting to conclude the paper with an example of image processing that makes use of shape and context in an elementary manner.

6. Automated analysis of ultrasonic records of British Rail track

British Rail track is inspected ultrasonically for defects by a vehicle travelling at *ca.* 32 km/h (Johnson 1971). This vehicle records the data from ten ultrasonic probes – five on each rail – on 35 mm film. Defects are detected by specular reflexion of ultrasound beams at optimally chosen angles. Specular reflexion also occurs from normal features in the track such as bolt holes, rail ends and the rail bottom. Specular reflexions are recorded provided their signal strength exceeds that of a set, but variable, discriminant level. A recording simply establishes the presence or absence of a signal and gives no information about its strength, i.e. it is observed as a black mark on films. The film record employs the B-scan mode and the location of the scatterer is determined with respect to reflexions from the top and bottom of the rail (except for the high-angled echoes) from a knowledge of the two-way travel time. The shape of the mark provides a measure of the length and direction of the reflexion surface. The context of the mark is used to determine whether it has been generated by a normal or abnormal source in the rail.

Ultrasonic reflexions from rail present almost an ideal case for the application of automated processing techniques once the problems associated with the acquisition of data have been solved, since:

(i) Data are acquired in a linear manner from an engineered material: steel.

(ii) A large proportion of the data is repetitive and uninteresting so that data reduction methods can reduce the need for visual inspection with no loss of significant data.

(iii) The reflexion sources are known, and possess distinguishing characteristics which enable them to be allocated to classes. Normal echoes are ascribed to bolt holes, bond holes, raid ends, misalignment of the probe etc. Defect echoes have to be recognized in the background and context of normal echoes. In fact, the normal echoes provide further information about their location in the track.

(iv) Processing by machine can achieve equality with a trained evaluator, except in abnormal circumstances, provided the recordings are of a reasonable standard.

(v) Evaluation speeds comparable with those of a trained evaluator can be achieved and the inspection results are not subject to the loss factors which are a necessary part of human evaluation.

The film records obtained by British Rail are now evaluated by machine (Hawker 1974) and the results obtained are leading to continually improved analysis procedures. Film provides a data base and is associated with a large range of variations about the norm, which provide a serious test of the designed analysis algorithms. The reduction of data from the film records before analysis has also proved useful in designing the next phase of automated processing with the use of an on-board computer system (Gardner & Hawker 1976).

This system processes the signal from each probe separately by its own microprocessor-based time digitizer. A data reduction factor of at least ten is required from these modules. A mixture of analogue and software processing permits the necessary speeds of signal handling and processing to be achieved. Special software has been written for a PDP11/10 to examine the reduced signals and to decide the significant data which need recording on magnetic tape. It should be emphasized that although considerable data reduction takes place, only the regular, normal reflexions from the top and bottom of the rail are not recorded. Information about all reflexions within the rail will be recorded. Finally, the data stored on magnetic tape will be analysed by the analysis algorithms developed for film analysis.

For the future, the installation of an on-board computer paves the way for the real-time recognition of defects, better control over data acquisition and savings on film costs. It encourages improved data acquisition at higher speeds.

7. Conclusion

The application of image processing to radiographic and ultrasonic images is in its infancy. It has been shown that it is already a valuable tool for image enhancement; the future will undoubtedly provide improvements in classification which will lead to automated interpretation.

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Discussion

R. HALMSHAW (*AP4 Branch, R.A.R.D.E. Fort Halstead, Sevenoaks, Kent, U.K.*). I was pleased to hear the clear distinction made between image processing and image enhancement, and I should like to add to the words of caution expressed on the prospects of obtaining useful image enhancement after digitization on any image which has noise: on radiological images the noise is frequency-dependent and not 'white'. The human eye is a very powerful tool and can clearly distinguish images on radiographic film which one has the greatest of difficulties in showing even on a digitized scan, particularly on a background of varying density.

A. NEMET (22 *Denbigh Gardens, Richmond, Surrey, U.K.*). Dr Gardner, in referring to the automatic installation used in the British Rail test car, said that the equipment can be changed over from automatic operation to human, visual, operation in cases where automatic inspection is unsatisfactory. Can he say how one can automate this change-over and if this is impossible how one decides on this beforehand?

W. E. GARDNER. The on-board computer installation simply replaces the film-recording system and ensures that all the *necessary* information for evaluation of the state of the rails has been stored on magnetic tape. The routine analysis of these data is automatic, but the operator can request that the machine should stop in cases where the automated analysis is unsuccessful. This implies that some data have been collected that do not fit the prescribed analysis software. In these cases the unusual (or unsatisfactory) data can then be displayed for visual interpretation before the machine is asked to continue with automated interpretation.