ADVANCED ENHANCEMENT TECHNIQUES FOR DIGITIZED IMAGES

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Abstract

Computer image enhancement of digitized x-ray and conventional photographs has been employed to reveal anomalies in aerospace hardware. Signal processing of these images included use of specially-developed filters to sharpen detail without sacrificing radiographic information, application of local contrast stretch and histogram equalization algorithms to display structure in low-contrast areas and employment of other unique digital processing methods. Edge detection, normally complicated by poor spatial resolution, limited contrast and recording media noise, was performed as a post-processing operation via a difference-of-Gaussians method and a least squares fitting procedure. In this manner, multi-image signal processing allowed for the precise measurement (to within 0.02 inches, rms) of the Inertial Upper Stage nozzle nosecap motion during a static test firing as well as identifying potential problems in the Solid Rocket Booster parachute deployment.

1. INTRODUCTION

A goal of image enhancement is to improve image quality so that important information may be more easily detected and displayed. In nondestructive evluation (NDE), the purpose of the enhancement process is to display the low contrast detail of cracks, voids or inclusions, or to better aid in the definition of boundaries (e.g., edges or part orientations) than can usually be perceived by the unaided eye.

For space, military, and medical applications, image enhancement methods are highly developed and proven to be useful in extracting additonal information from the imagery. In comparison to these uses, those of industrial radiography can be relatively simple and straightforward. Recently, there has been dramatic reductions in cost of necessary equipment; thus it is reasonable to consider image enhancement tools as a pragmatic addition in radiographic interpretation. This paper reviews some of these tools, illustrates various applications and provides a practical basis for their effective utilization.

The NDE image recording environment is often not conducive for enhancement. Low pixel resolution, poor signal-to-noise ratios and limited contrast frequently reduce image information content. Through *a priori* knowledge of detector behavior and structural geometry, and statistical analysis of the signal data, image-specific enhancement algorithms can be applied to the digitized data. An adjunct of this process provides enhanced, structure-revealing imagery. In this manner, difficult to obtain parameters can be measured under working conditions.

This paper is divided into the following sections: Section 2 details some of the enhancement and edge detection techniques employed in NDE to assess material and structural performance. Section 3 presents several case studies which illustrate the application of these techniques in NDE. Section 4 presents a summary.

2. IMAGE ENHANCEMENT AND EDGE DETECTION TECHNIQUES

Image enhancement and edge detection techniques are two of the major considerations in the overall approach to NDE image utilization. Other important parts of the procedure are summarized in Figure 1. The raw NDE imagery is first digitized at high resolution. Statistical analysis of this digitized data, combined with knowledge of the sensor and of the hardware being examined, is used to develop image-specific enhancement and detection algorithms. Finally, optimal estimation procedures are employed to extract engineering variables from the processed data.

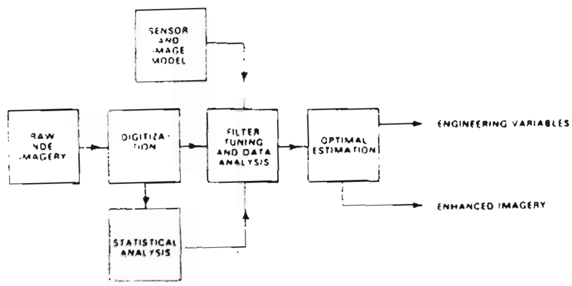

Figure 1. An Overview of the NDE Image Analysis Approach.

Image enhancement techniques fall into two main categories, global and adaptive (or image-wide and local). Each of these categories is discussed below. Digital enhancement algorithms have been well documented[1-7] and serve to remap image information from an imperceptable to a visible range. Edge detection techniques are subsequently used for extracting location information. This allows for the accurate mensuration of features and structures.

Global signal processing is the term applied to algorithms which revalue pixels irrespective of their location within the image. Mathematically, the process can be represented by:

$$o[n,m] = T\,(i[n,m]) \qquad (1)$$

where T is some revaluation function which takes the input pixel value, $i[n,m]$, and remaps it to an output value, $o[n,m]$. Typical functions for T include standard contrast stretching (selectively increasing the image gain), histogram revaluation where a narrow range of contrast is (non-) linearly spread over a larger domain, and pseudo-color enhancement, the remapping of a grey scale image into a color space. The latter method is utilized whenever a grey scale remapping is insufficient to allow discrimination of certian details. This procedure exploits the fact that the human eye can perceive subtle variations in color and intensity better than changes in intensity alone.

Since all of these functions can be readily implemented through fast hardware and lookup tables, global enhancement techniques are implemented in an interactive mode that optimizes the visibility of a component in the image. Furthermore, by specifing a limited area for enhancement, the region of interest can be examined without distorting features elsewhere in the image. As an example of this regional processing, an original digitized x-ray of an Inertial Upper Stage (IUS) rocket motor is presented in Figure 2a. The region of interest is located on the left side of the image.

(2a)

(2b)

Figure 2. An Example of the Global Enhancement Process. Shown is the Thermal Boot Region of an IUS Rocket Motor Nozzle.

This section, called the thermal boot area, was enhanced using a global contrast stretch and is seen in Figure 2b. Here, one can observe a feature known as the thermal boot void in relation to the motor's nosecap and certain instrumentation wires.

Comprehensive reviews of adaptive enhancement techniques can be found in Tom[1] and Lim[2]. These methods utilize a variable "window" about a pixel location to obtain information used for the pixel processing. Hence, the remapping function T is dependent on the location of the sliding analysis window. Mathematically, this is represented by:

$$o[n,m] = T_{n,m}(i[n,m]) \;. \qquad (2)$$

The local measurements that can be used to affect the revaluation function include the computation of the contrast mean and variance, histogram analysis of the intensity distribution and measurement of the spectrum magnitude. The former two statistical quantities are computationally rapid and are used for "local contrast stretch" algorithms which remove variations in global brightness and increase the contrast of local details. This enhancement technique has been useful for revealing nonuniform lamination structure in x-ray images of carbon-carbon composites presently used in some rocket motor exit cones.

A local histogram measure of image intensity is used to implement a "histogram equalization" enhancement. This technique generates contours of equal intensities which can be used to detect density anomalies. An example is presented in Figure 3 where early stages of stress cracking along the leading edge of a turbine blade is revealed. The area of lower density (which might indicate a small crack) is evidenced by the skewing of the contour lines along one of the blade "fingers".

(3a)

(3b)

Figure 3. An Example of the Local Enhancement Process. Illustrated is the Leading Edge of a Turbine Blade.

Enhancement techniques are useful for subsequent signal processing as well as for visualization. Having discerned a foreign object, inclusion or void. post-enhancement analysis is used to quantify the anomaly. As discussed above, the measurement of image intensity variation yields an estimate of the relative change in material density. However, enhancements of time-sequential images may reveal the motion of internal components. To accurately measure this motion, as well as record structural dimensions of any type, edge detection algorithms must be applied.

Although there are numerous methods to detect edges in imagery [8], the fundamental goal of all algorithms is to compute a space differential of the form:

$$o[n,m] = \frac{d}{dx}\,\frac{d}{dy}\,(i[n,m]) \;. \qquad (3)$$

This can be implemented either by finite impulse response or spatial frequency domain filters. Such a technique is sufficent to reveal an "ideal" edge - one which is uncorrupted by noise or blurring. However, in the NDE domain, a method applicable to noisy imagery is required.

The Marr-Hildreth technique[9,10] is such a method, using a gaussian filter to normalize pixel intensities over a variable local window before a space differential is applied. Through the variation of the window size, the dimension of the edge can be regulated: the smaller the window, the more localized the boundary. The algorithm thus detects intensity variations (edges) at a coarse resolution where signal noise is attenuated and precisely defines the boundary at a finer resolution. By utilizing both sets of boundaries, the "edge of interest" can be located. Having determined such a region, prior structural knowledge can be used to estimate the precise location of a component. In this way, a known boundary will allow for a least-squares fitting of the ideal to the detected edge. The overall edge extraction procedure is illustrated in Figure 4.

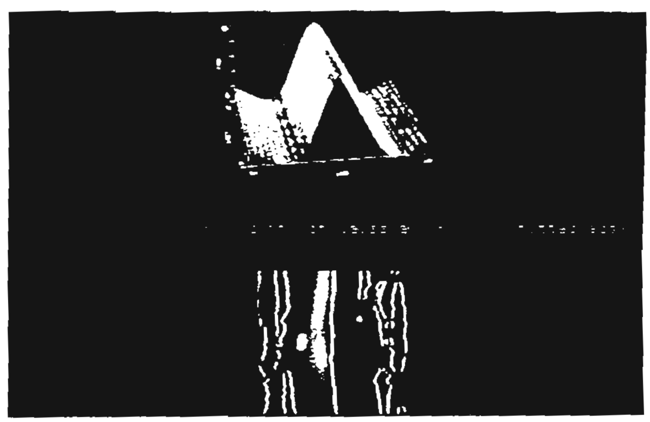

Figure 4. An Overview of the Edge Location Technique Employed in NDE Image Processing.

3. CASE STUDIES

In this section, the application of digital enhancement and signal analysis techniques to NDE images will be illustrated through two recent aerospace hardware investigations, both of which involved identifying anomalous behavior from time-sequential imagery. The first concerned the analysis of radiographs taken during a live test firing of an IUS rocket motor at the Arnold Engineering Development Center. The 450 KeV x-ray images were recorded on photographic film at three-second intervals throughout the 110-second burn. The second example focused on analysis concerning the deployment of the Space Shuttle's solid rocket booster (SRB) parachutes. These images were recorded on 35 mm film taken by a high speed camera.

For the first NDE case study, the IUS rocket nozzle analysis is reviewed. The unsuccessful launch of a tracking data relay satellite (TDRS) in the summer of 1983 began an investigation of the IUS rocket motor. As part of this inquiry, x-ray images of a December 1983 IUS firing were manually reviewed. This preliminary review could not definitively assertain structural motion during the burn sequence, and digital signal processing of the data was requested.

The signal processing sequence of the IUS imagery began with digitization of the radiographs into 50 micron pixels in order to characterize features of interest at high resolution. Subsequent pixel averaging resulted in Figure 2a. To reveal imbedded structure in the image, a variety of enhancement procedures were employed: the thermal boot void was made visible through a global contrast stretch, the silicon and carbon phenolic interface was revealed by averaging multiple images and then performing a local contrast stretch. The resultant enhanced images are represented by Figure 2b. Based on specification diagrams such as the one illustrated Figure 5, edge detection filters were designed to delineate the upper surface of the thermal boot void and the nosecap base. The relative distance between these edges are plotted in Figure 6 as a function of burn time. In this way, the nosecap motion was confirmed with a measurement uncertainty of 0.02 inches and 1.5 seconds, rms. The enhanced images also revealed density differences in the thermal boot convolute during the burn. This region suffered a burnthrough late in the firing sequence. Aided by this analysis, the IUS motor was redesigned; the first (and successful) launch of the reconfigured motor occurred late in 1984.

As a second NDE case study, the analysis of the SRB parachute deployment is cited. These solid rocket boosters were designed to be reusable, but high velocity impacts from initial launches caused several SRB's to sustain severe damage. As part of the NASA investigation, mission footage of SRB parachute release was

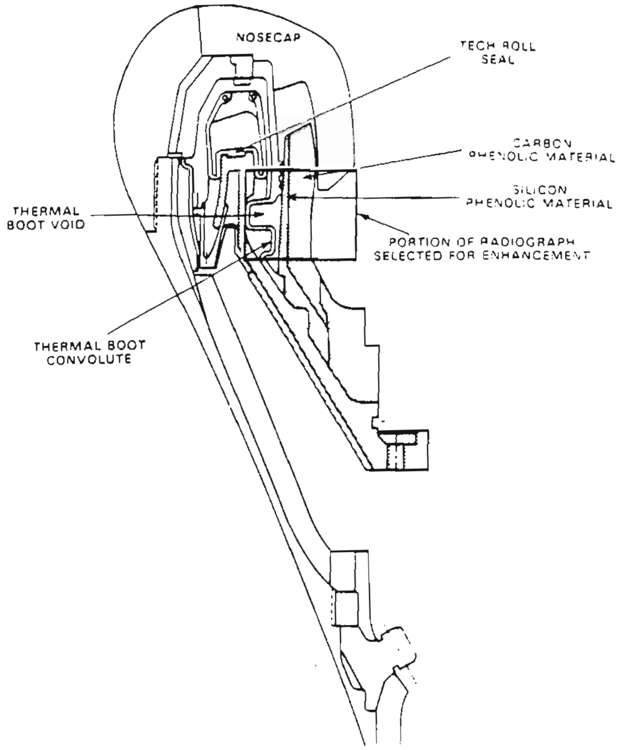

Figure 5. Schematic Illustration of an IUS Rocket Motor Nozzle.

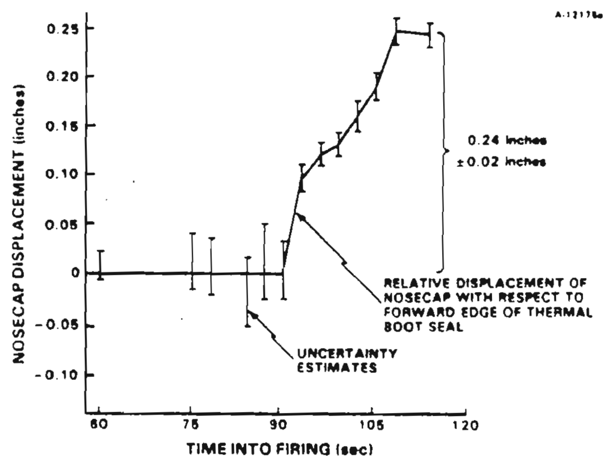

Figure 6. Displacement of IUS Nosecap Relative to Thermal Boot as a Function of Burn Time.

analyzed to determine deployment dynamics. The motion picture images were digitized and globally enhanced to reveal the manner in which the parachute unfolded. Subsequent edge definition algorithms allowed orientation measurements to be made of the parachute canister to deployment as a function of time. Figure 7a shows an enhanced image of the canister with the main parachute unfolding underneath it. Figure 7b illustrates the preliminary boundaries detected

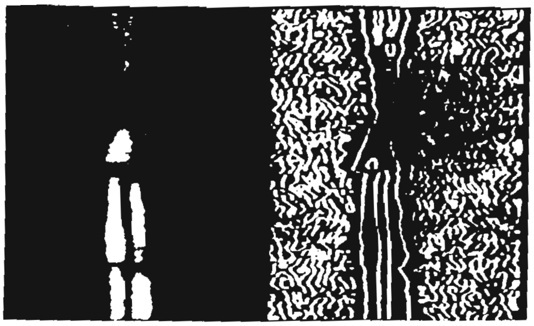

Figure 7. Enhancement and Edge Location Results for a Frame of an SRB's Parachute Deployment.

using the gaussian edge definition algorithm. While all motion was within design specifications, the enhanced images showed the parachutes deploying externally to the canister, which was not expected. This behavior is graphically illustrated in Figure 8. Here the angle between the parachute and the deployment canister is plotted as a function of time. The oscillations correspond to the parachute unfolding. Later design modifications have resulted in reducing splash-down velocity and lowering the amount of SRB impact damage.

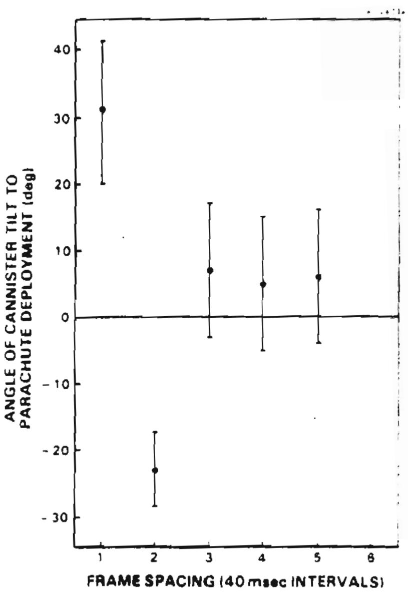

Figure 8. Orientation of SRB Parachute Canister Relative to the Unfolding Process as a Function of Time.

4. SUMMARY

Modern image enhancement and signal processing techniques are being employed to extract all of the information contained in industrial NDE images. Application of these digital tools to x-ray and photographic images has resulted in the observation and measurement of engineering parameters not previously visible. Use of edge location algorithms on enhanced, time-series NDE imagery has permitted the precise quantification of features and materials in situ and under working conditions.

5. REFERENCES

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