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IMAGE ENHANCEMENT FOR RADIOGRAPHIC NON-DESTRUCTIVE INSPECTION OF THE AIRCRAFT

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Abstract

Traditional radiography is a non-destructive inspection (NDI) process widely used for the detection of cracks and damage in aircraft structures. However a significant limitation is that it relies on visual assessment by the operator for identification of defects from the radiographic image. Digital radiography allows all the benefits of producing significant increases in magnification and image clarity, as well as efficient management of digital images.

Image enhancement allows more accurate interpretation of digital radiography indications. In this paper, image enhancement methods are investigated for NDI inspection of the aircraft. The wavelet thresholding technique is applied to reduce the radiographic image noise. The contrast and brightness of the image is adjusted using gamma correction and contrast limited adaptive histogram equalization to enhance perception of defects. These are used to eliminate noise and background artifacts and to smooth sharp edges, but also tend to remove some of the detail in small objects.

1. Introduction

Non-destructive inspection (NDI) is widely used in many fields, particularly for the detection of cracks and damage in aircraft structures. One of the most important techniques used in NDI is radiography that is based on the transmission of X-rays or Gamma rays through an object to produce an image on radiographic film.

The interpretation of a radiograph is being done manually by experienced interpreters in the field. It is time and manpower consuming work. In addition, visual assessment by the operator for identification of defects based on film radiography is very subjective, inconsistent and sometime biased. Digital radiography allows all the benefits of producing significant increases in magnification and image clarity, as well as efficient management of digital images. The computer technology has developed very quickly in terms of both hardware and software. So, it is possible to use computer vision to detect the defects instead of a human being. Image enhancement is a significant part for automated radiograph inspection systems. Enhanced image could allow the inspector to safely, quickly and accurately perform the necessary visual inspection. The inspector, with the aid of computer enhancement and intelligence, examines the imagery for surface defects.

From the Fig. 1, Fig. 2 we can see that the image is low contrast, high noise and the background is not uniform. The defects are all quite small and their positions are random. These factors make defect detection difficult. So, it is necessary to enhance the contrast and reduce the noise before defect recognition.

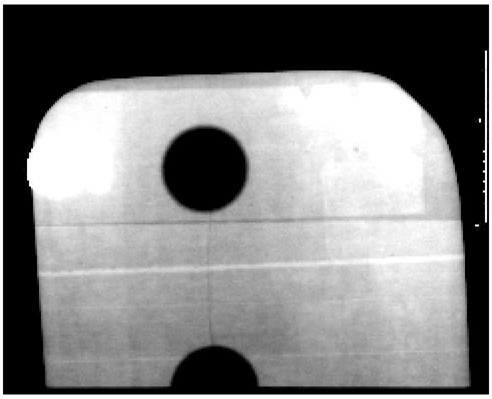

Figure 1: *A radiographic image*

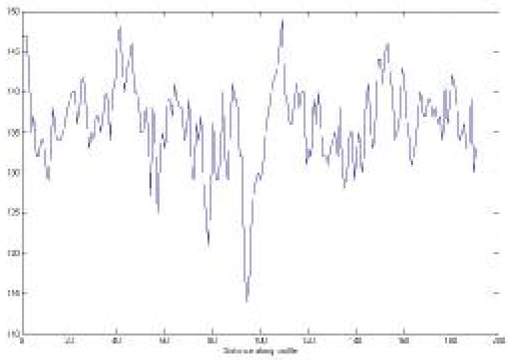

Figure 2: *Gray level profile*

Currently, most researchers use histogram equalization to enhance contrast of radiographic images and use median filter to reduce the noise of radiographic images [1] [2] [3]. In this paper we propose to wavelet thresholding technique, gamma correction and contrast limited adaptive histogram equalization to enhance perception of defects.

2. Noise Reduction

2.1. Median filter

Median filter is a most frequently used technology to remove the noise from the radiographic image. The median filter deploys a small mask template, which is usually 3×3 or 5×5. The template operation maybe calculated by either correlation or convolution operators. The median filter replaces a pixel's gray level with the median value of its neighborhood.

$$G'(x,y) = median\{G(x_1,y_1) \mid (x_1,y_1) \ is \ in \ N(x.y)\} \quad (1)$$

where $N(x.y)$ is the immediate neighbors of the pixel (x,y).

2.2. Wavelet Thresholding

In this paper, wavelet thresholding is applied to remove the noise of the radiographic image. ”Wavelet” is a relatively new but rapidly growing area. Basically, it refers to a class transforms with an added advantage in its ability in scaling and translating. Just like ”Fourier Transform”, it can act as a filter. It is this behavior that leads to its widely accepted use in vastly different areas. Some of the areas are image, video and audio coding, communication and noise suppression. Given the abundant literature on basic wavelet theories, one can easily find extensive presentations on the topic of interest. For example, [4] [5] [6] have now become classics. In most areas, ”Wavelet Transform” has taken the place of the early ”Fourier Transform” due to its flexibility both in terms of scaling and translation.

Wavelet thresholding (first proposed by Donoho [7] [8] [9]) is a signal estimation technique that exploits the capabilities of wavelet transform for signal denoising and has recently received extensive research attentions recently. Wavelet denoising attempts to remove the noise present in the signal while preserving the signal characteristics, regardless of its frequency content.

It involves three steps: 1. Calculate the wavelet transform. 2. Threshold the wavelet coefficients and discard (setting to zero) the coefficients with relatively small or insignificant magnitudes. By discarding small coefficients one actually discards wavelet basis functions that have coefficients below a certain threshold. 3. Compute the inverse wavelet transform to get the denoised estimate.

The radiographic image without noise is represented as a two-dimensional matrix $g = \{g_{ij}\}$.

The noisy radiographic image $f = \{f_{ij}\}$ is modeled as

$$f_{ij} = g_{ij} + n_{ij}\,;\; i\,j = 1,\ldots,N \qquad (2)$$

where $\{n_{ij}\}$ is *i.i.d* as $N(0,s^2)$.

Let**Y** = *W***f** denote the matrix of wavelet coefficients of **f**, where *W* is the two-dimensional wavelet transform operator. The wavelet decomposition of the radiographic image is done as shown in Fig.3. In the first level of decomposition, the image is split into 4 subbands, namely the *HH*1;*HL*1;*LH*1 and *LL*1 subband. The *HH*1 subband gives the diagonal details of the image. The *HL*1 subband gives the horizontal features while the *LL*1 subband is the low resolution residual consisting of low frequency components and it is this subband that is further split at second level of decomposition. The *LL*1 is split into *HH*2; *HL2; LH2* and *LL*2 subbands.

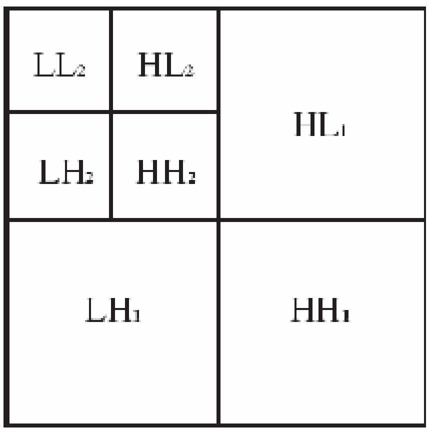

Figure 3: *Subbands of the 2-D wavelet transform*

The wavelet thresholding denoising method filters each coefficient Y_{ij} from the detail subband with a threshold function to obtain $\hat{X}_{ij}$. The denoised estimate is then

$$\hat{g} = W^{-1}\,\hat{X} \qquad (3)$$

where W^{-1} is the inverse wavelet transform operator.

The threshold determination is an important question when denoising. This threshold is given by $s\sqrt{2\log M}$ where s is the noise variance and *M* is the number of pixels in the image. It is proved in [8] that the maximum of any *M* values i.i.d as $N(0,s^2)$ will be smaller than the universal threshold with high probability, with the probability approaching 1 as *M* increases. Thus, with high probability, a pure noise signal is estimated as being identically zero.

2.3 Experiment result

We reduced the radiographic image using median filter and wavelet thresholding as shown in Fig. 5, Fig6. Gray level changing is the main feature of the defects, the method that can remove the noise as well as affect the sharpness of the edges least is better for defect recognition. From Fig. 6, we can see wavelet thresholding is more visually appealing and adapts to discontinuities in images than median filter.

We also compare these two methods on Signal-to-Noise Ratio (SNR) of denoised image. SNR is defined as:

$$SNR = 20\log_{10}\frac{mean(I)}{std(I)} \qquad (4)$$

where *I* is the image.

Table 1 shows wavelet thresholding improves the SNR better than the median filter.

Table 1: Signal-to-Noise Ratio (Ref Fig 5,Fig6)

	Wavelet thresholding	Median filter
SNR	1.9883	1.9691

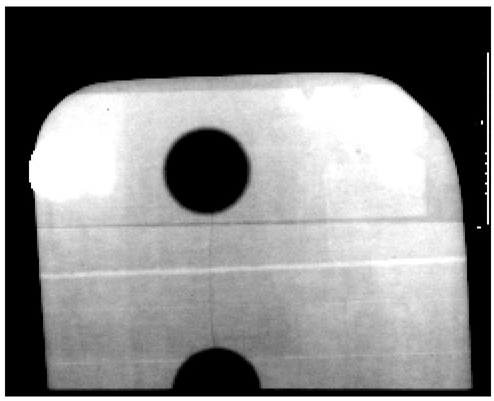

Figure 4: *Original Image*

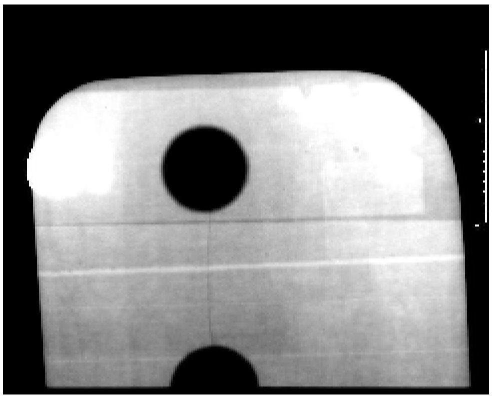

Figure 5: *Denoised using wavelet thresholding*

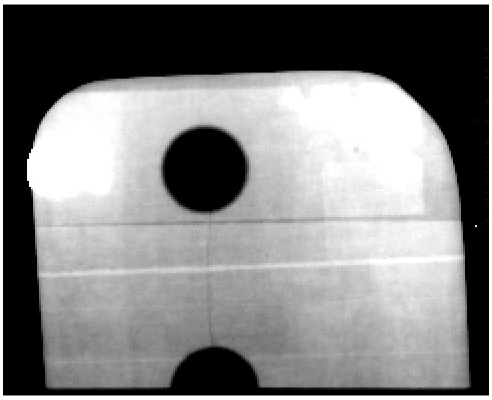

Figure 6: *Denoised using median filter*

3. Contrast Enhancement

3.1. Histogram equalization

Currently, the most frequently used technique to enhance the contrast of radiographic images is histogram equalization (HE). It is based on the assumption that a good gray-level assignment scheme should have equally distributed brightness levels over the whole brightness scale. Individual pixels retain their brightness order. However, the values are shifted so that they are equally distributed over the brightness scale. The result of the brightness transformation should be that the cumulative histogram becomes a straight line.

If G' is the transformed gray value corresponding to the original gray value G of any pixel, the principle of histogram equalization postulates that

$$G' = F(G) = G'_{\min} + \Delta G' \cdot H(G) / N \qquad (5)$$

where $\Delta G' = G'_{\max} - G'_{\min}$, $G'_{\max}$ and $G'_{\min}$ represent the upper and lower limits of the transformed gray values respectively, $H()$ represents the cumulative histogram of the gray values of the original images, and N represents the number of pixels over which the histogram is taken.

3.2 Proposed method

In this paper, firstly the brightness of the image is adjusted using gamma correction, and then the local contrast of the image is improved using contrast limited adaptive histogram equalization to enhance perception of defects.

3.2.1 Gamma correction

Gamma correction operation performs nonlinear brightness adjustment. Brightness for darker pixels is increased, but it is almost the same for bright pixels. As result more details are visible.

3.2.2 Contrast limited adaptive histogram equalization

HE transforms image pixels based on overall image statistics. Adaptive histogram equalization (AHE) involves selecting a local neighborhood centered around each pixel, calculating and equalizing the histogram of the neighborhood, and then mapping the centered pixel based on the new equalized local histogram. [10]. For example, at each point in an input image we could consider a 8×8 window around that point. The 64-element histogram could then be used to determine a mapping function to histogram equalize that point based on the neighborhood. Since each point would be based on its own neighborhood, the mapping function can vary over the image.

Contrast limited adaptive histogram equalization (CLAHE) seeks to reduce the noise produced in homogeneous areas by basic adaptive histogram equalization, and was originally developed for medical imaging, has been successful for the enhancement of portal images [11]. The homogeneous areas can be characterized by a high peak in the histogram associated with the contextual regions since many pixels fall inside the same gray range. With AHE, a local histogram is calculated and used to obtain the final value. High peaks in the histogram lead to large values in the final image because of integration. This problem can be corrected by limiting the amount of contrast enhancement at every pixel, which is achieved by clipping the original histogram to a limit.

3.3 Experiment Results

We enhanced the radiographic images by HE, Gamma correction and CLAHE. The result of histogram equalization on the radiography image can be seen in Fig.6. As a digital radiographic image has only a finite number of gray scales, an ideal equalization is not possible. It causes some pixels with initially different brightness values to be assigned the same value, and other values to be missing altogether. Form Fig.6 and Fig.7, we can see that the histogram equalization enhances the contrast for brightness values close to maxima in the histogram and decreases contrast near the minima. That is, it improves the contrast in the image in areas of poor contrast at the expense of those areas where there is already good contrast. Fig.6 shows that histogram equalization in its basic form can give a result that is even worse than the original image. Large peaks in the histogram can also be caused by large areas of similar brightness. Frequently these correspond to areas of background, and are essentially uninteresting. The effect of histogram equalization on these areas is to enhance the visibility of noise. The feature of interest in the radiographic images such as defects need enhancement locally. However, the technique does not also adapt to local contrast requirements; minor contrast differences can be entirely missed when the number of pixels falling in a particular gray range is small.

Applying Gamma correction on the image in Fig. 5 results in image that can be found in Fig. 8. Brightness for darker pixels is increased, and more details are visible. Then applying CLAHE on the image in Fig. 8 results in image that can be found in Fig. 10. The defect contrast is improved. At the same time, the background noise is greatly reduced. In fact, CLAHE is an improved version of AHE. It can overcome the limitations of standard histogram equalization and AHE.

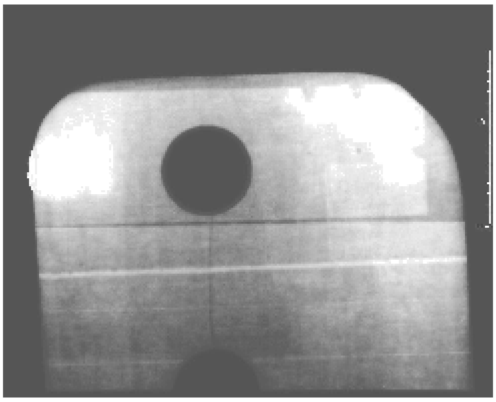

Figure 6: *Image after histogram equalization*

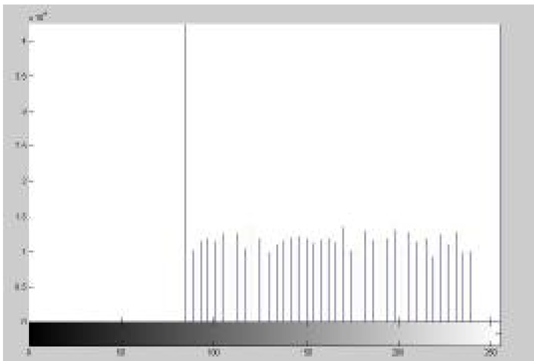

Figure 7: *Histogram after equalization*

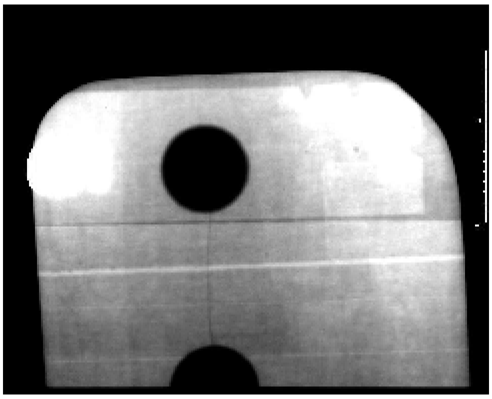

Figure 8: *Image after Gamma correction*

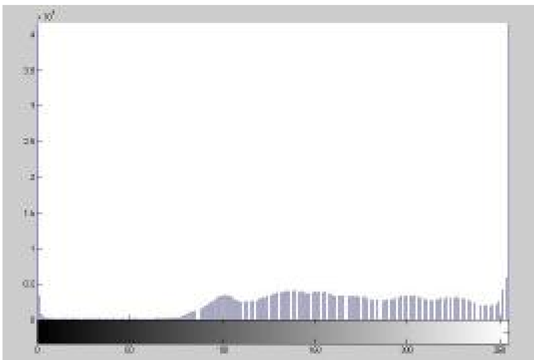

Figure 9: *Histogram after Gamma correction*

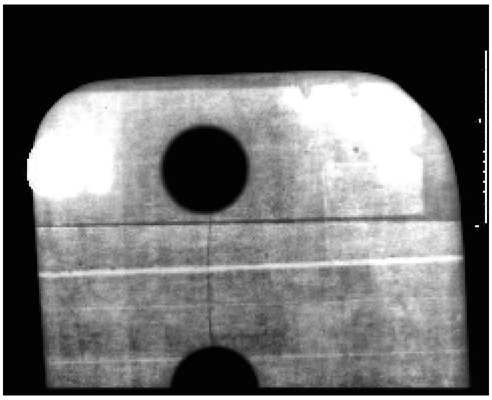

Figure 10: *Image after CLAHE*

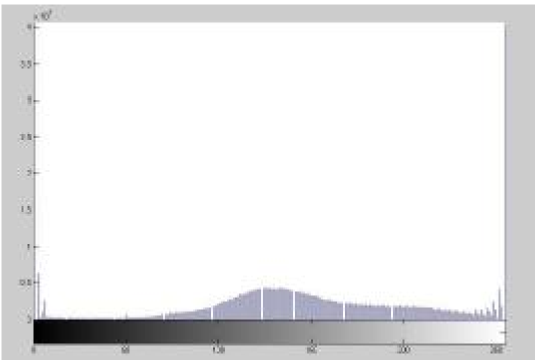

Figure 11: *Histogram after CLAHE*

4. Conclusions

In this paper, we proposed using wavelet thresholding, Gamma correction and contrast limited adaptive histogram equalization to enhance digital radiographic images for inspection of the aircraft. The comparative analysis between the proposed methods and currently frequently used methods has showed the effectiveness of these methods. The wavelet thresholding technique can remove the image noise while keep the sharpness of defects' edges well. Gamma correction and CLAHE not only improved the local contrast of the radiographic images but also reduced the noise produced in homogeneous areas. These are used to eliminate noise and background artifacts and to smooth sharp edges, but also tend to remove some of the detail in small objects.

5. References

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