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MELBOURNE, VICTORIA

REPORT

MRL-R-1109

DETECTION OF FUZE DEFECTS BY IMAGE PROCESSING METHODS

Michael J. Chung

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ABSTRACT

This paper describes experimental studies of the detection of mechanical defects by the application of computer processing methods to real-time radiographic images of fuze assemblies. The experimental results confirm that a new algorithm developed at Materials Research Laboratory has potential for the automatic inspection of these assemblies and of others that contain discrete components. The algorithm has been applied to images that contain a range of grey levels and has been found to be tolerant to image variations encountered under simulated production conditions.

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1. INTRODUCTION

Image processing methods are available as computer packages. Some are operator-interactive and may be applied to an image until a visually suitable result is obtained. Other methods exist which are used in production environments which automatically detect differences in size or shape of simple silhouettes. By combining the concepts of image enhancement and automatic detection, the analysis of radiographic images by computer processes may provide a suitable alternative to present visual methods of fuze inspection which are expensive, time consuming and subject to error.

This report discusses the application of a commercial software package [1] to radiographic images of the AN306 and M215 fuzes and also describes results obtained from the application of a new method developed at the Materials Research Laboratory (MRL) to images of these fuzes obtained under simulated production conditions. This method has already been successfully applied to target discrimination [2], mathematical modelling of texture perception [3], and machine classification of textures [4]. The method tested experimentally in this study is based on using a global search algorithm to optimize a general operator for the task of pattern recognition (and is described in [5],[6]). The generation of an optimized convolution operator is a key step in the algorithm.

The experimental results presented are used to:

(i) determine which image processing methods are best suited to be used in conjunction with real-time radiographic techniques to improve inspection speed whilst maintaining reliability in determining the soundness of fuze assemblies,

(ii) determine the robustness of these methods to production conditions and,

(iii) determine the suitability of these methods for an automatic inspection process.

The image analysis was carried out by computer software on a VAX 780 computer. Inert AN306 and M215 fuzes containing simulated defects were provided by Munitions Filling Factory (MFF), St Marys. For this assessment, only those defects, which if present in active fuzes, would result in hazardous situations, were considered.

2. EXPERIMENTAL DETAILS

Real-time radiographic techniques have been shown [7] to produce electronic images which are of suitable quality for the visual detection of hazardous fuze defects. As these good quality images are used for computer processing, it is expected that simple methods are adequate for any image enhancement required prior to processing.

The radiographic images of the AN306 and M215 fuzes are complex and contain a large range of grey levels. Therefore, a digital system with software capable of handling a large number of grey levels (e.g. 256) is necessary for the analysis of these images. Access to the results of image processing is usually by means of a computer's visual display terminal.

2.1 Fuze Assemblies

Seven inert AN306 fuzes were provided by MFF St Marys and from these a standard fuze and six other fuzes, each containing one critical defect, were assembled. These defects were:

1. pin missing
2. initiating detonator spring missing
3. delay pellet missing
4. stirrup sleeve missing
5. direct action striker missing or in armed position, and
6. magazine not screwed home.

These features are shown in Figure 1.

Six inert M215 fuzes, five containing one critical defect and one used as a standard, were assembled by MFF St Marys. The defects were:

1. striker pin missing
2. cut back too long
3. no cut back
4. loose powder in cut back, and
5. primer holder missing

These features are shown in Figure 2.

2.2 Experimental Conditions

Two X-ray sources at 150 kV and 320 kV, were used to produce radiographic images of the AN306 and M215 fuzes and are described in [7]. It is expected that variations in image quality may occur on a production line due to image noise and registration errors. To simulate these conditions, radiographic images were digitized at various X-ray tube voltages to produce noisy images and at various offset positions to produce registration errors.

The 512 x 512 x 8 bit digital images were stored on 8 inch single sided, double-density floppy disks and displayed on a DEC 11/73 colour graphics system. The images may be displayed in RGB pseudo colour or monochrome.

For certain types of image processing, windows within an image were used to reduce computer processing time and to reduce global effects occurring over the image which might be large enough to dominate localized effects which represent the defects.

3. IMAGE PROCESSING

A library of 91 digital images of the AN306 fuze and 30 digital images of the M215 fuze, with different features and taken under different imaging conditions, was assembled.

Images of the AN306 fuze were digitized with two different frame stores. The two frame stores had identical resolution and one possessed a digital image filtering capability. The images of the M215 were digitized without filtering.

A digitized image of the AN306 fuze which was used as a standard is shown in Figure 3 and an image of the M215 fuze which was used as a standard is shown in Figure 4.

Two types of computer image processing methods are considered, firstly, basic operations (i.e. one-to-one pixel mapping) and secondly, linear filtering which involves the application of the MRL algorithm outlined above.

3.1 Basic Operations

Subtraction of images is expected to show promise in detecting small differences between two images. Subtraction of images was examined by introducing relative differences into a pair of AN306 fuzes and also a pair of M215 fuzes. The AN306 test sample had the initiating detonator and spring removed and the pin inserted in an incorrect position. The M215 test sample had the primer holder missing. The images of the two pairs of fuzes were digitized in turn under identical imaging conditions and care was taken in placing the test sample in the same position as the standard fuze. The images of the AN306 fuze were subtracted and the results shown in Figure 5. The result of subtracting the M215 images is shown in Figure 6.

The differences due to the initiating detonator, spring and pin are clearly identifiable in Figure 5 because of their well defined shapes and regions of higher intensity. Similarly, there is a region of higher intensity in Figure 6 which would correspond to a missing primer holder.

Subtraction thus offers a means to detect absent or misplaced components in an assembly. However, both Figures 5 and 6 show an outline image of the respective fuzes which is due to a small misalignment between the positions of the assemblies. This effect would cause problems when determining features such as the rotational position of springs or sections through cylinders. For the experimental imaging conditions used [7], which are considered to be similar to those expected under production conditions, the width of the image outline corresponded to a variation of about 0.1 mm in the position of the fuze assemblies being radiographed. Attempts to eliminate this effect by carefully repositioning the fuzes and again registering their images was not successful. In addition, attempts to eliminate the misalignment effects by computer translation of the images were not completely successful and an outline of about 2 TV pixels was the best result obtained. These results show that aligning an assembly in three dimensions for image subtraction could be difficult and that for any method of positioning fuze assemblies, such as a mechanical jig or robotic arm, must have the ability, in this application, to reposition assemblies to be within 0.1 mm.

Each image can be represented as a grey level histogram with a mean and standard deviation. Differences between a standard image and the image with a defect may be expected to be reflected in differences between the statistics of the histogram, such as the mean and standard deviation. If the differences are significant, they may be used as the basis of an automatic defect detecting system.

The mean and standard deviation of the histograms of the grey levels contained in windows centred on the defects for the standard and defective AN306 fuzes are shown in Table 1. These results show that there is not a great difference in the distribution of grey levels in the windows of the standard and defective fuzes.

These results indicate that for the AN306 fuze, the defect feature, in most cases, is not sufficiently prominent to enable statistical detection methods to be reliable. As this method of analysis of fuzes does not appear promising, similar measurements on the M215 fuze were not carried out.

Histogram equalization [8] of an image modifies its histogram to one of uniform density, i.e. the operation produces a new histogram with a fixed mean and standard deviation of grey levels for all images. The mean and standard deviation of the modified histogram is selected by a priori means to enhance the existing image. For this application, the best result is one which shifts the mean towards the centre of the grey level range and increases the standard deviation of the distribution. This effect would increase the range of grey levels, giving an image of higher contrast which may enhance the differences between images.

The histograms of the AN306 and M215 standard fuzes drawn as continuous functions are shown in Figures 7 and 8. Most of the image information is contained in the grey level range of 0 to 100. These images were histogram equalized [1] and the discrete-level histograms of the resulting images are shown in Figures 9 and 10. These histograms visually show a more uniform intensity and spread due to a quantization of the grey levels than the originals shown in Figures 7 and 8. However, this large change in the histogram is not reflected in the digital image shown in Figure 11 where there is only a small visual improvement in contrast, accompanied by a reduction in image detail.

The complexity of an image may be reduced by thresholding grey levels [9] of regions of the image which are not required by the particular processing method. An example of such regions are image backgrounds and these levels may be selected for "elimination" by inspection of the image or its grey level histogram. These regions are "eliminated" by assigning another grey level to them which is sufficiently different to those levels of the surrounding features (e.g. white level, 255; black level, 0).

The removal of superfluous information (e.g. background) by histogram thresholding may simplify the image data for further processing and in the extreme case, produce a silhouette which would aid simple automatic detection of defects. Selecting suitable grey level thresholds may be done by using an image's histogram or more accurately, by an interactive manual control which enables cross hairs to be positioned on the required grey level. An example of histogram thresholding of grey levels below 45 and above 70 is shown in Figure 12. The lower threshold of 45 was chosen because it represents the background grey levels of the image and the upper threshold represents the most common grey level in the body of the fuze assembly.

The resultant image has been degraded from the original, producing a more complex, ill-defined image which is unsuitable for the inspection process. This image also serves to illustrate the complexity of the fuze images produced by radiographic methods and the need for a spectrum of grey levels to describe these images.

Histogram equalization and grey level thresholding methods have been combined and applied to images giving results no better than the individual processing described above.

3.2 Simple Linear Operations

Linear operations require the convolution of images with known functions which enhance certain characteristics of the image. Ideal step functions which simulate low pass and high pass filters were convolved with an image of an AN306 fuze. The results are shown in Figures 13 and 14 respectively.

Images produced by these processing methods are not considered to be visual improvement from the original images and further work on simple filtering was discontinued.

3.3 Application of MRL's Algorithm to Image Processing

Present automatic inspection systems use a binary imaging method [10] to produce a silhouette which is presented to the computer's decision making process. The main disadvantage of a binary image in the present application is the loss of grey scale information which results in an inability to detect all of the fuze defects if they are imaged over a range of grey levels.

A key step in the algorithm developed at MRL is the generation of an optimized convolution operator. The two-dimensional digital convolution of this operator with a grey scale image may be expressed as a summation of the form [9]:

$$h(i,j) = \sum_{m=-b}^{m=+b} \sum_{n=-b}^{n=+b} f(m,n)g(i-m, j-n) \quad b = 0, 1, 2, 3, \ldots \qquad (1)$$

where g(i,j) is the input image of dimension (M,N), f(m,n) is a square matrix of size (2b+1) designed to enhance a particular feature of g and h(i,j) is the output image. The discrete summation is carried out over i = (b+1) to M-(b+1) and j = (b+1) to N-(b+1) to avoid edge effects. This process is represented by Figure 15.

Research at MRL has produced a computer algorithm which maximizes the differences between two systems of several variables quickly and accurately [2,5,6]. This method is not restricted by the number of grey levels within an image. It may be applied to inspection methods by using images containing predetermined defects and creating a 5 x 5 matrix (mask) for the function f described in equation (1). This mask thus represents the maximized difference between the "standard" and "defective" images. Convolution of the mask with an image will produce a numerical output and by comparison of this output with that obtained from either a "standard" or "defective image", a decision can be made by computer as to the integrity of the image under inspection. A block diagram of this inspection process is shown in Figure 16. A mask is created for each specific image defect and is convolved in turn with images of the fuze assemblies under test.

Masks of predetermined defects were produced by MRL's algorithm for both histogram equalized images and normal images. The mask was convolved in turn with both types of images. For all sets of AN306 images, best results were obtained with the MRL algorithm operating with the unequalized images. Examination of the equalized images has shown a loss of fine detail in the features used to create the convolution masks. Lack of image detail would cause resulting masks to be of a general nature and not specific enough to select detailed features. Thus it is considered that histogram equalization is not useful for this type of processing. Results from the analysis of a AN306 fuze is shown in Table 2. Similar measurements were made with images of the M215 fuze and best results were again obtained from the MRL algorithm operating on unequalized images. Results from this processing are shown in Table 3. From Tables 2 and 3 it can be seen that all defective fuze assemblies were detected although in some cases a "defect" was detected where none was present. This implies that the method is "fail safe".

The robustness of this processing method to production conditions was investigated by using digital images with known signal-to-noise ratios and linear offsets. The signal-to-noise ratios of the images were of the order of 30, 36 and 40 dB which corresponds to imaging conditions produced by the X-ray tube with voltages of 80, 100 and 130 kV respectively. A typical set of results are shown in Table 4. Here, image A2.131 is used as a standard and images B2.131, C2.131 and D2.131 contain a defective stirrup sleeve and were digitized in identical positions with X-ray tube voltages of 130 kV, 100 kV and 80 kV respectively.

The results obtained show that masks created from images of comparable signal-to-noise ratio will detect defects in images with signal-to-noise ratios similar to or less than that used for mask creation. Masks created from images with different signal-to-noise ratios will detect defects in images with lower signal-to-noise ratios.

Errors which may occur due to a shift in the relative positions of the windows used to create a mask and the window used in the inspection process were examined by passing masks over standard and defective images, both of which have been shifted a predetermined distance. These errors may occur by movement of the fuze prior to image registration or by careless positioning of the inspection window on the image.

The images were shifted by computer methods with shifts to the left and the right of the standard window position of up to 80% of the width of the window used for the creation of the mask. The results have shown that generally, masks generated for a specific feature are insensitive to this amount of image shifting. However, when another dominant feature is introduced into the window region due to shifting of the image, it will react with the mask and may cause confusion in the interpretation of results. In some cases, however, this spatial independence quality can limit the detection of some defects. Table 2 shows several "false alarms" in detecting the magazine of the AN306 being screwed home. In this example, the only feature in the window of the image of this particular defect was a straight edge, dividing two grey levels. The algorithm would react with this feature to give similar results no matter where it was positioned within the window. Additional image processing software was written which binarized the window image and calculated the areas of the two levels, then compared them with the standard. This method was successful for this particular defect. Thus, the amount of relative shift of the window and image that can be tolerated is determined by the spatial structure of the assembly being examined.

The size of the window determines the computational speed of the convolution process and the most suitable size is considered to be one which produces the optimum discrimination between "standard" and "defective" image. Optimum discrimination was found empirically to occur with a window size which consists of the feature under examination surrounded by a border of the same size as the mask used in the convolution process.

3.4 Computer Requirements

All processing of the 512 x 512 x 8 bit images was carried out on a VAX 780 computer. Software was used which enabled the size of the integer numbers used in the mathematical processes to be selected as 32 bit words or 64 bit words. In general, percentage errors which may occur in, for example, subtraction of numbers will be reduced by using 64 bit words during calculations. The results obtained using the two word lengths were comparable, showing there is no significant improvement in accuracy to be gained by using a 64 bit machine. The average time taken to analyze each defect in the AN306 and M215 fuzes was six seconds and represents the time taken for the convolution of an average window of 60 x 50 elements with a 5 x 5 mask. This processing speed may be reduced by increasing the size of the computer used in the convolution process or by hard wiring the processing method into a computer card. The first option is expensive and the resulting decrease in processing time may not be any better than that obtained by a hard-wired processing version. It has been found empirically that hard-wired convolution methods in a microVAX computer can convolve a 512 x 512 image with a 3 x 3 mask in the order of one second. It is expected that the same computer could convolve a 512 x 512 image with a 5 x 5 mask in approximately 3 seconds.

4. CONCLUSIONS

1. Basic image processing methods and simple linear filtering did not improve the images obtained from real time radiographic techniques.

2. The distributions of the grey levels in the windows of the standard and defective fuzes are similar and as a result, statistical methods are considered unsuitable for automatic processing.

3. The new MRL method has been shown to be "fail-safe" for the detection of defects in images of fuze assemblies. Experiments have shown it to be robust under various imaging and registration conditions and thus it has potential for automatic inspection applications.

4. The MRL method has been shown to have some limitations due to its spatial independence properties. However, these may be overcome by the careful positioning of windows on the image and by minor additional processing.

5. ACKNOWLEDGEMENTS

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TABLE 1

Means and standard deviations of the grey level histograms
of windows of standard and test fuzes

Defect Type	Window Size TV pixels		Test Fuze		Standard Fuze A.081	
	X	Y	Mean	Standard Deviation	Mean	Standard Deviation
Setback spring Missing B.081	38	74	53.5	25.2	54.3	22.9
Pin Missing C.081	34	36	34.6	8.8	35.4	8.3
Delay Pellet Missing B.179	21	38	48.6	11.3	59.1	12.0
Stirrup Sleeve Damaged E.081	87	35	43.5	18.6	54.3	25.6
Direct action Striker missing F.081	78	107	91.7	35.8	67.0	21.6
Delay Pellet Missing & Sleeve damaged G.081	61	58	69.1	5.1	95.6	14.3
Magazine not screwed home N.081	29	19	139.6	35.7	148.9	36.4

TABLE 2

Results of the analysis of the AN306 fuze for defects using the MRL method

D correctly assessed, defect present
N correctly assessed, defect not present
D# defect detected when none was present

MASK / FUZE	Setback Spring	Pin	Delay Pellet	Stirrup Sleeve Damaged Window 1	Stirrup Sleeve Damaged Window 2	Direct Action Striker	Delay Pellet & Sleeve	Magazine Not Secured
Standard	N	N	N	N	N	N	N	N
Setback Spring	D	N	N	N	N	N	N	N
Pin	N	D	N	N	N	N	N	D#
Delay Pellet	N	N	D	N	N	N	N	N
Stirrup Sleeve	N	N	N	D	D	N	N	D#
Direct Action Striker	N	N	N	N	N	D	D#	N
Delay Pellet & Sleeve	N	N	N	N	N	N	D	D#
Magazine Not Secured	N	N	N	N	N	N	N	D

TABLE 3

Results of the analysis of the M215 fuze for defects using the MRL method

D correctly assessed, defect present
N correctly assessed, defect not present
D# defect detected when none was present

MASK / FUZE	Striker Spring	Cut back Too Long	No Cut Back	Primer Holder	Loose Powder
Standard	N	N	N	N	N
Striker Spring	D	N	N	N	N
Cut back Too Long	N	D	N	N	D#
No Cut Back	N	N	D	N	N
Primer Holder	N	N	N	D	N
Loose Powder	N	N	N	N	D

TABLE 4

Effect of signal-to-noise ratios of images on the MRL processing method

Images Inspected						
Image	Defect	X-Ray (kV)	SNR (dB)	Images used with A2.131 to Generate Mask		
A2.131	No Defect	130	37	N	N	N
B2.131	Sleeve damaged	130	37	D	*	*
C2.131	Sleeve damaged	100	30	D	D	*
D2.131	Sleeve damaged	80	25	D	D	D

N correctly assessed, defect not present
D correctly assessed, defect present
* missed defect

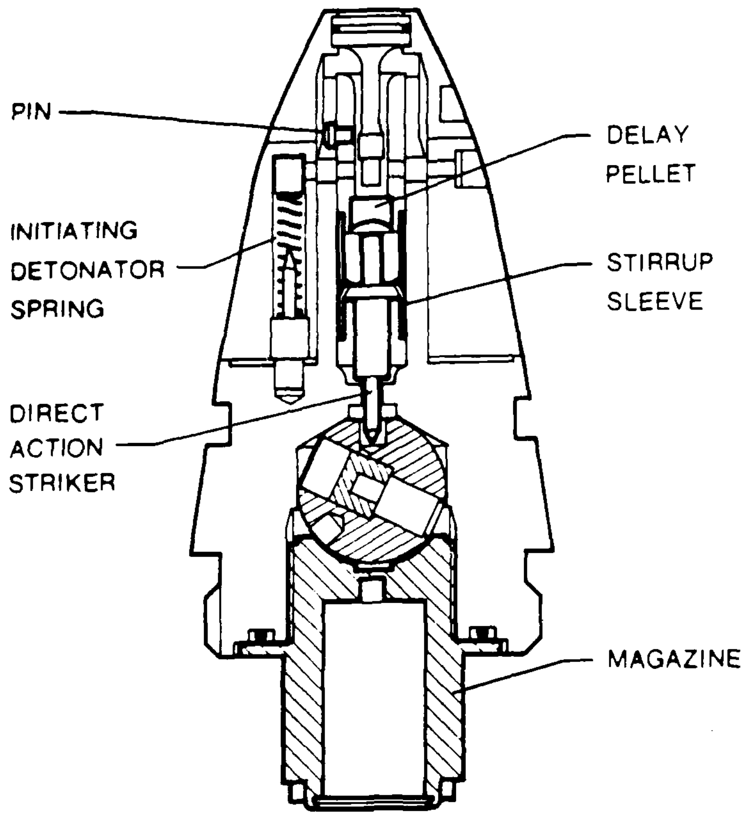

FIGURE 1 Diagram of an AN306 fuze showing six features, each of which is a hazardous defect.

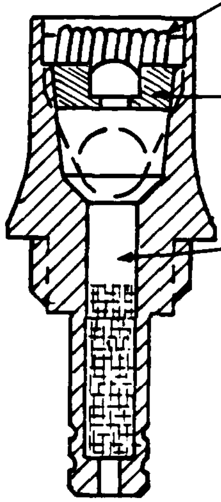

FIGURE 2 Diagram of an M215 fuze showing three features, each of which is a hazardous defect.

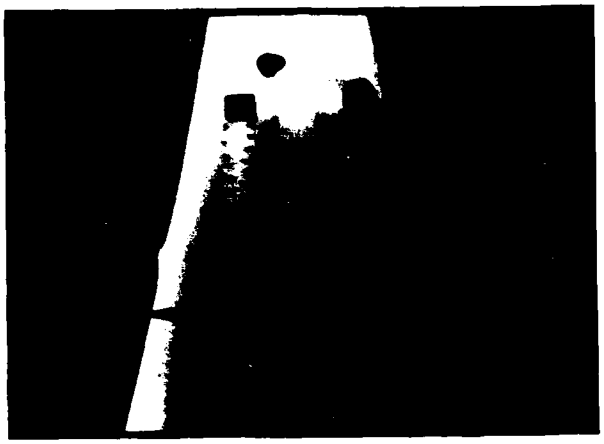

FIGURE 3 A digitized image of an AN303 fuze used as a standard for defect detection.

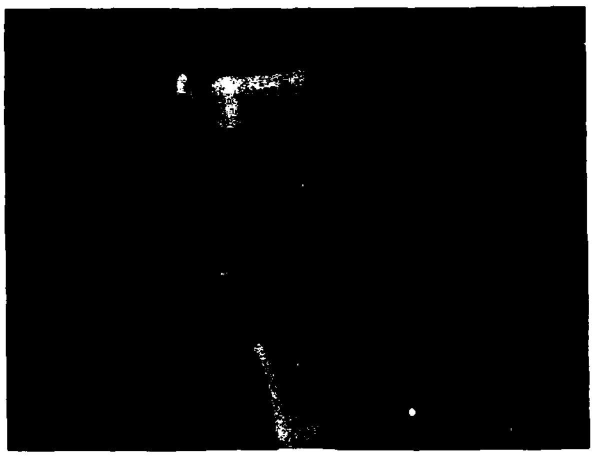

FIGURE 4 A digitized image of an M215 fuze used as a standard for defect detection.

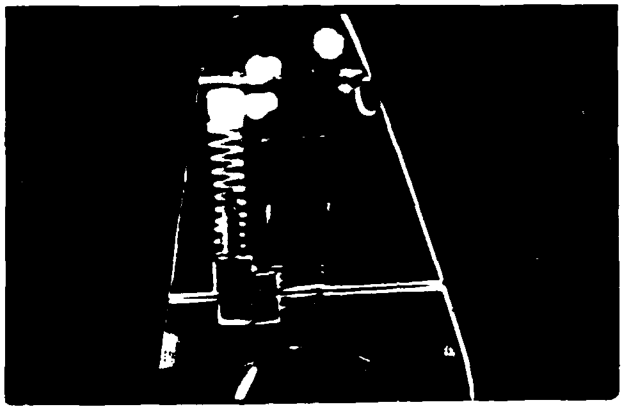

FIGURE 5 Image produced after subtraction of two images of AN306 fuzes. One fuze contained the defects; spring and initiating detonator missing and the pin in an incorrect position.

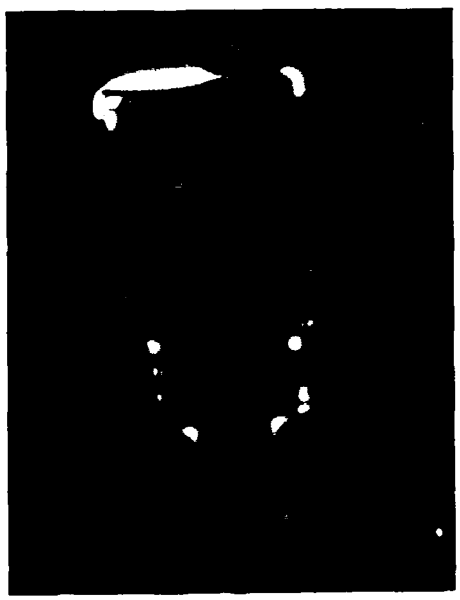

FIGURE 6 The result of subtracting two M215 fuze images.

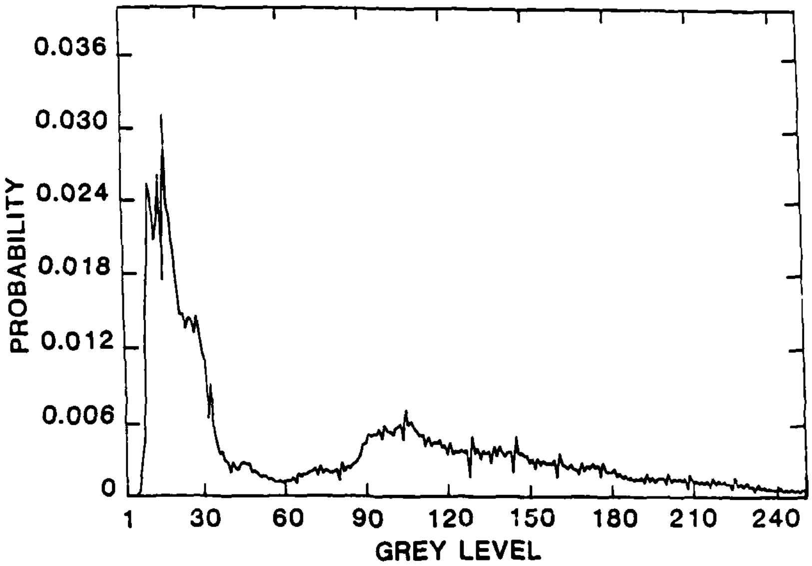

FIGURE 7 Histogram of the image of the standard AN306 Fuze.

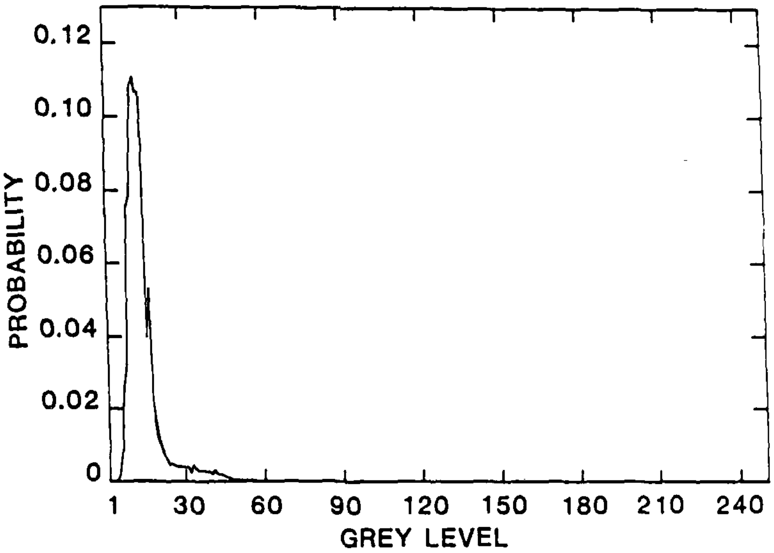

FIGURE 8 Histogram of the image of the standard M215 Fuze.

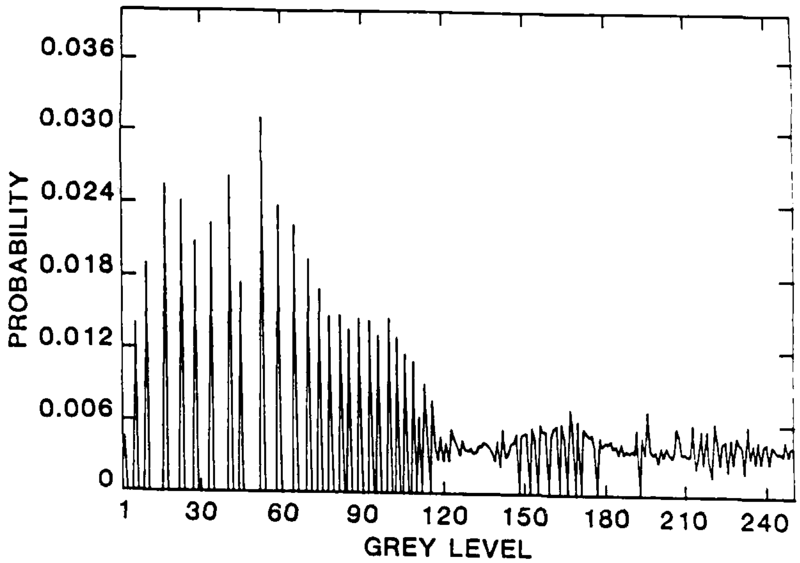

FIGURE 9 Histogram of the equalized image of the standard AN306 fuze.

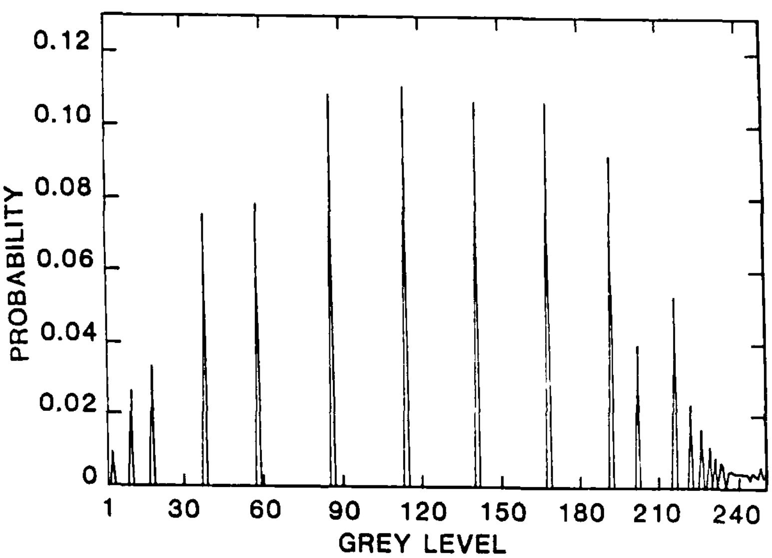

FIGURE 10 Histogram of the equalized image of the standard M215 fuze.

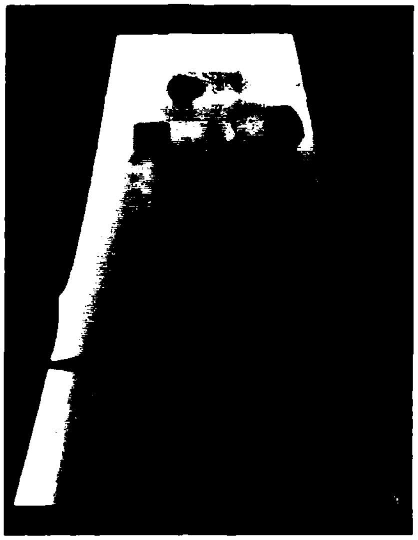

FIGURE 11 Histogram equalized image of the standard AN306 fuze.

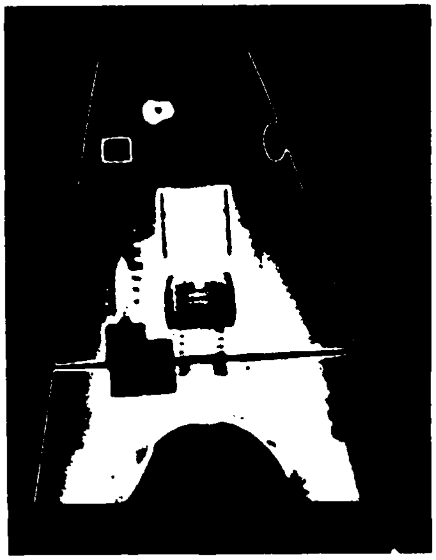

FIGURE 12 Digital image of the standard AN306 fuze thresholded below grey level 45 and above grey level 70.

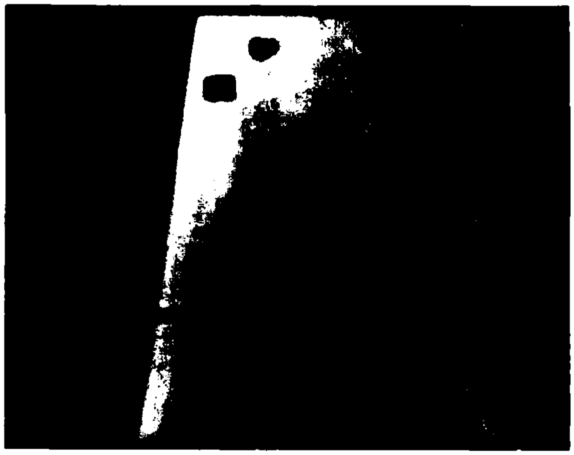

FIGURE 13 Image of the AN306 showing effect of low pass spatial filtering.

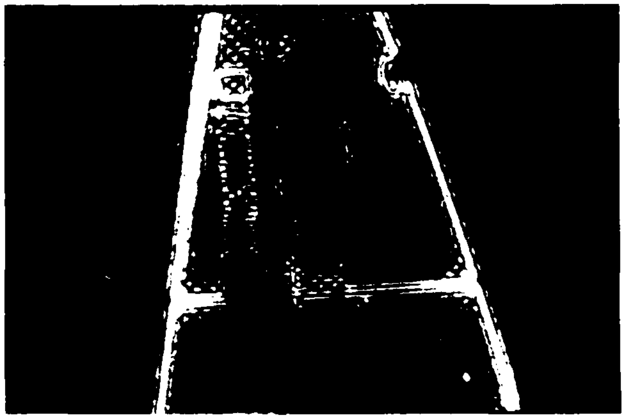

FIGURE 14 Image of a AN306 fuze showing effect of high pass spatial filtering.

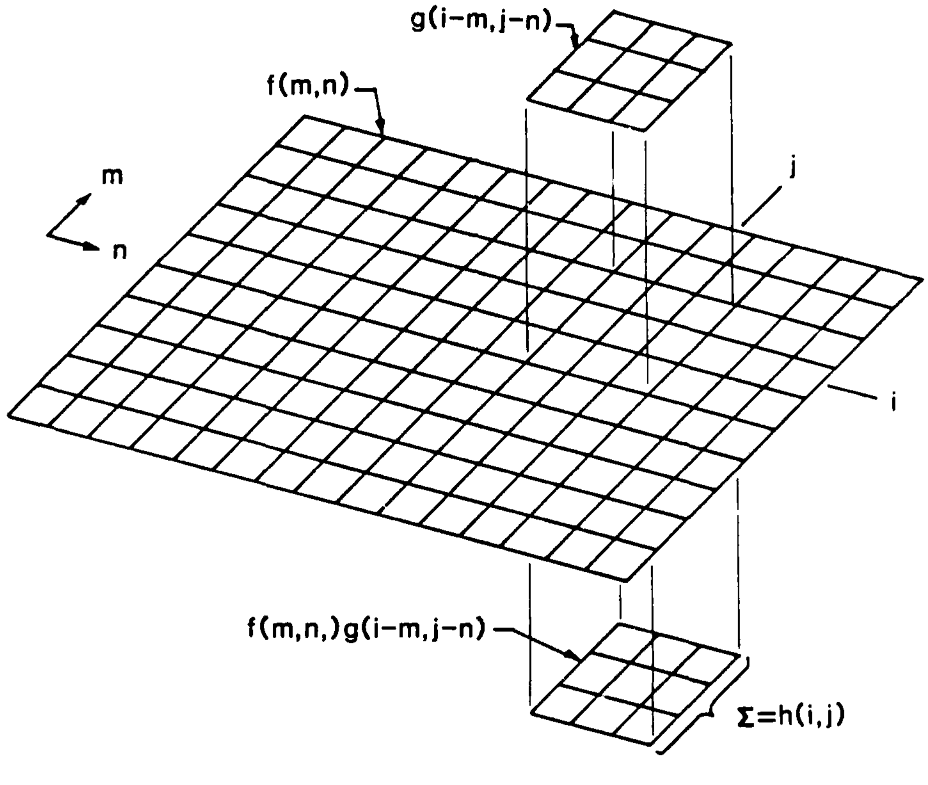

FIGURE 15 Basic scheme for digital convolution [9] for the case where b = 1, M = 10 and N = 15.

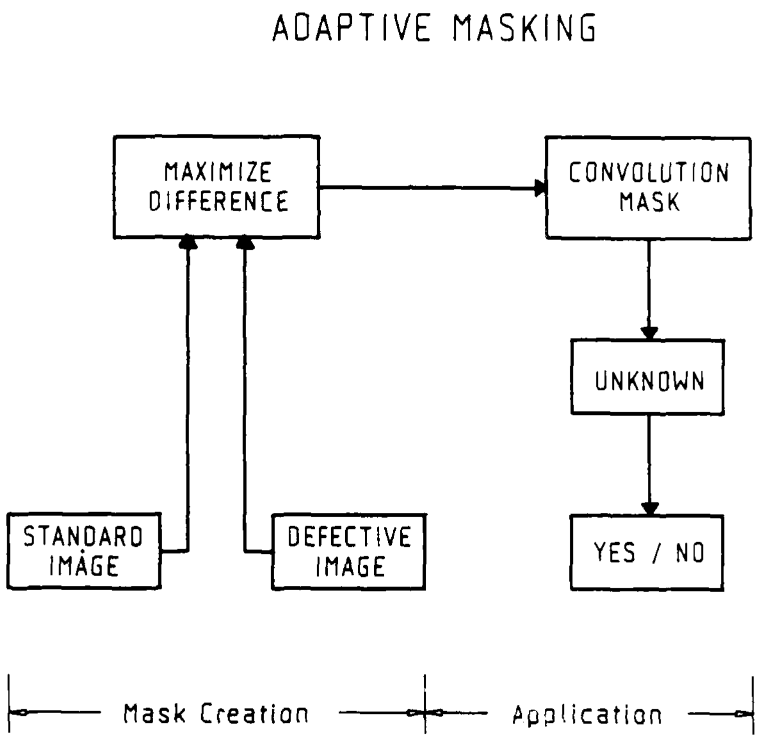

FIGURE 16 Diagram showing the MRL method applied to the inspection process.

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Detection of fuze defects by image processing methods

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ABSTRACT

This paper describes experimental studies of the detection of mechanical defects by the application of computer processing methods to real-time radiographic images of fuze assemblies. The experimental results confirm that a new algorithm developed at Materials Research Laboratory has potential for the automatic inspection of these assemblies and of others that contain discrete components. The algorithm has been applied to images that contain a range of grey levels and has been found to be tolerant to image variations encountered under simulated production conditions.

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