Automated Defect Recognition Software for Radiographic and Magnetic Particle Inspection

B. Stephen Wong¹, Xin Wang²*, Chen Ming Koh³, Chen Guan Tui⁴, Jian Xu¹

¹Singapore Institute of Manufacturing Technology, Singapore
²Department of Mechatronics and Biomedical Engineering
  Faculty of Engineering and Science
  Universiti of Tunku Abdul Rahman (UTAR), Malaysia
³Singapore Technologies Aerospace, Singapore
⁴Republic of Singapore Air Force (RSAF), Singapore

* Corresponding author: bswong@SIMTECH.a-star.edu.sg
Abstract
This paper will describe the development of Automated Defect Recognition (ADR) software for the detection of cracks around aircraft rivets. A second application is for the automated detection of cracks from magnetic particle inspection (MPI) images.

The basic important processes are preprocessing such as averaging, edge detection using the Canny edge detection algorithm and then finally defect characterisation to differentiate actual defect images from noise images.
For the aircraft fastener software the development of software capable of detecting cracks around an actual aircraft wing will be described. Difficulties are the sensitivities which need to be achieved and the differentiation of actual defect images from noise images. One important parameter to achieve this is the length/width ratio of the indication.

1. Introduction
Radiography inspection is one of the most important non-destructive inspection methods for aircraft wing spar inspection. Traditionally, radiography inspection is time and manpower consuming. In addition, human inspection of cracks and damage based on film radiography is very subjective, inconsistent and sometimes biased. To improve on the speed and efficiency of radiography inspection, digital x-ray system is preferable over traditional film based x-ray. It is desirable to develop a computer aided system to assist in the interpretation of digital radiographic images to increase the accuracy and efficiency of the interpretation.

In this paper a system is described which can radiograph a wing of a military aircraft. A 300 micron focus spot, mini focus x-ray tube was used as the source and an amorphous silicon flat panel was used for the detector. An algorithm is also described for the automatic evaluation of cracks around the rivets in the aircraft wing spar.

2 Robot Guided X-Ray System for Aircraft Wing Inspection
A robot guided digital X-ray imaging system as shown in Figure 1 was developed for automatic aircraft wing inspection. The manipulator system automatically moves the x-ray tube and the digital sensor along the wing of the aircraft. Digital radiographs are taken as the system moves and the whole wing area can be built up gradually (See the green boxes at the right hand side of Figure 1). A focus of attention is to inspect the rivets along the wing spars.
Figure 1 Robot guided scanning manipulator over an aircraft wing

Figure 2 shows an aircraft wing spar radiograph. In this radiograph, line (fatigue) cracks created on specimens are taken along with the wing spar image. The cracks were first produced by a fatigue process on a thin aluminium plate, about 2mm thick. These plates were then placed on top of the wing to simulate cracks inside the wing spar. The cracks are circled in yellow. There are numerous rivet holes in each radiograph, and these areas are high risk regions for fatigue cracks.
3 Crack Detection Algorithm

Firstly the algorithm developed by Wang et.al [4] was tested using some aircraft wing spar images. The presence of noise either gets mistaken as cracks, or they drown out the crack features from the algorithm (Figure 3), thus some improvement is needed to increase the accuracy of the algorithm. In addition to the algorithm which recognizes cracks through grey level gradients and dimensions of features detected, other parameters need to be considered to make crack detection more accurate.
Suggested improvements include the removal of rivet holes from the region of interest, as well as using thresholds instead of edge detection to find rivet holes.

3.1 Improvement on Region Of Interest (ROI) generation

As seen in the test on image No. 2 as shown in Figure 3, there is wrong detection marked within the rivet holes. However, the likeliness of a crack occurring on a rivet is very low, thus the need to detect cracks within the rivet area is questionable. The edge of rivet holes is also sometimes mistaken as a crack as seen from image No.2. It is evident that the rivet itself is causing some problems to the accuracy of detection. This compounds the problem of having the rivet holes area included in the ROI as it clearly interferes with the crack.

To solve the problem of a rivet hole interfering with crack recognition, the rivet hole is removed from the ROI, leaving only the area around the rivet.
Figure 4 (a) Binary image of holes in test image No. 1. (b) Expanded mask area. (c) Slightly expanded mask area. (d) Final ROI.

Figure 4 shows the ROI obtained when the new algorithm is used on test image No. 1. Figure 4(a) is the binary image of holes detected, Figure 4(b) is the enlarged masking area by and 4(c) is the slightly increased masking area to cover edges of hole. The final ROI is obtained by the subtracting the result of the second from the third, and the result can be seen in Figure 4(d). The result of this final operation on test image No.1 is shown in Figure 5(a). Figure 5(b) shows the final crack detected on test image No. 1 when the new algorithm is included, where all cracks are detected instead of 4 out of 5 as found previously.
Figure 5(a) Edges detected within new ROI of test image No. 5. (b) Final detection with new algorithm.

3.2 Hole Detection by Thresholding

In image No. 1 of Figure 3, one of the cracks is not detected. On closer inspection this is because the undetected crack is recognised as a single object together with the hole. This results to the crack being filtered out together with the hole as they did not have a shape that resembles cracks. Figure 6 shows the edge detected crack and hole are joined as one entity.

Figure 6 ROI of image No.1 in Figure 2 shows crack and hole grouped as a same object.

Figure 7 shows the result of image No. 2 in Figure 3. There are four wrong detections, with three of them on the rivet hole and identifying the rivet as a crack. Another wrong detection marks the edge of a specimen hole as a crack. The white lines are IQI wires added and meant to simulate cracks, so their detection is considered acceptable. The dark coloured hole, which is the specimen hole, is not detected. Figure 8 shows the possible hole features after edge detection. It can be seen that the dark specimen hole is not fully detected by canny edge function. As a result, the hole is not an enclosed object and can not fill it up to form a masking area. As a result, a crack from the specimen is not detected. The edge of the specimen hole is however in the ROI of the true rivet hole, and mistaken as a crack.
In image No. 4 of Figure 3 the algorithm fails entirely, because the rivet hole is not detected. Failure to detect rivet holes results to failure to set a ROI, thus nothing will be detected. The reason of failing to detect rivet hole is the same as the reason specimen holes could not be detected in image No.2 and No.3, and that is because the edge detected rivet hole is not complete to form an enclosed object.

The tests conducted on image No.2, No.3 and No. 4 showed that the Wang’s algorithm has problem detecting rivet holes when edge detection could not form an enclosed object on the holes. This means that even the slightest failure of edge detection in detecting a small part of a hole will lead to the entire hole being neglected, thus cracks missing any possible cracks around such holes.

The authors therefore propose an alternative method of detecting the rivet holes which is less punishing on imperfect accuracy, and that is by thresholding instead of by edge detection.
Thresholding is the simplest method of image segmentation. From a grayscale image, thresholding can be used to create binary images. In image thresholding, a range of grey level is selected, and only pixels that satisfy the grey level range are selected. Therefore, this method is very useful in images where the relevant objects have a distinct difference in grey levels to the background.

The new algorithm requires a threshold value to be explicitly defined first, 110 for the case shown. If rivet holes are bright pixels, they will be selected by picking pixels in the original picture that is more than the threshold. If the hole pixels are dark, then they will be selected by calling for pixels less than the threshold. The rest of the algorithm is similar to the Wang’s algorithm, which performs recognition of rivet holes by their area and eccentricity.

![Figure 9](image1.png)

**Figure 9.** (a) Result of thresholding on test image No. 8. (b) Final detection on test image No. 8 with new algorithm.

Figure 9(a) shows the effect of using thresholding to find rivet holes in test image No. 4. The holes can be found, but together with some IQI wires that are meant to simulate cracks. The algorithm is able to make detections in the end, as shown in Figure 9(b).

The flow chart of new algorithm is shown in Figure 10. And the detection results using new algorithm is shown in Figure 11.
4 Experimental results

The new algorithm was tested on 7 images as shown in Figure 11. Images no 1 to 5 were from thin aluminium plates with fatigue cracks in them. Images 6 and 7 were from the aircraft wing.

<table>
<thead>
<tr>
<th>Image No.</th>
<th>Original Image</th>
<th>Final Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1" alt="Original Image" /></td>
<td><img src="image2" alt="Final Detection" /></td>
</tr>
</tbody>
</table>
Table 1 shows the detection results using the new algorithm. The table is not statistically realistic because the defects were relatively large with good contrast. However some indication of the length of the cracks is shown in the final column. A pixel equates to a length of 200 microns.

**TABLE 1** Results of image test with new algorithm

<table>
<thead>
<tr>
<th>Image No.</th>
<th>Number of Cracks</th>
<th>Correctly detected cracks</th>
<th>Minimum detectable crack length (pixels)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>25</td>
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<td>7</td>
<td>2</td>
<td>2</td>
<td>21</td>
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5. **Automated Defect Recognition Software for Magnetic Particle Inspection**

Figure 12 (a) shows a digital camera image of fluorescent magnetic particle inspection indications. The specimen is a steel plate with quench cracks it. Figure 13 (b) shows an ADR software processed image of these indications. The background noise has been effectively removed but some of the lower contrast defects on the right hand side of the image are not detected. Therefore a conclusion from the image is that the procedure can only detect about 90% of the defects.

![Figure 12 (a) Fluorescent MPI indications (b) Indications after ADR software processing](image)

5. **Conclusions**

The radiography of an actual aircraft wing creates a very complex structured radiograph. The objective has been to automatically detect using ADR software, cracks around the rivets in the wing spars. To minimise false indications the inspection zone is reduced considerably. Firstly the rivets themselves are detected using a thresholding procedure. Then a zone around the rivet is created which is the Region of Interest and cracks are inspected for only in this Region of Interest. The software also shows some sensitivity to detecting fluorescent MPI indications.

6. **Acknowledgements**

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7. References


