Chapter 5

ALGORITHM TESTING

An algorithm involving correlation-based filters, the Hough transform, and information fusion techniques has been developed in this research as described in Chapter 4. This chapter presents the test results of detonator detection using this algorithm. The images that were used here were obtained from the AS&E inspection system. Both single-orientation and multiple-orientation images were tested, and the effect of image variations on the algorithm performance was investigated. An accuracy analysis was also carried out.

5.1. Test Results for Single-Orientation Detection

In this section the effect of image variations on the performance of the algorithm is examined. The image variations include object overlapping, the luggage position on the conveyor, and small variations in the detonator orientation.

5.1.1. Effect of Object Overlapping

It may be assumed that a detonator will typically overlap with other objects in an x-ray image. Because of this, the effect of overlapping has been closely examined. In this chapter part (a) of all the figures contains the original x-ray images, part (b) contains the peak output images with the positive detection results of the middle-point filter highlighted, part (c) contains the end output images for both left- and right-ends with the positive detection results
of the end-point filters highlighted, and part (d) contains final output images with the location of the detected detonator highlighted. In the test images, the detonator is overlapped with a wooden board (Figs. 5.1a, 5.2a, and 5.3a), a box of fudge (Figs. 5.4a, 5.5a, and 5.6a), a piece of electrical wire (Fig. 5.7a), and a pair of shoes (Figs. 5.8a and 5.9a). The wooden board has a uniform background and it can be seen that the algorithm works well in spite of overlapping (parts b-d of Figs. 5.1-5.3). Although the box of fudge has a varying background, the algorithm still works well because the detonator is considerably darker than the fudge (parts b-d of Figs. 5.4-5.6). The piece of wire is introduced because of its similar shape to the detonator. This is to test whether the algorithm will be able to distinguish the detonator from other narrow objects to prevent false matches. It was found that although the peak detector picked out a part of the wire (Fig. 5.7b), the end detector clearly eliminated the wire (Fig. 5.7c), and no false alarm occurred (Fig. 5.7d).
Fig. 5.1. Example of the detonator partially overlapping a wooden board. The luggage bag also contains a box of fudge, a circuit board, and a coil of wire. The highlighted points mark the positive detection results of the filters. (a) Original image. (b) Output using the middle-point template. (c) Output using the endpoint templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.2. Example of the detonator overlapping a wooden board slightly. (a) Original image. (b) Output using the middle-point template. (c) Output using the endpoint templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.3. Example of the detonator completely overlapping a wooden board. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.4. Example of the detonator overlapping a box of fudge. The luggage bag also contains a pair of shoes, and clothes. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present. Since there are only three pixels highlighted and they are difficult to see, the output has been enlarged.
Fig. 5.5. Example of a detonator partially overlapping a box of fudge. The luggage bag also contains a box of fudge, a circuit board, and a coil of wire. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.6. Example of a detonator completely overlapping a box of fudge. (a) Original image. (b) Output using the middle-point template. (c) Output using the endpoint templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.7. Example of a detonator overlapping a coil of wire. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.

To further investigate the extent of overlapping, the detonator is overlapped with a pair of shoes with a slight different amount of overlapping (Figs. 5.8a, and 5.9a). However, it was found that in one image the filter was able to successfully detect the detonator, while in the
other image the algorithm did not pick out the detonator even though a part of the detonator showed up in the peak output (parts $b-d$ of Figs 5.8-5.9). This suggests that a subtle change in the image can affect the performance of the algorithm significantly.

Fig. 5.8. Example of a detonator partially overlapping a pair of shoes. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.9. Example of a detonator completely overlapping a pair of shoes. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator was not detected.

Notice that in some cases, such as shown in Fig 5.5d, the output does not lie on the top of the detonator. The reason is that in the algorithm once a detonator is detected, the center of the current window is highlighted. If the orientation of the detonator is not exactly along the diagonal axis of the current window, the highlighted point will not lie on top of the detonator.
5.1.2. Effect of Luggage Position

The luggage position on the conveyor is varied to investigate its effect on the performance of the algorithm since it is important to be able to accurately detect detonators regardless of the luggage position on the conveyor.

Eight different positions across the conveyor were tested with the two extreme cases positions shown in Figs. 5.10-5.11. In the first four positions the detonator was overlapped with a board, while in the last four positions no overlapping was used. This was caused by the sizes of the luggage and the conveyor on the AS&E system. In order to get the images at the rightmost positions, the luggage had to be reversed to fit on the conveyor. The test results (Figs. 5.10d, and 5.11d) show that in all eight images the detonator is successfully detected, indicating the effectiveness of the algorithm regardless the luggage position.
Fig. 5.10. The luggage is as far as possible from the x-ray source. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.11. The luggage is near the x-ray source. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
5.1.3. Effect of Orientation Variation

5.1.3.1. In-Plane Orientation Changes

Using middle point template and the end-point templates that were taken at the orientation $\phi = 60^\circ$, the actual detonator orientation was changed from $\phi-20^\circ$ to $\phi+15^\circ$ at $5^\circ$ increments. Because of the x-ray system that we used, for $\phi = 60^\circ$, the orientation of the detonator in the image was 39.2°, and its apparent orientation changed from 24.6° to 61.6°. The correlation between the physical orientation and the image orientation of the detonation is listed in Table 5.1. Figs. 5.12-5.13 show the output results with image orientations 26.6° and 55.8°. From these results we can see that when the image orientation is changed between 26.6° to 55.8°, both the middle-point and the end-point filters have correct outputs and the detonator is detected. Any further rotation, for example when the orientations are at 61.6° and 24.6°, the middle-point filter does not have good output results and the detonator cannot be detected. It is concluded that at image orientation 39.2°, the orientation tolerance is 55.8° - 26.6° = 29.2°, and it changes with different orientations.
Table 5.1. The correlation between the physical orientation and the image orientation of the detonator.

<table>
<thead>
<tr>
<th>Physical Angle (degrees)</th>
<th>Image Angle (degrees)</th>
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<tr>
<td>40</td>
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<td>70</td>
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<td>75</td>
<td>61.6</td>
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Fig. 5.12. Example of the detonator with an in-plane orientation in the image of 26.6°. The detonator completely overlaps a board. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.
Fig. 5.13. Example of the detonator with an in-plane orientation in the image of 55.8°. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.

5.1.3.2. Out-of-Plane Orientation Changes

For out-of-plane orientation changes, the same method was used to test the orientation tolerance. Because it was difficult to measure the out-of-plane orientation, we gradually changed the orientation until the detection algorithm failed. Then the out-of-plane orientation was measured at that point. It was found that the detection algorithm worked well when the
changing of out-of-plane orientation was smaller or equal to $30^\circ$. Fig. 5.14 shows the output results when the out-of-plane orientation change is $30^\circ$.

Fig. 5.14. Example of the detonator with an out-of-plane orientation of $30^\circ$. (a) Original image. (b) Output using the middle-point template. (c) Output using the end-point templates, both left and right. (d) Final result. The detonator has been detected, and no false matches are present.