Chapter 6

CONCLUSIONS

This thesis presents a part of the research that has been performed at Virginia Tech on developing a prototype automatic luggage scanner for explosive detection. The focus of this thesis is the automatic detection of elongated objects (detonators) in x-ray images using matched filtering, the Hough transform, and information fusion techniques. The major conclusions drawn from this work can be summarized as follows:

1. A variation of matched filtering was found to be reasonably effective for both single orientation and multiple orientation detection, while a Gabor-filtering method was found not to be suitable for this problem.

2. A sophisticated algorithm has been developed for detonator detection in x-ray images, and computer software utilizing this algorithm was programmed to implement the detection on both UNIX and PC platforms.

3. The effects of object overlapping, luggage position on the conveyor, and detonator orientation variation were investigated using a single-orientation detection algorithm. It was found that the effectiveness of the software depended on the extent of overlapping as well as the objects the detonator overlaps. The software was found to work well regardless of the position of the luggage bag on the conveyor, and it was able to tolerate a moderate amount of orientation change.

4. The software was also tested for arbitrary in-plane orientation detonator detection. The output results depend on the complexity of the image. The software works well when no object is overlapping the detonator, while it has both successes and failures when various objects are overlapping the detonator.

5. The speed of the software depends on the size of the original image and the computer. For an original image with a size of 350×450 pixels, the processing time of the software running on a Pentium 120 PC under Windows NT environment is about 6 minutes.

For future work, several things should be considered to improve the algorithm. First of all, it is very important to overcome the problems of overlapping buttons and zippers, since this kind of overlapping occurs often and can cause the middle part detector to miss a significant part of the detonator. Second is to reduce the thresholds for the middle point filter and the end point filters to get more non-zero output pixels on the detonator and use a more intelligent algorithm to get rid of the false positives from this filter. Third is to try to detect other devices and materials which may be associated with an explosive device (such as a battery, wiring, or high explosive), and then perform a more sophisticated information fusion.

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APPENDIX: IMAGE REGISTRATION

Multisensor fusion is an important part of materials characterization. Before the AS&E x-ray luggage inspection system was improved, it could only provide high energy transmission and backscatter images, while the Fiscan system could provide both high energy and low energy transmission images. So, in order to accomplish multisensor fusion, the image registration between these two systems was required.

The registration is carried out in two steps: the first is for the vertical direction (also referred to as the column direction), and the second is for the horizontal direction (also referred to as the row direction). In the vertical direction, we deal with the registration along the x-ray beam plane, and in the horizontal direction, we deal with the registration along the moving direction of the conveyor.

In order to register the images of the two systems along the column direction, an imaginary cylinder is used. This means that for both systems, for every column we project each pixel onto a common cylinder. These are shown in Fig. A.1 and A.2. On this cylinder, we assume that every two adjacent pixels form an equal angle of incidence.

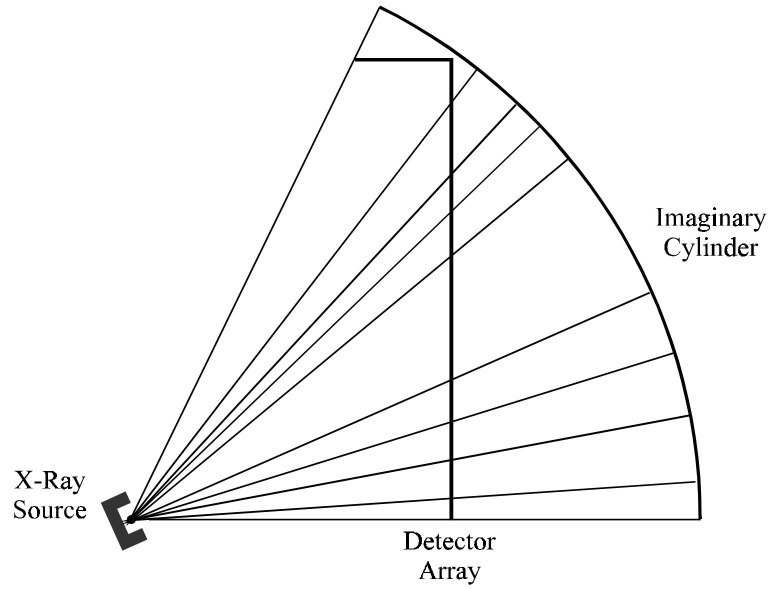


Fig. A.1. Projection of the AS&E image onto the imaginary cylinder.

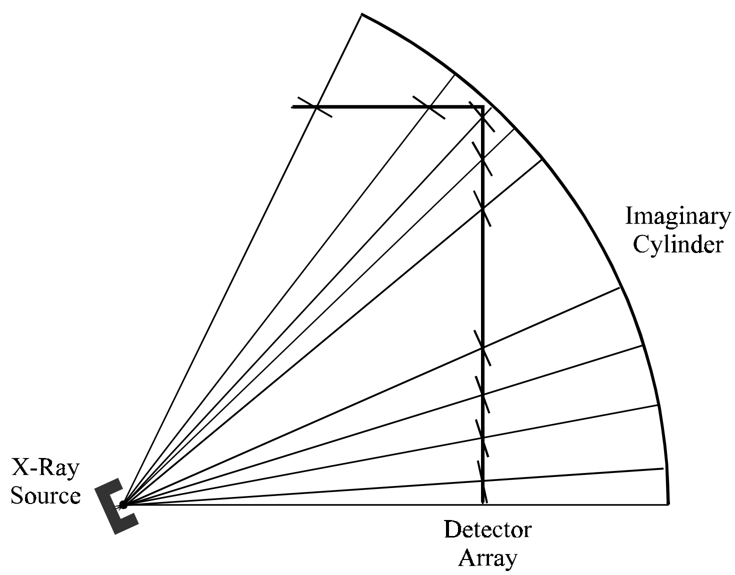


Fig. A.2. Projection of the Fiscan image onto the imaginary cylinder.

Since the incidence angle can be calculated using equations (2.3) and (2.6), the corresponding pixel location on the cylinder for each sample can be determined. In the

AS&E system, for an arbitrary column, the incidence angle of the ith pixel on this column is

$$\alpha = \arctan\left\{\frac{1}{2}\left[1+\tan\left(\theta i - \frac{\pi}{4}\right)\right]\tan(\gamma)\right\} \tag{1}$$

Here γ is the angle that corresponds to the total scan range of the x-ray beam. Let N be the pixel number of each column; then the corresponding pixel location on the cylinder is

$$i_c = \alpha \Big/ \left(\frac{\gamma}{N}\right) \tag{2}$$

In the Fiscan system, $\alpha_1, \alpha_2, \cdots, \alpha_{16}$ can be determined by using equations (2.4) and (2.5). Also, the ith pixel must be on the kth board, where $k = \left\lfloor i/32 \right\rfloor$. So, the incident angle of the ith pixel on an arbitrary column is

$$\alpha = 2\alpha_1 + 2\alpha_2 + \cdots + 2\alpha_{k-1} + \frac{\alpha_k}{16}\left(i - 32(k-1)\right) \tag{3}$$

The corresponding pixel location on the cylinder is

$$i_c = \alpha \Big/ \left(\frac{\gamma}{N}\right) \tag{4}$$

Fig. A.3 shows the relationship between the AS&E system detectors and the imaginary cylinder. Fig. A.4 shows the relationship between the Fiscan system detectors and the imaginary cylinder.

After the projection, since i_c is not an integer, linear interpolation is used to calculate the gray value on every pixel. At this point, the registration along the vertical direction (column) has been done.

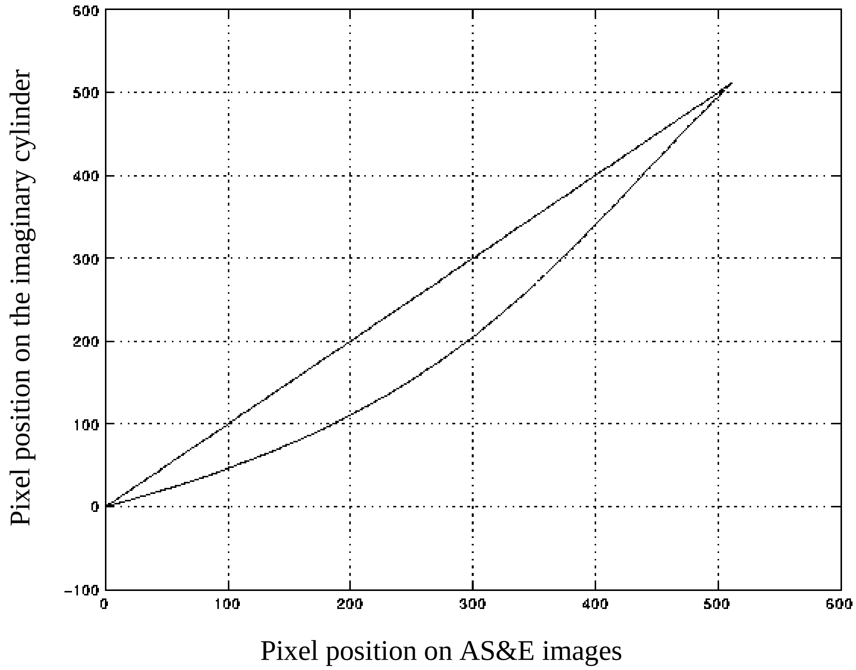


Fig. A.3. Relationship between the AS&E images and the imaginary cylinder projection (curved line). The straight line represents the case of ideal pixel-to-pixel correlation.

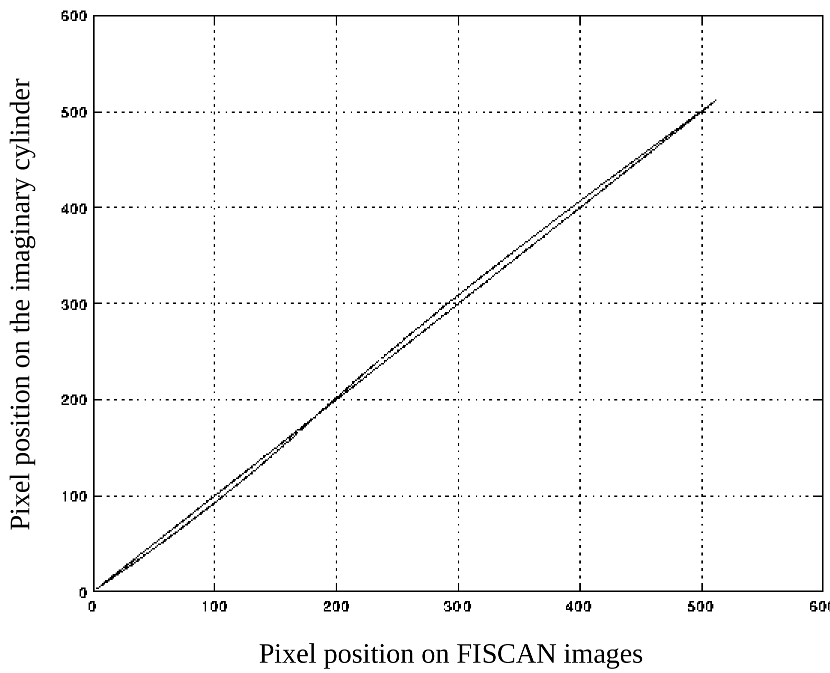


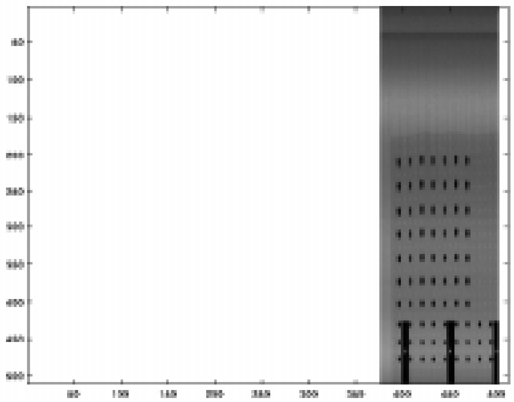
Fig. A.4. Relationship between the Fiscan images and the imaginary cylinder projection (curved line). The straight line represents the case of ideal pixel-to-pixel correlation.

In the horizontal direction, the difference between the two images from the two systems is caused by the different belt speeds on the two systems. For the same luggage, if the image from the AS&E system has d_a columns (width), and the image from the Fiscan system has d_f columns, then the ith column on the Fiscan system image, say i_f, is corresponding to the i_ath column on the AS&E system image, where

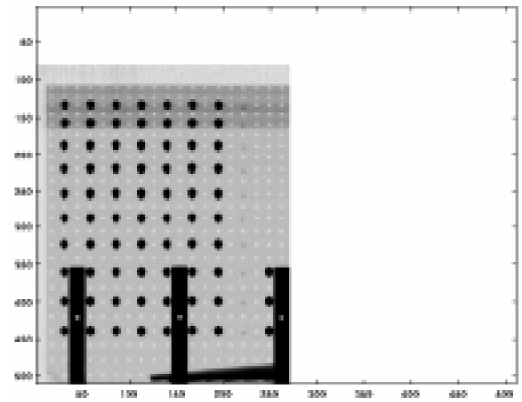
$$i_a = \frac{d_f}{d_a} i_f \tag{5}$$

The same interpolation method is used to correct the difference along the horizontal direction (row).

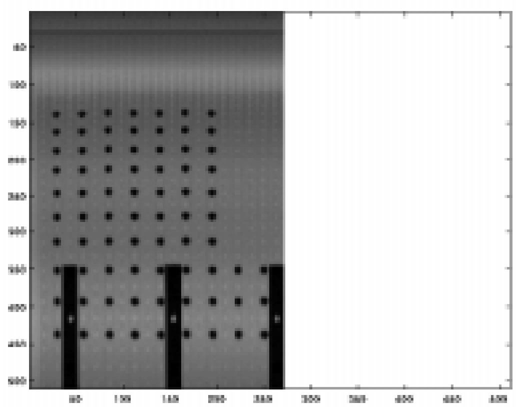
Fig. A.5 shows a typical result of this registration process. Fig. A.5*a* and *b* are the initial images from the AS&E system and the Fiscan system. Fig. A.5*c* and *d* show the results after the registration. Fig. A.6 is the difference of Fig. A.5*c* and *d*, and it can be seen that the two images are overlapping well.



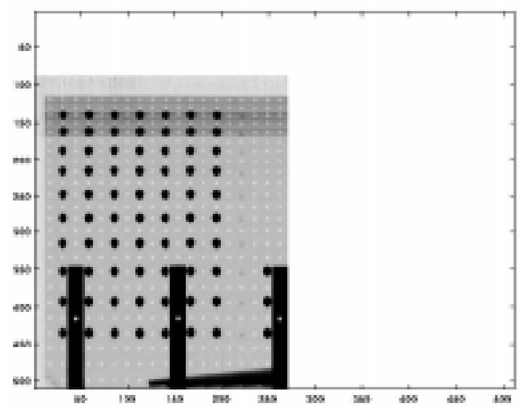
(*a*)



(*b*)



(*c*)



(*d*)

Fig. A.5. Illustration of image registration. (*a*) AS&E original image. (*b*) Fiscan original image. (*c*) AS&E image that has been projected onto the cylinder. (*d*) Fiscan image that has been projected onto the cylinder.

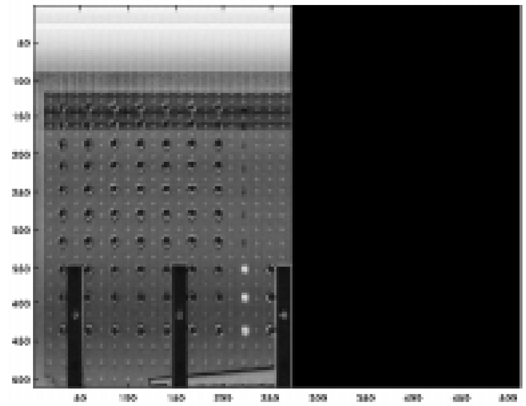


Fig. A.6. Image, computed by subtracting Fig. A.5*c* from A.5*d*. Bright pixels indicate large absolute difference values, and dark pixels indicate small absolute difference values.

VITA

Wenye Liu was born on June 14, 1966 in Dalian, China. She received her Bachelor of Science degree in Radio and Information Engineering from Wuhan University, Wuhan, China, 1988. Afterwards, she worked as a research assistant at Dalian Institute of Chemical Physics, Chinese Academy of Sciences. Her research project involved developing computer software for simulation and optimization of chemical processes in analytical instruments. She joined the graduate program at Virginia Tech in 1995, and her research interest includes image processing, and computer vision. Her thesis describes the algorithm developing and software testing of automatic detection of elongated objects in x-ray images.