Chapter 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

X-ray devices have demonstrated the ability to characterize a material at molecular and atomic levels. This ability is particularly important for detecting plastic explosives, where object shape information cannot be used. To characterize a material, its *density* and Z_{eff} must be known. The *R-L* plane detection method is the first algorithm that uses complete *density* and Z_{eff} information to determining an object's material type. This *R-L* plane detection method represents a step forward in material characterization. This detection method requires the knowledge of *true* gray levels of an object of interest in four sensing modalities: high-energy transmission, low-energy transmission, forward scatter, and backscatter. Value *R*, a Z_{eff} related information, can then be computed using high- and low-energy transmission data. Value *L*, a *density*-related information, can then be computed using forward scatter and backscatter data. Chapter 2 gives a full discussion on this *R-L* plane method.

The investigation then switches to determine the basic structure of the image processing system that is used to determine an object's *true* gray levels in all four sensing modalities. Being able to determine the *true* gray levels of an object of interest is no easy task. First, since the computation is done in different sensing modalities, all four images for the same bag must be carefully registered. The registration algorithm would have been much easier and accurate if the images have less noise. In Chapter 6, the noise of a row of air image clearly demonstrates how severe this noise is. This noise directly contributes to the errors of the registration program. Still the algorithm worked on 98% of the images that had been tested. In this sense, the registration algorithm is a robust algorithm.

To remove image noise, an edge-preserving smoothing algorithm is used to filter an image. Without this smoothing algorithm, an image will be segmented into thousands of small regions and many of the small regions have only 1 or 2 pixels. These small regions are formed apparently due to the appearance of severe image noise. These 1 or 2 pixel regions do not represent any real meaningful regions and will adversely affect the computation of *true* gray levels for object of interests. Using the smoothed images for segmentation, small regions with only 1 or 2 pixels will not appear, and regions being segmented are more accurately in representing objects partially or in their entirety. Some smoothing results were shown in Chapter 6. One problem with this algorithm is that the original algorithm that uses an ideal converging condition, and this makes the algorithm run too slowly. With a modification to the ideal converging condition, the program runs significantly faster, and the resulted smoothed image looks no difference from the image smoothed using the ideal converging condition.

Due to the appearance of *textile* objects in luggage, it is difficult to precisely segment a bag image into regions that represent objects partially or in their entirety. After extensive literature search, region-growing algorithm is found to be suitable for this task. This algorithm was tested on over 100 images from very simple scenarios to very complicated scenarios. Some of the results were shown in Chapter 4 and Chapter 6. The regions being segmented were reasonably accurate. The original algorithm developed by Manos runs too slow. A new implementation of Manos's algorithm significantly improves the running speed.

With regard to the mathematical overlap models, Chapter 5 dedicates most of its discussion on this topic. The high- and low-energy transmission overlap models that were developed using experimental data are quite accurate in determine an object's *true* gray levels. The experimental results shown in this chapter have demonstrated the precision of these two models. The forward scatter and backscatter overlap models are not as accurate as those transmission overlap models. However, the experimental data in Chapter 5 clearly indicate that using those models, the computation of *true* gray levels of an object when overlap occurs is still significantly improved. There are many factors that may have contributed to the errors. Those factors can be correctly identified and removed. The models can be made much more precise with further research in this topic.

In a 2D image, objects of interests often overlap with other background objects that make the precise computation of *true* gray levels almost impossible. By applying exterior criteria, the *true* gray levels of an object of interests can be relatively accurately computed in many scenarios. In Chapter 5, such an algorithm for computing *true* gray levels is developed. Although the algorithm mainly focuses on the computation in high- and low-energy transmission modalities, with accurate scatter overlap models, it can easily be applied to the forward scatter and backscatter modalities. A complete test of this algorithm is given. After experimenting on over 100 images and 400 objects, it was found that the accuracy of this algorithm running in transmission modalities was quite high. Chapter 6 summarizes the findings.

The research work presented in this dissertation represents a step forward in using image-processing algorithms to improve material characterization. The method for determining *true* gray levels is unique. Based on the research result presented in this dissertation, it is author's belief that further improvement in this research direction will directly contribute to the improvement of material characterization.

Material characterization using x-ray technologies is a very active and important research topic in the past two decades. It will remain such for a long time to come. The FAA has spent hundreds of millions of dollars in material characterization related research in order to improve air travel safety. Any improvement in this research is significantly important towards the ultimate solution to accurate material characterization. Possible directions of future research are discussed in the following.

Since the scatter overlap models are not that accurate, an improvement to the overlap models in the forward-scatter and backscatter modalities is necessary. The *true* gray level algorithm can then compute *true* gray levels in all four sensing modalities by incorporating these models.

The current image-processing system provides *true* gray levels for objects of interests. These *true* gray levels are then used by the material characterization system to determine whether it is explosive material or not. However, the data that material characterization system needs for accurate computation may be more than just *true* gray levels. Information such as region size can also be used by the material characterization system. The types of information and the formats of these data provided by the image-processing system for material characterization needs to be determined by experiments in the future.

The current image-processing system still needs more than 12 seconds to process an image with size of 300 by 400 on a Pentium II 400 MHz PC. The overall time used for image collection, image-processing, and material characterization should not be over 6 seconds when this system is used for real-time inspection. The current algorithms need further improvement to achieve a speed that can run in real-time.

Once the scatter overlap models are made accurate, the image-processing system needs to be collected with the material characterization system for intensive and comprehensive tests. This is the first step for developing a fully operational real-time explosive inspection system.

Since the image-processing system is designed with solving general inspection problems in mind, it should also work on other inspection algorithms such as the cargo vehicle inspection problem. Whether this system is working or not on other general inspection problems, some further experiments are still needed to test its abilities and determine aspects that need to be improved.