Operator-assisted Threat Assessment: Adaptation of a Focus-of-attention Technique to the Identification of Potential Threat Regions in Carry-on Baggage Imagery

Regina K. Ferrell[a*], Kenneth W. Tobin[a], Besma A. Abidi[b]

[a]Oak Ridge National Laboratory[†], Oak Ridge, Tennessee
[b]University of Tennessee, Knoxville, Tennessee

ABSTRACT

The Oak Ridge National Laboratory (ORNL) has adapted and evaluated an image-based approach for assisting x-ray baggage screening personnel in identifying potential threat items in x-ray imagery of carry-on baggage. The technique seeks to identify threat items including guns, knives, grenades, pipebombs, and improvised explosive devices. ORNL's methodology has focused on identifying and testing the region-based image characteristics that could potentially indicate a threat object. ORNL's focus-of-attention (FOA) technique breaks with traditional pattern- or template-based techniques for object identification by analyzing small, local spatial regions and the neighborhood relationships of these regions through a decision method based on historical precedence through a training process. Regions that could potentially contain items that pose a threat are assessed and displayed to an operator with a confidence value for the assessed threat. Operator assisted technologies such as the ORNL's FOA, represent a necessary step in the evolution of reliable and accurate inspection systems that achieve full automation.

INTRODUCTION AND BACKGROUND

In a set of recommendations made to the Federal Aviation Administration (FAA) in July of 1997, the National Materials Advisory Board advocated the investigation of methods to automatically detect weapons in carry-on and checked baggage. Besides advocating the implementation of weapon detection capability for x-ray carry-on baggage systems, the board further recommended that future security systems minimize the role of human operators in monitoring and detection and instead capitalize on unique human capabilities in the resolution of alarm [1]. This use of image processing and pattern recognition to detect weapons or threatening objects is not a simple task. For the carry-on baggage inspection task, single view single energy x-ray systems were originally employed based on costs and throughput requirements. The mapping of randomly oriented 3-D objects under inspection to the 2-D x-ray image displayed to the screener are not optimal conditions for classical scene analysis; methodologies and techniques relying on precise segmentation, template matching or shape recognition have demonstrated poor performance to date. These techniques are further hampered by the wide variety of objects found in carry-on baggage, the random orientation of objects, and the possibility that important objects are completely or partially occluded by denser innocuous objects. An attempt in the early 90s to identify guns and several other weapons in x-ray imagery had very limited success partially because of the reliance on weapon shape and the difficulty of identifying objects that were positioned in poor perspective relative to the scanning beam [2]. Techniques that have relied on template matching and other object segmentation approaches to recognition are ineffective and typically result in the detection of false positives or negatives in the data

To enhance the ability of x-ray inspection equipment operators to determine what they are viewing, over the last decade manufacturers have developed x-ray based baggage inspection systems using dual

[*]R.K.F. (Correspondence): Email: ferrellrk@ornl.gov; WWW: http://www-ismv.ic.ornl.gov; Telephone: (865) 574-5730; Fax: (865) 5746-8380.
[†]Prepared by the Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831-6285, operated by UT-Battelle, LLC for the U.S. Department of Energy under contract DE-AC05-00OR22725.

energy or backscatter technology to characterize material properties. These technologies use data from dual sensors to determine the atomic mass of materials in the bag and present this data to the operator via a pseudo-color display where color is an indicator of the material characteristics of the objects imaged, e.g., to differentiate organics from metallic materials. A common scheme is to display organics, and therefore potential explosive materials, as orange and metallic materials as a blue or green shade. X-ray system software components that go beyond this colorizing scheme and attempt to identify organic material that have an atomic number measurement of an explosive are currently on the market as an additional feature on several commercial systems. Ensuring that all explosive materials are detected while limiting the number of false positive detections is a challenge these systems face.

As technology improves, it is desirable to look for ways to enhance this capability by (1) developing techniques to detect other relevant threat objects such as weapons, (2) developing techniques to improve the reliability of detecting threat objects, and (3) extending present threat assessment technology to the application of the next generation of sensing technologies. The human expert makes decisions to inspect a luggage item based on a complex thought process that accounts for many factors in the image other than overt object shape. As a simple example, a region in the image that is very dense will be a cause for physical inspection since no data is available for the operator to view. Similarly, a dense region adjacent to a highly textured region resulting from an electronic component may result in a physical inspection as well. Thus, region characteristics play an important role in the human decision-making process. Shape-based object recognition methods do not account for this non-shape response.

ORNL has proposed their FOA methodology for identifying potential threat items in carry-on baggage. The concept is to assist the x-ray screener in identifying regions within the x-ray image that contain items with similar spatial and material characteristics to expected threat objects. The technology indicates such regions to the operator and gives a confidence level associating the region with a particular threat category. This concept allows the screener to focus his attention on resolving the items within particular regions of the image, therefore maintaining their attention on the inspection task and reducing the potential to miss important items due to boredom or fatigue.

FOCUS OF ATTENTION CONCEPT

The FOA method evaluated and tested at ORNL was an outgrowth of research and development efforts over several areas. The concept of identifying regions where a threat is most likely to be located arose out of research in the automated screening of digital mammograms for cancer. A technique was developed using fractal encoding to pinpoint Focus of Attention Regions (FARs) where anomalies exist. Algorithms to detect anomalies such as microcalcifications are then performed only in the focus-of-attention regions. Because digital mammograms are extremely large images, generally on the order of 10 Mbytes, the process of applying detection algorithms only in the FARs greatly reduces the number of detection computations necessary to detect microcalcifications. An unexpected side benefit to this technology was a reduction in false positive detections of microcalcifications without a decrease in true detections [3].

The FOA method was optimized and tested on x-ray image data from a single view inspection tool. This image was then broken into a fine grid of individual blocks for analysis. A number of image features were measured for each block. Based on these measurements, the initial threat assessment and confidence value were assigned to each block. Once all the blocks were analyzed, adjacent blocks were regrouped, isolated blocks were potentially eliminated, and groupings of blocks were identified as regions for further analysis. A set of region-based image characteristics was measured for each region. These measurements were then used to determine the threat potential for that region and the confidence of that assessment.

Figure 1 shows three paths for x-ray baggage inspection. The unassisted x-ray screener faces a difficult, stressful, somewhat repetitive task of evaluating the safety of carry-on baggage. There is pressure to minimize the number of hand inspections, to keep the line moving smoothly, and to carefully evaluate the contents of each bag to determine the presence of a potential threat. The job has a low pay scale, a high stress factor, and a high turnover rate. Consequently, the quality of the screening performed varies from

operator to operator and may wane due to fatigue near the end of a shift. A totally automated system would scan the bag, declare it safe, or sound an alarm and require a manual inspection. A fully automated system has the requirement of extremely high reliability in the detection of threats and a very low number of false detections. Such a system could provide consistent performance, but carries the potential for failure by not having the capability to see and perceive exactly as a human does. A necessary intermediate step in the development of automated systems is a system that assists the human operator in monitoring for threats. The operator assist system provides a path for more consistent screening performance across a variety of operator skill levels. This approach aids in ensuring a level of equitable attention to each bag regardless of other operator factors such as fatigue, stress due to long lines, etc. This approach takes full advantage of the strong cognitive abilities and experience of the human operator.

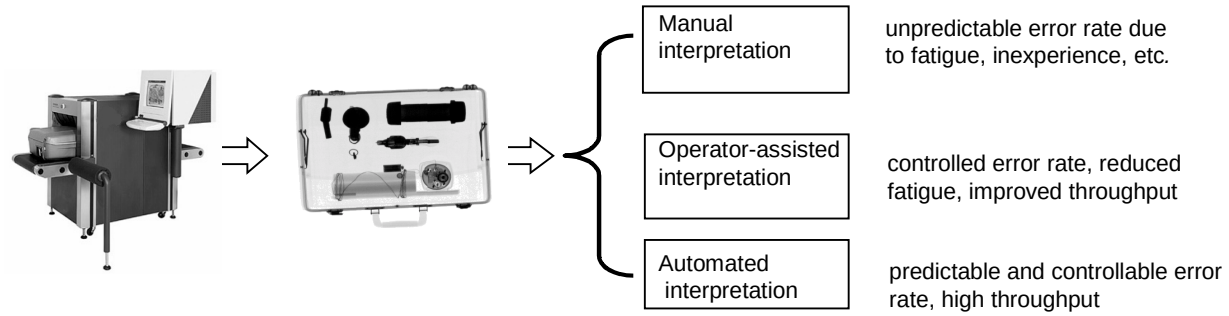

Figure 1 Schematic showing the evolution of baggage inspection data processing from manual to assisted to fully automated capabilities.

CATEGORIZATION OF THREAT ITEMS

The FOA method is intended as an aid to the operator in identifying regions in the x-ray that indicate potential threat items. It does not seek to specifically identify what type of threat item is found. It should be noted though that an FOA region can be subsequently processed through additional means to attempt an identification. This approach has resulted in fewer false positives and missed detections in the case of medical diagnosis for mammography, and it is anticipated that this philosophy will adapt to baggage inspection environments and automation as well. ORNL is currently working to add and test a capability that will indicate what type of threat objects that the region resembles. Presently, however, the technique merely classifies a region as a high, medium, or low threat. Guns, knives, pipebombs, grenades, and opaques are examples of items categorized as high threats. Improvised explosive device components such as batteries and electronics are categorized as medium threats. These could be considered a high threat if coupled with the existence of wires and a suspicious organic material. This technology makes no attempts to identify explosive material at this time, but relies on already developed manufacturer's capability to perform this detection and testing is underway to incorporate material characteristics in the future. The FOA technology supplements manufacturer's detection capability in this area by coupling the manufacturer's detection with the detection of the other improvised explosive device components. Low threat objects are defined as regions whose initial low level image characteristics indicated a potential to contain a threat object, but a higher-level analysis reveals a low probability as a threat object. In the test sets here, umbrellas, coins, scissors, staplers, etc are categorized as low threat objects. Since the September 11 attack, some of these objects may need to be re-categorized as high threats.

In the process of refining and testing this technology, a database of x-ray images of threat and non-threat objects was created by scanning available threat items, items from the National Safe Skies Alliance test kits, and common travel objects in a variety of configurations. This database was categorized and image regions segmented and labeled. For testing and evaluation purposes, binary "mask" images were created to pinpoint the location of particular items in some images. Image characteristics are measured and evaluated over small rectangular blocks to develop an initial threat potential for each block. Based

on the initial threat assessment and confidence value for each block, a grouping and elimination operation creates larger regions for analysis. If no significant blocks are found, the image is categorized to contain no threats. Another set of spatial characteristics is measured over these grouped regions and a final threat assessment is made and the region assigned as a high, medium or low threat for overlay and presentation to an operator.

RESULTS

In order to evaluate this technology, ORNL acquired a data set of x-ray baggage imagery by setting up and scanning both threat objects and benign objects in baggage using an x-ray scanner made available to us courtesy of a local company. Their machine enabled us to acquire and save16 bit tiff images of our bags. Cropped examples from the dataset of some high, medium, and low threat items in various poses are shown in Figure 2.

(a) **(b)** **(c)**

Figure 2 Sample images from the test data set showing high threat items in (a), medium threat items in (b), and low threat items in (c).

Cropped examples showing the regions detected by the FOA method are shown in Figure 3.

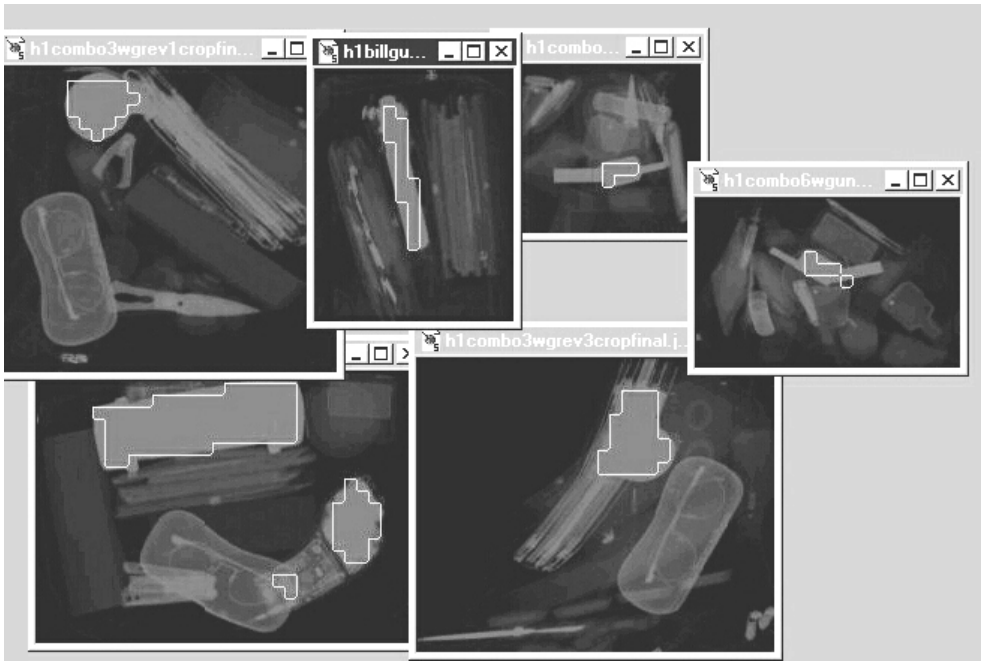

Figure 3 Cropped and enhanced examples of regions detected by the FOA method. The top images show FOA regions containing a grenade and guns. The bottom two images show FOA regions containing a pipebomb, cellphone electronics and batteries, and a grenade.

From the data set collected a test data set of images containing combinations of items was chosen. Of those images, 29% of the images contained no threats, 59% of the images had a high-level threat item, and 22% of the images had a medium level threat item. Many images had both a high and a medium level threat item. A high-level threat item is defined as a gun, grenade, pipebomb, or knife. A medium level threat item is defined as a single potential component of an improvised explosive device such as batteries, wires, and explosive material. No attempt was made to identify explosive material with this methodology, but plans are underway to incorporate detection capability from other sources, e.g. dual-energy systems, into the FOA model.

The first step in evaluating the technique is to determine performance at determining potential threat regions in the image. If a threat object is not detected in the individual block analysis and connectivity operations, it cannot be identified as a threat item during regional analysis. It is also necessary to evaluate the ability to minimize false detections. Of the images with no threats, 59% of those images passed through the block potential region identification without a false indication of a threat. The remaining images had some object that required regional evaluation. Of the images with threat regions, no threat regions were missed in the block potential; however, several threat items resulted in two fragmented regions for evaluation. The initial block analysis and grouping yields regions for region-based evaluation and threat assessment. Table 1 details segmentation performance achieved on the data set. A threat that is split into two or more regions is counted only once in column 3 of the table.

Table 1 - Performance of threat assessment on specific high threat objects.

	Single region	**Two or more regions**	**Region extended beyond 1 item**
High threat	88%	12%	3%
Medium threat	86%	0%	5%
Low threat	75%	25%	0%

Each of the regions analyzed was assessed as a high, medium, low, or unknown threat. An unknown assignment was given when the highest membership value assigned was less than a particular threshold. Table 2 shows performance of the test set across low, medium, and high threat classes. The methods were developed under the philosophy that the primary goal is to have a very minimal number or no missed high threats and a secondary goal of minimizing the number of false positive threat detections. The performance metric is an indication of the number of correct “classifications” with a half credit given for unknown classifications. As an operator-assisted system, an unknown assignment merely indicates to the operator that this may or may not be an item requiring further investigation. For this reason, an “operator performance” metric is included with the philosophy that an unknown characterization basically gives the operator a potential detection and calls for operator judgment in resolving the threat.

Table 2 – Threat assessment confusion matrix showing system performance on data set.

	High Threat Class	**Medium Threat Class**	**Low Threat Class**	**Unknown**	**Performance**	**Operator Performance**
High Threat Items	52%	0	1.5%	46.5%	75%	98%
Medium Threat Items	20%	15%	0	65%	47%	80%
Low Threat Items	23%	0%	8%	69%	35%	76%

A further breakdown of performance for type of high threat items is show in Table 3

Table 3 - Performance of threat assessment on specific high threat objects.

HighThreat breakdown	High Threat	Medium Threat	Low Threat	Unknown	Performance	Operator Performance
Guns	51%	0%	2%	47%	74%	98%
Pipe bombs	73%	0%	0%	27%	86%	100%
Grenades	11%	0%	0%	89%	63%	100%
Opaques	100%	0%	0%	0%	100%	100%

CONCLUSIONS

As more sophisticated, but presently slower and costlier, sensing capabilities develop and mature, an operator-assist approach to threat object detection provides an interim aide and acts as a stepping-stone toward fuller automation of screening operations. A technology that assists the operator in detections reduces errors due to fatigue and provides a higher consistency between operators. The FOA method shows excellent promise for detecting a variety of threat objects and has the flexibility to make use of already developed manufacturer capability in explosive materials detection.

Plans for future work in this area include the testing and evaluation of performance on more subtle threats items. Since September 11, the list of banned carry-on items has increased. A planned enhancement to the technology will integrate material and spatial characteristics for improved reliability in detection. The integration and testing of several classification techniques to further verify the technology approach and the characterization of threat regions will be ongoing over the next year.

ACKNOWLEDGEMENTS

This work has been funded by the Federal Aviation Administration through a cooperative agreement with the National Safe Skies Alliance.

REFERENCES

[1] Second Interim Report To The Federal Aviation Administration Technical Center. National Materials Advisory Board. Committee On Commercial Aviation Security. National Research Council. Washington, D.C. July 1997.

[2] CAXSS-An Intelligent Threat Detection System, T. Feather, L. Guan, A. Lee-Kwen, R. Paranjape, SPIE Conference Applications of Signal and Image Processing in Explosives Detection Systems, November, 1992.

[3] Front-end Data Reduction in Computer-aided Diagnosis of mammograms: A Pilot Study, H. Sari-Sarraf, S.S. Gleason, Robert M. Nishikawa**,** SPIE Conference on Medical Imaging, February, 1999.