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CONTRABAND DETECTION SYSTEM USING X-RAY IMAGES

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ABSTRACT

An important aspect for the overall security in a nuclear facility is to detect the introduction of contraband that can be used to damage the facility or the people in it. Contraband detection is commonly done by metal detectors and X-ray scanning machines. Although there have been several technological advances in the area of explosives detection, the problem of weapon detection is still very dependent on human vigilance. This paper will present a study of an automated weapon detection system based on X-ray image processing. Given reference images of certain types of contraband, the system first extracts their unique features and stores them in a database. Once the database is established, images from an X-ray scanning machine are checked to determine whether any clutter in the image can possibly contain a given contraband. The system then alerts the operator with a video display of those threat clutters. The implementation and operation of the system will be discussed in detail.

I. INTRODUCTION

Although there have been several technological advances in the area of explosives detection in the last few years, the problem of weapon detection is still very dependent on human vigilance. With the current operational system and the most sophisticated X-ray scanning machine, there is no way we can guarantee that an operator takes full advantage of the machine's technology. Although human operators are very good at recognizing partial or occluded shapes in the X-ray images, the screening process requires a very high degree of attentiveness and concentration. As time goes on and the number of screenings increases, the effectiveness of human detection will inevitably decrease. Moreover, since the screening job in many instances, is a low paid and monotonous one, it provides very little motivation to the operators.

In an attempt to enhance the current operational system, the X-ray Image Scan Processing System (XISPS) has been developed. The main objective of the system is to identify and bring to the operator's attention cluttered areas in a bag that can possibly contain certain types of contraband, e.g. handguns. The approach is based on two basic assumptions. First, there is an associated risk level with a dark or cluttered area in a bag that an operator can not determine its content. Figure 1a-b shows images of two bags that contain a gun and a grenade at two different orientations. It is nearly impossible to conclude that there is a gun present in a small area of one bag in Fig. 1b. The second assumption is that any

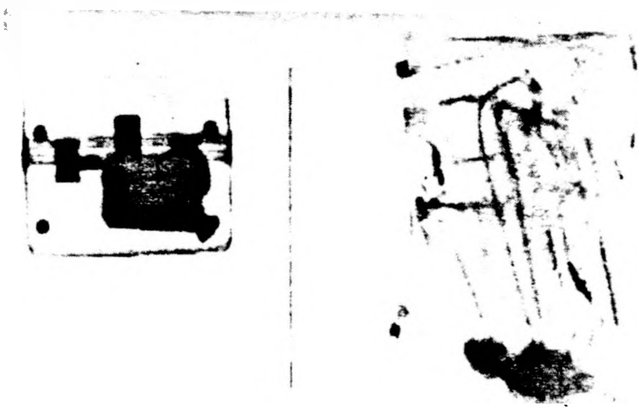

Figure 1a: X-ray images of two bags that contain contrabands: a grenade in the left bag and a handgun in the right bag.

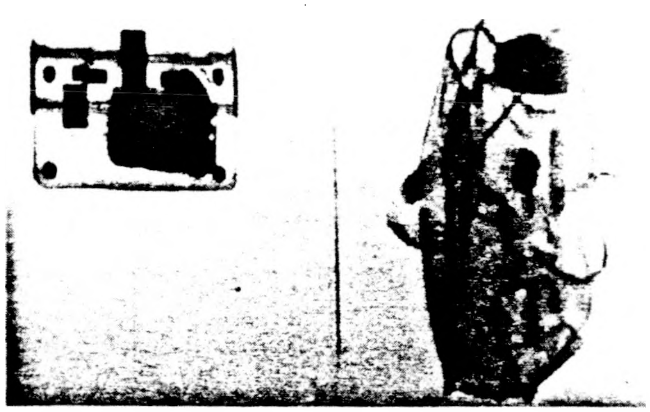

Figure 1b: Same two bags in Fig. 1a from a different orientation.

attempt to pass a contraband through an X-ray machine will be done by disguising or disassembling the contraband. Therefore the main target of the detection should be ambiguous areas in a bag that a certain contraband can be hidden.

II. SYSTEM DESCRIPTION

1. System Overview

The XISPS consists of two major processes: 1) Feature extractor and database, 2) Threat clutter detector and classifier. The inputs and outputs of each process and their relationship are shown in Fig. 2. Before the system can be used to detect threat clutters, a reference contraband image and feature database must be established. Different reference contrabands at various 3-D orientations are passed through an X-ray scanning machine. These reference X-ray images are stored on an optical disk recorder for operator training and assessment. Several features are also extracted from these reference images and stored in the contraband feature database.

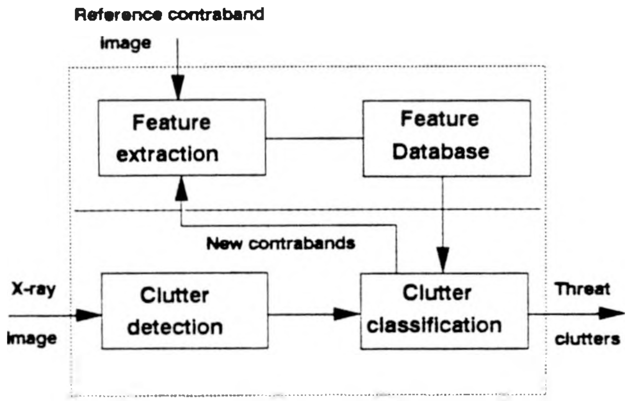

Figure 2: Block diagram of major system processes.

In the detection mode, a supervisor selects certain type(s) of contraband (at a specific 3-D orientation) from the database for threat clutter analysis. The threat clutter detector and classifier uses the extracted features from the selected contraband to determine whether any clutter in the image of the screened article can possibly obscure the contraband. If a different type of contraband is found while the system is in the detection mode, the database can be updated by introducing the new contraband to the feature extractor and database. More details of the two major processes are presented in the following sections.

2. Feature Extractor and Database

The purpose of this process is to extract unique features from a contraband's X-ray images, and establish a contraband image and feature database for later threat detection. Given images of a certain type of contraband, e.g. a handgun at different 3-D orientations, the process extracts and computes several unique features of the gun at each orientation. These features are then combined into a more general set of features that is somewhat invariant to changes in shapes and sizes at different orientations. Some of the extracted features are the area, image density mean and variance, axis lengths of a best fit ellipse, major axis angle, line segments of the polygon approximation of the contour, etc. Images of the contraband can also be stored in the database for training new operators or for the assessment of threat clutters. The basic structure of the database is shown in Fig. 3.

For a certain type of contraband, e.g. handguns, there are many different types with widely varying shapes and sizes. In addition, there are numerous possible ways that they can be placed inside a bag. Therefore, finding a robust technique to combine several features of the same class of objects into an invariant set of features is a critical part of the feature extraction. Otherwise the size of the database will become unmanageable and the processing time will increase proportionally to all the possible presentations and placements of a contraband in a screened baggage image.

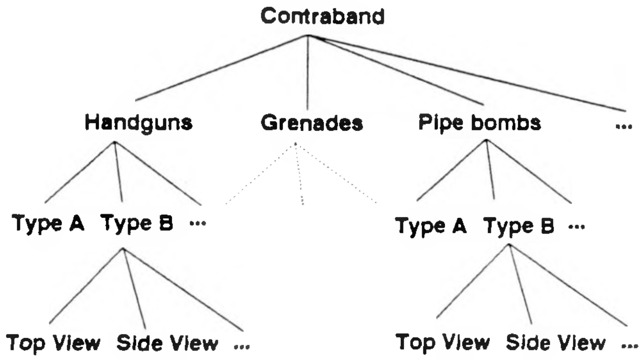

Figure 3: Example of a contraband database basic structure.

Currently, the extracted features are only invariant in 2-D and a limited number of 3-D orientations of a contraband item. In order to determine whether a clutter can possibly contain a given contraband item in the database, the system has to examine the clutter with the extracted features from many different 3-D orientations of the contraband (i.e. all elements of the bottom layer in Fig. 3.)

3. Threat Clutter Detector and Classifier

A threat clutter is defined as an area in an X-ray image that can possibly obscure a contraband item (in the database) with a certain level of confidence. The threat clutter detector consists of three basic tasks: clutter segmentation, clutter detection and clutter classification.

3.1. Clutter segmentation

The main purpose of clutter segmentation is to separate areas of an image into two classes of picture elements (pixels) based on their image intensity levels and their relationship with the neighboring pixels. In general the first class consists of areas that an operator can easily determine what is in it; the second class includes areas that are too dark or too cluttered (busy) to determine what is in it. The second class of pixels is then input for threat clutter detection.

One question that needs to be resolved in segmenting clutters is "how dark/busy is too dark/busy?" Since the goal is to detect a certain type of contraband, it is reasonable to assume that the dark or busy level should be derived from the contraband itself. However, the intensity level of the same contraband at different orientations can vary not only in the same scanning machine but also from one machine to another. Given such uncertain information, a probabilistic method is used to reduce ambiguities in the segmentation process rather than making firm the decision at once. Initially each pixel in the image is assigned a probability that it belongs to class 1 or 2 (dark or light). The probabilities of its neighboring pixels are then examined to confirm the correctness of the initial assignment, and adjustment is made according to the compatibility of the pixel with its neighbors. The process is repeated until most assignments are consistent with those from the previous iteration.

3.2 Clutter detection

All pixels in the image that are assigned to the second class are now ready to be grouped into connected clutters for further analysis. Moreover, the information about each bag in the image is also extracted at this stage. The baggage information such as height, width, and area provides a quick way to check whether a bag could contain a given contraband. It also helps to determine which bag the clutters belong, and how busy or how dense the bag is.

The grouping process is done on a line-by-line basis using a distance connectivity criteria. A group of pixels is considered to be a clutter if and only if they are in a certain distance range both vertically and horizontally. Many attributes of each clutter are also calculated at the same time. Some of these attributes are the area, axis lengths, axis angle, and perimeter. Any clutter that is too small compared with the contraband's area will be rejected at this time. The final output of the clutter detector is a list of potential clutters with their associated attributes for clutter classification.

3.3. Clutter Classification

This step is to determine whether or not a selected contraband image can possibly be included by the potential threat clutters. If the inclusion is not obvious, then the inclusion location of the contraband in the clutter will also be determined and reported to the operator. The approach is to use successive tests from a simpler one to a more complex one to eliminate non-threat clutters and to confirm threat clutters. Although clutter classification is the most computationally intensive process in the XISPS, it can be done in parallel if more than one processing unit is available.

The first simple test is to reject or accept a clutter using different derived image ratios from a selected contraband item and the potential threat clutter, such as the area ratio, major and minor axis ratio, or maximum disk inscribed. Clutters with a larger area than the test contraband and a good compactness measure will be declared as threat clutters at this point. (A compactness measure is defined as a combination of the ratio of the clutter's area and perimeter, and the ratio of the best fit ellipse area and the clutter area.) The remaining clutters will then be checked whether or not they can possibly contain the maximum inscribed chords of the contraband. The last test is contour matching using a minimization technique.

The final output from the clutter classification process is the list of threat clutters with their locations and attributes. The contour outlines of these threat clutters will then be overlaid on the original X-ray image to alert the operator about the threat areas. Fig. 4a-b shows the X-ray image of a passenger bag and a threat clutter found by the system, respectively. Fig. 4c shows the inclusion location of a handgun from the database on the threat clutter.

4. User interface

An important requirement of the XISPS is to make it transparent to the X-ray scanning machine operator. The less an operator has to adjust the system parameters the more desirable it is. More features on the operational screen can sometimes be distracting to the operator rather than useful. Therefore it is our intention that in the operational mode, the user features will be minimal; only in the supervisor and maintenance modes will the full user features be available.

III. CURRENT SYSTEM STATUS

The proof-of-concept system was completed in January 1990. It demonstrates that using the techniques described in section II, threat clutters can be detected successfully. The current system hardware consists of an image processor from Imaging Technology Inc., an 80386 personal computer and an optical disk recorder. X-ray test images of contrabands and passenger baggages were obtained from a local airport and stored on the optical disk for testing. Most of the intensive computations are executed on the PC. The image processor is used for image acquisition and noise filtering. All software is written in C and runs under the MS-DOS operating system. Currently the processing time is proportionally increased with the number of clutters in a bag. On the average, it takes about 40 seconds to process one clutter.

IV. FUTURE DEVELOPMENT

The second phase of the project is to implement the current techniques on faster and more suitable hardware. The main objective of this phase is to detect threat clutters using a single contraband item at a selected 3-D orientation in

Figure 4a: X-ray image of a passenger bag.

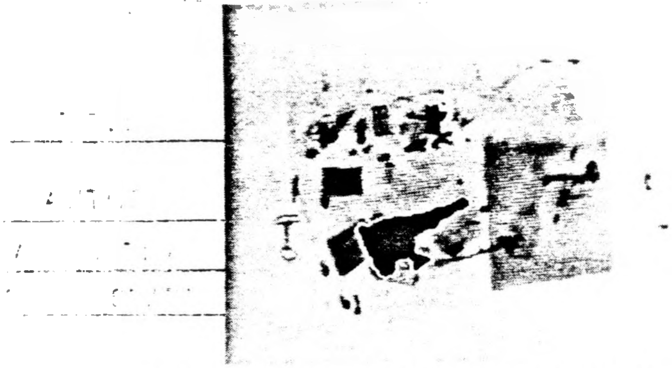

Figure 4b: Threat clutter found by XISPS.

Figure 4c: The inclusion location of a handgun from the database on the threat clutter.

1-2 seconds from the time the baggage image is captured. The prototype system will be tested in an actual working environment to determine its effectiveness. A user interface will also be provided for operators.

Since the information given by a line scan X-ray machine is relatively limited, the use of images from an enhanced machine such as a dual energy beam or a back-scattered system is being considered. Organic and inorganic materials can be recognized much easier with images from such machines. In addition, images that are constructed from several different scanning angles from an orthogonal beam machine or a fast computerized tomographic scanning machine (CT scan) can provide more information about objects in the bag. One drawback is that these machines are much more expensive than a line-scan X-ray machine.