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AN IMAGE PROCESSING SYSTEM FOR THE MONITORING OF SPECIAL NUCLEAR MATERIAL AND PERSONNEL

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ABSTRACT

An important aspect of insider protection in production facilities is the monitoring of the movement of special nuclear material (SNM) and personnel. One system developed at Sandia National Labs for this purpose is the Personnel and Material Tracking System (PAMTRAK). PAMTRAK can intelligently integrate different sensor technologies and the security requirements of a facility to provide a unique capability in monitoring and tracking SNM and personnel. Currently many sensor technologies are used to track the location of personnel and SNM inside a production facility. These technologies are generally intrusive; they require special badges be worn by personnel, special tags be connected to material, and special detection devices be mounted in the area. Video technology, however, is non-intrusive because it does not require that personnel wear special badges or that special tags be attached to SNM.

Sandia has developed a video-based image processing system consisting of three major components: the Material Monitoring Subsystem (MMS), the Personnel Tracking Subsystem (PTS) and the Item Recognition Subsystem (IRS). The basic function of the MMS is to detect movements of SNM that occur in user-defined regions of interest (ROI) from multiple cameras; these ROI can be of any shape and size. The purpose of the PTS is to track location of personnel in an area using multiple cameras. It can also be used to implement the two-person rule or to detect unauthorized personnel in a restricted area. Finally, the IRS can be used for the recognition and inventory of SNM in a working area. It can also generate a log record on the status of each SNM. Currently the MMS is integrated with PAMTRAK to complement other monitoring technologies in the system. The paper will discuss the system components and their implementations, and describe current enhancements as well as future work.

INTRODUCTION

An important aspect of insider protection in production facilities is the monitoring of the movement of special nuclear material (SNM) and personnel. For years strict working procedures and rules have been used to prevent theft or loss of SNM and to monitor personnel within production facilities. Only recently have systems been available to monitor SNM and personnel, such as the Personnel and Material Tracking System (PAMTRAK) developed at Sandia. PAMTRAK can intelligently integrate different sensor technologies and the security requirements of a facility to provide a unique capability in monitoring and tracking SNM and personnel. Currently different sensor technologies are used to track the location of personnel and SNM inside a production facility. An active radio frequency (RF) device with a mercury switch known as a WATCH (Wireless Alarm Transmission of Container Handling System) is attached to SNM to monitor its movement within the facility. Sensitivity of the mercury switch can be adjusted so that even a light touch can be detected by the WATCH. The two-person rule or personnel tracking are implemented using a special RF badge with a tamper-proof fiber optic loop. Normally the badge is in a dormant state until the person with the badge enters an active field. The badge is then excited by an antenna or when the fiber loop is removed from it. When the badge is excited, it will transmit a signal to the receiver. Thus the presence or absence of personnel in a designated area can be monitored. Because active tags must be used for each monitored item, the overall cost of the monitoring system will increase proportionally with the number of items. Moreover, these technologies are generally intrusive. They require that special badges be worn by personnel at all times, special tags be connected to material and special detection devices be mounted in the area. Video technology, however, is nonintrusive since it does not require direct attachment of any equipment to personnel or to the SNM. With the low cost of cameras, video capture boards, and the ever increasing performance of personal computers, video technology and image processing can be effectively used to enhance or complement other technologies in solving the problem of insider protection.

SYSTEM FUNCTIONAL DESCRIPTION

The original concept of the image processing system described in this paper can be attributed to the Visual Artificially Intelligent Surveillance System (VAIS) [1] that was developed at Sandia in 1988. The underlying thesis of the current image processing system is that effective personnel and SNM monitoring should be ubiquitous, with minimal interference to the people and the working environment. The current system consists of three basic components: the Material Monitoring Subsystem (MMS), the Personnel Tracking Subsystem (PTS), and the Item Recognition Subsystem (IRS).

Material Monitoring Subsystem (MMS)

The main function of the MMS is to monitor and detect movement of SNM in regions of interest (ROIs). A ROI is an area within an image that is defined by the user for the detection of movement. Up to 25 ROIs can be defined in a scene, and the ROI can be of any shape and size. Because multiple cameras are used with the MMS, an object in a scene can have many ROIs associated with it. Figure 1 shows examples of ROIs of the same object from two different cameras.

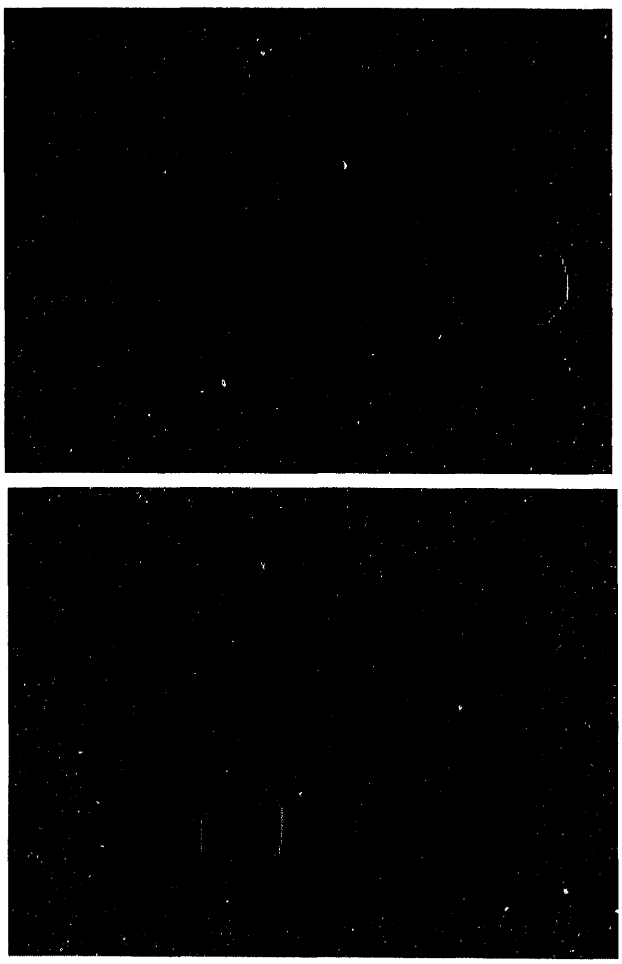


Figure 1. Examples of ROIs from two different cameras

In many motion detection systems, the ROI must be defined by rectangles. False alarms can occur in the ROI even when there is no movement of an object because of the unoccupied space of the object inside it. Such false alarms will be eliminated if the ROI shape is the same as the object. There are also several advantages of motion detection using multiple cameras:

1. The system can be used in an unstructured environment where there may be a lot of movement in the working area.
2. There is a reduction of false alarms caused by shadows or changes in lighting.
3. A detection volume can be created around an object instead of a 2-D detection plane as in a single camera detection system.
4. The loss of a single camera will not adversely impair the detection capability of the system.

Currently there are two selectable methods for the detection of motion in a scene. The first method can detect very sensitive and subtle motion. An application for this method would be when all workers have left the work area and the SNM still requires protection. The second method is less sensitive to shadows or changes in lighting and can be used when there is activity near the protected objects.

Personnel Tracking Subsystem (PTS)

The purpose of the PTS is to track the location of personnel in an area using multiple cameras. It can also be used to implement the two-person rule or to detect unauthorized personnel in a restricted area. The restricted area can be defined in a similar fashion as the ROI in the MMS. Using the PTS in combination with the MMS, we can effectively protect an area containing SNM during nonworking hours by restricting any personnel movement in the working area, around the SNM general area and around each occurrence of SNM in the working area. Thus several layers of protection can be created using the two subsystems to prevent theft or loss of SNM. The PTS can be also be used for safety purposes where unauthorized or untrained personnel will be restricted from entering radioactive zones.

Currently the subsystem uses three cameras to track two moving objects and resolve their location in the scene. One restriction is that the line of sight of the cameras should either be parallel or orthogonal to the ground plane. A typical camera setup is shown in Fig. 2 where two cameras are parallel to the ground level and the third one mounted on the ceiling.

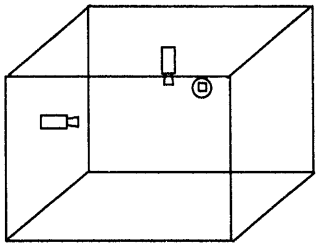


Figure 2. Typical camera setup for the Personnel Tracking System (PTS)

Item Recognition System (IRS)

The IRS can be used for the recognition and inventory of SNM in a working area. In a typical working environment, SNM can be freely moved around the area for processing. The security concern for this environment is not whether the SNM is moved, but which SNM has been moved, when it is moved, and whether it is the same SNM after it returns to the original storage. While the main purpose of the MMS is to prevent SNM (or any object) from being stolen, the goal of the IRS is to ensure that the identification of SNM (or an object) is known and verified as it is worked on. The MMS will notify an operator if item A from the list of all SNM in the working area is moved, but it is the IRS that will alert the operator when item A is replaced by a fake object or when there is a new item added to the list. A log record for each item of SNM and the SNM list can be also generated by the IRS for inventory purposes.

HARDWARE DESCRIPTION

All subsystems are implemented using 486 PCs with low-cost video capture boards. The PCs are single-board computers housed in a small footprint chassis. There are no special coprocessors or accelerators in the subsystems. All software for each subsystem can be stored and run from a single board of nonvolatile RAM thus eliminating the need for hard disks. The overall hardware cost for each subsystem is less than $3000, excluding the cost of cameras and video display monitors.

Video inputs from different cameras to the subsystem are handled by a simple 4-to-1 multiplexer built in-house. The multiplexer is controlled and powered by the parallel port of the computer. Several multiplexers can be cascaded to provide switching capability for more than four cameras. Because the PCs are single-board computers inserted into passive backplanes, overall processing speed can be significantly improved with a faster CPU such as the Pentium.

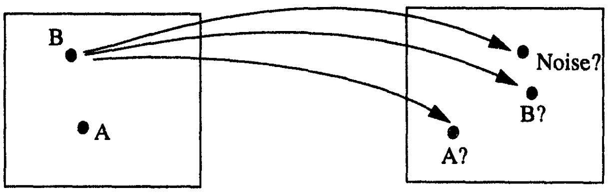
IMAGE PROCESSING TECHNIQUES

The motion detection algorithm used in the MMS is an enhanced version of the change detection algorithm implemented in the Target Cueing and Tracking System (TCATS) [2]. Because the MMS is primarily used for interior detection and the TCATS is for exterior detection, the assumptions of drastic illumination variation due to large shadows cast by clouds and camera motion in windy days can be eliminated. Moreover, unlike natural objects in a field (e.g., tumbleweeds, grass, and sand pile) that differ significantly in texture, many of the man-made objects in a room or a facility have uniform texture. Therefore, motion detection in the MMS is based on the principle of image intensity mean shift rather than changes in texture as in exterior motion detection algorithms. However, to accommodate slow changes due to shadows cast by people moving around the working area, the background scene (reference image) is updated by a time constant. By adjusting this time constant, we can adjust the rate of update between an incoming scene (current image) and the background scene.

The motion detection method based on the principle of intensity mean shift is very sensitive to any type of change. A light touch on an object will trigger a detection. Depending on the type of application, this sensitivity may or may not be a desirable attribute. The MMS also includes a different motion detection method that is based on motion around the objects' edges in the scene. This method uses both the time and spatial temporal for the detection of motion. It assumes that the edges of objects in the scene can be extracted from the background's scene, i.e., the objects' intensity values around their edges are distinguishable from the background image intensity.

In order to track multiple targets <u>and</u> resolve the targets location in a 3-D scene, the PTS must be able to make an association of the targets from different cameras. An example is depicted in Fig. 3 where the mapping from the detection of targets from camera 1 to camera 2 is a 1-to-many mapping.

Theoretically, the association problem can be solved for n targets in a scene with m sensors (cameras) where $m \geq n + 1$. The difficulty arises when extraneous clusters are detected in a scene as in Fig. 3. Moreover, because movements of people in the working area are often erratic instead of predictable, as in an exterior environment, a

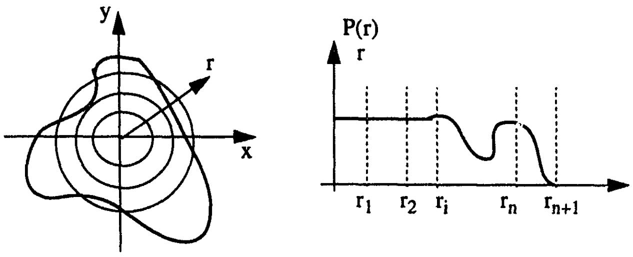


Detected targets from camera 1   Detected targets from camera 2

Figure 3. The association problem from multiple cameras

typical frame-by-frame tracking method may not work well. Currently the tracking is accomplished in the following manner. Motion detection is done on all views from different cameras to isolate targets from the background. Assuming that the line of sight of two cameras is parallel to the ground plane, moving people can be found by integrating all changed pixels vertically. Similarly, an integration is done along the radius line for the third ceiling-mounted camera. Since the physical locations of the cameras are known, the association of the targets detected from the two cameras parallel to the ground plane can be resolved using the target information from the ceiling-mounted camera. Once the associations of the targets are made, the image coordinates of the detected targets can then be transformed into the world coordinate. A 3-D rendered scene is used to display the working area and the moving targets in the area.

A simple feature extraction method is used in the IRS for object classification and recognition. The feature vector extracted from an object is the total number of pixels along the concentric rings radiated from the object's centroid as in Fig. 4. Using this method, for example, the normalized projection (P(r) / r) of a circle is a step function. Thus the object contour can be simply coded with two values.



Object and its concentric rings   Normalized projection of object

Figure 4. Feature extraction method

Similarly an irregularly shaped object can be coded with *n*+1 values where *n*+1 is the total number of concentric rings, i.e., quantization steps. A more efficient way is to first find the circumscribed circle and then perform the normal projection.

An important aspect of the image processing techniques in all subsystems is the use of multiple cameras for motion detection, object recognition, and target tracking. Although volumetric detection and irregularly shaped ROIs are not new concepts, they are particularly useful for the implementation of the protection-in-depth concept in physical security. Using multiple cameras and irregularly shaped ROIs, a tight and bounded volume can be placed around a protected object. The tightness of the detected volume can also be adjusted by changing the ROI masks in each camera view.

FUTURE WORKS

We are working on a different tracking system that uses multiple low-cost infrared detectors on a rotating platform. The system can be used in conjunction with the video-based tracking system or as a stand-alone system. Currently the PTS requires that the cameras must either be parallel or orthogonal to the ground plane. To relax this restriction, a different algorithm has been developed. With the new algorithm cameras can be placed anywhere in the working area. Both the new tracking system and the enhanced PTS are scheduled for completion by October 1994. The PTS and IRS will eventually be integrated with PAMTRAK to enhance the monitoring and tracking capability of the system. The main thrust of our effort is to make interior security as transparent to operators as possible. Security should enhance productivity instead of reducing it. To do that it should be ubiquitous yet accommodating to the working environment and to the personnel.

ACKNOWLEDGEMENT

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