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TEST AND EVALUATION OF PANORAMIC IMAGING SECURITY SENSOR FOR FORCE PROTECTION AND FACILITY SECURITY

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ABSTRACT

This paper describes the design and preliminary test results of a 360-degree scanning, multi-spectral intrusion detection sensor. This moderate-resolution, panoramic imaging sensor is intended for exterior use at ranges from 50 to 1500 meters. This Advanced Exterior Sensor (AES) uses three sensing technologies (infrared, visible, and radar), separate track processors and sensor fusion to provide low false-alarm intrusion detection, tracking, and immediate visual assessment. The images from the infrared and visible detector sets and the radar range data are updated as the sensors rotate about once per second. The radar provides range data with one-meter resolution. This sensor has been designed for low-cost, easy use and rapid deployment to cover wide areas beyond, or in place of, typical perimeters, and tactical applications around fixed or temporary high-value assets. A prototype AES has been developed and preliminary test results are presented. This sensor represents a growing trend to use low-cost thermal imaging sensors, combined with other devices and advanced processing, for protection of U.S. military forces and other national assets.

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INTRODUCTION

The Advanced Exterior Sensor (AES) is an intrusion detection and tracking system for wide area coverage in ground-based security applications. The requirements are to detect human and vehicle intrusions across various terrain and environmental conditions. It has been designed to be rapidly deployable and simple to set up and operate, and suitable for both day and night operations.

The AES integrates three sensor technologies (thermal infrared waveband, visible waveband, and microwave radar) with three motion detection target trackers and a sensor fusion software module to achieve higher performance than single technology devices. Wide areas are covered by continuously scanning the three sensors 360 degrees in about one second. No commercial-off-the-shelf (COTS) system exists today that combines these technologies.

Sensors capable of wide area, stand-off intrusion detection are gaining increased importance in applications ranging from upgraded fixed perimeter security to rapid-deployment force protection on peace-keeping missions. Adding imaging and motion detection capabilities to wide area sensors enhances their usefulness and provides the operator immediate visual alarm assessment.

Video motion detection (VMD) systems have been applied primarily to closed-circuit television (CCTV) cameras around perimeters; however, recent evaluations show nuisance alarms are still high [Ringler-95], and most applications have focused on clear zones, not unstructured areas.

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The AES project was designed to include VMD by capitalizing on faster processors and advanced detection and tracking algorithms. One goal of the AES project is to combine these in an affordable package.

DESIGN REQUIREMENTS FOR AN AES

At the beginning of the *AES* project, the following general requirements for a stand-off intrusion detection sensor were identified:

1. Capable of wide area coverage (hundreds of meters for humans and vehicles).
2. Detection and tracking of multiple targets.
3. Capable of detecting a wide range of penetration scenarios.
4. High probability of detection (Pd).
5. Low nuisance alarm rate by discriminating humans and vehicles from nuisance sources.
6. Capable of 24-hour operation in varying environmental and climatic conditions.
7. Limited mechanical moving parts.
8. Capable of sectorized assessment while maintaining detection in the remaining areas.
9. Passive (low electromagnetic signature).
10. Low life-cycle cost.

Additional requirements and clarification of these parameters were derived from related programs, interviews with individuals in the security field, operational requirements documents, and other agencies and sources.

SPECIFIC DESIGN PARAMETERS

The *AES* was designed to detect and track humans and vehicles in accordance with the ranges summarized in Table 1. Targets moving as slowly as 0.25 meter per second (0.1 m/sec desired) are to be detected as well.

The *AES* was designed to reduce nuisance alarms based on motion of the objects. The *AES* detects motion in a full 360° while assessing alarms from other locations by continuous azimuth scanning. The system can accommodate uneven terrain by varying the elevation angle during rotation, but this has not yet been fully implemented.

Initial detection and tracking performance, as described later, is meeting expectations and any refinements to the infrared sensor will result in overall system improvements.

Table 1. Detection range requirements.

Target	Conditions	Range (req'd)	Range (desired)
Upright human walk/run 0.6x1.65 m 1.0 m ²	Clear, good visibility	500 m	750 m
	Light rain, humid	350 m	525 m
Crawling human head-on 0.5x0.3 m 0.15 m ²	Clear, good visibility	250 m	375 m
	Light rain, humid	200 m	300 m
Truck/van 1.5x1.5 m 2.3 m ²	Clear, good visibility	1000 m	1500 m
	Light rain, humid	800 m	1200 m

COMPONENTS OF THE AES

The *AES* consists of three major components. The Remote Sensor Module (RSM), shown in Figure 1, is a rotating sensor pod that is placed in the field and remotely connected over a high-speed data link to a high-speed Data Processing Module (DPM). Eventually, multiple RSMs and DPMs (used in combination) can be networked to cover a very large facility. A single Display Control Module (DCM) is used to configure and control an RSM and DPM.

REMOTE SENSOR MODULE

An infrared sensor was selected to provide good quality imagery in both day and night conditions, with some advantage during poor weather as well. A lead-selenide (PbSe) linear infrared array, operating in the 3-5 micron thermal infrared band, was selected as the primary sensing device in the *AES* RSM.

Figure 1. Remote Sensor Module

Performance modeling of the system using a 160-element PbSe linear array predicted the Minimum Resolvable Temperature Difference curve shown in Figure 2 [see also Pritchard-94]. Also shown in this figure are measured MRTD values taken before and after some system refinements, including detector replacement and focus adjustments. Performance of the infrared sensor is not as good as predicted, however, and some additional investigations are under way.

Figure 2. AES MRTD Comparison

A visible-waveband imaging sensor and a microwave radar sensor were chosen to complement the infrared sensor. The visible band sensor effectively supplements the limitations of an infrared sensor during periods of low thermal contrast in warm background, daytime operation.

A radar has been included to overcome rain and fog obscuring the infrared sensor. The radar developed for the *AES* is a frequency modulated, continuous wave (FMCW) radar with area moving-target indication (AMTI). The chosen frequency (17 GHz) was based on rain clutter and human signature modeling. Additional details of the system are described in [Pritchard-95 and Garcia-97].

DATA PROCESSOR MODULE

The DPM (Figure 3) consists of an industry-standard VME backplane and industrial quality enclosure, a custom Fibre Channel receiver and demultiplexer board, a high-speed PowerPC-based control computer, and two, dual Texas Instruments 320C80 digital signal processors.

Figure 3. Data Processor Module

The *AES* infrared and visible motion detection (segmentation) software development was based on an adaptation of the spatio-temporal constraint equation technique [Munno 93]. The radar digital signal processing is primarily 4096-point fast Fourier transform (FFT) operations with some additional coherent averaging and infinite-impulse response (IIR) filtering. The tracking software uses the output of the basic motion detection software; then *feature-based* sensor fusion software is used to combine the outputs of the three trackers to achieve an overall confidence value of the detection [Nelson-96].

DISPLAY AND CONTROL MODULE

A common personal computer (PC) is used as the DCM in the *AES*. The special requirements are that it have an ethernet port for communication to the networked DPM suitable display for gray-scale imagery with color overlays. Although not implemented for the proof-of-concept system, the DCM will eventually have the capability to connect to and control multiple sensor modules and display imagery from each. Figure 4 shows a sample PC screen displaying a 10-degree wedge of the full 360-degree image. The imagery shown is from the visible sensor and is at an angle of 194 degrees from north.

APPLICATIONS

Figure 5 shows a conceptual *AES* application with only four sensor modules at each corner of a one square-kilometer protected area covering an excess of one square mile. The DPMs are co-located and connected together with an ethernet connection. The RSMs are connected to the DPMs over an optical fiber cable.

Figure 5. Proposed 4-AES Application

Figure 4. Sample AES DCM Screen

Many other configurations can be conceived using multiple RSMs, depending on the local site requirements. For small applications, two units can be deployed to capitalize on the ability to overlap coverage and protect a site up to 300 meters on a side. For large rectangular sites, such as runways, six units could be deployed.

PRELIMINARY AES TESTING

VEHICLE DETECTION

Preliminary testing to detect vehicles moving within the field of regard has been completed. Vehicles have been successfully detected and tracked in several scenarios. Vehicle traffic on a freeway 4.2 km away is routinely detected and tracked. Small trucks, cars, and vans are also routinely detected and tracked on an access road to the test facility at Sandia National Laboratories. Figure 6 shows a detection and track box around a vehicle at a distance of approximately 4 km in daytime imagery using the visible camera. This vehicle was simultaneously detected by both the visible and infrared trackers.

**Figure 6. Vehicle Detection at 4.2 km
(Daytime, Visible Image)**

Figure 7 shows a detection of a vehicle at 4.2 km at night in infrared imagery. Actual detection ranges may vary depending on environmental conditions. This vehicle is beyond the range of the radar. The radar range cut-off is 1500 m.

**Figure 7. Vehicle Detection at 4.2 km
(Night, Infrared Image)**

PEOPLE DETECTION

Preliminary performance testing to detect people walking and running shows detection ranges in clear conditions of 500 m or more. Figure 8 shows an example of detection of a person walking in a field during the day at 550 m. The person was detected by both the infrared and visible sensors. Figure 9 shows detection of a person at night using just the infrared sensor. This person is also at 550 m.

**Figure 8. Detection of Person at 500 m
(Daytime, Visible Image)**

**Figure 9. Detection of Person at 500 m
(Night, Infrared Image)**

Some additional test data has been taken to detect crawlers. Figure 10 shows detection of a crawling person in the daytime at approximately 350 m. The image is from the visible sensor.

Although a large amount of test data has not yet been acquired and analyzed, the results to date indicate good detection and tracking performance with the infrared and visible sensors. When the radar becomes fully operational, additional testing will be performed and detection rates are expected to increase. Some further testing will also be performed using different targets and during adverse weather conditions.

Figure 10. Detection of Crawler at 350 m (Night, Infrared Image)

SUMMARY AND FUTURE EFFORTS

The *AES* design combines infrared imaging and visible linear arrays with an area MTI radar in a rotating sensor module. The data processor is implemented as a separate module, remotely located near the operator's display and control unit. The first operational prototype was completed in early 1998 and performance testing has begun. The system is designed to be easily deployed and be effective in many weather conditions. This is accomplished by integration and complementary processing of the signals from three discrete sensors.

Data processing requirements play a major role in the *AES* system design. The detection and tracking algorithms were developed to reliably detect moving objects in low signal-to-noise conditions and operate on scenes where little or no activity is expected.

Additional testing of the prototype *AES* will be performed to better understand the capabilities of the system to detect humans and vehicles in varied and dynamic clutter environments.

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