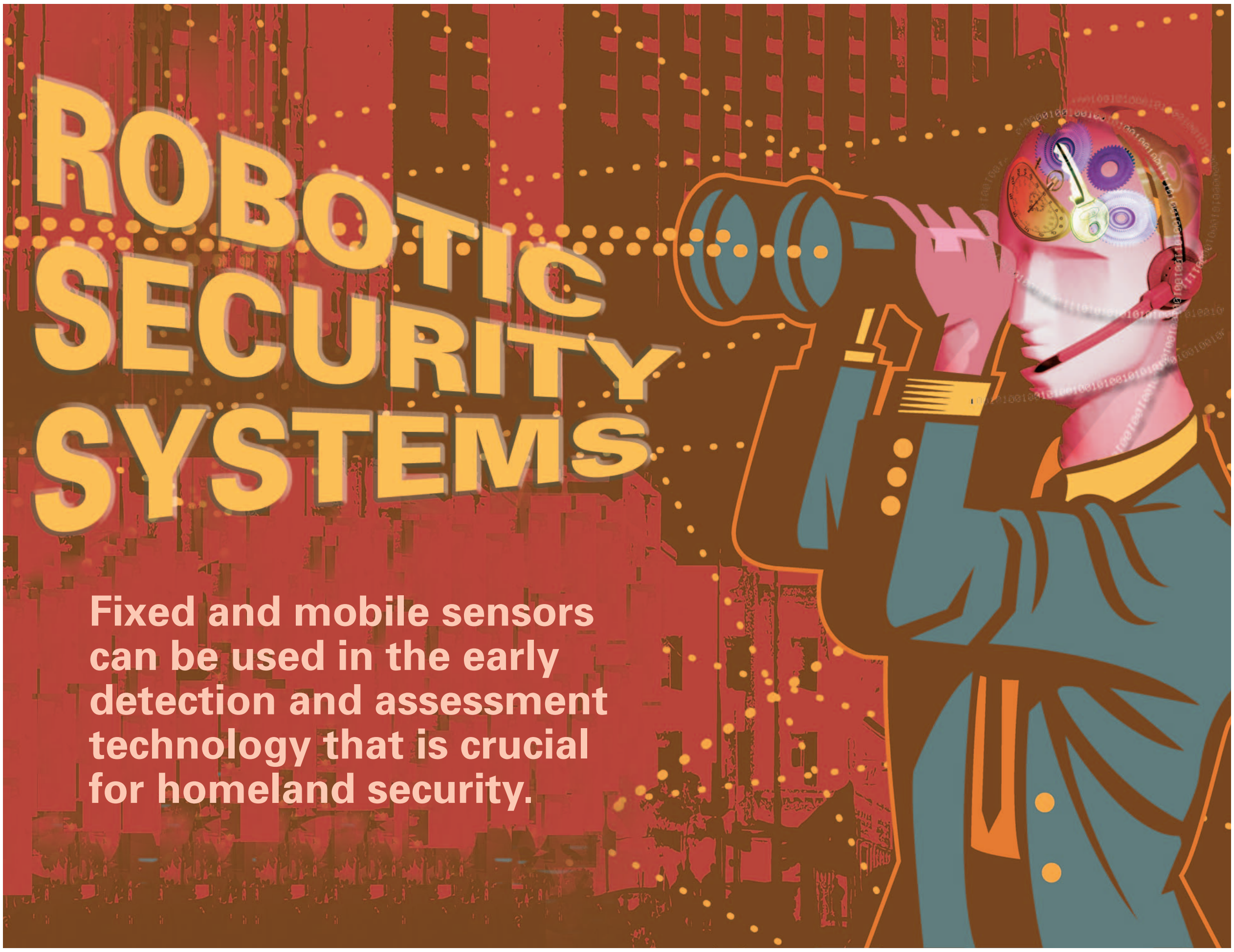

ROBOTIC SECURITY SYSTEMS

Fixed and mobile sensors can be used in the early detection and assessment technology that is crucial for homeland security.

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H.R. Everett

The tragic events of September 11 underscored beyond a shadow of doubt that America is no longer invulnerable to large-scale terrorist attack, and the investigations since conducted into the nature of the threat have unveiled essentially limitless possibilities for more to come. The potential introduction of weapons of mass destruction into such a scenario only furthers the ability of a small group of dissidents with relatively limited military assets to wreak enormous havoc through asymmetrical warfare or terror. The principle defense against surprise attacks of this or any other nature is advanced warning, which inherently depends upon the timely and accurate collection and assessment of appropriate information.

Given the dire consequences of further unanticipated or undetected terrorist action, the appropriate application of advanced *detection* and *assessment* technology to homeland security is more than just critical—it has become imperative. Business as usual, no matter how diligent, will prove hopelessly inadequate in the long run. The threat is simply too broad and diverse, the perpetrators too hard to isolate and monitor, and the vulnerabilities they seek to exploit too numerous and geographically dispersed. A system of robotic security platforms that automatically respond in an adaptive fashion to potential disturbances reported by a broad-area field of fixed unattended sensors represents a powerful new defensive tool for mitigating the terrorist threat.

Background

The primary purpose of any robotic system is to perform some useful task that a human either cannot or would prefer not to do and to hopefully do it better, cheaper, safer, and more reliably. For mobile robots, the predominant challenge is one of perception, in that the very nature of mobility introduces a never-ending sequence of dynamically changing variables that continuously alter the physical relationships between the moving platform and its surroundings. Fixed-place industrial robot applications involving high-volume repetitive functions (i.e., assembly, welding, spray painting) enjoy a definite advantage in that the working environment can be reasonably structured to optimize results. For a mobile system, such a priori structuring is simply not practical, especially in outdoor environments, due to the increased complexity and uncertainty of the surroundings.

Turning an autonomous mobile robot loose in an unstructured environment, however, represents a daunting challenge. After billions of dollars invested in research over multiple

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decades, the most intelligent autonomous robots in existence today are still orders of magnitude less capable than their most inept human counterparts. The human body is an incredible machine, and replicating even its most basic functionality is an arduous task. Effective perception is a critical precursor to intelligent behavior, and fusion of multiple disparate sensor inputs is currently the most effective way to emulate human capabilities in this regard [1].

The Mobile Detection Assessment Response System (MDARS) represents one of the very first applications to be successfully addressed by an autonomous robot.

Progress to date in the field of autonomous mobile robots can be broken down into three general categories: 1) move from point A to point B, 2) do it without running into anything, and 3) perform some useful mission. Much progress has been made in the first two areas, to the point where autonomous navigation in semistructured indoor scenarios has been realistically achieved [2]. Many of the technical challenges have been adequately addressed as well in outdoor environments and extensively published in the literature [3], [4]. Accordingly, the principal focus for the remainder of this article will be on category three, the application payload that supports the mission. For purposes of illustration, we will examine the Mobile Detection Assessment Response System (MDARS) program managed by the product manager, Physical Security Equipment (PM-PSE), Ft. Belvoir, Virginia, in that it represents one of the very first applications to be successfully addressed by an autonomous robot.

Early Efforts

The fundamental problem with automated physical security systems is as follows: if the sensitivity is turned up enough to achieve a satisfactorily high probability of detection, the nuisance alarm rate also goes up, and security personnel subsequently lose confidence in the system. The ROBART series of research prototypes has served in developing the component technologies needed to address this issue under the MDARS robotic security program. While ROBART I (1980–1982) could only detect a potential intruder, ROBART II (1982–1992) could both detect and assess (Figure 1), with the assessment goal being the elimination of nuisance alarms [5]. The assessment algorithm was supported by seven different types of detection sensors:

1) acoustic, which triangulated a relative bearing to any source of noise
2) vibration, which picked up floor vibrations
3) passive infrared, which sensed changes in thermal radiation
4) microwave, which detected an RF Doppler shift due to motion
5) optical, which responded to sudden changes in ambient lighting
6) ultrasonic, which detected changes in sonar range indicative of motion
7) video, which looked for motion in the surveillance camera field of view.

The focus of ongoing research with ROBART III (1992–) is more geared towards response [6], supported by passive infrared, microwave, active ladar, and video sensors (Figure 2).

Each of the sensor subsystems listed above was assigned a confidence factor based on susceptibility to nuisance alarms, and its effective volumetric coverage was mapped into a polar representation relative to the robot's position. ROBART II employed a four-zone model covering the forward 180° [5], with no coverage to the rear (to facilitate testing and demonstrations in a laboratory environment). The assessment algorithm was based on the heuristic that a human target would be detected by multiple sensors that showed a correlation in their geometric estimation of disturbance location, whereas spurious nuisance detections would not correlate. A composite threat score is calculated for each zone, based on a summation of the confidence-weighted contributions for each of the alarmed sensors in that zone, and the operator alerted to any situation where the composite threat exceeds a predetermined alarm threshold.

Fig. 1. ROBART II, a laboratory prototype used to develop the intelligent security assessment and autonomous navigation algorithms later employed on the MDARS-Interior security robot.

When the algorithm was ported over to the MDARS-Interior robot (Figure 3), the number of zones was increased to 24 with full 360° coverage, and the optical and vibration sensors were eliminated to reduce complexity. In addition, a temporal assessment function was added to the "snapshot" assessment employed on ROBART II, which further examined a history file of prior zone activity to help discriminate purposeful motion from random noise. If adjacent sensors were found to have activated in a distinct sequence (i.e., from left to right, for example) as a function of time, indicative of lateral motion across multiple zones, then the composite threat scores for those zones were increased accordingly. Details of the assessment algorithm and associated detection sensors are presented by Smurlo [7]. A broad agency announcement (BAA) contract was awarded to Cybermotion, Inc. in 1994 to optimize the hardware configuration for production, replacing the bulky staring array with a rotating scanner assembly employing a passive infrared sensor, Doppler microwave, and flame detector.

The problem with automated physical security systems is if the sensitivity is turned up enough to achieve a satisfactorily high probability of detection, the nuisance alarm rate also goes up.

State of the Art

The most advanced robotic security system to date is seen in the MDARS-Exterior platform (Figure 4) being built by General Dynamics Robotic Systems, Westminster, Maryland, under a system design and development (SDD) contract with PM-PSE. The initial BAA prototype employed a Doppler radar and infrared (FLIR) camera mounted on a pan unit to enable a step-and-stare solution to the need for 360° coverage. This approach did not support the requirement for omnidirectional detection capability, in that the unit was basically blind to any motion outside the instantaneous (static) field of view. Accordingly, the final BAA prototype employed a rotating frequency-modulated continuous-wave (FMCW) radar developed by STS, Inc., Scottsdale, Arizona. In this fashion, any additional targets approaching from other directions will still be detected, even while the FLIR is preoccupied in tracking the first target.

This philosophy of high-resolution, narrow field-of-view assessment sensors (in this case the FLIR) being trained on suspected disturbances reported by wide field-of-view but relatively low-resolution sensors (i.e., the 360° scanning radar) is a key element of the MDARS design. The analogy would be that of a person's focused concentration on some area of interest picked up by his or her peripheral vision or hearing. (The complementary use of fixed-loca-

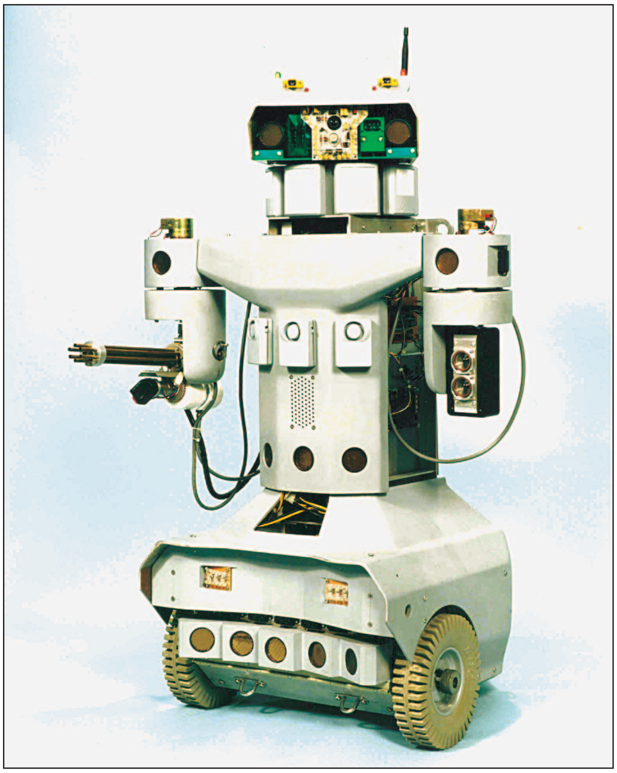

Fig. 2. ROBART III, the technology development platform for pursuing improved navigation and nonlethal response capabilities for MDARS-Interior.

Fig. 3. The SDD version of the MDARS-Interior robot patrolling at Susquehannah Army Depot, Pennsylvania.

tion sensors throughout the operating environment to cue the robot is a natural extension of this philosophy, as will be discussed in the next section.)

Unattended sensors provide a historically recognized capability for effective force multiplication in security and surveillance roles, particularly in the case of perimeter defense.

The STS millimeter-wave radar does an excellent job of detecting intruders out to 300 meters when the robot is not moving, but its relatively narrow vertical field-of-view limits effectiveness on nonlevel terrain. Accordingly, a tilt axis was incorporated into the SDD version (Figure 5) to automatically nod the beam in accordance with surrounding terrain elevation data. To address intruder detection on the move, a parallel effort is underway with the Applied Research Lab at the University of Texas in Austin to investigate a human-presence detector. The output signals from passive microwave and infrared sensors mounted on a rotating turntable are fused together to isolate a unique signature based on human emissivity. Additional information is gathered by a collocated laser rangefinder to improve reliability in this detection process, which is for the most part insensitive to the motion of the robot. For improved video assessment, an interesting technique under consideration at the University of Maryland seeks to differentiate intruder movement from that of a large animal by identification of a characteristic pattern associated with the periodic motion of the human gait [8].

Integration with Fixed Sensors

Unattended sensors provide a historically recognized capability for effective force multiplication in security and surveillance roles, particularly in the case of perimeter defense. Scaling up their traditional concept of deployment to the degree necessitated by the growing terrorist threat, however, introduces a number of problems that must be systematically addressed to achieve the required success. At the lowest levels, human involvement must be replaced by intelligent networked sensor arrays that preprocess the data, to eliminate the need for security guards to monitor large banks of remote camera displays in real-time, for example. Otherwise the significant expansion in sensor coverage needed to address effective detection will be impractical.

In addition, the assessment of the resultant filtered information must be expanded to include the systemic analysis of the totality of information, with a temporal perspective, to significantly increase the chances of pulling out trends or patterns that can focus attention on suspicious activity that would otherwise not be obvious from a snapshot perspective. And third, the detection function itself must be capable of immediate adaptation in response to the aforementioned assessment, so that the process brings more scrutiny to bear on any suspicious anomalies, to facilitate even more accurate classification.

The distributed interactive video array (DIVA) concept pioneered by the University of California, San Diego, employs a large-scale redundant cluster of dispersed video sources to accomplish high-resolution, broad-area surveillance over a large field of regard [9]. Efforts are now underway to integrate DIVA functionality into the MDARS system. From an operational perspective, the fundamental purpose of the system is to detect traffic, both vehicular and pedestrian in nature, and to automatically investigate any such detection for purposes of further assessment and response. The full-volume detection capability is supported by an array of wide field-of-view sensors with their inherent low resolution (i.e., 360° video, wide-angle video, radar, acoustic arrays). High-resolution reconfigurable sensors such as zoom cameras or robotic sensors are

Fig. 4. The MDARS-Exterior SDD prototype in operation at the Force Protection Equipment Demonstration IV (FPED IV) at Marine Corps Air Station, Quantico, Virginia.

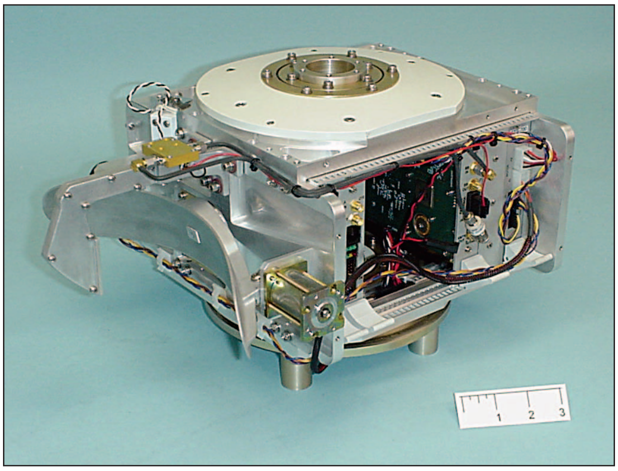

Fig. 5. Third-generation FMCW intrusion-detection radar built by STS, Inc., for the MDARS-Exterior robot.

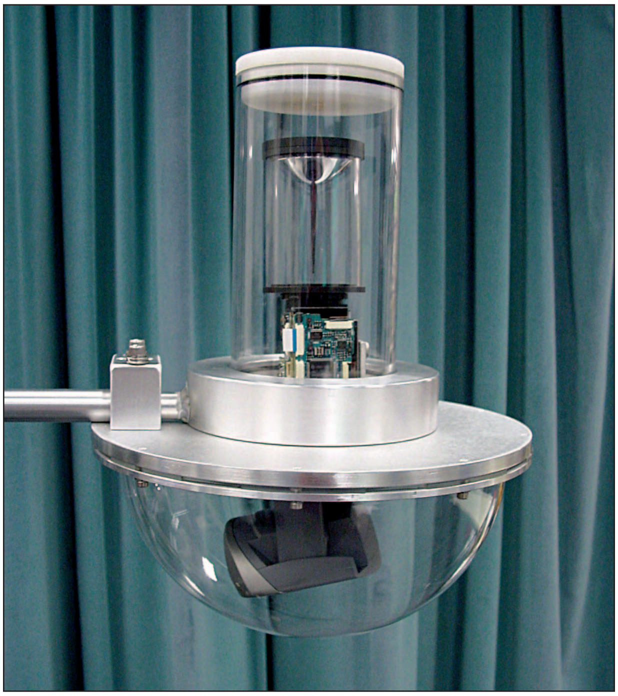

Fig. 6. Early prototype of a DIVA sensor employing an omni-directional camera (top) for peripheral vision to cue a high-resolution pan-tilt-zoom camera (bottom) for directed surveillance and assessment.

brought to bear on any detected anomalies for closer scrutiny (Figure 6). This hierarchical approach retains 360° peripheral awareness, while employing automatic focus-of-attention with event-driven servoing to dynamically increase the effective acuity and resolution in emergent regions of particular interest.

The event-action paradigm allows automatic selection of optimal views (perspectives and resolutions) within a very large area of coverage by defining an event and the associated action to be taken in response to that event, thereby assuring enhanced performance under varying conditions. It also supports dynamic relocation of self-registering sensors (human placed, robot placed, or robot deployed) to adjust the performance or focus of the network on an as-needed basis. For example, autonomous robots would automatically respond to an area of suspicious activity to take up positions of optimal perspective to assist in assessment. The robot-deployed intrusion detection and assessment sensor packages bring enhanced acuity to bear specifically on any confirmed sources of motion, heat, or noise, with the added flexibility of further relocation as needed to track a disturbance.

The concept provides for synergistic enhancement of individual sensor performance by collectively assessing relevant data (including that collected by nonvideo-type sensors) amassed by the entire distributed array and sharing the appropriate subset of that information on an as-needed basis. The benefits can be seen in both improved assessment of already collected information (i.e., two sensors report a similar disturbance with geographical correlation) or even in improved detection probabilities for an upcoming event (i.e., one sensor advises another of an approaching target in time for the alerted sensor to reconfigure pan, tilt, or zoom to maximize its effectiveness).

This approach also avoids needless operator distraction, which is critical to success. Information passed up the hierarchy is essentially filtered to ensure proper response to an actual intruder, without annoying nuisance alarms that could potentially obscure a bona fide threat detection. The net effect is that a human operator can now efficiently oversee a significantly larger number of unattended sensors, and with a much higher probability of detecting suspicious events that otherwise could have been masked by legitimate ongoing activity in the same area.

For more information see: www.spawar.navy-.mil/robots/.

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