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A Review of Physical Security Robotics

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Abstract

As an outgrowth of research into physical security technologies, Sandia is investigating the role of robotics in security systems. Robotics may allow more effective utilization of guard forces, especially in scenarios where personnel would be exposed to harmful environments. Robots can provide intrusion detection and assesment functions for failed sensors or transient assets, can test existing fixed site sensors, and can gather additional intelligence and dispense delaying elements. The Robotic Security Vehicle (RSV) program for DOE/OSS is developing a fieldable prototype for an exterior physical security robot based upon a commercial four wheel drive vehicle. The RSV will be capable of driving itself, being driven remotely, or being driven by an onboard operator around a site and will utilize its sensors to alert an operator to unusual conditions. The Remote Security Station (RSS) program for the Defense Nuclear Agency is developing a proof-of-principle robotic system which will be used to evaluate the role, and associated cost, of robotic technologies in exterior security systems. The RSS consists of an independent sensor pod, a mobile sensor platform and a control and display console. Sensor data fusion is used to optimize the system's intrusion detection performance. These programs are complementary, the RSV concentrates on developing autonomous mobility, while the RSS thrust is on mobile sensor employment.

Introduction

While design and development of Intrusion Detection and Assessment systems for high security sites has progressed to a fine art, there are still a number of areas where these systems have difficulties coping with potential problem areas. As an example, there is no "perfect" sensor technology available, and sensors will fail. Sensors thus need to be tested periodically to verify proper operation, and, if they do fail unexpectedly, supplemental intrusion detection means must be found for the security zone until the sensor can be brought back on-line. With today's security systems, the answer to both periodic testing and interim security measures is to assign valuable manpower to the problem. Similarly, if temporary assets requiring a high level of security are moving through a site, or if the site itself is temporary, fixed site intrusion detection and assessment systems typically do not have sufficient flexibility to adapt to these unique, and changing, requirements. Here again, the typical

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response to these situations is to utilize increased security staffing to augment the physical security system. Unfortunately, we end up using vital manpower to address problems with a system whose primary intent was to increase physical security protection **while alleviating manpower requirements**. The manpower intensive approach is costly today and will grow increasingly more painful as manpower costs continue to grow and, especially in the military, as manpower becomes less available.

Based upon the perceived need to increase the flexibility of physical security systems, Sandia National Laboratories began a new security robotics initiative in the mid 1980's which was principally funded by the Department of Energy's Office of Safeguards and Security. This program was directed towards developing, and subsequently testing, appropriate technologies for robotic physical security systems. While Sandia's robotic's program has now branched out to include synergistic research into battlefield robotics, a large portion of its programs are still directed towards physical security. Three of Sandia's primary security robotic R&D systems are described below.

<u>Sandia Interior Robot (SIR)</u>

A large number of interior intrusion detection and assessment systems are installed in areas where deployment of guards and support personnel may be unwise either from safety, economic or security concerns. The Sandia Interior Robot (SIR) was the first system to be developed under the new initiative and was oriented towards developing an autonomous robot capable of navigating under its own power to perform security related tasks.

SIR was designed as a laboratory testbed to investigate the fundamental technological issues behind the concept, i.e. to develop navigation algorithms, and to evaluate sensing devices and methodologies on an interior mobile platform. The completed system, Figure 1, was capable of utilizing onboard ultrasonic sensors to map out an unknown building, store that map image, and to then autonomously conduct either directed or random security patrols of the building. SIR could be directed to the site of a failed sensor, and using its ultrasonic sensors (or additional sensors as necessary) could perform the backup security function. By communicating with the alarm reporting system, SIR could move to the area of coverage of an intrusion sensor, wait for that sensor to clear, and then "walk" test the detection pattern for that sensor. As a laboratory testbed, SIR was not outfitted with appropriate target signatures for all sensor technologies.

The initial SIR design philosophy was to use a remote host computer to perform the algorithm development in a high-level language and to integrate that computer, or its functional equivalent, onboard in later stages of system development. While this next phase of the development was never actually implemented for SIR, it has been implemented on the other robotic platforms described here and has been shown to be readily achievable. Thus, "SIR" actually consists of two main elements: a mobile robotic platform and a remote host computer. The mobile platform contains an onboard central processing unit (CPU) that handles data transmission, via a radio link, and controls the hardware operations of motors and sensors on SIR. The host computer is the primary interface to SIR and also performs the high-level navigation functions such as path planning and execution, obstacle avoidance, and position determination. The man/machine interface for SIR, although fairly complete from an engineering perspective, would require refinement for operational usage.

Mounted directly on top of SIR is a circular array of 30 Polaroid ultrasonic (sonar) transducers used for navigation and intrusion detection. Also installed on SIR are navigational sensors which include a magnetic compass, an odometer, and an optically encoded steering gearhead/motor; a passive infrared motion sensor is attached for intrusion detection. A remotely controllable Charged-Coupled Device (CCD) television camera, used for assessment and teleoperation, is mounted on a panning platform and is slaved to SIR's front wheel.

Either manual or autonomous operation of SIR is available to the user. In the manual mode, all functions are controlled by an operator from the remote host computer control keyboard. Data from SIR is displayed on the host computer monitor screen in graphics and written format. In the autonomous mode, the SIR awaits instruction from the control console to perform any of several tasks including: security patrol, alarm assessment, and failed sensor backup. The security patrol task consists of selecting destinations in the building, either randomly or from a predetermined list, and navigating to those points utilizing path planning, dead reckoning, obstacle avoidance, and positional error correction. SIR is continually transmitting video back to the control console and may be commanded to stop at any time to use its passive infrared motion detector for intruder detection. In the event of an alarm, the operator is notified and the location of the alarm is displayed on his monitor along with the robot's location and its CCD camera's field-of-view. If a remote sensor goes into alarm, SIR will use the location of the alarmed sensor as a destination for its path planner, and will proceed to that location via the shortest path, providing video information along the way. The task of backing up, or providing alternative sensor coverage for, a failed IDS sensor, makes use of the 30 ultrasonic range finders as a programmable motion sensor. SIR is capable of using software controlled range sensitivities to produce a custom-configuration of the ultrasonic sensor coverage area that can be virtually any shape or combination of shapes required for the specific area. SIR automatically returns to its power station and recharges itself when its batteries are low.

Robotic Security Vehicle (RSV)

The follow on Robotic Security Vehicle program was oriented towards applying the lessons learned with SIR towards developing very similar functional capabilities for an exterior security vehicle. The exterior RSV is intended to travel autonomously on improved roads in the structured environment of a secure facility with controlled access and limited traffic. It would conduct continuous or random patrols autonomously with detection and assessment capabilities, or travel autonomously to a specific location in response to an alarm. The operator could then teleoperate the RSV offroad to dispense deterrents or to further investigate a suspicious incident. While functionally very similar to SIR, the exterior navigational capability is much more complex due to the unconstrained environment, much larger territory, and larger uncertainties in real world navigation. Because of this greatly increased complexity, the decision was made early on to focus the program upon developing and demonstrating the autonomous navigation capability. The Remote Security Station program, discussed last, addresses a number of additional functions required for real world deployment of a "robotic" physical security system.

The RSV system has three major subsystems: a mobile platform, a command driving station, and a navigation system. A 1980 Jeep Cherokee was chosen as the initial mobile platform for the the proof-of-concept development program and has become known as the Sandia Mobile Autonomous Navigator (or SandMAN). The Jeep was outfitted with an onboard vehicle control system, a navigation/ mission control computer, electromechanical actuators, and a variety of sensors to assist the operator in assessing the vehicle's status. These sensors monitor velocity, heading, distance traveled, actuator positions, pitch, roll and heading. Additional navigation aids on the vehicle include a steering slaved driving camera and a Del Norte Technology microwave-beacon position location system. A second camera, used for surveillance, is mounted on a pan and tilt platform.

SandMAN's navigation system resides entirely onboard the vehicle. It processes all communications between the vehicle and the system's command driving station (CDS). Functionally very similar to SIR, SandMAN's navigation system performs the four tasks for autonomous operation: map making and the real-time autonomous travel function, current position estimation, path planning and path following. The navigation system relies on a set of road maps stored in the computer memory. The roads that the vehicle is expected to travel autonomously must be premapped using the navigation system to track vehicle location as the roads are driven either through teleoperation or by an on-board driver. Road mapping data is calculated during the initial drive from "dead-reckoning" and the position location system and then stored. Subsequent autonomous path following is accomplished by comparing the current estimate of vehicle position with the desired path, and steering the vehicle in the appropriate direction. Testing to date has shown that the current system will indeed autonomously travel a road network with a mean error of 0.5 meters (standard deviation of 0.9 meters) from the ideal path, while continuously moving at speeds up to 24 Km/H. Preliminary work underway in a related project is demonstrating refined obstacle detection and avoidance capabilities not presently available on SandMAN.

The command driving station (CDS) is much more sophisticated than SIR's and manages all phases of the RSV by directing teleoperation, mission control, and autonomous operation from the console via radio communications links. The CDS is designed to accommodate multiple vehicles, surveillance sensors, detectors and dispensable deterrents. The command driving station is configured for use by one operator with multiple visual displays and various controls. The center monitor displays the color video from either the vehicle's driving or surveillance camera, as requested by the console operator. The second "command" screen is a high resolution, menu-driven graphics monitor that displays text for initiating operator commands such as vehicle and mode selection functions. A nine-key numeric pad is used as the primary means of moving around the command screen menu and selecting the appropriate commands. The last display is a map of the site's road network. It displays the vehicle's position and heading and the field of view of the surveillance camera. The desired destination of the autonomous travel is selected on the map using a trackball and is typically constructed by sequentially designating a series of roads. Teleoperation of the vehicle uses a spring-return steering wheel and separate brake and throttle pedals. Vehicle transmission gears are selected through the command screen.

Testing with the existing system is continuing as time permits, but the original SandMAN vehicle is being replaced by an updated platform, developed over the last two years, in anticipation of field evaluation of the RSV system. The new vehicle is a GMC Jimmy, and while functionally identical to the Jeep Cherokee, is greatly improved in its engineering detail, its appearance and its flexibility of usage for operational security personnel (see Figure 2.) Design of the vehicle has been especially directed towards emphasizing the three expected modes of operation: autonomous, teleoperation, and manual. As necessary, a security guard, in connection with Security Control Center cooperation, could remove the vehicle from remote operation back into normal manual control in less than 30 seconds. In addition, with an emphasis upon increasing the flexibility of the system's processor and increasing the payload space available for investigating mobile activated deterrents, the onboard computing and support hardware has been combined into a single VMEbus based system.

In addition to the replacement of the original testbed vehicle, several enhancements to the RSV are desirable prior to operational test and evaluation of the system. Inclusion of a refined obstacle detection and avoidance subsystem on the new vehicle is essential, and update of the command driving station, although not strictly required, would increase its ease of use by security personnel. The system is currently not outfitted with security specific sensors or activated denial mechanisms and should be updated as appropriate. With the above caveats, the system is ready to move from development to field evaluation, and, following final checkout of the new vehicle, Sandia will attempt to install the RSV at a DOE site for test and evaluation.

Remote Security System (RSS)

The Remote Security System program, funded by a military sponsor, was initiated to more broadly address how robotic systems might alleviate the security problems outlined earlier. As a sister program to the RSV, the RSS program focuses on how to remotely provide the appropriate security functions; a proof-of-principle system was developed to evaluate the appropriate technologies and concepts of deployment. The RSS system consists of three main system elements, a fixed but portable sensor/assessment pod which includes a portable weather station; a mobile, teleoperated sensor/assessment platform (see Figure 3); and a command/control console which integrates remote control of the two remote platforms with the security functions inherent in intrusion detection and assessment systems.

The Man-Portable Security Station (MaPSS) is the tripod mounted version of the RSS sensor/assessment pod and includes both security and weather sensors. The intrusion detection and assessment (IDA) station is mounted on a platform that can tilt and revolve to adjust the field of view of the onboard sensors and CCD camera. The station's sensor suite consists of a passive infrared motion sensor, a video camera, a ground surveillance radar, an omni-directional acoustic array, and a directional microphone. The acoustic array is placed on the ground near the IDA pod. The video camera serves a dual purpose: as an assessment tool and also to detect motion. Full video imagery is transmitted back to the control console where it is displayed to the operator and is also processed by a Sandia developed video motion detection system. The sensor suite was chosen to be representative of the types of sensors which might be chosen for a specific site application. All video, intrusion, weather and command data is transmitted between the MaPPS unit and the control console via fiber optic links.

The Telemanaged Mobile Security Station (TMSS) is based on a Honda 350 four-wheel drive all-terrain vehicle. It has an onboard computer, electric actuators, and radio links that relay sensor information to the control console and allow the console operator to control the vehicle. The operator teleoperates TMSS by use of a television monitor and a joy stick and functional switches. TMSS has the same sensor types as the portable station except there are no weather or acoustic sensors and a commercially available doppler microwave sensor has been substituted for the military ground surveillance radar. Use of existing intrusion sensor technology on the two IDA pods was a major goal of the RSS system. The vehicle's IDA platform is mounted on a pneumatic mast that can be raised to a maximum height of 10 feet for surveillance while the rest of the vehicle remains hidden.

The RSS control console was designed to act primarily as a security officer's interface to the multiple IDA pods/platforms, with the robotic vehicle control as a secondary function. While use of existing sensor technology improves the cost effectiveness of the overall system, available sensors are typically designed for fixed site applications with very rigid mounts and nicely groomed fields-of-view. On the portable/mobile pods neither of these conditions are met, and so much larger nuisance alarm rates would be expected; fusion of the sensory information in order to reduce the nuisance alarm rates was, thus, a major goal of the RSS system. Raw sensor alarms from TMSS and MaPSS are sent to the control console where they are combined with weather information and the operator's previous historical assessments in a sensor fusion algorithm. Alarms only get passed to the operator when this alarm threshold is greater than the operator specified limit. The use of multiple, synergistic sensors along with the sensor fusion algorithm increases the probability of detection while reducing the nuisance alarm rate.

The control console consists of two black and white video monitors for alarm assessment, a color graphics monitor used for digitized map displays (a map digitizer is included with the system), and a color computer/video monitor for alarm display and system control. The final monitor is equipped with a touch screen and is used as the operator's primary interface to the system. It can also be switched to a video mode to be used as a driving monitor. In addition to the general host computer mounted in the console, the system also includes specialized processing boards for the video-motion sensor processing and for the acoustic sensor system. While the RSS console was designed for installation in a security control center, it has been deployed in the rear of a step van during field operations.

Several enhancements are planned for the RSS. These include advanced sensor processing techniques utilizing neural networks, secure and covert radio frequency communication links, transfer of the autonomous navigation capability from the RSV project, and computer software additions that would allow the RSS console to integrate up to five MaPSS or TMSS stations.

## Future Endeavors

While the programs described above have necessarily examined generic capabilities and system implications, future work will be more oriented towards addressing and fielding systems to specific security requirements. With the capabilities and technologies developed above, task oriented robotic systems can provide, as examples, perimeter intrusion sensor test support robots and remotely controlled, surveillance and activated denial robotic defense posts. These and similar systems are possible with today's technology and should increase the flexibility of today's physical security systems while alleviating manpower requirements and their associated costs.