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Sandia National Laboratories Proof-of-Concept Robotic Security Vehicle

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INTRODUCTION

Several years ago Sandia National Laboratories developed a prototype interior robot [1] that could navigate autonomously inside a large complex building to aid and test interior intrusion detection systems. Recently the Department of Energy Office of Safeguards and Security has supported the development of a vehicle that will perform limited security functions autonomously in a structured exterior environment. The goal of the first phase of this project was to demonstrate the feasibility of an exterior robotic vehicle for security applications by using converted interior robot technology, if applicable. An existing teleoperational test bed vehicle with remote driving controls was modified and integrated with a newly developed command driving station and navigation system hardware and software to form the Robotic Security Vehicle (RSV) system. The RSV, also called the Sandia Mobile Autonomous Navigator (SANDMAN), has been successfully used to demonstrate that teleoperated security vehicles which can perform limited autonomous functions are viable and have the potential to decrease security manpower requirements and improve system capabilities.

SYSTEM DESCRIPTION

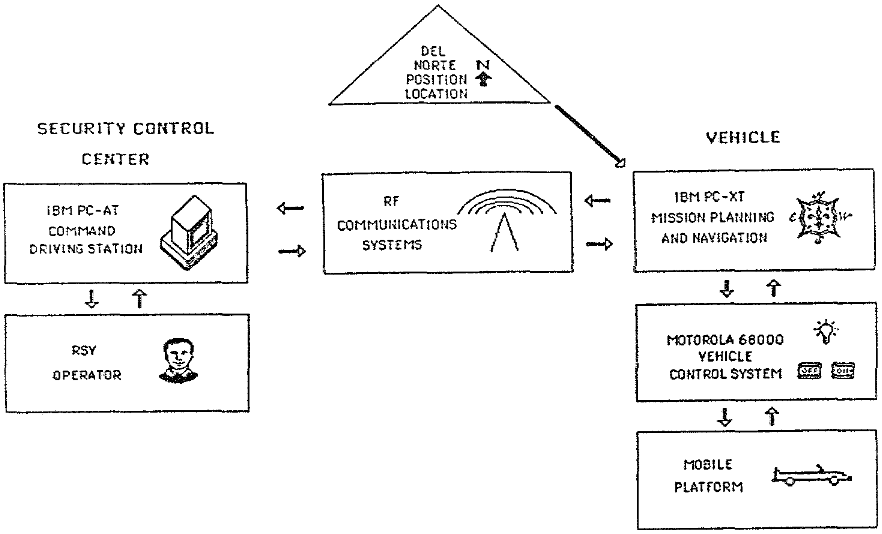
The Robotic Security Vehicle system consists of the following subsystems: mobile platform, vehicle control, communications, command driving station, position location, and navigation. These subsystems are described in the following sections and included in Fig. 1, a block diagram of the RSV system.

Mobile Platform - An American Motors Corporation (AMC) Jeep Cherokee, shown in Fig. 2, was modified to provide a testbed for developing concepts in remote control (teleoperation) and computer controlled autonomous travel [2]. Electro-mechanical actuators control the throttle, brake, transmission, and steering. A single actuator provides control for the throttle and brake through a pivot lever arrangement. The steering actuator is coupled through a chain drive directly to the steering column. The vehicle's automatic transmission is shifted by an actuator connected to an in-line floor shifter.

Sensors installed on the Jeep provide feedback on vehicle status. These sensors monitor velocity, distance traveled, actuator positions, pitch, roll, and heading. Additional navigation aids on the vehicle include a steering slaved driving camera and a Del Norte position location system. A second camera, used for surveillance, is mounted on a pan and tilt platform.

The vehicle electrical system has been modified to provide 24 Vdc as well as 12 Vdc on the vehicle. A 24 Vdc to 110 volt 60 Hz AC inverter was installed to supply power to equipment located in two instrument racks located in the back of the vehicle.

All vehicle control and data acquisition functions are processed through a Motorola 68000 CPU which forms the base of the vehicle control system (VCS). The navigation computer, an IBM PC/XT, is installed on the vehicle, and connected to the VCS, the position location system, and the communications system.



ROBOTIC SECURITY VEHICLE SYSTEM
FIGURE 1

ROBOTIC SECURITY VEHICLE
FIGURE 2

<u>Vehicle Control System</u> - The vehicle control system (VCS) is generally responsible for performing vehicle control and data acquisition. System computing power is based on a Motorla 68000 processor module operating on a VMEbus. Other modules in the system are connected to the processor module via the VMEbus and sub-busses. Components forming the VCS are: a Motorola processor board (MVME 110-1), parallel input/output board (MVME 410), analog to digital converter board (MVME 600), dual serial communications port board (MVME 400), and a custom built pulse width modulation board.

The VCS is responsible for controlling three actuators; steering, transmission shift, and brake/throttle. The VCS also controls the surveillance camera's pan and tilt unit, and the camera zoom and focus functions.

Three forms of data are received and processed by the VCS; serial, parallel, and analog. Data processed by the VCS is primarily provided by the vehicle status sensors. Additional VCS data acquisition channels are available to accommodate any specialty sensors required during experimentation.

A VCS specific software control program, loaded into programmable memory on the Motorola 68000 processor module, performs all of the necessary functions required by the vehicle control system. These functions include vehicle control, data acquisition and processing, and serial communication between the VCS and the navigation computer.

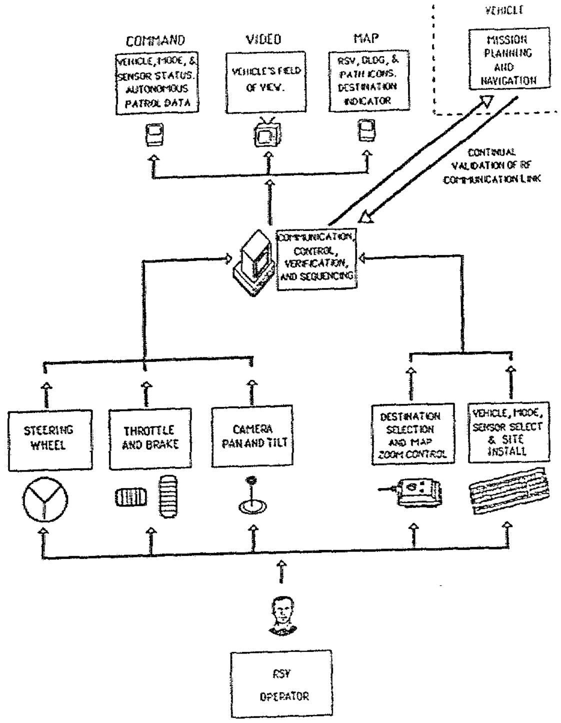
In order for the VCS software to initiate a control function, the vehicle control system's processor module must first receive a control command over its serial port.

Similarly, data acquired by the VCS can only be transmitted when a request for data command is received. Control commands and data requests are usually initiated by the navigation computer and transmitted to the vehicle control processor module's serial port. Control commands and requests for data can, however, come from the command driving station but they still pass through the navigation computer.

<u>Communications Systems</u> - There are two forms of communication supported on the RSV, data and video. Data communication between the vehicle and the command driving station, including vehicle control, is performed by a set of Repco RDS-1200 full duplex radio frequency (RF) data modems. Video transmission from the vehicle to the command driving station is accomplished using an RF video transmitter and receiver system currently under development at SNL.

<u>Command Driving Station</u> - The command driving station (CDS) manages all phases of the RSV operation by directing teleoperation, mission control, and autonomous operation. It also provides vehicle status and location information to the operator. The CDS will accomodate multiple vehicles, surveillance sensors, detectors, and dispensable deterrents. A block diagram of the CDS is shown in Fig. 3.

Software for the robotic security vehicle project was designed to permit the simultaneous operation of



RSV COMMAND DRIVING STATION

FIGURE 3

multiple vehicles by a single operator. Any vehicle may be placed in either autonomous or teleoperation mode; however, only one can be teleoperated at a time since teleoperation requires the full attention of an operator. The RSV software is written in the C language and makes use of commercially available graphics and communication libraries. Command queues provide the capability that all communications generated by the CDS must be received and responded to by the vehicle prior to transmission of the next command. In addition, interrupt services available through DOS are used to sychronize handshaking during operational periods when communication between the CDS and the vehicle is critical (ie. when the vehicle is moving). Failure on either end to transmit or receive the required handshake results in an automatic shutdown wherein operations cease and the vehicle is brought to a halt.

The command driving station is configured for one operator with 3 visual displays and various controls, all managed by an IBM PC/AT computer. The center monitor displays the color video from either the vehicle driving camera or surveillance camera, as requested by the console operator. Video from both cameras will be shown continuously on prototype and later RSV systems. The command screen is a high resolution, menu-driven graphics monitor that displays text for initiating operator commands. The screen is logically divided into quadrants, plus a small section in the center to select vehicle status, and a band at the bottom for error/diagnostic messages. The upper left portion of the screen contains vehicle and mode selection functions; the upper right shows mode specific commands; the lower left gives the current status of the security sensors; and the lower right does the same for the activated deterrents.

The complexity of the operator's task is minimized by limiting the input devices and permitting input of only valid selections. The main input device, used for selecting menu options, consists of a nine-key numeric pad. These keys are used essentially as "arrow" keys to navigate around the command screen. Commands are initiated by pressing the "enter" key. Other keys are used only when new path names are entered. The menus change depending on the vehicle mode, allowing only valid operator input. For example, other vehicles cannot be selected if the operator is currently teleoperating one.

The last display is a map of the previously driven road network. It shows the vehicle heading and position in real time, and the direction the surveillance camera is pointing. The desired destination of autonomous travel can be selected on the map using a trackball. Distances between any two points on the map can be calculated by using the trackball to identify the points. New patrol paths can be constructed from previously driven segments using the map. This display also has a zooming/panning feature that provides a larger scale view of areas of the map selected using the trackball.

Control devices in the command driving station include vehicle driving controls, a pan/tilt joystick control for the surveillance camera, and the map trackball described above. The driving controls used during teleoperation are a spring-return steering wheel, and separate brake and throttle pedals. Vehicle transmission gears are selected through the command screen.

<u>Position Location System</u> - The position location system is a commercially available system manufactured by Del Norte Technology of Euless, Texas. The position of the vehicle is calculated by a digital distance measurement unit (DDMU) located on the RSV. Five times each second the DDMU sends a radio signal to two, remotely located transponders. Each transponder echos the signal back to the DDMU which measures the elapsed time. Knowing the velocity of radio signal propagation, the DDMU can infer the distance to each transponder within one-tenth meter. Since the transponders are positioned at known locations, the position of the RSV can be ascertained to an accuracy of about one meter using a method known as trilateration.

The entire system is powered by 12 Vdc with the transponder's power coming from batteries and the DDMU's power coming from the RSV. The DDMU can be used up to 5 kilometers away from the transponders if the signal's path is line-of-sight. Up to nine DDMUs can use the same set of transponders at the expense of slower update rates.

<u>Navigation System</u> - The navigation system, which resides in an IBM PC/XT computer, relies on a set of road maps stored in onboard computer memory as lists of x, y points. This method inherently introduces structure to the operating environment by defining traversable paths and enabling that information to be stored and recalled at will. The autonomous navigation software resides entirely onboard the vehicle and performs four major tasks; current position estimation, map making, path planning, and path following. Data from several sensors are combined using sensor fusion techniques to improve navigation accuracy.

The basic vehicle position is estimated by calculating the position and orientation in a two dimensional (x,y) internal world model using a dead reckoning navigation algorithm. That estimate is periodicallly updated with true position data from the beacon system using a weighted sum method to eliminate dead reckoning error accumulation.

The roads that the vehicle is expected to travel autonomously are mapped using the navigation system to track vehicle location as the roads are driven either through teleoperation or by an onboard driver. Data in the form of x,y position and current vehicle heading are sampled every 2 meters as the vehicle moves, and are stored in onboard memory as a two dimensional array by the map maker.

Path planning within a system of roads is accomplished by initially relating how the roads intersect with each other in the form of a linktable. That linktable is used as a guide to joining appropriate road lists together into a continuous list of points, beginning at some start position and proceeding to a destination. When selecting mapped roads to join together into a continuous list of points to traverse, the linktable is used as a very fast way to access the map data indirectly and avoid a time consuming search through the actual map data.

A sequential list of points is needed to define a path to follow, and this is accomplished by either of two methods; auto-path planning or manual route designation. Auto-path planning is performed by a search algorithm using the vehicle's current postion and a destination requested by the remote operator. It plans the shortest route to the destination based on actual route length. Manual route designation bypasses the shortest-route search algorithm and allows any particular route to be specified by the operator.

A velocity profile for the vehicle is planned next, using a set of performance criteria to determine the desired vehicle speed. The result is stored next to the position and heading data in the continuous path follow list at each point along the route. The desired target velocity is used by a cruise control algorithm in the vehicle control system to control the brake/throttle actuator during autonomous path following.

Path following is accomplished by comparing the current estimate of vehicle position with the desired path, and steering the vehicle in the appropriate direction. The objective is to decrease to zero the computed lateral error between the closest point on the path and the vehicle's position, by using a classical closed-loop control algorithm. The difference between the vehicle heading and the bearing angle of the current road segment is computed to derive the steering angle required to simply parallel the road. If the lateral error distance from the path to the vehicle is outside a defined deadband limit, an additional convergence angle must be calculated to bring the vehicle closer to the road.

TESTING AND CONCLUSIONS

A network of roads of approximately 1.7 km was laid out at Sandia National Laboratories' Robotic Vehicle Range in order to develop and demonstrate the RSV navigation capabilities as they could be applied to a small fixed security site. The RSV was teleoperated satisfactorily from the command driving station utilizing the communications and vehicle control systems. The onboard navigation system, including the position estimation, map making, path planning, and path following routines supported autonomous travel along the defined roads to within 0.48 meters of the intended path. The average standard deviation error was 0.9 meters, while continuously moving at speeds up to 7 KPH over path lengths of up to 1600 meters each.

Successful teleoperation and autonomous navigation of the RSV from the system command driving station have demonstrated the feasibility of the Robotic Security Vehicle concept for a structured exterior environment. Further development should produce faster and more accurate path following, and obstacle detection and avoidance capabilities.

FUTURE PLANS

The Jeep Cherokee will continue as the test bed for on-going activities which include completing development of fully autonomous random patrolling and consolidation of the vehicle control system and navigation system computers in a VME based multi-tasking computing system. Longer term plans include implementing advanced navigation, intruder delay, and detection and assessment capabilities.

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