Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)
1993 Elsevier Science Publishers B.V.

Air Force Construction Automation/Robotics

A.D. Nease and E.F. Alexander

Air Force Materiel Command/Wright Laboratories
Air Base Operability and Repair Section
139 Barnes Drive, Suite 2, Tyndall AFB FL 32403-5319

Abstract

The Air Force has several unique requirements that are being met through the development of construction robotic technology. The missions associated with these requirements place construction/repair equipment operators in potentially harmful situations. Additionally, force reductions require that human resources be leveraged to the maximum extent possible and more stringent construction repair requirements push for increased automation. To solve these problems, the United States Air Force is undertaking a research and development effort at Tyndall AFB, Florida, to develop robotic construction/repair equipment. This development effort involves the following technologies: teleoperation, telerobotics, robotic vehicle communications, automated damage assessment, vehicle navigation, mission/vehicle task control architecture and associated computing environment. The ultimate goal is the fielding of a robotic vehicle capable of operating at the level of supervised autonomy. This paper will discuss current and planned efforts in range clearance/explosive ordnance disposal, hazardous waste cleanup, fire fighting, and automation of routine civil engineering operations.

1. INTRODUCTION

There currently exists in the United States many previously closed military installations, installations currently scheduled for closure, and operational installations encompassing areas that may contain buried/unexploded ordnance (UXO). These installations must be rendered safe by detecting and clearing the UXO. The hazardous conditions surrounding these operations not only inhibit manned operations, but also require additional manpower and equipment for backup support. Current manpower-intensive methods cannot safely complete the detection/cleanup/repair in a cost-effective manner.

The Air Force construction automation/robotics program is involved in a tri-service effort to provide the necessary automation/robotic technology required to solve the range clearance problem. This technology provides a telerobotic means of executing peacetime range clearance as well as post-attack Explosive Ordnance Disposal (EOD) and operating surface repair and recovery during wartime. As manpower becomes more critical to the Air Force of the future, the benefits of unmanned ground vehicles (UGV's) to the peacetime range clearance and wartime base recovery missions become more obvious and important. The UGV can perform these missions in a dangerous environment while human operators and/or combat airbase personnel remain in a safe shelter.

It should be noted that there are other missions, both wartime and peacetime, that lend themselves to application of the technology being developed under the UGV program. Airbase fire fighting/fire detection, hazardous waste handling/cleanup, and the automation of routine Air Force civil engineering operations are other areas that will benefit from this technology **(Fig 1)**.

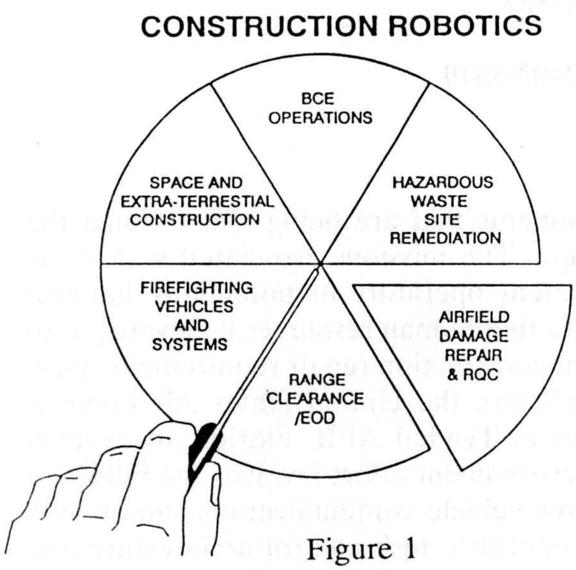

Figure 1

2. CRITICAL TECHNOLOGIES

The Air Force Wright Laboratories has developed a telerobotic excavator, a John Deere 690C, that has a teleoperational capability as well as on-board smarts in the form of preprogrammed functions. Drawing on technological and operational concepts generated, in part, from testing the John Deere telerobotic excavator system, efforts toward producing a mature construction automation/robotic UGV concentrate on several critical technology areas: a) communications, b) navigation/guidance, c) mapping/sensors, d) vehicle/platform, and e) task control architecture/computing environment.

2-1. Communications

The construction automation communications system has been developed in two phases with a demonstration provided in each phase. In phase 1, the fixed operator control station and the existing robotics excavator communication links were developed and tested to evaluate their performance in a PC environment with a single vehicle. Phase 2 involves multiple vehicle communications in a VME-based environment. The command and control link provides a two-way digital data link between the control center and the vehicle(s). This link operates at 34,800 baud at ranges up to 5 miles in the 1433 MHz band. Responses to the control center over the return link occurs only from the specific vehicle addressed by a preceding control center transmission over the C/C link (**Fig 2**). A one-way video link transmits a standard 525 line color or B/W signal at 1795.5 MHz. In addition, the comm system formats and encodes data for transmissions over the identified system links, decodes received transmissions, manages link operation and interfaces the links to the end using equipment.

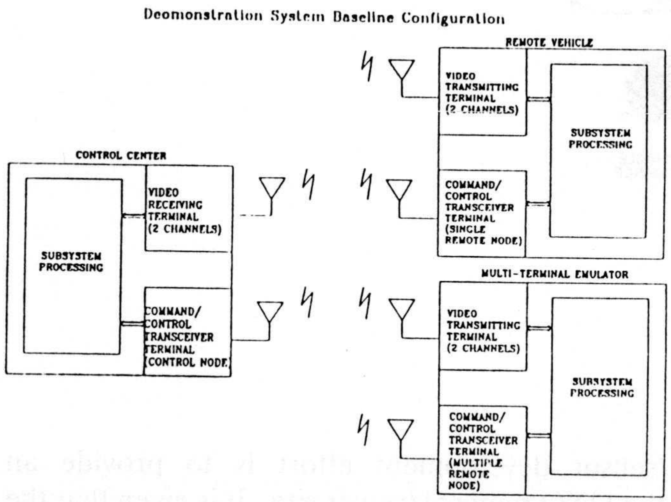

Figure 2

2-2. Navigation

A robotic construction vehicle navigation system is being developed to provide the capability for the UGV to move autonomously from its storage area/shelter to the clearance site, position itself within working range of a previously detected UXO with positional accuracy of +/-6in, to move autonomously among several sites, and then return to the storage area upon completion of the mission. The heart of the system is a Modular Azimuth Positioning System (MAPS) ring laser gyro inertial navigation system. The MAPS will be updated at approximately 3 minute intervals by a kinematic differential Global Positioning System (GPS). The kinematic differential GPS builds on accuracy of standard differential GPS by comparison of phase differences between reference station and remote receiver. The nav system will be given initial vehicle position/orientation, UXO location (digital map), and first site position and required orientation. A plan for vehicle motion will be generated off-line and executed with the aid of obstacle detection sensors (**Fig 3**). The nav system is being developed on a "mule", a small 4-wheel vehicle used to provide an "anywhere" test capability. The INS portion of the system has been successfully demonstrated. The complete INS/GPS system will be demonstrated in July, 1993.

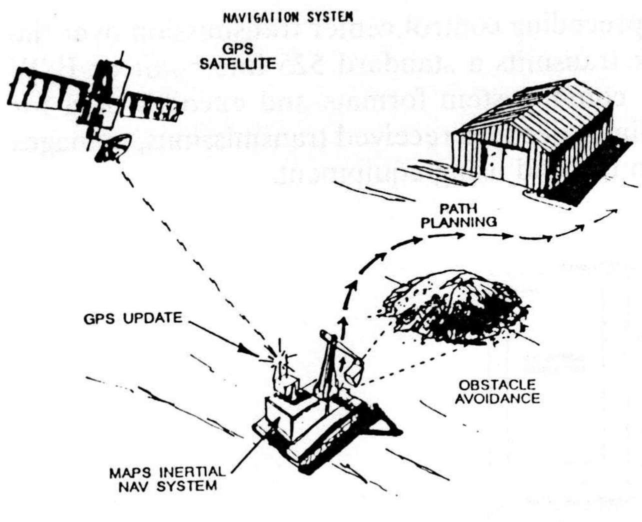

Figure 3

2-3. Mapping/Sensors

The objective of the mapping/sensor development effort is to provide an autonomous capability to characterize the UXO removal/repair site. It is given that the vehicle reference point remains constant and that displacement is known from the reference. First, a 2-dimensional camera and an electronic distance measurement (EDM) device will be used to size the site from a stationary vehicle. Multiple images will be spliced together to form the composite 2-D image. Image analysis of the collected data of the site will be used to estimate the location of the UXO as it is exposed and determine the ordnance/fuse type. This information will be verified using EDM to locate and confirm the actual site perimeter versus false edges created by lighting problems. A 3-D wire frame, perspective view, model will be laid over the 2-D image with vertices at all confirmed points. The volume of the crater/repair site will be estimated using first and second order approximations of the wire frame model. The multiple 3-D images will be spliced together to form the work space environment containing as much of the repair site area as possible. The information displayed will be the classification and centroids of objects of interest in the area as well as the edge of the repair site. The data will be provided to the vehicle control system. Analysis and tests will be made to incorporate information from the second ambiguity region of the scanner. Rules for use of the laser scanner will be developed where appropriate as well as scene requirements and conditions. The initial demo will be done from a fixed base and will show the capability of this technology and the associated software to solve the problems involved with mapping/characterizing a repair site for a remote operator and/or an autonomous vehicle.

2-4. Testbed Vehicle

The new robotic testbed vehicle is being designed and built from the ground up as a next-generation construction robot (**Fig 4**). This vehicle will be an all-terrain, low ground pressure, rubber tracked machine powered by a 275 hp Cummins diesel engine.

A 5kw generator that can provide AC and DC power for the on-board electronics as well as for field testing of systems will be driven from by the main diesel engine. The vehicle hydraulic system will be a closed-center, load-compensating system that will feature in-cylinder position/force sensors and servo valves mounted directly on the cylinders/actuators. The VME-based, on-board computer will be housed in a shock-proof, climate controlled enclosure designed for easy access. The key to this vehicle is that it will build on the lessons learned with the existing robotic excavator.

CONSTRUCTION ROBOT

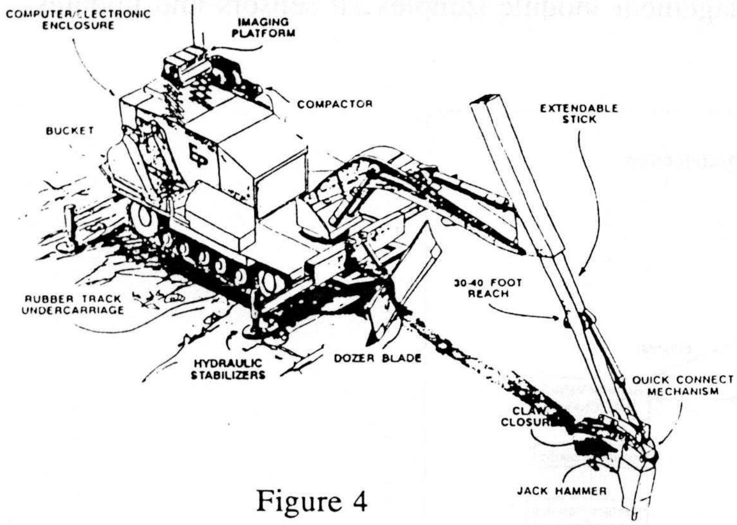

Figure 4

2-5. Architecture and Computing Environment

The system development platform consists of Sun Sparc/2 workstations which provide a UNIX platform for compilation and development. Graphics/simulation work is being done on a Silicon Graphics IRIS 4D/310VGX workstation. All units are interconnected via Ethernet communications links (Fig 5). The VXWorks Operating System provides a UNIX-like realtime multitasking platform for VME targets. The OS allows for a small, reconfigurable kernel and provides the necessary speed and multitasking capabilities. VXWorks enjoys wide R&D community support as do the Sun and Silicon Graphics platforms.

The control station and remote vehicle platforms act as VME targets that allow for multiple CPU processing and exchange of information across a common bus. The multiple CPU's process concurrently while individual CPU's process multiple tasks concurrently. The individual CPU's are dedicated to functional areas or tasks and exchange information with the common memory area.

The control station functional structure provides a communications module that communicates between remote vehicles and the control station. This link also provides for communications between CPU's across the bus. This system provides separate channels for emergency messages, remote control functions, and vehicle status information. The operator interface module provides functions for remote control, displays status information, provides the interface to autonomous functions and routines for emergency or error handling. The task coordination module provides coordination between the remote vehicles. The navigation module incorporates UXO site information into a global repair area map.

The remote vehicle functional structure consists of a system planning and arbitration module that performs overall task planning, task control, error handling, and arbitration of system resources for contending CPU's and tasks. The navigation & guidance module integrates INS, GPS, and embedded vehicle sensor information and performs path planning. This module also integrates IR/acoustic sensor information and performs rudimentary obstacle avoidance. The vehicle control module integrates sensor information to initiate and control vehicle movement. The imaging module integrates laser scanning and video images to produce a local repair map for the system planning module. The sensor management module samples all sensors and updates common memory.

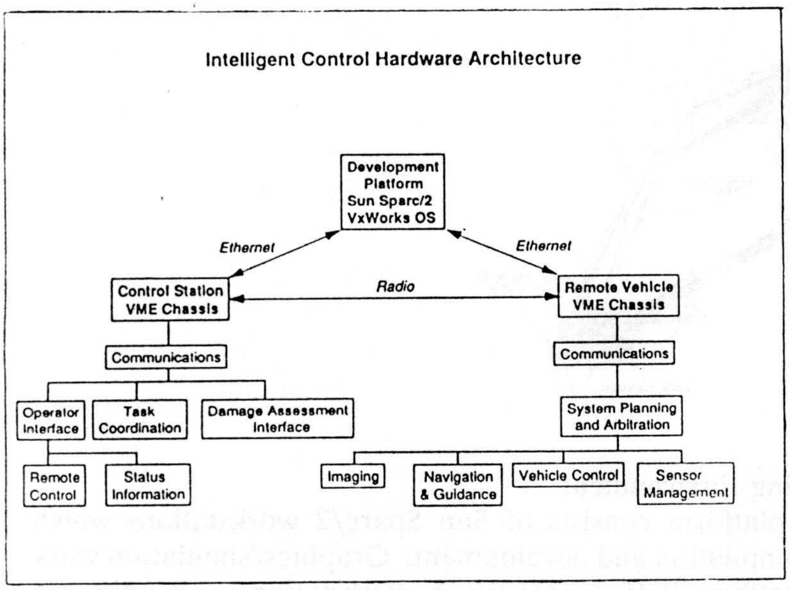

Figure 5

3. CONCLUSION

System integration will be conducted as an in-house effort. The AFMC/WL/FIVCO robotics program currently has 8 engineers and support personnel and a laboratory dedicated to the successful completion of the program. The Air Force realizes the critical nature of robotics development for missions that are hazardous, repetitive or both. The array of missions goes beyond range clearance and EOD to include robotic fire fighting/surveillance, hazardous material handling, and space construction activities as well as the automation of routine Air Force Civil Engineering tasks. The bottom line requirement for robotic construction equipment can be summed up in three words: FASTER, SAFER, CHEAPER.