N93-32110

Air Force Construction Automation/Robotics

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ABSTRACT

The Air Force has several missions which generate unique requirements that are being met through the development of construction robotic technology. One especially important mission will be the conduct of Department of Defense (DOD) space activities. Space operations and other missions place construction/repair equipment operators in dangerous environments and 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 US Air Force is undertaking a research and development effort at Tyndall AFB, Fl., to develop robotic construction/repair equipment. This development effort involves the following technologies: teleoperation, telerobotics, construction operations (excavation, grading, leveling, tool change), robotic vehicle communications, vehicle navigation, mission/vehicle task control architecture and associated computing environment. The ultimate goal is the fielding of a robotic repair capability operating at the level of supervised autonomy. This paper will discuss current and planned efforts in space construction/repair, explosive ordnance disposal, hazardous waste cleanup, and fire fighting.

INTRODUCTION

The policy of the Air Force (AF) with regard to space is that, given the mission, structure, expertise, and history of the AF, it is the service especially and uniquely qualified to carry out DOD space operations. Additionally, the AF will be the major provider of space forces for the nation's defense. The Air Force envisions three areas of space operations: earth-based/launch support, orbital, and lunar/extra-terrestrial.

The work described in this paper is being done at the AF Civil Engineering Laboratory (CEL) which supports the AF Civil Engineering and Services (CE&S) organization. The CE&S Space Master Plan, in the time frame present-to-2000, specifically requires that advances in robotics technology be sought to enhance ongoing operations in dangerous environments. In the time frame 2000-and-beyond, the plan calls for the determination and development of uses of robotic construction equipment developed for terrestrial AF civil engineering work to be applied to extra-terrestrial construction operations.

The current robotic technology development effort at the CEL is sponsored by the Office of Secretary of Defense (OSD) Unmanned Ground Vehicle (UGV) program. This project will develop a telerobotic means of executing post-attack (and peacetime) Explosive Ordnance Disposal (EOD) and operating surface repair and recovery. As manpower becomes more critical to the Air Force of the future, the benefits of mobile robotics (UGV's) to the wartime recovery mission and peacetime range clearance missions become more obvious and important. The UGV can perform the mission in the post-attack environment while human operators and other airbase personnel remain in a safe shelter.

It should be noted that there are other missions, in addition to space construction and airbase recovery, under the purview of the Air Force Civil Engineer that lend themselves to application of the technology being developed under the OSD/UGV RRR program. As mentioned above, weapons range clearance of UXO is a good use of robotics technology. Airbase fire fighting/fire detection and hazardous waste handling/cleanup are other areas that will benefit from this technology. (see Figure 1)(PIE CHART)

CRITICAL TECHNOLOGIES

The Air Force Civil Engineering Support Agency (AFCESA) 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 RRR/Construction 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.

a. Communications:

The RRR/construction automation communications system is being developed in two phases with a demonstration planned for each phase. In phase-1, the fixed operator control station and the existing RRR robotics excavator communications' links will be developed and tested to evaluate their performance in a PC environment with a single vehicle. Phase-2 will involve multiple vehicle communications in a VME-based environment. The command and control link will provide two-way digital data link between the control center and the vehicle(s). This link will operate at 9600 baud at ranges up to 5 miles in the 1433 MHz band. Responses to the control center over the return link will occur only from the specific vehicle addressed by a preceding control center transmission over the C/C link (Fig 2). A one-way video link will transmit a standard 525 line color or B/W signal at 1795.5 MHz. In addition to the above, the comm system will format and encode data for transmissions over the identified system links, decode received transmissions, manage link operation, and interface the links to the end using equipment.

b. Navigation:

A robotic construction vehicle navigation system is being developed to provide the capability for the repair vehicle to move autonomously from its storage area/shelter to the repair site and then to move autonomously among several repair sites and 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, repair site location (digital map), and first repair 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. This system will be demonstrated in early 1993.

c: Mapping/Sensors:

The objective of the mapping/sensor development effort is to provide an autonomous capability to characterize the crater/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 crater/repair 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 crater/repair site will be used to estimate the location of the perimeter and the deepest part of the site. This information will be verified using EDM to locate and confirm the actual 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.

d. Testbed Vehicle:

The new robotic testbed vehicle will be 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 250 hp Caterpillar diesel engine. A 5kw diesel generator that can provide AC and DC power for the on-board electronics as well as for field testing of systems will be located forward of 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.

e. 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 will be 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, re configurable 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 will 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 will provide 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 damage assessment module incorporates damage 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.

CONCLUSION

Much of the technology being developed under the current CEL construction automation program can be used as a base for robotic space construction activities. Because of the expense of supporting humans in the lunar environment, very few will be available for the actual construction and maintenance of facilities. Semi-autonomous operation will be the rule rather than the exception for lunar construction machinery.

Some special considerations for lunar construction equipment will be basic design problems. Machine mass is obviously critical. Boosting mass from the earth to the lunar surface is incredibly expensive. The upper affordable limit for a lunar construction robot is probably 40,000 lb. Since traction is a linear function of vehicle mass, operation in 1/6 g on the moon will mean using innovative anchoring techniques or adding mass once on the moon. The addition of mass to the vehicle brings up a whole new set of problems: manueverability, inertia, etc. Sealing and lubrication of moving parts in a hard vacuum and in the presence of the lunar dust will be a challenge. A key development in the AF construction robotics program has been that of the multipurpose machine with the capability to carry and change, as required, an entire suite of tools. It's obvious that this will be an important attribute of the lunar/extra-terrestrial construction robot. Clearly, none of these problems is insurmountable, and the time to begin solving them is now.

System integration for the current OSD-funded program will be conducted at Tyndall Air Force Base as an in-house effort. The AFCESA/CEL 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 to which this technology can be applied is very broad and certainly includes space construction (lunar/extra-terrestrial) and earth-based (launch support). The bottom line requirement for robotic construction equipment can be summed up in four words: FASTER, SAFER, CHEAPER, BETTER.

CONSTRUCTION ROBOTICS

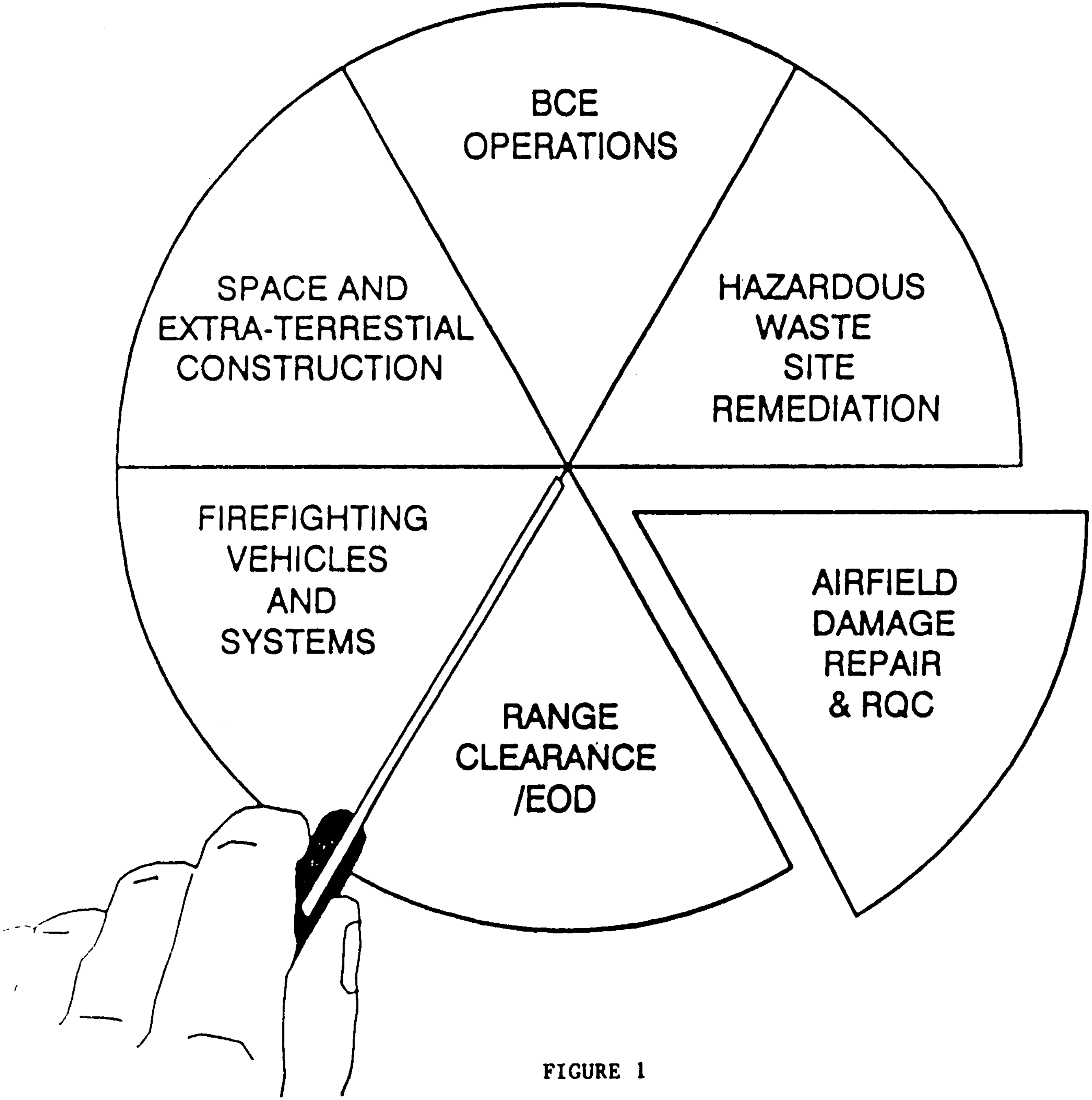

FIGURE 1

Deomonstration System Baseline Configuration

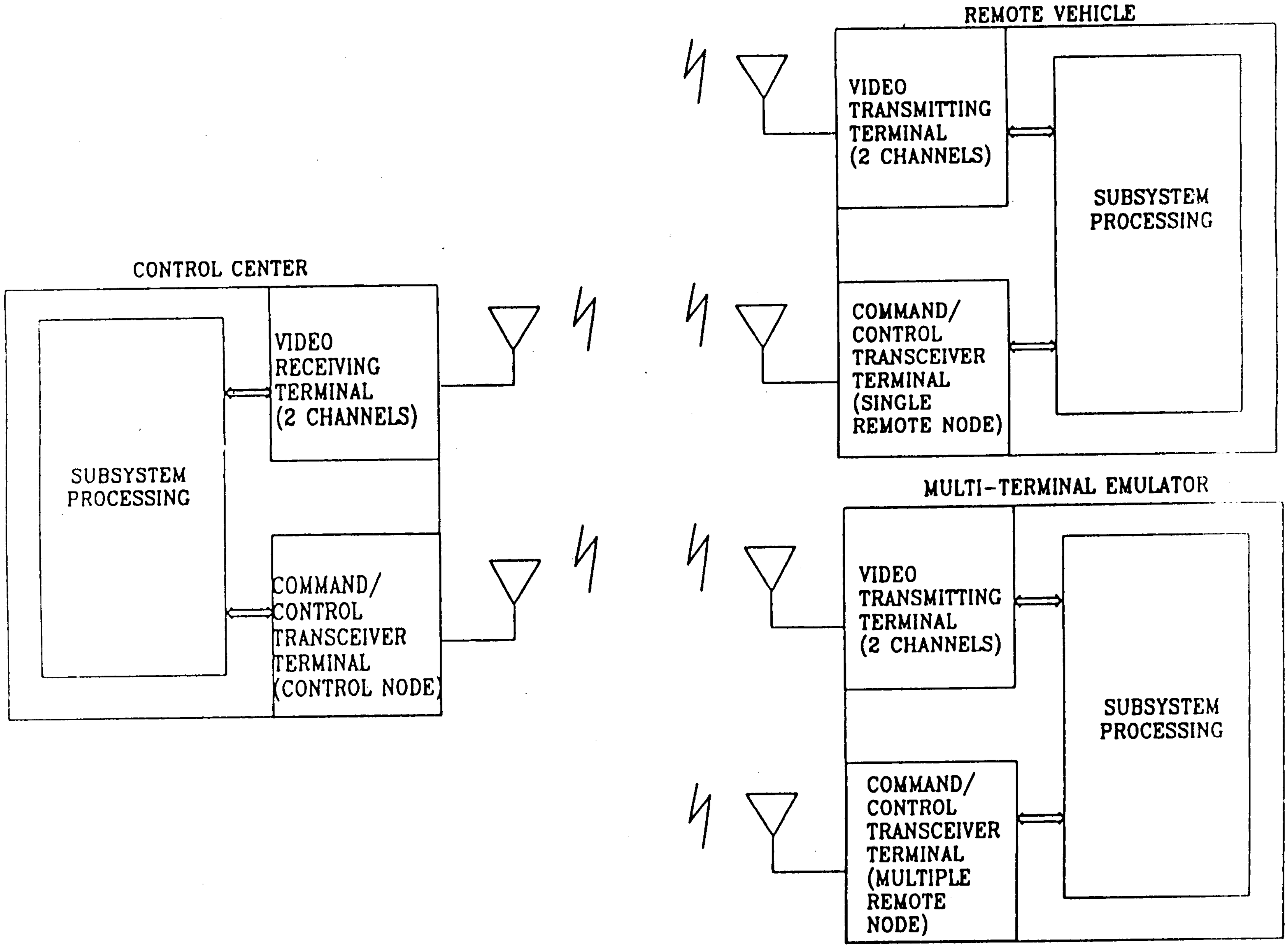

FIGURE 2

Off-Line Path Planning

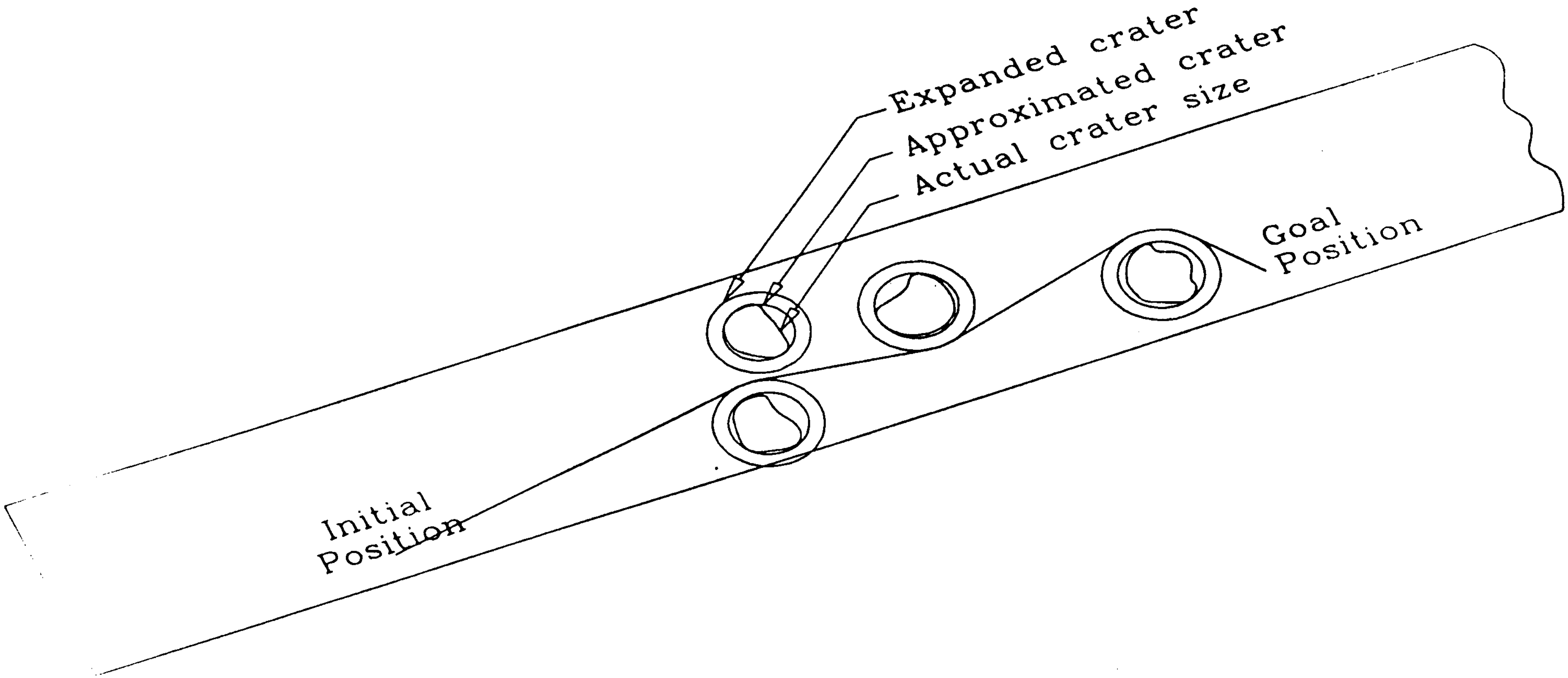

FIGURE 3

CONSTRUCTION ROBOT

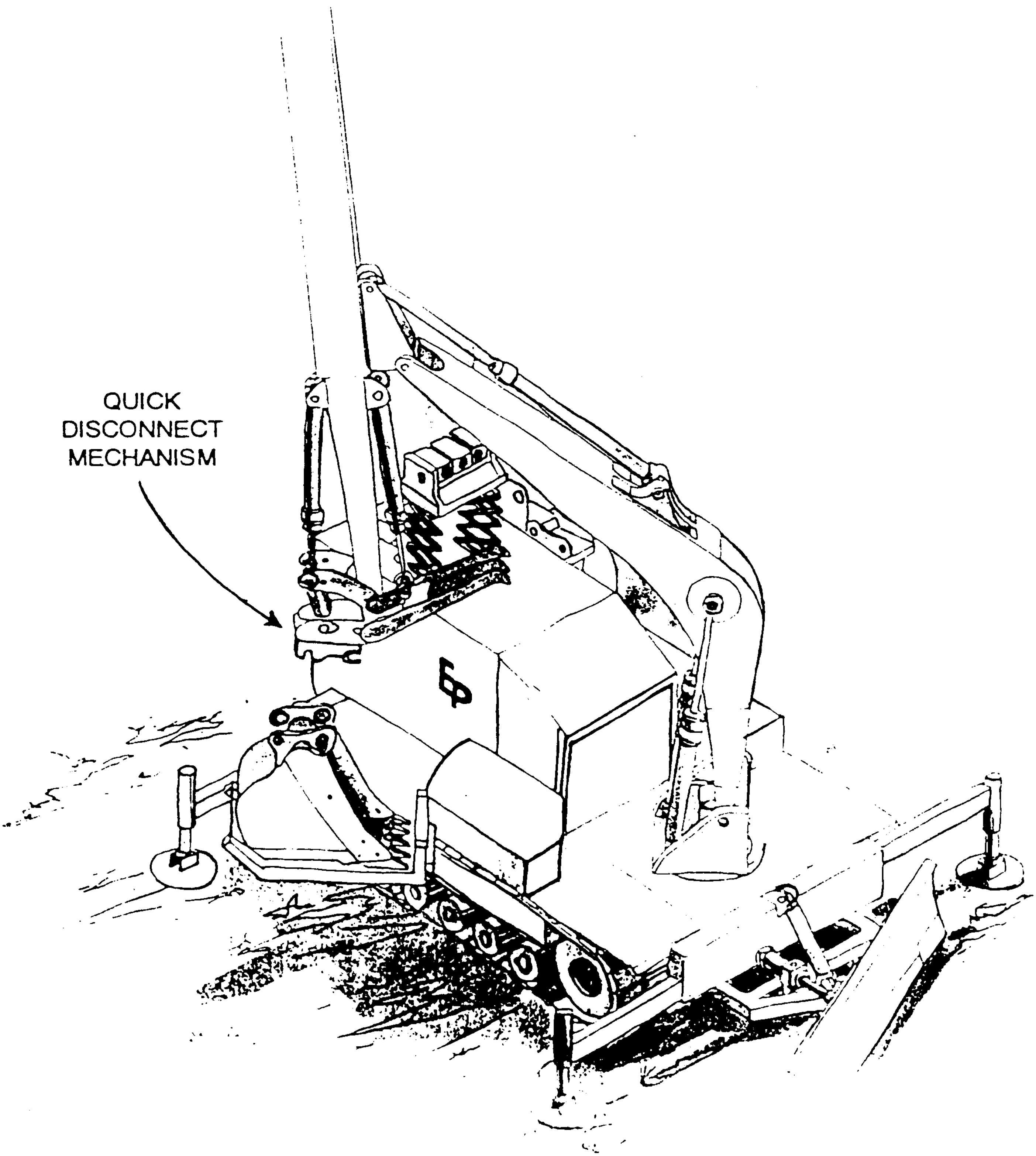

FIGURE 4

Intelligent Control Hardware Architecture

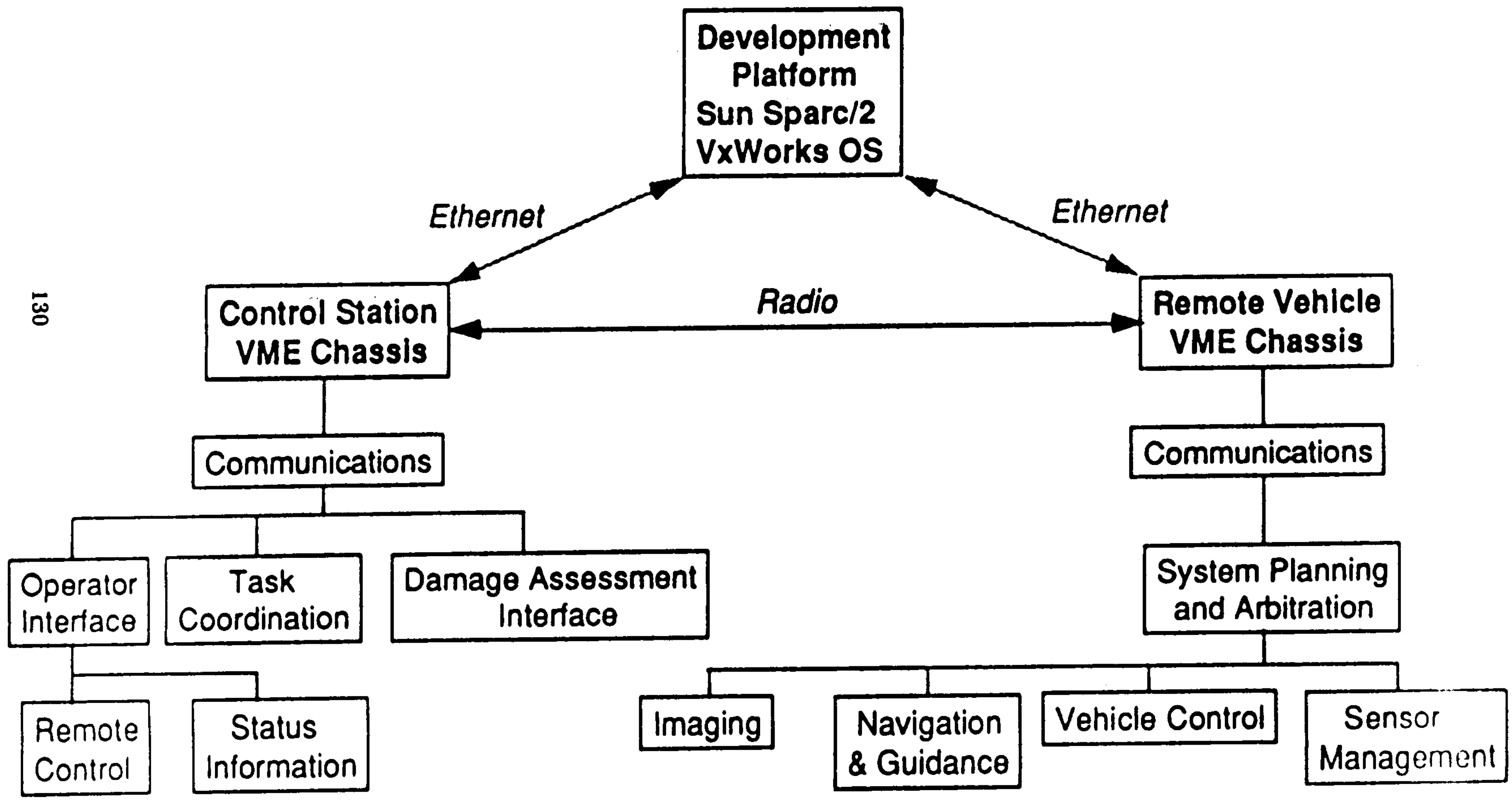

FIGURE 5