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As the army focuses on bringing fewer men to the forefront of the battle, robotic assets will become more prevalent. The soldier will need to be able to control these assets from a portable, rugged, and robust Operator Control Unit(OCU). It is important that the soldier's mobility and situational awareness not be adversely affected by this task. Although many of today's fielded systems are wearable or fit within a brief case, they still can cause a deterioration in the soldiers overall performance. A lightweight, non-intrusive solution is required with an interface that is easy to use, but robust enough to control multiple assets and their many functions. This paper will focus on the in-house development of an OCU for a lab-robot that parallels the OCU developed to support the Dismounted Mule operations that were a part of the Vetronics Technology Integration (VTI) effort in February, March, and April of 2003.

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Operator Control Units for the Dismounted Soldier

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ABSTRACT

As the army focuses on bringing fewer men to the forefront of the battle, robotic assets will become more prevalent. The soldier will need to be able to control these assets from a portable, rugged, and robust Operator Control Unit(OCU). It is important that the soldier's mobility and situational awareness not be adversely affected by this task. Although many of today's fielded systems are wearable or fit within a brief case, they still can cause a deterioration in the soldiers overall performance. A lightweight, non-intrusive solution is required with an interface that is easy to use, but robust enough to control multiple assets and their many functions. This paper will focus on the in-house development of an OCU for a lab-robot that parallels the OCU developed to support the Dismounted Mule operations that were a part of the Vetronics Technology Integration(VTI) effort in February, March, and April of 2003.

INTRODUCTION

The technology and requirements for OCUs are continuously evolving. Early systems featured up to five operators and large control stations, such as the 1970s Soviet lunar robot "Lunokhod". Modern units normally are configured to fit inside a briefcase sized enclosure (see Figure 1) or are man wearable, such as the one displayed in Figure 2. As the battlefield continues to move towards a more urban setting, it is advantageous for these systems to become less cumbersome. With the ever-increasing advancements in processor speed it, is realistic to expect that OCUs will continue to decrease in size while still increasing in capability.

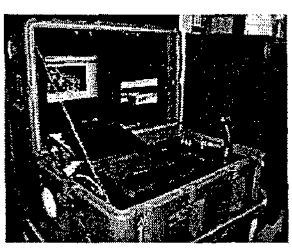
Figure 1: Briefcase OCU


Figure 2: Man - Wearable OCU

To this end, members of the Tank Automotive Research, Development, & Engineering Center (TARDEC) Vetronics Robotic Mobility Team have begun in-house development of a prototype PDA OCU for autonomous and tele-operational interfacing with an Unmanned Ground Vehicle(UGV). Members of Carnegie Mellon Robotics Institute have developed an OCU for the dismounted solider experiments within the Vetronics Technology Integration 2003 demonstration.

OCU MODELS

This paper will focus on two OCUs currently under development. Both OCUs use similar hardware (COMPAQ iPAQ, Wireless LAN, Serial GPS), but have a different focus. The TARDEC model is based on a robot-centric perspective. The CMU model is based upon a controller-centric perspective; focused on aiding the dismounted soldier as well as monitoring and controlling semi-autonomous vehicles.

TARDEC MODEL

The following section details the TARDEC in-house effort towards developing an OCU for its lab-robot.

Concept Development

In an effort to do in-house testing of mobility and sensor algorithms developed by contractors, and to further their own research efforts, TARDEC started developing a lab-robot in October of 2001. The robot was designed to incorporate various sensors such a; laser radar (LADAR), DAY TV, Differential Global Positioning Systems (DGPS), Digital Compass, and Non-Contact Optical.

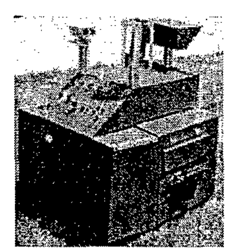
Figure 3: Lab Robot

As the robotic platform neared completion, mission needs changed and the original OCU concept of a Laptop and Desktop-emulation software was abandoned. In an effort to parallel the OCU development of the VTI contractor, the TARDEC effort opted for a new platform based on a commercial PDA.

The new OCU would need to encapsulate the following functions: Mode Control, Complete Manual Functions, Comprehensive Diagnostics, Limited Debugging, and Follower Capability.

Mode Control

The lab-robot has multiple modes of operation depending on what mission is being run, what sensors are being tested, and what algorithms are being developed. These various modes and their parameters need to be interfaced through the OCU.

Complete Manual Functions

The OCU needs to be able to control all of the various sub-systems individually through a manual control functionality of their interface. This can be as simple as jogging the speed-controllers, to as complex as sending a test message through the IP client.

Comprehensive Diagnostics

Each of the various sensors on the robot has one or more dedicated processes. These processes send out diagnostic messages to the IP server. The OCU needs to be able to read and filter these messages.

Limited Debugging

From a development standpoint, it would be nice to have access to limited debugging functions from the OCU, so that every problem with the robot wouldn't require the downtime involved with linking up to the development system.

Follower Capability

One of the robot's missions will be to follow the operator. This is currently done by dropping GPS breadcrumbs among other things. To accomplish this, the OCU will need to know its current GPS position.

Hardware Specifications

Why the iPAQ?

After looking at many of the available commercial PDAs and Pocket PCs; we eventually selected the Compaq iPAQ. This was based on a number of factors. First, the iPAQ has one of the larger usable viewing areas. They don't restrict a portion of the screen to text entry like the Palm Series. Second, Compaq offers a lot of options and add-ons, as do many of the vendors supporting their product line. Third, the iPAQ runs Windows CE 2.0 as a standard configuration. This was the OS of choice for our development environment. Fourth, there was a very impressive OCU at the AUVSI summer conference in Orlando, FL using the iPAQ. Finally, the iPAQ was the PDA selected by the VTI contractor.

Figure 4: iPAQ

What other components are needed?

After selecting the PDA, two pieces of hardware were required – a wireless PC card to connect to the robots IP server and a serial GPS card to get position data for the follower mode. In order for the iPAQ to support these two cards, a third piece of hardware would be required – a dual slot PC card expansion pack.

The '2.4GHz Wireless Compact Flash Card Kit' from SMC was selected as the network adapter. This was based on SMC being the manufacturer of the robot's wireless hub and their support of the iPAQ's Operating System (OS). The current card runs the 802.11b standard, but may need to be upgraded due to bandwidth limitations with the streaming video.

The 'World Navigator' from Teletype GPS was selected for the GPS receiver. This card was selected because of the easy access to positioning data and availability of tech-support. As an added benefit, this particular model has built in support for a DGPS correction signal.

Finally, a dual slot PC card expansion pack was required so that the iPAQ could access both PC cards.

Software Specifications

In order to develop and code a robust OCU three criteria needed to be met: a solid foundation through a proven development environment, proven and easily accessible peripheral interfacing through established drivers, and reliable communications with the robot to be controlled.

A Proven Development Environment

The TARDEC OCU was developed under 'MobileVB' from AppForge. This development package offered many benefits: First, they have a great reputation in the PDA Application Development Industry and a very comprehensive online support program. Second, by being an add-on to Microsoft's Visual Basic, they offer a look and feel that already has a wide acceptance level. Third, a majority of the lab-robot's processes were coded in part or in full in Visual Basic. This allowed for a lot of commonality and software reuse. Finally, they offered built-in support for all of the OCU's specified hardware making interfacing a breeze.

Peripheral Interfacing

By taking advantage of the inherent capabilities of the development environment, interfacing to the wireless network adapter and the GPS card was almost seamless. The client/server package developed for the lab-robot was very easy to port over to the OCU environment; as a result, the wireless adapter was running in a matter of days. And the GPS card spoke in a serial National Electrical Manufacturers Association (NEMA) format that was easily processed by the development environment. All in all, the interfacing to the OCU's peripherals was made easy by the selection of a robust development environment.

Communication with the Lab Robot

All of the robot's processes are built on an application of a custom TCP/IP client/server package developed for this project. By choosing the OCU's development environment to be compatible with this application, it was possible to greatly increase the speed of development, as well as the reliability of the end product. The OCU currently sees communications in the 2.5-4Mbps range, over a distance of about 200m. This is typical and to be expected of the 802.11b standard. Although, due to low frame rate on the streaming video, the hardware may need to be changed to 802.11a or 802.11g to alleviate the bandwidth crunch.

Human Factors

The TARDEC approach to OCU development is robotic-centric. That is, this OCU was designed with a specific robot in mind: in this case, the Lab Robot. A major advantage to this approach is that by knowing the details of the robot, you can customize the OCU to a very fine degree. The design goals for the TARDEC OCU are operator independence, intuitive interface, and robust control.

Operator Independence

The OCU was designed so that it would not need to be reconfigured when it was passed from operator to operator. A left-handed user would interface with the OCU in the exact same fashion as right-handed person would. The majority of this type of development was done by the manufacturer of the iPAQ, but the screen layout and control placement was done with this concept in mind.

Intuitive Interface

This concept incorporates two fundamental principles – recognizable controls and predictable progression. The first part of this concept can be met by following the standards established by Microsoft Windows©. Therefore, it is possible to layout a form such that the operator recognizes every push-button, combo-box, and selection list for what it is. They will recognize the control and know how to use it. The second part can be met by making screen changes in a predictable fashion. It would be quite difficult, if not impossible, to place everything needed to control a robot on one screen. Therefore, logical progression must be used to traverse the multitude of screens needed for complete control. If all of the robot's sensors are accessible from the PDA, they should be accessible in a similar fashion.

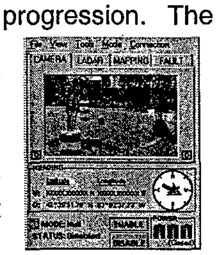

Figure 5: TARDEC OCU

Robust Control

This is accomplished by making key features available as they are needed and keeping the operators input to a minimum. If a sensor is not being used in a given mode, than it should not waste screen space by being displayed. If a specific function is required, the operator shouldn't have to search through multiple menus to find it.

CMU MODEL

Carnegie Mellon approached the dismount OCU system from the perspective that today's commercial of the shelf (COTS) parts are sufficiently cheap and powerful to allow a demonstrable and viable OCU to be constructed quickly and inexpensively. Our reliance on COTS components allowed us to focus on developing a strong application framework that gave substantial flexibility in interacting with the Dismount and the Robotic Vehicle. This flexibility proved to be critical when integrating the OCU with the vehicle.

Concept Development

The guiding principle behind the OCU developed by Carnegie Mellon for the 2003 VTI demonstration is that for humans to interact successfully with Robotic Vehicles the interaction must be simple and high level.

This desire for simplicity manifested itself in a number of ways throughout the application interface. First, for any human to successfully interact with a robotic vehicle there must be a simple and effective set of commands available to the user. Secondly, access to the commands through the interface should be consistent. Thirdly, the view of the data, specifically Vehicle positions and Dismount positions, must be clear and concise.

Simple Commands

When considering the tasks that need to be accomplished; there are only three necessary to a Dismount Follower application: Goto, Follow Me, and Stop. In addition to these commands, the user is permitted to select the maximum speed of the vehicle. This OCU is not intended to give the operator tele-operation control of the vehicle. The direct mechanical control of the vehicle is left to vehicle specific mechanisms.

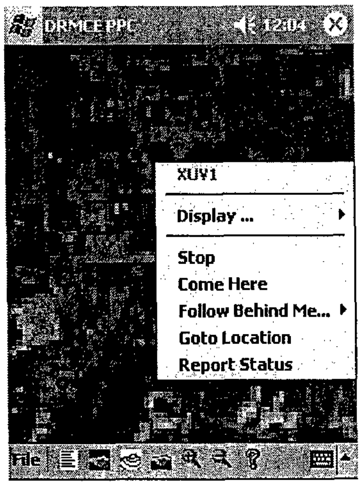

Figure 6: Robot control interface

Interface Consistency

The Dismount OCU itself has only one operational mode; however, the Robotic Vehicle it is maneuvering with can be executing different commands (as outlined above). In each operational mode, different commands are sensible to execute. One school of thought holds that only the applicable options should be shown to the user at any given time. This can be confusing to the user. The CMU system always presents the same set of options to the user; however, options, which are not available to the user, are "grayed out" so that there is no impression that an option is "lost." The interface available to the Dismount is menu driven and uses the native "tap and hold" mechanism to trigger display. When the user taps and holds on the screen, whatever is closest to the location of the tap, displays it's configuration menu (see Figure 6, above).

Figure 7: Dismount and Robot displayed in Aerial Image with each entity displaying its path in red.

Data View

In the Dismount Following application, the goal is to be able to tell the Robotic Vehicle to follow behind the Dismount by a distance that will not keep the Vehicle in constant visual contact. Further, for the system to be effective and usable, it cannot be the case, that the Dismount must constantly "mind" the Robotic follower. These two statements form the backbone of the requirements for the Data View. To accomplish these goals, a set of overhead maps was chosen for display. The maps that were chosen were an Aerial Image, a Topographic Map, and a Digital Elevation Map (DEM). Only one map from the set is displayed at a time. On the currently displayed map, the paths of the Dismount and the Robotic Vehicle are displayed (see Figure 7). This method of information display allows the user to understand the present and historical situation quickly so that the system can be set into motion and then ignored unless the Robotic Vehicle notifies the dismount that it is in trouble. For the purposes of this application the Robotic Vehicle is considered to be "in trouble" if it gets stuck: cognitively or mechanically.

Hardware Specifications

The hardware selection process was driven by two facts. First of all this is a system for use by Dismounted Soldiers. Because of this, the entire system, including batteries, had to be small enough to be worn. The second consideration was cost and speed of development. As mentioned above, a system composed of COTS components worked quite well for development and fielding.

We broke the necessary hardware into the three following categories: computing and display devices, localization devices, and communications devices.

For the computing and display device we selected a Compaq iPAQ. There were a few reasons for this choice. First of all, the iPAQ has great flexibility in interacting with other hardware systems since it supports industry standard interfaces: Serial, USB, and PCMCIA. Of particular interest to us was the ease of integrating PCMCIA cards. The number, variety, and low cost of PCMCIA cards made the use of them very attractive. Secondly, the iPAQ comes with Windows CE™ natively installed in ROM. Microsoft also provided a free compiler for the Windows CE™ environment when development of this application was started.

For localization, we experimented with 2 different devices. First of all we used an integrated GPS and dead reckoning unit. This unit, the Dead Reckoning Module produced by Point Research Corporation, is self-contained and internally integrates GPS information and dead reckoning information using a Kalman filter. The unit behaved reasonably, in most field experiments, generating acceptable position estimates even during GPS outages. The major problem with the unit, for the Robotic Follower application, is that it trades accuracy of positioning for extended battery life. This reduced accuracy was a problem when in the field with a Robotic Vehicle.

Figure 8: The CMU OCU system

When the Dead Reckoning Module failed to give a good enough path for robotic following, a GPS only unit was used. The selected GPS device is a Wide Area Augmentation System (WAAS) and had tremendous accuracy. In practice we got 1 meter accuracy much of the time. In the future, it may well be worth the effort to replace the GPS unit in the Dead Reckoning Module with a higher accuracy GPS unit.

For communications, the immediate thought was to use 802.11(b) wireless communications. These cards are ubiquitous, inexpensive, and effective. For the field trial, an access point was placed onto the robotic vehicle. In the future it is worth considering replacing an access point based network with an ad hoc peer to peer network to remove the infrastructure requirements from the system. It is not reasonable to expect that the Dismount Soldier will be able to install a network infrastructure as the robot follows him in the field.

Software Specifications

The software for the Dismount Soldier OCU was designed from the very beginning to be robust and extensible. To maximize the robustness of the application we decided to develop in C++ and use the Model View Control architecture (MVC). The MVC architecture is well suited to this application since it has a number of research items. The ability to encapsulate the research items in a sensible way allowed us to easily substitute different versions of components for testing purposes.

A further advantage of the MVC architecture is that the Dismount Soldier OCU must be very small and portable thereby imposing strict limits on the View layer of the application. Because the View layer is independent of the application control (Control layer) and the data (Model Layer), a new view can be constructed on the same application base. This would allow a "command" view of the data; using a larger display and showing a wider ranging view of the situation than any single Dismount could have.

One important design decision was that the Dismount OCU would treat the Robotic Vehicle as a black box. The communications between the OCU and the Robotic Vehicle were simply structured commands and status messages sent over a wireless Ethernet connection using a UDP/IP (datagram) socket. This method of integration was selected so that any robot that can support a UDP/IP socket and process the simple commands can be integrated with the Dismount OCU without changing the OCU itself.

For development and compilation, we used the Embedded Visual C++® 3.0 development environment and Microsoft® ActiveSync®. This environment was the most sensible choice since it has good User Interface support for the Windows CE® platform.

Human Factors

The CMU OCU development was focused on creating a simple, easy to understand system that was not tightly tied to any single robotic vehicle. The CMU OCU effort was never focused on debugging the Robotic Vehicle, but rather on getting the Dismount Soldier to be able to maximize the effectiveness of Robotic Vehicles in the field.

Field Results

The Carnegie Mellon Dismount OCU went into the field as part of the VTI demonstration that took place in February and March of 2003. In the field a number of things were learned and areas for improvement of the system were found.

Previous to the field experiments, the Dead Reckoning Module was the localization device of choice for the OCU. When in the field though, it became apparent that the Dead Reckoning Module's power/accuracy trade off sacrificed too much accuracy to be useful for a Dismount Following Application. In consultation with the vendor, it is clear that adjustments can be made to the unit which will increase the unit's accuracy while decreasing it's battery life. A further investigation of this device and its capabilities would be appropriate.

There is a constant struggle between map detail and map size in the application. While the iPAQ is a powerful device, its memory is not boundless and is far less than is available on a standard desktop machine. This trade off in detail and size forced us to select map resolutions on the order of 8 meters per pixel. This resolution was acceptable for most tasks that the OCU was to handle; however, it made directing the robot to "Goto" a location in the map a difficult task. With practice the operator became more adept at selecting specific points in the map; however, a few simple improvements in the user interface would aid in this greatly. One improvement would be the addition of a compass. Showing a compass heading for the dismount in the display would greatly increase the speed at which the map can be understood. The map is always oriented with north at the top of the display though that is not the way that the dismount is always facing. With a displayed compass heading for the dismount it should be easier to reconcile the real world with the displayed representation. The other item that should help in this regard is higher resolution maps.

Another thing that became quite obvious is that the Dismount OCU's greatest liability is power. The reliance on COTS components created a system that was power hungry. In commercial uses the expectation is that the user is never too far from a power source and can plug the system in to charge when the power gets low. When in the field, power is much harder to come by and the runtimes between recharges must be much higher. The CMU OCU was targeting a 4-hour runtime without requiring any recharges. This turned out to be more challenging than anticipated. Due to desired runtime and the power hungry components the battery weight in the system was easily over 50% of the total system weight.

CONCLUSION

The capability to control robotic assets from a commercial PDA is a realistic option today. Current limitations in wireless communication, which adversely affect the video feedback and other large packets of data, will be overcome with advancements within wireless communication. Additional ruggedisation of the PDA will be required to protect the hardware from the harsh conditions it would likely encounter in any fielded operation. As the capability of processors continues to advance, the size of OCUs will continue to decrease and the capability will continue to increase. The in-house testing of the TARDEC OCU has produced encouraging results. The system will be operational tested in the June 2003 International Ground Vehicle Competition. Collaboration with TARDEC and Carnegie Mellon may occur as part of future VTI Demonstrations (2004 or 2006).

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Bruce Brendle, Deputy Associate Director, Vetronics Technology Business Group, TARDEC

Jeff Jaczkowski, Team Leader, Robotic Mobility Team, TARDEC

REFERENCES

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Carnegie Mellon

Operator Control Units (OCUs) for the Dismounted Solider

Concurrent Design Approaches

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Engineering Center
(TARDEC)

Carnegie Mellon University,
Field Robotics Center

UNCLASSIFIED

TARDEC OCU Model

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2

THE ROBOTICS INSTITUTE

OCU Development Concept

- Control a known robotic entity from a PDA interface
  - Tele-op, Follower, Debug capabilities
- Model work of VTI contractor
  - Similar hardware/concept
- Develop in-house expertise

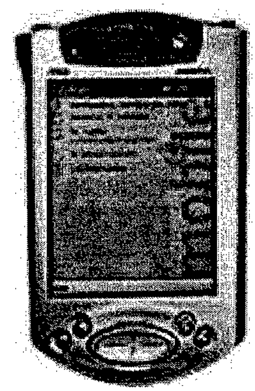
OCU Key Features

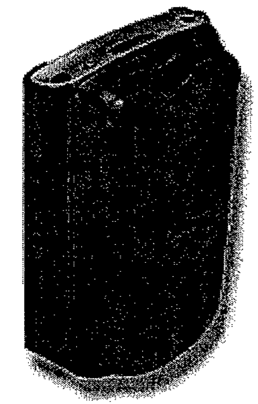
- Windows CE Operating System
  - Can Program using Visual Basic with AppForge Mobile VB
  - Intuitive Windows interface
- Hardware
  - Dual PC Card Expansion Pack
  - Serial and USB interface

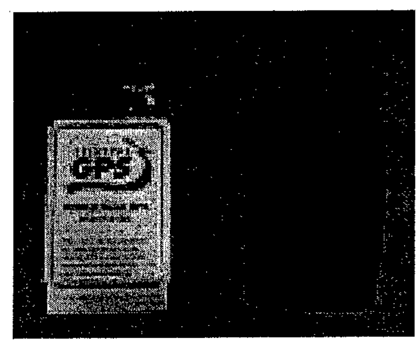
4

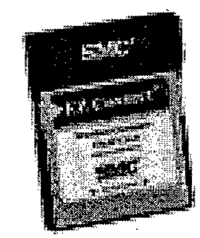
Hardware Architecture

- Compaq IPAQ 3850
  - Dual-Slot PC Card Expansion Pack
- Communications
  - SMC 2.4 Ghz 802.11b wireless Ethernet
- Navigation
  - Teletype PC Card GPS receiver

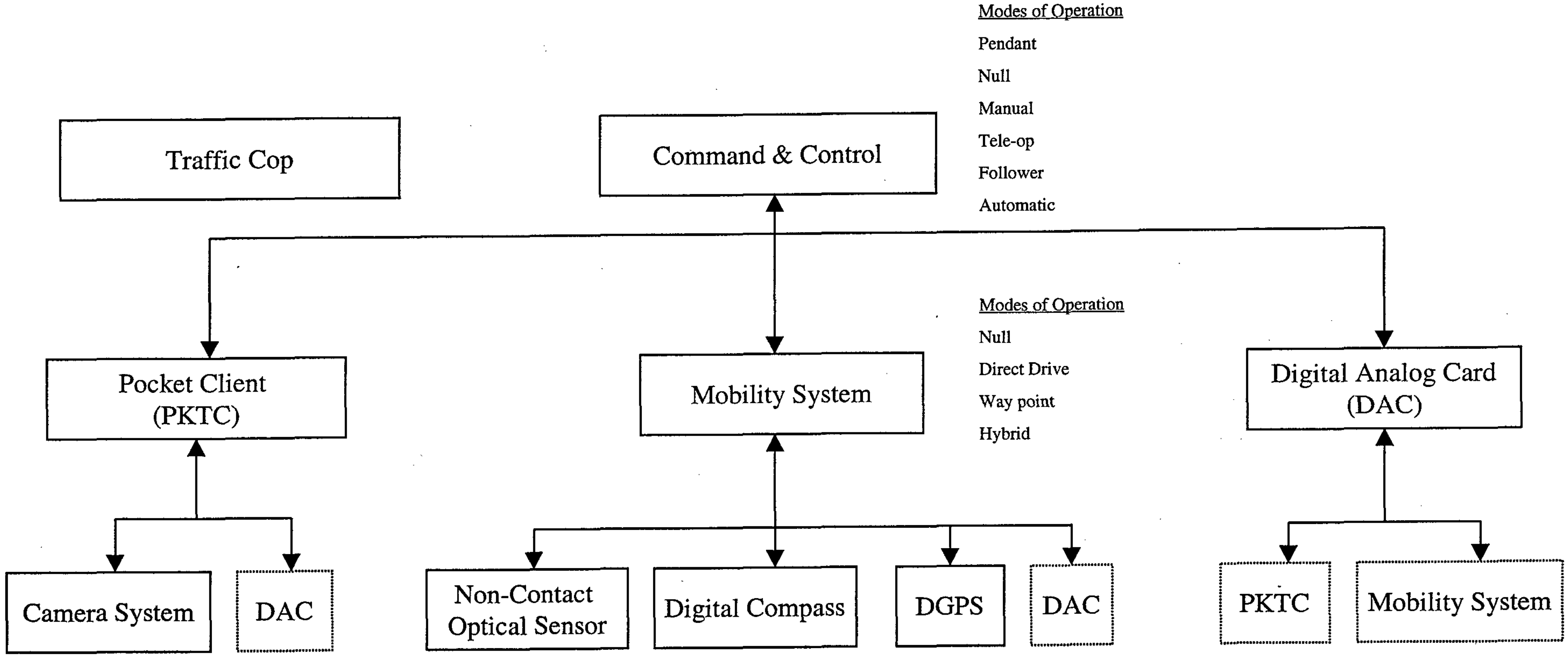








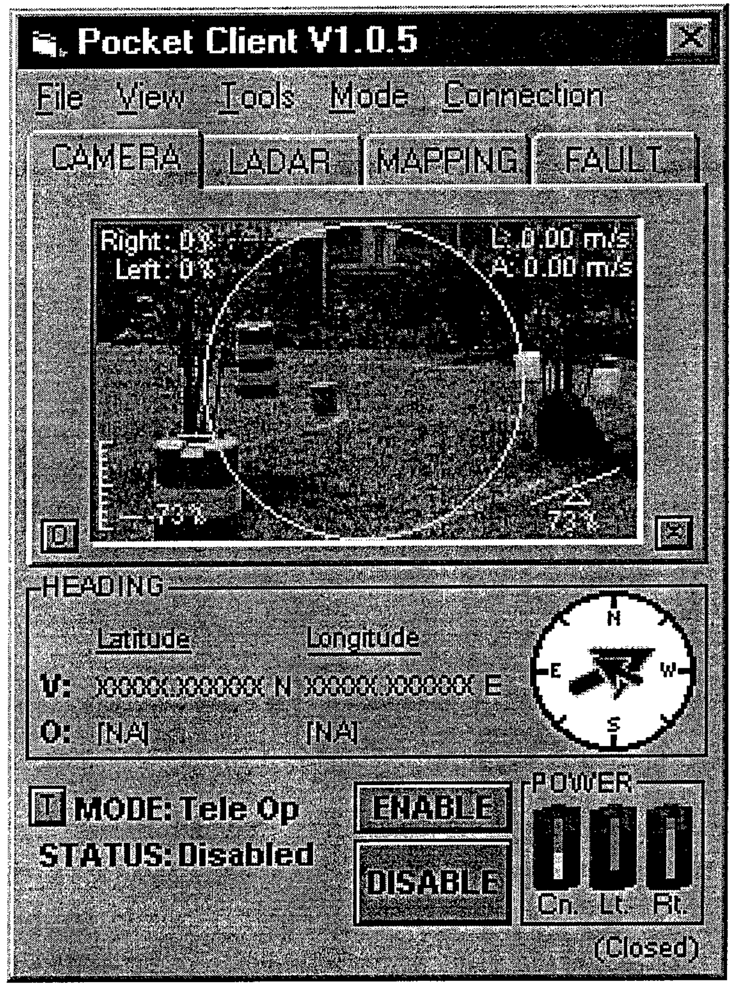
Software Architecture



6

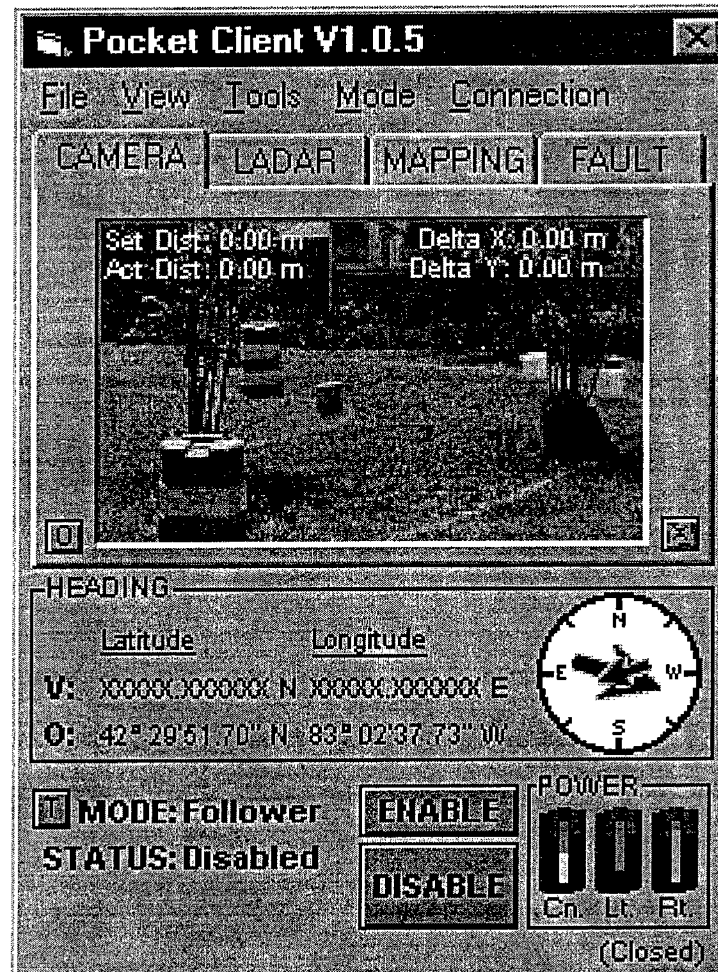
OCU Tele-operation

- Control mobile robot from short distance at non-LOS locations
  - Percentage-Based Drive Control
  - On-Screen vehicle video, orientation, location, battery life, and velocity displays

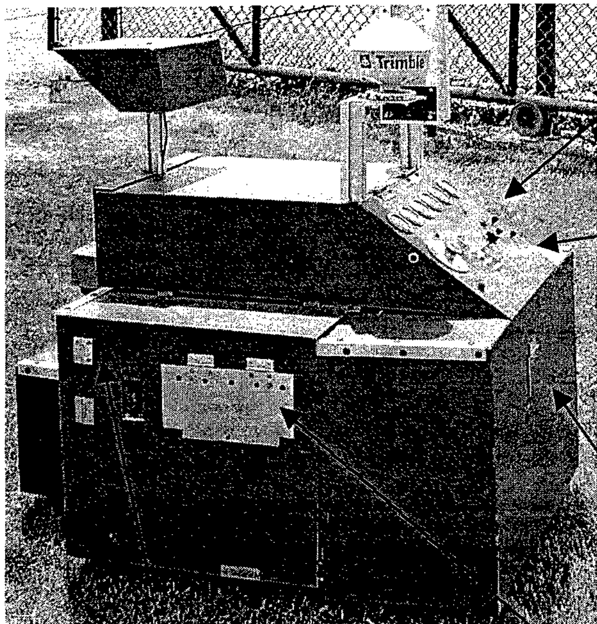


OCU Follower

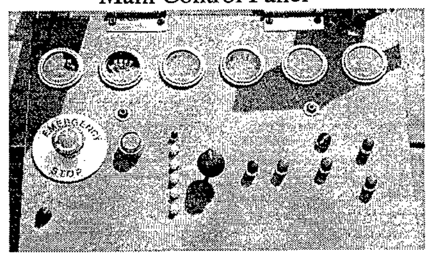
- Operator Drops GPS breadcrumbs while traversing a path for the mobile robot to follow
  - Set time and distance offset
  - Operator does not need to interact with PDA



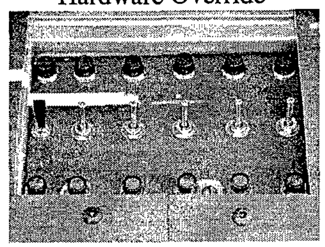
Lab Robot

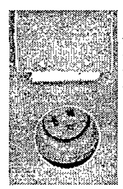


Main Control Panel

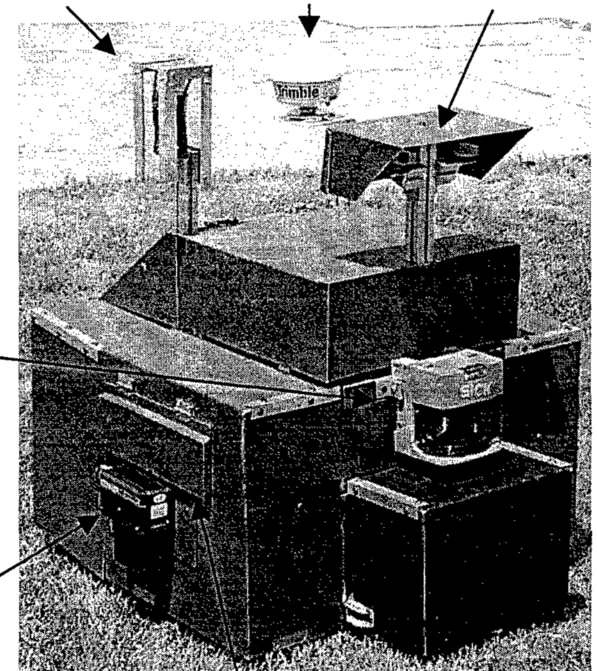


Hardware Override

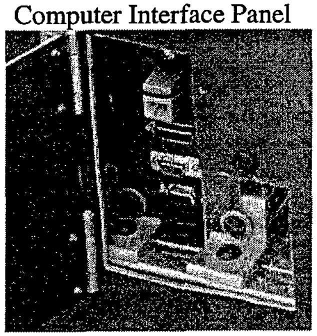




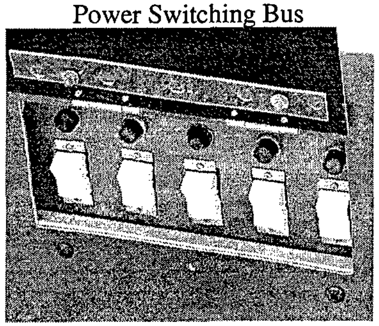
External Power Inlet (110VAC)



Computer Interface Panel



Power Switching Bus



Breaker & Fuse Panel

OCU Conclusions

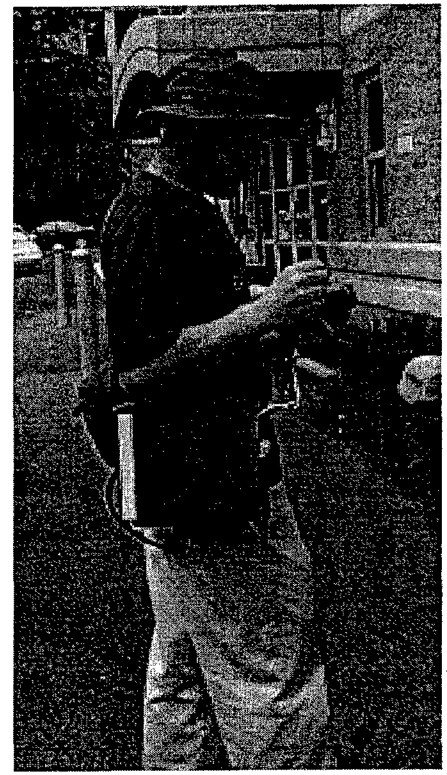
- Tele-operational control is resource intensive and requires faster processor and network communication
- Leader/Follower capability is realistic with COTS OCUs
- Ruggedization of COTS PDA would be required for any fielded operation

Operator Focused Autonomous Robot Control

Scott Thayer & Bill Ommert
Carnegie Mellon University,
Field Robotics Center

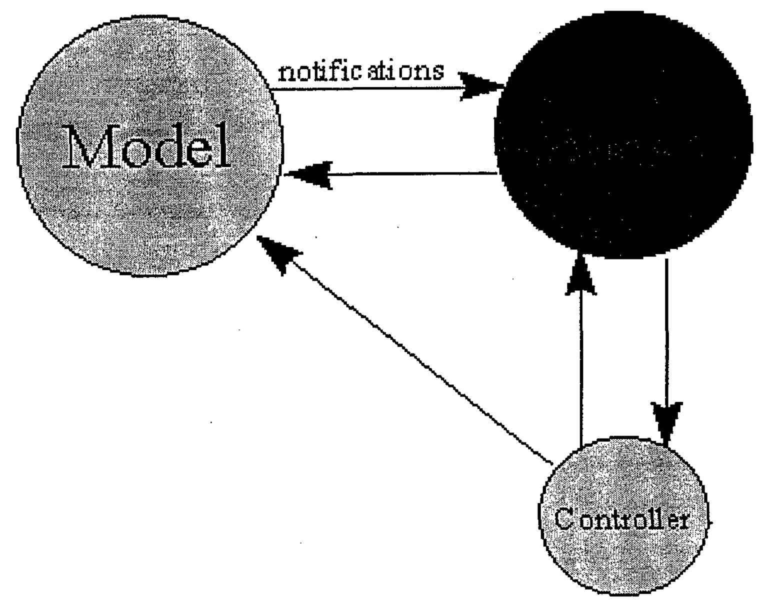
System Hardware Architecture

- Compaq iPAQ
  - modified desk cradle
  - PCMCIA expansion sleeve
- Communications
  - Wireless Ethernet
- Localization
  - Garmin 16a marine GPS
  - Point Research Corp. Dead Reckoning Module (DRM)

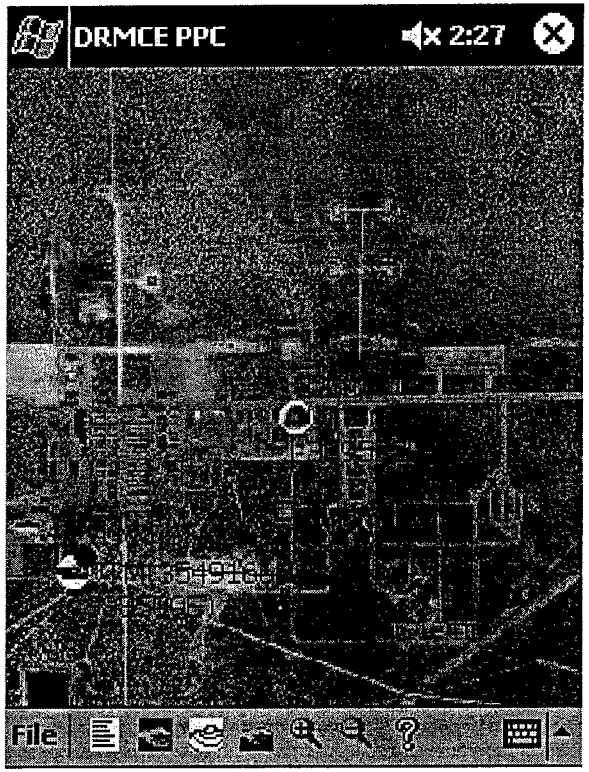


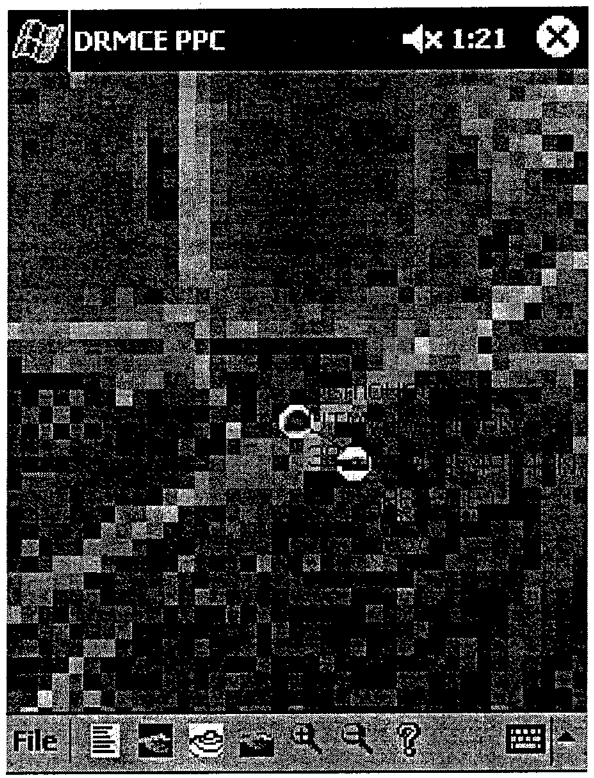
System Software Architecture

- Model View Controller (MVC) architecture
  - Widely accepted as a good model for interface application design
  - Allows "skinning" of the application without affecting the data handling or control flow



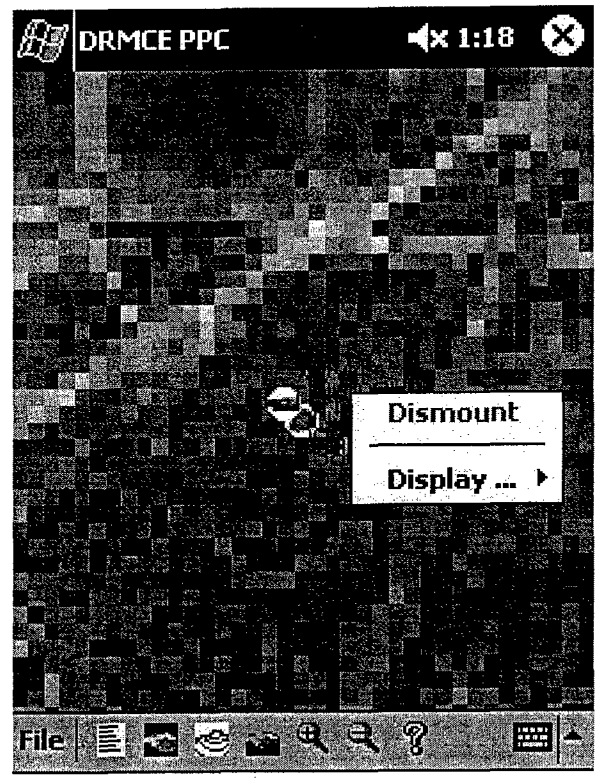
Tracking Interface





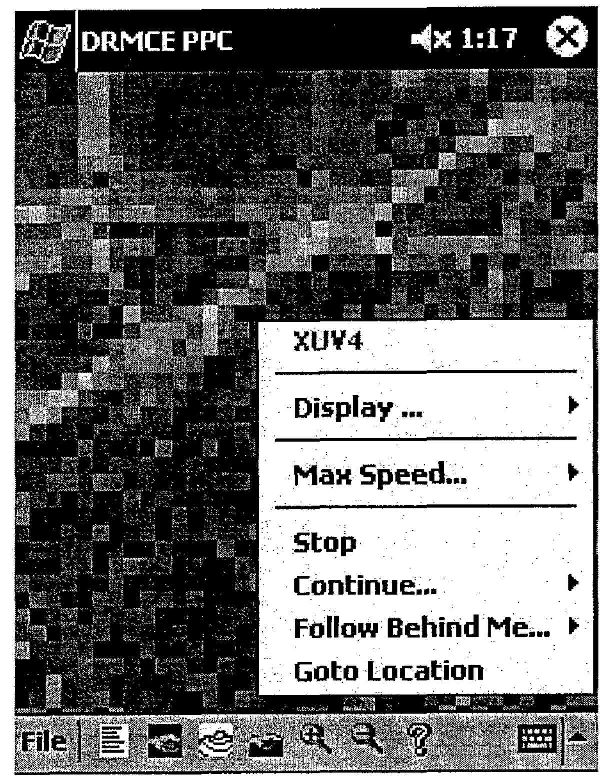
Control Interface

- Use native interface mechanisms
  - Tap and Hold
  - Context Menus
- Interface must be consistent regardless of application state

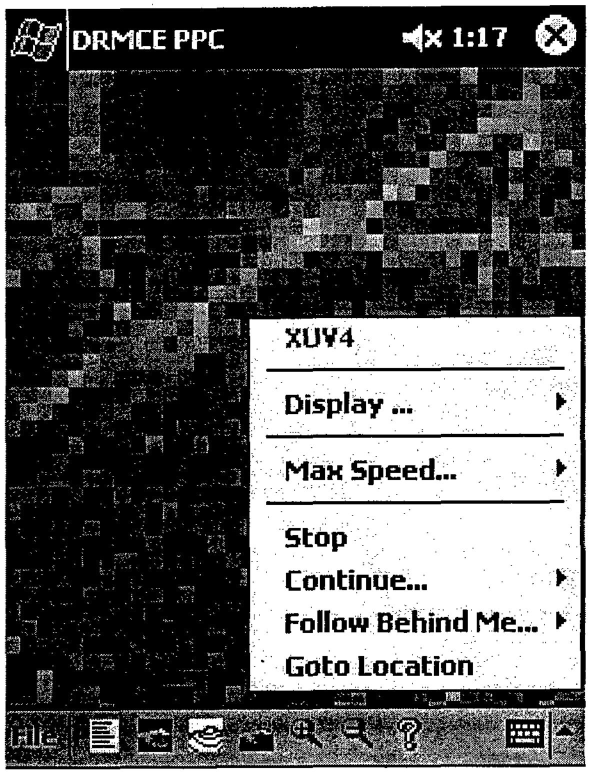


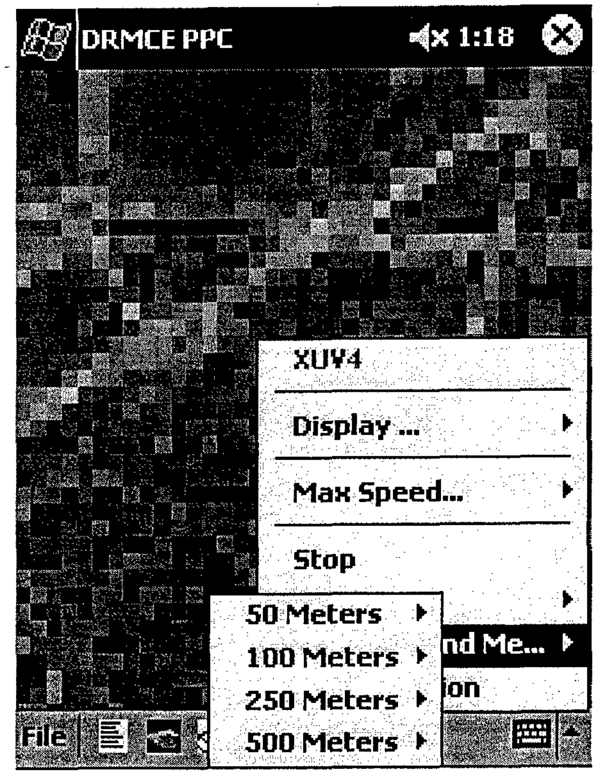
Control Interface: Robot

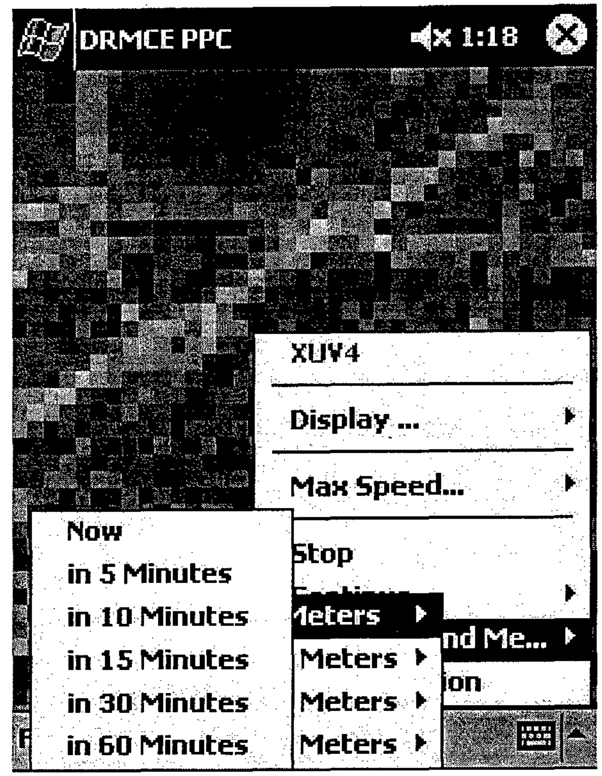
- Supports all basic Display configuration options
- Allow Max Speed to be set
- Autonomous Follow
- Autonomous Goto
- Stop



Control Interface: Follow





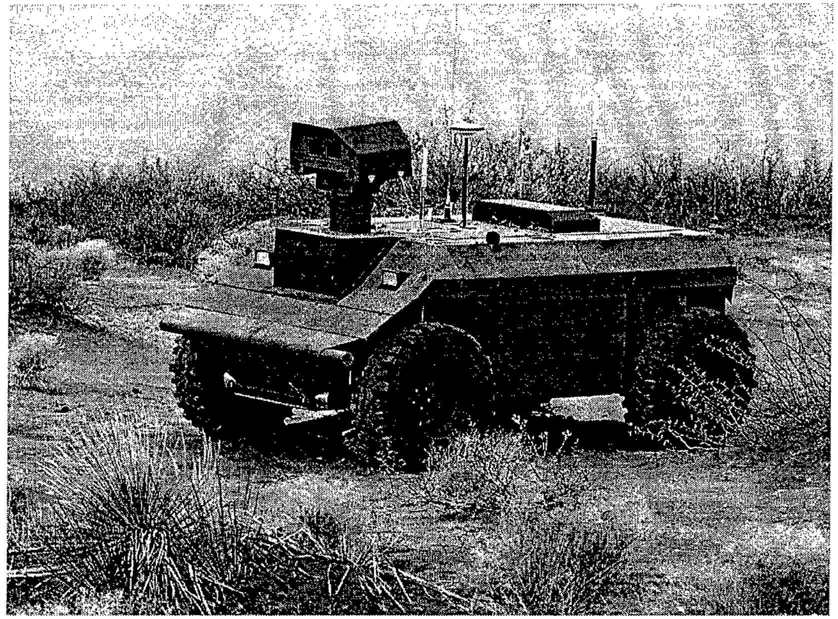


Dismount OCU Tradeoffs

- Screen size vs. Portability
- Level of map detail available to the user vs. runtime of the system
- Runtime vs. System Weight
- Stateless interface vs. complexity of control

Work at McGregor Range

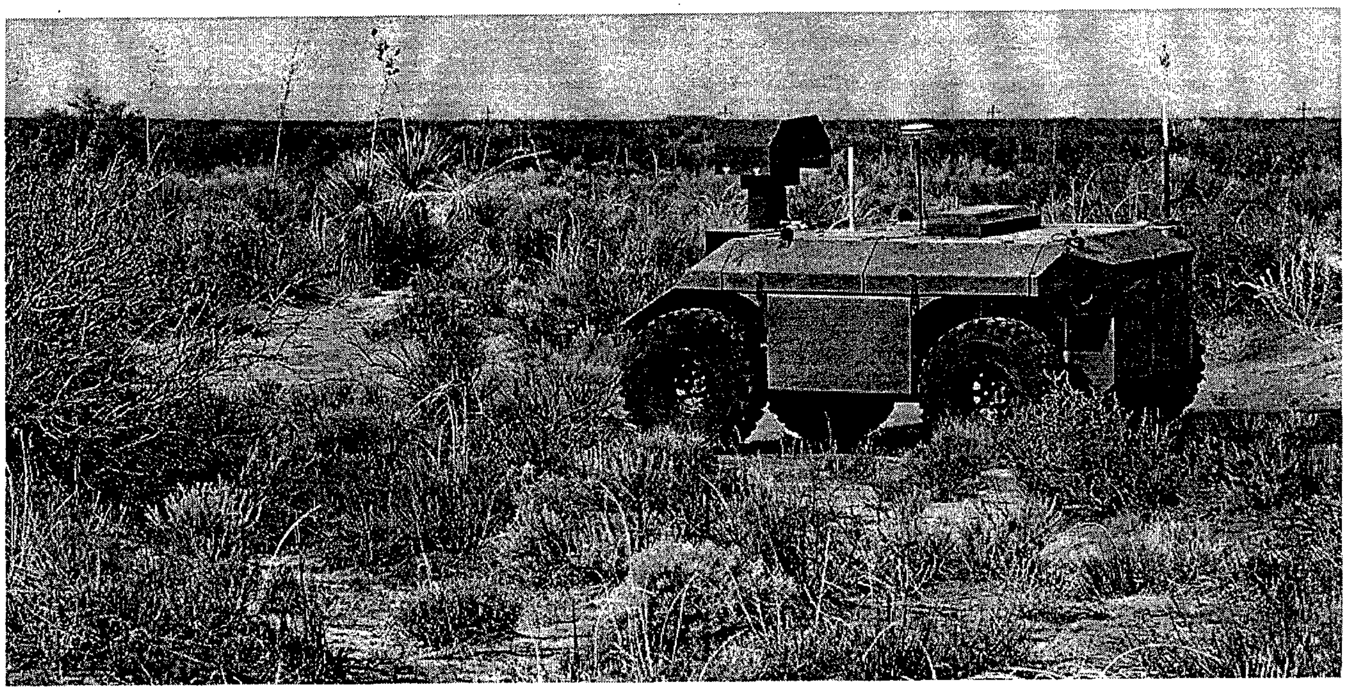
- Dismount OCU integrated with GDRS XUV robot
- Robotic following
  - Used for multiple hours in path following.
  - Traverses of .5 kilometer through desert terrain.



THE ROBOTICS INSTITUTE

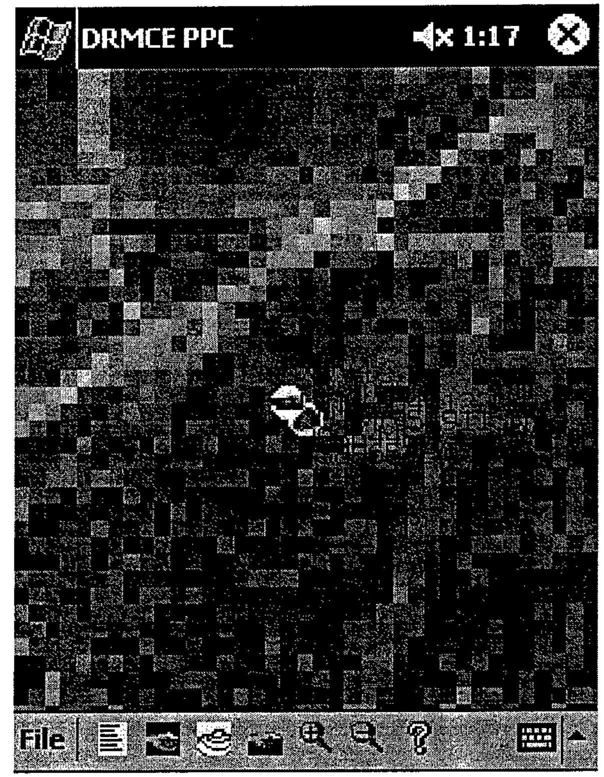
Results

VETRONICS TECHNOLOGY INTEGRATION



Results: OCU Interface

- Orientation can be hard to discern from the maps quickly.
- OCU should provide a non-visual alert cue so that user doesn't have to constantly watch the display.
- Each Entity should have a unique path color.
- Text layout should be smarter to avoid overwriting.



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Results: OCU Hardware

- COTS parts are power hungry
- Problems in strong sun
  - Screen visibility
  - IR sensor interference
- iPAQ has limited expandability
  - 2 PCMCIA slots which must be local to the iPAQ
  - One serial port
  - One USB port without a root hub

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Paper + Briefing

OPSEC REVIEW CERTIFICATION

(AR 530-1, Operations Security)

I am aware that there is foreign intelligence interest in open source publications. I have sufficient technical expertise in the subject matter of this paper to make a determination that the net benefit of this public release outweighs any potential damage.

Reviewer: Bruce Brendle | GS-14 | Deputy Associate Director, Vetronics

Name | Grade | Title

Signature | Date: 5/8/03

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Publication/Presentation/Release Date: 11 June, 2003

Purpose of Release: NDIA conference proceedings

An abstract, summary, or copy of the information reviewed is available for review.

Reviewer's Determination (check one)

1. Unclassified Unlimited.
2. Unclassified Limited, Dissemination Restrictions IAW ______
3. Classified. Cannot be released, and requires classification and control at the level of ______

Security Office (AMSTA-CM-XS):

Concur/Nonconcur ______ Signature ______ Date: 2 JUN 03

Public Affairs Office (AMSTA-CM-PI):

Concur/Nonconcur ______ Signature ______ Date: 3 JUN 03

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