AUGMENTED TELE-OPERATION

Robert Chesney
Canadian Centre for Mine Action Technologies

Abstract

The Canadian Centre for Mine Action Technologies[1] (CCMAT) was established in 1998 with the goal of developing technology for humanitarian demining. One component of the research program is the development of an effective, generic, tele-operation kit for demining applications.

Co-located with the Suffield laboratory of Defence R&D Canada (DRDC Suffield), CCMAT draws on extensive experience in the development of tele-operated systems for military applications, including remotely operated mine detection systems. Combining this experience in the development of tele-operation systems with a requirements analysis for mechanized equipment in humanitarian demining, a systems concept for generic control systems was developed and implemented for trials and demonstrations.

A critical aspect of the systems concept is to expand or augment conventional tele-operation concepts with targeted automation features. Striking a balance between system capabilities and system complexity, the system is designed to maximize efficiency and reduce operator workload within an affordable and maintainable system architecture.

The paper describes the requirements definition process, the requirements identified, the system architecture and its current state of development, implementation and testing.

Keywords: Demining, humanitarian, Tele-operation, CCMAT, remote control

1. Background

Humanitarian demining is an onerous task, characterized by extremely slow, labour intensive procedures with significant risk to the demining staff. The extent of the areas that are mined, or that are potentially mined, is large enough that current clearance methods cannot resolve the problem in any realistic timeframe. Mechanically aided clearance methods, where machines assist in clearing vegetation prior to mine clearance, or in the detection and destruction (or removal) of mines has great potential to speed the process to the extent that large area clearance becomes possible. Unfortunately, most mechanical methods demonstrated to date have a significant potential for initiating the mines that they are intended to remove, either as a consequence, or as a side effect of the design. This requires that the operator be protected by a heavily armoured cab, or that the system be operated by remote control. Armour protection adds weight to the system and is difficult to adequately qualify for full protection under all circumstances; often leading to the use of remote control.

Once a system has been prepared for remote control, it becomes possible to insert relatively low cost technology to add automation, or robotic functionality, to the system. While a competent operator can perform most required functions by remote control of the system's actuators, automated control of some, or all, of the system functions can result in faster operation or fewer errors. Further, an automated system allows integration of data from position measurement systems and detector systems that is difficult for a human operator to assimilate.

The staff assigned to support CCMAT in this work had extensive experience in the development of tele-operation systems for military applications, including remotely operated landmine detection systems [1], however it was recognized that the humanitarian demining problem would raise different requirements than the military role. Hence, while relying on previous expertise the development of the concept and the hardware implementation for augmented tele-operation for humanitarian demining was based on a thorough requirements analysis that examined the operational context and constraints associated with the humanitarian mine clearance efforts.

As a part of the requirements analysis for this development certain observations were made about the typical operational environment. These observations provide motivation for many aspects of the implementation design. An overview of some elements of the operational context is included below.

1.1 Environment / Terrain

Mine clearance is an issue in many parts of the world ranging from temperate European climates through tropical and desert climates. Equipment

[1] Box 4000 Medicine Hat, Alberta, CANADA

operation would be required under a broad range of environmental conditions. However, operation in weather extremes, such as high rainfall rates or obscuring fog is unlikely.

The terrain the systems would have to operate over would be similarly varied, ranging from desert sand, through rocky soils to tropical swamps. Most operations would be expected to focus on trafficable routes or arable land, but slopes encountered may be significant and difficult for mechanized vehicles to traffic. Soil penetration resistance may range from easy to extremely difficult depending on soil type and moisture conditions. Some operations would be in built up areas, operating near buildings, on or near surfaced roads. Heavy damage to road surfaces and substantial rubble from collapsed or damaged building would often be encountered.

Vegetative cover may range from none, to very substantial tropical growth. In keeping with the likelihood that many operations will occur on arable land, significant growth would have to be assumed as the norm.

It is assumed that most remote control operations could be conducted with direct line of sight to the clearance equipment.

1.2 Crew Expertise

Crews assigned to mine clearance can not be expected to have a high degree of technical expertise relating to robotics, although they may be extremely competent in other areas. A substantial component of the crew will be indigenous to the area and may have little, if any, technical background. Crew members brought in from outside the area are more likely to be selected for their experience and expertise on mine systems and mine neutralization than for their computer or electronics skills. System specific training will likely be limited and staff turnover may be high and unpredictable.

1.3 Threat

The majority of the threat mines encountered are expected to be anti-personnel mines, with a mixture of blast and fragmentation types. Some anti-vehicle mines will be encountered, again with a mixture of types possible. The mines may have been emplaced for substantial periods of time and the fuzing mechanisms may no longer function as originally designed due to corrosion or other environmental effects. This is not meant to suggest that the fuzes would not function, rather that they will be less predictable than recently emplaced mines might be. It is expected that a significant number of A/P mines will be set up with trip wire activation, primarily connected to fragmentation mines.

Beyond the emplaced mine threat, unexploded ordnance in general, may be a threat. This would include unexploded bombs, bomblets, mortar shells and artillery munitions. Some of these munitions may be shallow, however, they could readily be quite deep (beyond 2 metres for bombs and heavy artillery).

1.4 Logistic support available

Logistic support is expected to be essentially limited to whatever the mine clearance team brings with it, or is capable of providing. Many clearance operations will occur in remote areas, with difficult supply routes. Local acquisition of equipment and services beyond simple mechanical repair and labour can not be assumed.

Very limited commercial communications capability can be assumed. Technical support requirements for the equipment will have to be addressed by on-site documentation, or whatever training can be provided to the clearance team before deployment. Again, local expertise to support electronics, or complex electro-mechanical systems, is likely to be limited.

Electromagnetic interference or frequency allocation issues would not often be a problem, however, fully defined spectrum allocation and control can not be assumed.

1.5 Measures of success

The goal in any clearance operation is to remove all of the mines, so that any subsequent user of the area will not be injured. Clearance percentage is therefore the most apparent measure of success. In reality, no clearance method will provide 100 % removal under all conditions, however, current manual methods (if rigidly adhered to) can come close. Mechanically aided clearance may not be able to routinely achieve similar results, depending on the method used.

Other criteria for success will be the clearance rate and clearance cost. Manual clearance rates have a broad range, due to the impact of the soil characteristics and the extent of metallic clutter encountered. Further, the rate will depend on the number of people assigned and the methods used. Hence, clearance cost (dollars per hectare), may be the best measure of success. Reducing the time to clear a given area is the most likely benefit for mechanical systems. Depending on system acquisition, deployment and operating costs, this may result in lower clearance cost. The ultimate decision on the cost-effectiveness of mechanically aided clearance, will be scenario dependent, but increasing clearance rate per unit system (life cycle) cost will always be a goal.

2. Applications Considered

The potential applications for mechanical aids in humanitarian demining are very broad. Not all of the potential applications would necessarily benefit from remote operation, however, many would. Examples of applications considered include:

- vegetation cutters;
- flails;
- ploughs;
- excavators;
- area search detectors; and,
- local search detectors.

The applications considered were not based on an evaluation of the relative merits of different techniques, rather they are presented in the context of an analysis of the types of control requirements that a generic machine of that type would need. The requirements are divided into five technical areas as follows:

- driving control requirements;
- navigation requirements, including path logging;
- actuator control requirements;
- visualization requirements; and,
- data interpretation support requirements.

Driving control encompasses all of the basic control and monitoring functions associated with the platform that the mechanical aid is mounted on. Navigation requirements refer to any requirements to monitor or control the path of the vehicle in a specific frame of reference, be that in absolute "map" coordinates, a relative coordinate system shared by several systems (including detector systems), or in regard to the previous path of the vehicle. Actuator control refers to the manipulation and monitoring of the mechanical aid to move it relative to the prime mover, or to control its actions in general. Visualization requirements refer to any operator requirements to see the operation of the vehicle, or implement, that can't be met by observing the vehicle from a distance. Lastly, data interpretation requirements include any requirement for data processing or graphical data display.

3. Control System Functional Requirements

The requirements analysis led to a set of functional requirements for a generic control system that could be used to operate a broad variety of mechanized equipment. These requirements include:

- control of the valves, relays and actuators to operate both the supporting vehicle and whatever implements may be attached;
- sensing feedback measurements for some of the actuators controlled;
- estimating the motion of the supporting vehicle (relative navigation);
- estimating the position of the vehicle (and possibly the "endpoint" of the implement) in an absolute or geo-referenced frame;
- operator controls for the system;
- indirect view of the area the vehicle is moving into or that the implement is operating in;
- detection processing and spatial registration of detection results;
- recording vehicle track, detector coverage, and detection data results as appropriate; and,
- integrated test tools for self test and system fault diagnosis;

Beyond the specific functional requirements identified, several additional goals were identified for the development work. Paramount among these goals was a desire to make the system easy to use. In addition, the system had to be as reliable as possible and simple to maintain in the event of breakdown. Cost reduction was also a goal. To this end a configurable system that could be augmented for more complex applications was identified as a requirement.

4. System Concept

There were sufficient parallels in the capabilities required for humanitarian demining, and those previously developed for military system, that a decision was made to exploit existing Canadian military system designs as a basis for development. While the military systems were developed for the control of more complex systems than those envisioned for humanitarian demining it is possible to remove high level functions that aren't required.

The system design separates into two logical blocks, the on-board control system and the operator control station. The on-board control system is based on the Ancaeus control system developed by DRDC Suffield. This system has been used in numerous projects including the landmine detection system described in Reference [1]. As applied to humanitarian demining it has a structure as shown in Figure 1. The minimum elements of the system are a data link[2] and the on board control core module. The core module is a custom designed single board computer based on a capable micro-controller. The board incorporates significant amounts of analogue and digital I/O, including several high current drive channels. Four serial communication channels are available along with two controller area network (CAN) fieldbus connections. The serial and CAN connections allow the core module to augmented, where necessary, by navigation instruments or a dedicated navigation processor where the system design warrants. Where required by the visualization requirements, the core module can also be augmented by a video multiplexer and video transmitter. The video multiplexer is used to allow several cameras to be mounted on the remote vehicle, with the view point selection controlled by the multiplexer (and ultimately the operator). The core module of the system was developed jointly by CCMAT and Amtech Aeronautical[3]. The core module can be packaged into a relatively small box (12 by 18 by 24 cm)and the electronics are cooled through case conduction; albeit with small fans to circulate air within the enclosure. The configuration built for CCMAT uses military connectors, however, less expensive industrial connectors can be readily substituted.

The operator control station chosen to support this work is a version of the Vehicle Control Station (VCS) that has been developed jointly between Defence R&D Canada and CDL Systems[4]. The block diagram for the operator control station is shown in Figure 2.

The software is portable to many computing platforms, but for the CCMAT implementation a PC based computer (running Linux) is used. The "core" elements of the control station are the PC and the data link transceiver. A generic control panel is used to provide the operator with conventional joystick and switch controls. The control panel is implemented as generic input devices that are assigned to control functions as part of software configuration; hence, the same hardware can be used or a variety of vehicles with only a change in the switch labels.

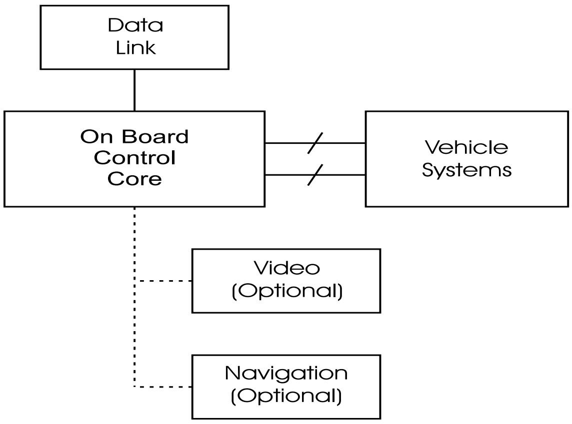

Figure 1: On-board Control System Block Diagram

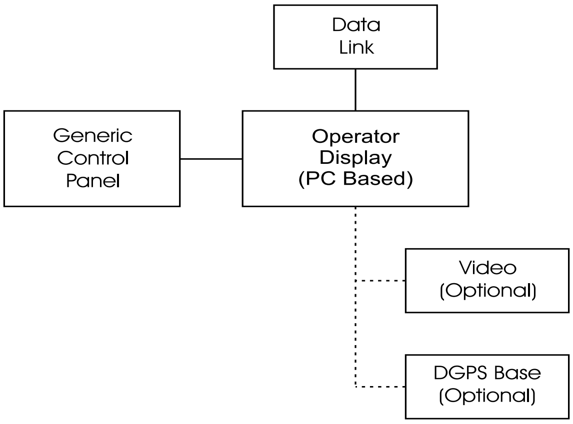

Figure 2: Operator Control Station Block Diagram

As in the case of the on-board control system, the control station configuration can be augmented to support video display for visualization. The system also supports operation of a differential GPS base station to provide correction data to a high accuracy on-board navigation system, if required.

5. Augmented Tele-operation

As noted above, ease of use was felt to be critical to improving the efficiency of mechanized equipment in whatever role that it is employed in. This goal is realized not only through conventional human factors design of the equipment and operator controls, but also in the integration of automation into aspects of system operation that are difficult for the operator. Typically these are tasks where the displacement from the vehicle removes conventional feedback, or in cases where it is difficult

[2] many commercial data links are available, depending on the transmission speed required and the frequency bands available

[3] Amtech Aeronautical Ltd, Medicine Hat, Alberta, CANADA – www.amtech-group.com

[4] CDL Systems Ltd, Calgary, Alberta, CANADA – www.cdlsystems.com

for the operator to visualize and react to abstract information.

Simple examples of this type of targeted automation include automated speed and steering control for the vehicle. In these modes the onboard control system manages engine throttle and gear selection, to maintain whatever speed the operator selects. Steering is also controlled to keep the vehicle on a straight path, unless the operator commands a turn. This frees the operator to focus on “mission related” tasks; these might include keeping a vegetation cutter at an appropriate height, or monitoring a detector system.

Examples of higher level automation that can be readily integrated include automated area coverage and actuator endpoint control. In automated area coverage, the operator merely defines the area for the vehicle to work in (perhaps to cut vegetation or to conduct an area detection scan) and the system manages the vehicle path to ensure that the area is methodically covered, with appropriate overlap. Examples of the screens used to define the area coverage and the resulting vehicle path plan are included as Figures 3 and 4. In many instances the operator will define the area by driving the vehicle around the desired work space and then use the vehicle path recording as the input to the area coverage task. Once the area coverage function is engaged the control system manages the basic vehicle path and speed, with the operator guiding the vehicle around obstacles and focusing their attention on payload operation.

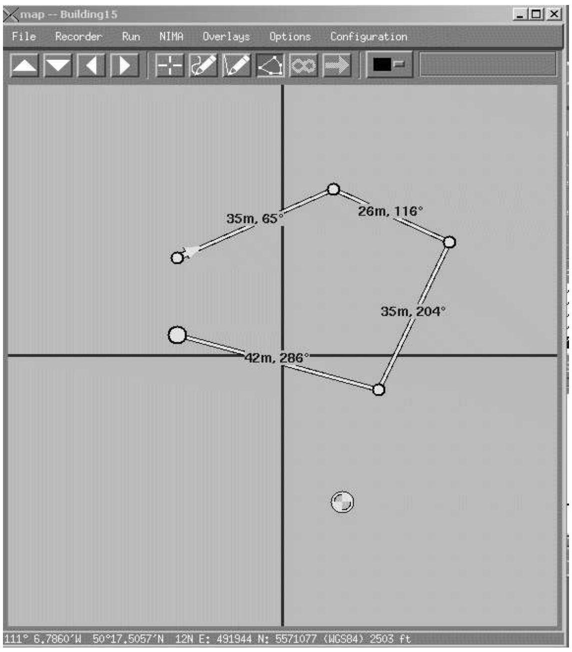

Figure 3: Area Coverage Boundary Definition

Automated endpoint control is simply a method of reducing the task complexity of operations that

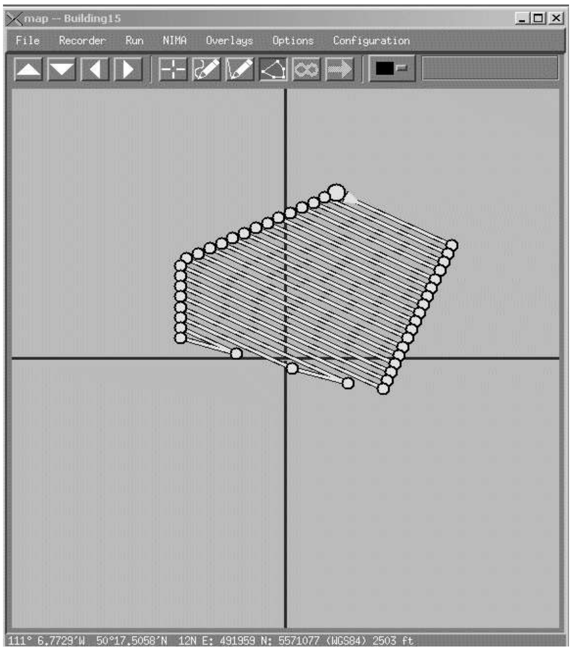

Figure 4: Area Coverage Vehicle Path Plan

use a manipulator, such as an excavator. Rather than having the operator control the motion of the excavator through controlling the individual actuators, the operator control the actuator in a Cartesian space relative to the vehicle (or relative to his visualization view point). The control system then computes the desired individual actuator motions to achieve the desired goal.This reduces the training requirements for some types of manipulators and offsets the lack of feedback that the operator suffers from in a remotely operated system.

6. Demonstration Platforms

CCMAT staff have recognized that theoretical concepts are a “hard sell” in the demining community, so a portion of the research effort is devoted to implementing the concepts in hardware to allow demonstrations in realistic environments. To that end a series of demonstrator activities are underway that exploit the tele-operation system discussed above. Two demonstrations are targeted directly at demonstrating the tele-operation system capabilities and a third exploits the system to demonstrate a scanning detector concept [2]. The first two demonstrators are based on a common platform, a Melroe BobCat. This vehicle has been extensively modified to remove all of the operator controls and to instrument all of the hydraulic actuators[5]. This vehicle can be readily switched between a variety of tools.

In the first demonstration, the vehicle will be

[5] current stroke position of the actuator is measured

equipped with a vegetation cutter. The automated area coverage capabilities of the control system will be exploited in this instance to investigate to what extent an operator can be more effective in this role with that class of operator aid.

The second demonstration on this platform will use an excavator attachment (also instrumented). The goal of this demonstration will be to compare and contrast operator effectiveness and ease of use in endpoint and conventional control modes.

Figure 5: Automated Scanner Demonstration Vehicle

The last demonstration investigates the use of an automated scanning system for conventional mine detectors. This system, when mounted on an unmanned vehicle (as pictured in Figure 5)can be used to detect and localize targets at a distance. This project exploits the tele-operation system to allow rapid integration of such a complex payload.

7. System Status

The development of this system is nearing completion. The control station software is merely minor interface changes to an existing product, and the underlying software is commercially available[6]. The onboard control system core system has been prototyped and is fully functional at this point in time. Minor design revisions will be incorporated in a second revision of the board by the development contractor[7]. Commercialization of the revised version may follow should the demonstrations warrant.

The demonstration platforms are both in the final stages of integration. Actual trials of the systems are expected to commence in November 2002.

[6] from CDL Systems, of Calgary, Alberta, Canada

[7] Amtech Aeronautical of Medicine Hat, Alberta, Canada

8. References

[1] J. E. McFee, V. A. Aitken, et al *A Multi-sensor, Vehicle-mounted, Teleoperated Mine Detector With Data Fusion* Conference on Detection and Remediation Technologies for Mines and Mine-like Targets III, Proc. SPIE, 3392, Orlando, FL, USA, April, 1998

[2] Robert Chesney, Yogadhish Das, *Terrain Adaptive Scanning of Conventional Mine Detectors* IARP Workshop on Robots for Humanitarian Demining(current proceedings), IARP, Vienna, Austria, November, 2002