Published by Elsevier Science on behalf of IFAC

TELEMATIC AND SHARED CONTROL OF MILITARY LAND VEHICLES

Bruce L. Digney *

* *Defence Research Establishment Suffield*
PO Box 4000, Station Main
Medicine Hat, Alberta, T1A 8K6, CANADA
BUS: 403-544-4123, FAX: 403-544-4704,
Bruce.Digney@dres.dnd.ca

Abstract: Many military applications will benefit from the use of unmanned vehicles. However communication realities have limited the effectiveness of the current direct teloperated vehicles. One solution is to increase the on-board autonomy of the vehicle. While this does reduce the communication requirements, the level of machine intelligence is not sufficient to insure operation in extreme situations. Proposed is a shared control solutions that is a synergistic partnership of on-board autonomy and the superior cognitive capabilities of the remote operator. This paper describes work at the *Defence Research Establishment Suffield* (DRES) in teleoperated vehicles, autonomous control systems and discusses the issues and benefits of shared control of military vehicles.

Keywords: Telematics, Unmanned Vehicles, Shared Control, Robot Learning

1. INTRODUCTION

Finite communication bandwidth has limited the situational awareness of the remote operator and transmission delays have limited the unmanned system's rate of change be much slower than the communication latencies the closed control loop. These limitations have led many robotics researchers to pursue higher autonomy in vehicles allowing control to reside onboard eliminating the need for constant communication to the remote operator. However, subsequent limitations in the cognitive capabilities of autonomous control systems have further led researchers to concede that a form of shared control is required. This is true for military applications that can benefit from unmanned vehicles with higher autonomy, but still require human level cognitive capabilities in extreme situations. Indeed, in military applications where lethal force is controlled or a machine error will result in the loss of human life fully removing the human from the loop is not an option. Presented in this paper is an overview of the Defence Research Establishment Suffield's (DRES's) tactical vehicle program including current teleoperated military vehicles and the *Autonomous Land Vehicle Program* (ALV).

2. UNMANNED MILITARY LAND VEHICLES

Research into military land vehicles at DRES has yielded many novel locomotion concept vehicles, teleoperation systems and fielded systems. These projects will be briefly described.

2.1 *Telematic Control with Anceaus*

The *Anceaus* telematic control system has been developed by DRES and is in current use in on many of the vehicles described in this paper (Brosinsky, 2001*a*). Video from the teleoperated vehicle is transmitted to the operator console.

This transmission uses a commercial line of sight video communication system that has difficulties dealing with signal drop out in urban or wooded areas. Additional state information is sent using a separate radio link. This link is capable of two way communication and is further used to send the operator commands to the vehicle. These commands are of a generic form (turn right, stop, etc) with the personality module on each particular vehicle translating the generic commands into specific actuator signals.

2.2 *Scout Vehicle*

Fig. 1. Unmanned Scout Vehicle

The scout vehicle of Figure 1 is a gasoline powered, hydraulic driven, skid steered vehicle used to demonstrate unmanned reconnaissance operations. Configured for teleoperation the scout has a sensor mast that supports a pan-tilt platform used for pointing colour as well as infrared imagery. Its world position is determined using differential GPS and it is steered by deferential control of the speed of the wheels on each side of the vehicle. Telematic control is implemented using the anceaus system. Configured for autonomous operation (as pictured in Figure 1) the scout vehicle has two forward range sensors, laser scanner and stereo vision.

2.3 *Caterpillar D7 Bulldozer*

Fig. 2. Caterpillar D7 Bulldozer

The Caterpillar D7 shown in Figure 2 is capable of both on-board human operation and telematic control. The remote operator controls the vehicle and the blade depth and angle by viewing video transmitted from forward looking cameras. A differential GPS determines the D7's position and orientation which is displayed on the operators console map. Blade control and earth working in general require a skilled operator even for onboard operation. When the control loop latencies are introduced blade control on teleoperated D7 is further complicated. Current work at DRES is striving to automate blade control as well as the repetitive movements common in earth working.

2.4 *Articulated Navigation Testbed (ANT)*

Fig. 3. Articulated Navigation Testbed (ANT)

Shown in Figure 3 is the *Articulated Navigation Testbed* (ANT) concept vehicle. The ANT moves using powered wheels mounted on the ends of powered legs. Each leg has a single controllable degree of freedom revolute joint at the shoulder that can rotate approximately 400 degrees. By lifting the wheels over obstacles the ANT can traverse extreme terrain. Each body module of the ANT has two legs attached to it with each modules connected using a powered articulated joint. The high number of degrees of freedom associated with locomotion alone preclude manual control for manned or telematic operation. A straight forward example of shared control would have have all time critical locomotion processes controlled by the on-board autonomy system with the operator specifying the desired vehicle pose and ground clearance to be maintained. Under extreme conditions the leg control automatic control may be inadequate. In such situations the shared control system allows relaxes the real time criteria and allows for explicit control of the legs by the remote operator. This will allow the ANT to progress through the extreme conditions albeit at a slower rate.

2.5 *Improved Landmine Detection Program (ILDP)*

ILDP shown in Figure 4 represents the culmination of five years of research into vehicles, telematic control and landmine detection systems at

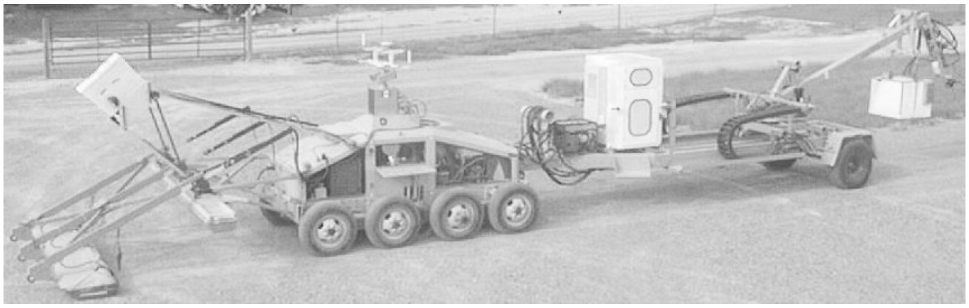

Fig. 4. Improved Landmine Detection Program

DRES. The ILDP vehicle rides on a bogey suspension with flotation tires that maintain a ground pressure below the level that would detonate anti tank mines. It detects landmines by looking for disturbed soil indications in the infrared images, metal content of the ground using electromagnetic signatures and changes in ground dialectic characteristics using ground penetrating radar. When the fusion of these sensors indicates to some threshold probability the presence of a landmine, then thermal neuron activation (TNA) is used as a confirmatory sensor. This requires that the vehicle stop and the TNA be placed over the suspect location. Once the TNA has confirmed the existence of a mine, the area is marked for later remediation. The vehicle is teleoperated using the *anceaus* system. Fusion of the sensor data is done automatically, but the analysis of the infrared imagery for disturbed soil is still performed by human operators. This is an example of a life critical situation where the automatic system is inadequate and a human operator must remain in the loop.

2.6 *Cognitive Colonies*

Fig. 5. Cognitive Colonies

Four robots of the Cognitive Colonies project (currently 10 robots in total) are shown in Figure 5. Cognitive Colonies is a joint project in distributed robotics between DRES, DARPA/ITO and Carnegie Mellon University (Scott Thayer and Digney, 2000). The concept is to deploy 100s or 1000s of small robots and have them cooperate to perform large-scale tasks. Distributed robotics provides greater flexibility, robustness and redundancy than a single large robot. The shear number of robots with their communication and manpower requirements make direct telematic control of all robots impossible. However, a remote operator may need to exert full control over any individual robot periodically.

3. AUTONOMOUS LAND VEHICLE PROGRAM

Given the limitations of current communication and teleoperation systems and real need to remove humans from the hazards of many military scenarios, DRES has began the *Autonomous Land Vehicle Program* ALV. The ALV program strives to increase on-board intelligence and allow for greater independence from the remote operator and hence lessen manpower and communication requirements. The following section describes the research that is contributing to the autonomous vehicle program.

3.1 *Reinforcement Learning of Hierarchical Control Structures*

The use of externally imposed hierarchical structures to reduce the complexity of a learning control system is well established. Within this imposed hierarchy, sequences of actions are abstracted (by hand) into skills and the robot is restricted to fine tuning the prespecified skills. It is clear that having the machine learn the hierarchical structure by itself is an important step to learning more broadly applicable behaviors. In this research (Digney, 1996*a*) (Digney, 1998), a Nested Q-learning technique has been developed that generates a hierarchical control structure as the robot interacts with its world.

3.2 *Assisted Learning*

Given the frailties of real machines and the long learning times required to achieve autonomous operation, it is clear that fully unassisted learning for robots is unrealistic (Digney, 1996*b*). Physical realities make the acquisition of enough training experience prohibitive. In biological agents information is passed through genetically hardwired vital initial behaviors (instincts) and the genetic predisposition to develop useful behaviors. Biological agents also benefit from long periods of infancy in which they are guided and protected before they become self-sustaining, let alone productive. These concepts are referred to as shaping. In this research, methods for pretraining and supplying initial guidance to prepare Nested Q-learning robots for future endeavours are being developed.

3.3 *Outdoor Navigation*

The first step to autonomous vehicles is have the vehicles move about in their world under their own control. This requires that the vehicles sense their surroundings, build models and then plan routes. DRES is developing obstacle avoidance and path planning algorithms based upon 2.5-D geometric models derived from forward-looking range sensor data (laser range finders and stereo vision). These models can represent positive and negative obstacles as well as terrain gradients, from which path planning algorithms can determine safe and optimal paths.

3.4 *Learned Trafficability*

While clearly necessary, geometric information is not sufficient to insure successful navigation in outdoor environments. Many barriers to navigation cannot be represented in a geometric model alone. Barriers such as soft ground, snow, ice, mud, loose sand, compliant vegetation, debris hidden in vegetation and annoyances such as small ruts and washboard effects do not appear in geometric representations (Digney, 2001), (Manduchi, 2000). Detection of these features and conditions will rely upon sensors such as colour vision, texture, IR imaging and instrumented bumpers. Moreover, many of these terrain conditions change their cues from region to region, season to season and even hour to hour. For instance, what image characteristics indicate soft ground in one region may, in another region, mean something different or be entirely meaningless. This changing nature of trafficability makes the need for learning control clear. DRES and its contractors are developing the *Learned Trafficability System* (LTS) that will learn the trafficability characteristics and then adapt as terrain conditions change.

3.5 *Control of Compliant Legs*

Control the many degree of freedom of the ANT's legs and body segments is further complicated by the fact that the wheels form a compliant link with the terrain (Brosinsky, 2001*b*). While at first inspection this may seem like a complication, but on further examination the compliance affords some tolerance to control imperfections and uncertain terrain models. Compliance is also a very important component of biological legs. It allows for the storage of energy during the parts of a gait cycle where energy is abundant and the releasing of that energy during the part of the cycle that energy is in demand. Control algorithms are being developed that allow for energy efficient locomotion.

4. SHARED CONTROL AT DRES

To achieve higher autonomy and yet achieve the performance level required by military applications DRES is developing shared control systems. Shared control is a partnership between the on-board autonomous control system and the remote operator. The autonomy system controls the vehicle during routine operations and the remote operator assumes control during extreme situations. The on-board autonomy system supervises its operation and when it becomes uncertain of its next action it notifies the operator whom assesses the situation and assists the vehicle. The autonomy system then resumes control of the vehicle. Communication and operator attention is kept to a minimum as the autonomy system supervises itself and communicates out only when necessary. Communicated information needs only be sufficient for the operator to determine how to assist the vehicle. For instance, still imagery and state information would be enough to assist a vehicle with a road hazard, but short video clips may be required to assess the intentions of other moving vehicles.

Shared control provides a synergy between operator and autonomous control that utilizes the strengths of both that is well suited to military applications.The benefits and issues involved with telematic, autonomous and shared control of military vehicles are now discussed as well as the research currently pursuing is summarized in the following sections.

4.1 *Military Benefits and Issues*

(1) **Hazardous and Hostile Environment:** Clearly the removal of soldiers from harms way while maintaining the full functionality of the vehicle is desirable. Furthermore, remote operators and autonomous control are more likely to remain calm and make better decisions when not in immediate danger.
(2) **Robot Must Win:** One must remember that conflicts are a competition. There is an hostile opponent, who is actively trying to destroy the vehicle and whatever telematic, shared control or autonomous system is

fielded it must be able to win. If it cannot prevail, having an unmanned vehicle is of little benefit.

(3) **Amplified Use of Manpower:** If a single operator can effectively control a greater number of vehicles then that force will have advantages over a force that requires one person or more per vehicle. By amplifying manpower a force would be able to field more vehicles or deploy the freed personal to other vital roles.

(4) **Persistent Attention:** Many military operations involve persistent observations that fatigue humans, quickly leading to inattentiveness and errors. In a clear application of shared control the machine would untiringly look for scene changes and then enlist human assistance to classify those changes.

(5) **Lethal Force Control:** Current ethical considerations do not permit automatic control of lethal force. Whenever lethal force is to be applied from an unmanned vehicle a human operator must be in direct control.

(6) **Life Critical Operations:** In contrast to lethal force situations there are other situations in which friendly forces are in danger from machine errors. Operations such as the infrared image classification used in the ILDP land mine detection vehicle is done by a human because the confidence of the automatic classification is not high enough to balance risking human lives on a machine error. However other processes such as the fusion algorithms are sufficiently capable and allowed to remain under automatic control.

(7) **Sacrificial Vehicles:** A grim reality of armed conflicts is that losses are acceptable and that sometimes vehicles and personal will be sacrificed for the benefit of remaining force. Clearly it would be desirable to sacrifice an unmanned vehicle. It must be kept in mind that the vehicle is not simply just sacrificed but destroyed while attempting some task. It is required that the unmanned vehicle must be at least as proficient at that task as an on board human.

(8) **Communication Silence and Jamming:** In practice reliable communication links are difficult to insure. This problem is even getting more difficult as forces move into urban areas, into building and underground installations. It is common for the enemy to jam or otherwise disrupt communications. Furthermore, in covert operations communication will give positions or intent away, so communication is kept to a minimum and performed through undetectable means.

(9) **Acceptable Path to Higher Autonomy:** The military community is unwilling to support large leaps in autonomy unless there is an incremental verifiable and demonstrable safe path. In shared control as automation technology matures it can be added and the vehicle gains a little autonomy. Progress is observed by the operator and the autonomy addition proves itself reliable or unreliable. Through such a incremental route levels of autonomy will be accepted that would never be if proposed in a single large step.

4.2 *Shared Control Research*

(1) **Active Hazards:** One of the main assumptions of shared control is that the world is sufficiently static and no harm will come to the vehicle while it waits for assistance. This assumption may hold in civilian applications but it is common that military applications are actively hostile. Evasive actions are often required faster than communication rates. The vehicle must now weight its action uncertainty against the uncertainty in receiving timely human assistance. Furthermore the vehicle must also weigh the relative dangers of inaction with the danger of those uncertain actions. This requires that the vehicle acquire some knowledge of the relative dangers of its world and the hostile entities within it.

(2) **Reverse Shared Control:** The usual flow of assistance if from the human operator to the autonomy system. The defining concept is that that the machine handles the routine and the human supplies the extra cognitive capabilities when required. While this will hold true in most cases there are cases where the machine can lend higher level assistance to a novice operator. For instance when the learned trafficability system has been trained to predict the trafficablity of a region the LTS can assist a novice on-board operator who is not yet familiar with the region.

(3) **Operators Apprentice:** A vehicle can be uncertain of its next action for two reasons. One is that the vehicle does not have the cognitive capabilities to even understand what state it is in. This would be the case where complex image processing is required and the vehicle cannot identify pertinent aspects of the scene. Second is when the vehicle can understand what state it is in, it just does not know what action to take. If in this situation if the vehicle could learn from the operator's assistance it would be less likely to require assistance in the future. Research is using current work in reinforcement learning, assisted learning and learning from imitation to facilitate learning from the operator's assistance signal.

(4) **Multiple Operators:** It is expected that during operation vehicles under shared control will be directed to perform tasks from many operators as well as receive assistance

from many operators. Prioritizing operator requests and ranking quality of assistance provided will be essential.

(5) **Asynchronous Assistance and Multitasking:** Given the realities of communication a shared control vehicle may be out of contact for long periods of time and latencies in assistance may be large. Assuming that a vehicle does not experience an actively hostile and fatal situation there are any number of non fatal situations that the vehicle can be in and in need of assistance. Instead of waiting for assistances which can be an arbitrary long period of time, it would be desirable for the vehicle to switch to another task and return to the problem task when assistance arrives. This capability to asynchronously interweave tasks and assistance will minimize time spent inactive while waiting for assistance.

(6) **Shared Control of Distributed Robots:** Control of many autonomous robots by a far fewer number of operators (in ratios of 100 robots to 1 operator) presents problems for conventional control interfaces. In the cognitive colonies project swarms of robots autonomously form and dissolve cooperating teams as required. As it is impossible for a single operator to direct at the individual robot level, the colonies control system autonomously directs the individual and robot teams. Current work on cognitive colonies at CMU is developing interfaces that impart the operators intentions to the colony and report back the current colony structure and progress. A shared control system must be able to assist the robots at both the individual and team levels. This requires that teams collectively understand the certainty with which they act and agree on when they are sufficiently uncertain to require assistance. As the tactics are generated by the colony the operator may suggest entirely new tactics or assist the team using its current self generated tactics.

(7) **Self-Forming Communication Relays:** A long established method for dealing with communication difficulties is to provide relays. Usually one or more relays are placed in a communication optimal locations and relay information between extreme locations. These are semi-stationary installations that function as relays then are disabled and relocated as needed. Advances in communication and ad hoc free forming communications networks are making it possible for these relay nodes to be mobile and the networks can dynamically configure itself by not only redirecting communication traffic, but by physically relocating the nodes. This capability is especially useful in urban operations as the communication can established and maintained within concrete canyons and the depths of building interiors with a moving force.

(8) **Communication Silence:** Operating without communication provides challenges for both human and autonomous vehicles, as the cost of giving away information must be weighted against the benefit of receiving assistance. In as shared control vehicle if the cost of breaking communication silence is too high, the unmanned vehicle may be able to continue in a reduced capacity, become ineffective or sacrificed.

5. CONCLUSIONS

The benefits listed in this paper make it clear that autonomous vehicles under a shared control system will play a major role in fielding unmanned military vehicles. Many research issues still need to be resolved but the synergistic arrangement of man and machine is sound. Research is required in autonomous control, perception, uncertainty modeling and human factors. Of particular importance is human factors in which the man machine interface will evolve as the the relationship between man and machine becomes more of a partnership and less direct master-slave.

6. REFERENCES

Brosinsky, Chris (2001*a*). The application of telematics in the canadian landmine detection capability. IFAC Conference - Telematics Applications in Automation and Robotics.

Brosinsky, Chris (2001*b*). Articulated navigation test-bed. SPIE-Aerosense.

Digney, Bruce L. (1996*a*). Emergent hierarchical control structures: Learning reactive hierarchical relationships in reinforcement environments. 4th International Conference of Simulation of Adaptive Behavior, SAB 96. MIT/Bradford Books. pp. 363–.

Digney, Bruce L. (1996*b*). Learning and shaping in emergent hierarchical control systems. In Proceedings of Space'96 and Robots for Challenging Environments II.

Digney, Bruce L. (1998). Learning hierarchical control structures for multiple tasks and changing environments. Simulation of Adaptive Behavior SAB98. MIT/Bradford Books.

Digney, Bruce. L. (2001). Learned trafficability models. SPIE-Aerosense.

Manduchi, Roberto (2000). Learning terrain classification for autonomous cross country navigations. Darpa MARS-SDR meeting.

Scott Thayer, Tony Stenz and Bruce Digney (2000). Cognitive colonies. Darpa MARS-SDR meeting.