Defence Research and Development Canada
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The Multi-Agent Tactical Sentry

Designing and Delivering Robots to the CF

J. Giesbrecht, S. Penzes, and B. Fairbrother

Defence R&D Canada

Technical Report

DRDC Suffield TR 2008-148

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Abstract

The Multi-Agent Tactical Sentry (MATS) represents one of the most advanced robotic systems in day-to-day military operation anywhere in the world. It addresses the Canadian Forces (CF) requirement to remotely detect Nuclear, Biological, and Chemical threats (NBC), integrating a suite of primary NBC sensors onto a remotely operated vehicle. The system was initially designed and built from the ground up at Defence R&D Canada – Suffield in under 30 months, and has become an operationally important component of the Canadian Joint Incidence Response Unit (CJIRU), and their continually evolving techniques, tactics, and procedures (TTPs). This paper describes the technology and development of the MATS system, but more importantly it examines the many lessons learned in designing and delivering a robotic vehicle to a military client.

Résumé

La sentinelle multi-agents tactique (SMAT) représente l'un des systèmes robotisés les plus perfectionnés au monde des activités militaires quotidiennes. Il répond aux besoins des FC de détecter à distance les menaces nucléaires, biologiques et chimiques (NBC) en intégrant une série de capteurs primaires NBC dans un véhicule commandé à distance. Le systme a été conu initialement et construit dans sa totalité à R & D pour la défense Canada – Suffield en moins de 30 mois et il est devenu une composante opérationnelle importante de l'Unité interarmées d'intervention du Canada (UIIC) et de ses techniques, tactiques et méthodes (TTP) qui sont en évolution constante. Cet article décrit la technologie et la mise au point du système SMAT mais il examine surtout les nombreuses leçons acquises lors de la conception et de la livraison d'un véhicule robotisé à un client militaire.

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Executive summary

The Multi-Agent Tactical Sentry

J. Giesbrecht, S. Penzes, B. Fairbrother; DRDC Suffield TR 2008-148; Defence R&D Canada – Suffield; August 2008.

Background: In 2003, researchers at Defence R&D Canada – Suffield undertook the Multi-Agent Tactical Sentry (MATS) project to develop a robotic vehicle capable of improving Canadian Forces (CF) response to Chemical, Biological, Radiological and Nuclear (CBRN) events. The project, based on the wealth of Defence R&D Canada – Suffield experience in both robotic vehicles and CBRN detection, was motivated to provide stand-off capabilities for these threats in the wake of world events at that time.

Principal Results: The MATS system uses an integrated CBRN sensor suite mounted on the back of a tele-operated robotic all-terrain vehicle. Control is provided through a groundstation mounted in a remote mobile command post relaying video, audio, and CBRN sensor data to the operators. As of 2008, Defence R&D Canada – Suffield has designed and delivered four MATS vehicles, four control stations and two command posts for use by the Canadian Joint Incident Response Unit (CJIRU). Defence R&D Canada – Suffield has also been an important contributor in creating realistic training scenarios to develop operator capabilities.

Significance of Results: MATS has been a landmark project within DRDC, delivering one of a kind capabilities directly into the hands of the CF. It has become the eyes and ears of the CJIRU, and continues to be used on a day-to-day basis. The system is not only technically advanced and well-suited to the job, but has also been a shining example that robotic assets can be reliable and easy to use.

During the course of the project, many lessons were learned about delivering projects directly to the CF, and more specifically about introducing robotics to a military client. Besides the technical development, it became obvious that the human factors and training issues must not be overlooked when developing a new piece of technology. Having direct interaction and feedback from the end users throughout the process was paramount to success. The military personnel were a valuable resource for important features and useability concerns, and consultation with them was key to their enthusiastic acceptance of the end product.

Future Plans: Work is still ongoing with the MATS project to expand its capabilities and roles. A robotic arm is being integrated to give the system the ability to interact with its environment, along with a 3D scene modeler to improve situational awareness. It is foreseen that robotic vehicles such as MATS will begin to move beyond niche roles with the CF and will be more and more a part of standard army equipment.

Sommaire

The Multi-Agent Tactical Sentry

J. Giesbrecht, S. Penzes, B. Fairbrother ; DRDC Suffield TR 2008-148 ; R & D pour la défense Canada – Suffield ; août 2008.

Antécédents : En 2003, les chercheurs de R & D pour la défense Canada – Suffield ont entrepris le projet de la sentinelle multi-agents tactique (SMAT) visant à mettre au point un véhicule robotisé capable d'améliorer la réponse des Forces canadiennes (FC) aux évènements chimiques, biologiques, radiologiques et nucléaires (CBRN). Le projet, basé sur la richesse de l'expérience de R & D pour la défense Canada – Suffield dans le domaine des véhicules robotisés et la détection CBRN, a été incité à fournir des capacités de détection à distance pour les menaces qui commenaient à peser sur le monde à cette époque.

Les résultats principaux : Le système SMAT utilise un capteur CBRN intégré monté à l'arrière d'un véhicule robotisé tout terrain opéré à distance. La commande s'effectue d'une station au sol montée dans un poste de commande à distance mobile communiquant les données des capteurs vidéos, audios et CBRN aux opérateurs. Depuis 2008, R & D pour la défense Canada – Suffield a conu et livré quatre véhicules SMAT, quatre stations de contrle et deux postes de commande devant tre utilisés par l'Unité interarmées d'intervention du Canada (UIIC). R & D pour la défense Canada – Suffield a aussi contribué de manière importante à créer des scénarios de formation réalistes pour mettre au point les capacités en opérateurs.

Portée des résultats : Le système SMAT est un projet majeur réalisé par RDDC consistant à livrer des capacités uniques en leur genre directement entre les mains des FC. Il est devenu les yeux et les oreilles de l'UIIC et continue à tre utilisé quotidiennement. Non seulement le système est-il techniquement supérieur et bien adapté à la tche mais il est aussi un exemple indéniable que les outils robotisés sont des atouts fiables et faciles à utiliser.

Durant le cours du projet, on a acquis beaucoup de leçons concernant la livraison directe de projet aux FC et surtout l'introduction de la robotique à un client militaire. Il est apparu évident qu'en addition de la mise au point technique, les facteurs humains et les problèmes de formation ne doivent pas tre négligés durant la mise au point d'un nouvel élément technologique. Il est d'une importance capitale d'interagir avec les entités finales et de tenir compte de leurs remarques tout au long du processus de la mise au point. Le personnel militaire a été une ressource précieuse concernant certaines caractéristiques importantes et les préoccupations relatives à l'utilisation ; les consulter a été à la clé de leur enthousiasme à accepter le produit fini.

Perspectives d'avenir : Les travaux du projet SMAT continuent pour étendre ses capacités et ses rles. Un bras robotisé est en voie d'tre intégré pour donner au système la capacité d'interagir avec son milieu et il est accompagné d'un modélisateur de scènes en 3 D pour améliorer la reconnaissance de son environnement. On prévoit que les véhicules robotisés tels que le SMAT vont commencer à tre utilisé par les FC au-delà des leurs rles traditionnels et feron de plus en plus partie de l'équipement militaire courant.

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1 Introduction

Defence R&D Canada – Suffield assists the Canadian Forces (CF) in the conduct of their operations through Science and Technology development. The personnel of the Autonomous Intelligent Systems Section (AISS) at Defence R&D Canada – Suffield have been developing, testing, and fielding unmanned systems for more than 30 years. While the current focus is on the definition, development, and exploitation of autonomous behaviours and systems, past effort was primarily focused on telerobotic operations. Both in the early days and today, it is believed that there is no substitute for having the man in the loop during military operations.

After the World Trade Center and Tokyo subway attacks, military organizations have expanded the abilities of their first responders to a wide variety of asymmetric threats. The Canadian Directorate of Nuclear, Biological, and Chemical Detection (DNBCD) provides national and international first response to Chemical, Biological, Radiological, and Nuclear events (CBRN). The Multi-Agent Tactical Sentry (MATS) robot fills the DNBCD requirement for standoff detection of these threats.

The MATS system (Figure 1) uses an integrated sensor suite mounted on the back of a tele-operated robotic vehicle. A groundstation mounted in a remote mobile command post removed from potential threats provides vehicle control, system status, CBRN data from sensors, and a video display from the vehicle. The mobile command post and custom built transport trailer allow the CF operators to respond and deploy very rapidly to CBRN events. Four MATS systems are now in service with the Canadian Joint Incidence Response Unit (CJIRU).

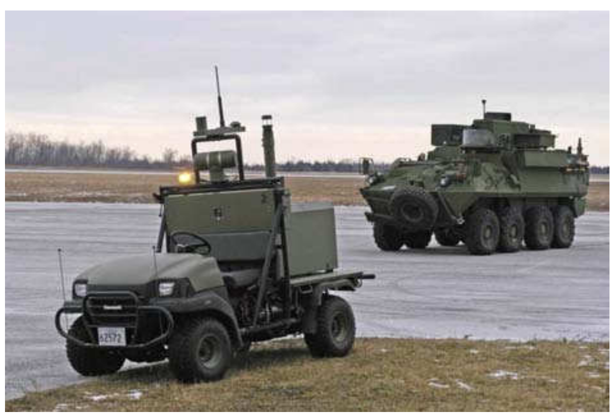
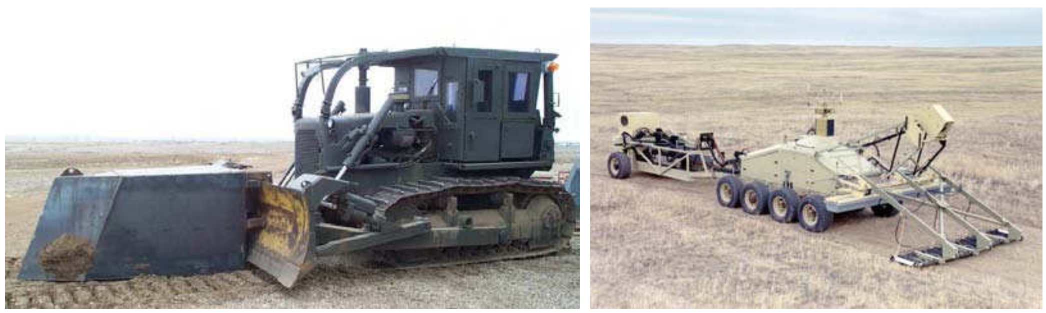


Figure 1: *The Multi-Agent Tactical Sentry.*

MATS has been a landmark project within DRDC, as it comprises one of the most advanced robotic systems in day-to-day military service anywhere in the world. CJIRU members commented that it is “the eyes and ears of the unit”. This paper presents the evolution and developments of the Multi-Agent Tactical Sentry project, and a description of its subsystems and the integration effort required to create the final system. More importantly, it describes the lessons learned in designing robotic vehicles for use by CF soldiers, and delivering such a system to a military organization. The key to the success of the MATS project has been the involvement of the CF client from the very beginning, continuing to the present.

2 Background

The MATS project results derived from various efforts at DRDC Suffield over the past three decades. Research in control and operations of remote vehicles was the primary driving factor, but expertise in systems integration, sensor fusion, and CBRN agent monitoring also contributed to the result. Early efforts were aimed at the development of a suitable control system architecture. The resulting ANCÆUS architecture has provided tele-operation capabilities for numerous systems, such as the robotic D6 Caterpillar shown in Figure 2(a). It served as the lead vehicle in a Canadian Forces urban assault exercise on an occupied building, with the blade-mounted ram creating an entry point for the soldiers.



(a) Tele-operated D6 Caterpillar (b) ILDP Prototype

Figure 2: *Tele-operated DRDC - Suffield robotic vehicles.*

Figure 2(b) shows another example, the Improved Landmine Detection Project (ILDP). It used a custom built platform (operated with the ANCÆUS control system) and an integrated suite of sensors to create an improved ability to remotely detect landmines. The expertise required to properly fuse the data from the disparate sensors for a more capable overall system (i.e. lower false alarm rates and higher probabilities of detection) was to prove useful during the course of the MATS project. The ILDP prototype went through a commercialization process. An engineering iteration was completed and General Dynamics Canada created the Improved Landmine Detection System (ILDS) shown in Figure 3. The CF has subsequently deployed this system in Afghanistan.

Defence R&D Canada – Suffield also has an active chemical and biological defence program. Staff of the Chemical and Biological Defence Section (CBDS) work to provide the CF with improved detection and protection against CB agents. Anticipating the CB threat during the Gulf War in 1991, they created a high priority project to provide perimeter defence for the CF areas of deployment in the Gulf. The result was the Mobile Atmospheric Sampling and Identification Facility (MASIF). Its deployment contained two parts, the Mobile Air Sampling Unit (MASU) and the Mobile AGent IDentification Unit (MAGIDU) (Figure 4(a)). Multiple MASUs remotely sample and detect CB threats and the portable MAGIDU field laboratory processes the results. The probability of use of CB agents in an

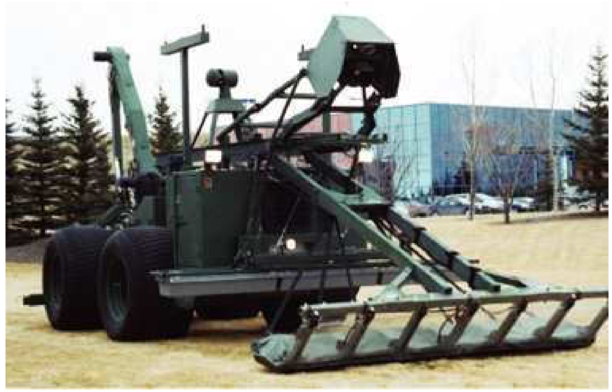
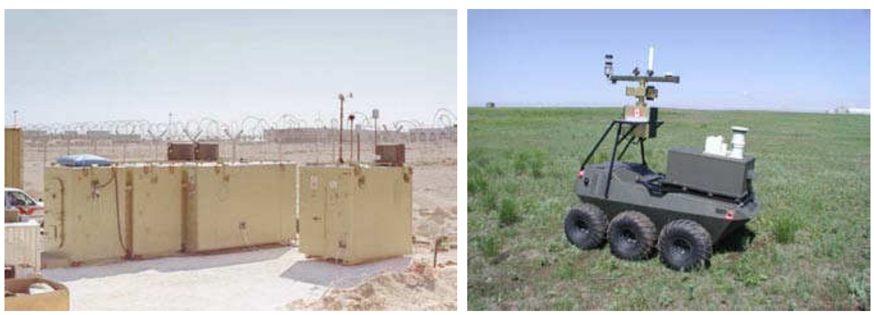


Figure 3: *The Improved Landmine Detection Systems (ILDS).*

asymmetric threat attack has lead CBDS staff to continue developing improved methods and hardware to detect and mitigate the effects. One notable result was the development and commercialization of the FLuorescence Aerosol Particle Sensor (FLAPS). FLAPS detects and characterizes airborne biological threats via particle size and fluorescence.



(a) MAGIDU and MASU units deployed during the Gulf War

(b) SCOUT vehicle with FLAPS unit

Figure 4: *Integration of detection and robot technologies.*

In the late 1990s AISS staff recognized the importance of integrating the robotic and CBRN capabilities. At that time, CBRN point detection systems required either static emplacement or handheld devices. Improved remote control of smaller vehicles combined with smaller fixed point sensors could provide substantially improved remote monitoring and detection of CBRN threats. This would have substantial impact on the CBRN techniques, tactics and procedures (TTPs) practiced by the Canadian Forces. The prototype effort is shown in Figure 4(b). SCOUT is an AISS testbed for various experiments in remote operations. The FLAPS unit used was a pre-commercial engineering unit. Local testing on the CFB Suffield Experimental Proving Ground (EPG) circa 2000 validated the concept and indicated that considerable gains were realizable through the proper integration of the remote sensor displays. This involved providing readouts from both the primary and ancillary sensors with a display of properly fused data from all of the onboard sensors. However, progress was dependant on the availability of AISS personnel who were involved in numerous other projects. That changed on Sept. 11, 2001.

3 Project Formulation

3.1 Project History

The Washington and New York terrorist attacks immediately caused stakeholders to re-assess the strengths and effectiveness of the asymmetric threat. Governments began to seriously pursue technical, procedural, and operational solutions to deal with the threat of asymmetric warfare. The CF DNBCD was tasked to create the Joint NBCD Company (Joint Coy), which came into service in December 2002. DNBCD staff repeatedly visited Defence R&D Canada – Suffield in the formulation stages, during which DNBCD senior staff were briefed about the ongoing creation of mobile CB detection system. Initial trials were already planned for CFB Wainwright in June 2003, which DNBCD and Joint Coy staff attended and participated in.

The trial plan called for two remote platforms to detect and localize simulated CBRN threats to verify the original design concept. The treed rolling hill environment at CFB Wainwright (versus the prairie environment at CFB Suffield) provided an added challenge to the trial series. During the various trial scenarios, biological and chemical agent simulants were dispersed and radiological check sources were placed, as shown in Figure 5. In this figure the pipe section simulates a downed chemical missile with vaporized chemical simulant. The military operators from the Joint Coy were only told of its existence and not its location. They were able to localize the threat through an upwind search pattern. The Scout vehicle's primary sensors were integrated in an upgraded enclosure containing air sampling and onboard data handling computers. The commercial earthmoving HAZMAT vehicle in the background was also modified for remote operations. It is shown spraying down the threat with an on-board basic decontamination suite.

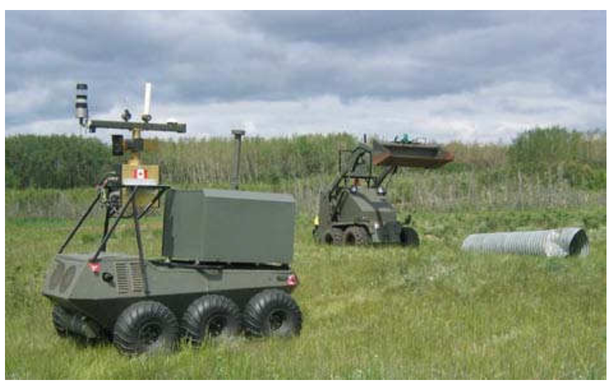


Figure 5: *CFB Wainright deployment scenario.*

With the success of the CFB Wainright exercise, the advanced prototype state, the alignment of the DRDC and DNBCD mandates, and the pressing requirement to address the threat, final project approval came in August 2003. This was the official start of the MATS project.

3.2 Project Delivery

DNBCD created a Statement of Requirement (SOR) identifying the need for a mobile CBRN detection capability. This mechanism allowed for the negotiations for the level of effort and project costs. Key deliverables were:

- Two MATS remote vehicles with integrated CBRN sensors (as provided by the DNBCD),
- Two portable groundstations to control the MATS vehicles,
- Provision of command and control infrastructure (e.g. video links, pan/tilt camera units, command links etc),
- An integrated display of primary, ancillary, and vehicle sensor data combined with suitable C2 (e.g. GIS) information,
- C2 infrastructure installation in a suitable command post (CP),
- Operator and maintainer training material and illustrated parts manuals,
- Operator and maintainer user and troubleshooting documentation.

Early delivery of one of the MATS vehicles in the summer of 2004 allowed operator and maintainer training on the CFB Suffield EPG. The vehicle was also deployed for early testing at CFB Trenton and CFB Petawawa without sensors. Final delivery to the Joint Coy came in November 2004 for their Capability Milestone 4 (CM4) exercise, at which time the operation of the MATS systems was qualified. DRDC personnel attended the CM4 exercise, providing operational and technical support. However, the Joint Coy personnel were already familiar enough with vehicle operation that the support was limited to system level operation and trouble-shooting.

Initial user trial success prompted the acquisition of two more MATS systems for the Joint Coy. A fifth unit was also built for DRDC development testing, and as a “hot spare”. DRDC agreed, provided that a commercial partner could be identified for manufacturing and integration support. Meggitt Defence Systems Canada was contracted to provide this service, and their staff were stationed at Suffield and were actively involved in the creation of MATS systems 3,4 and 5 which were delivered to the Joint Coy in November 2005.

Since the delivery of the 4 in-service MATS systems, the Joint Coy has become the Canadian Joint Incidence Response Unit (CJIRU), and the MATS systems has become a key component in their response team.

4 MATS System

DRDC personnel designed and manufactured the original MATS units at the Building 15 complex on the Suffield EPG. Solutions Thru Software, a local high tech contractor, provided groundstation software and hardware integration support. The DRDC manpower allocated to the project was approximately 5 full time equivalents. Over the 16 months of the project there were also various testing and integration support services beyond those identified in the original SOR. Examples include: prototype evaluation and preliminary integration of numerous primary CBRN sensors, modification of CF supplied command post mounted on a military pattern truck, acquisition, modification, and integration of command post infrastructure including a 36 foot pneumatic mast complete with compressor and controller, and suitability testing of various infrastructure components such as a CF Tactically Quiet 10kW generator. A picture of the first delivered system is shown in Figure 6. The remainder of this section provides details about the design of the system.

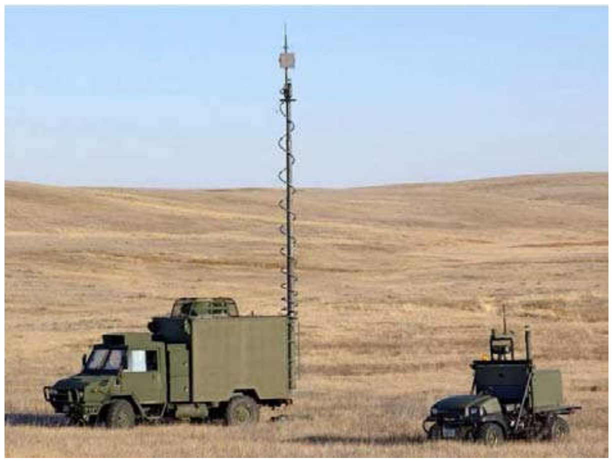


Figure 6: *The initial delivery of the MATS system.*

4.1 Vehicle

To convert the diesel-powered Kawasaki Mule 3010 into a robotic MATS vehicle several modifications and additions were made. As many vehicle parts as possible were left unmodified to improve the ability of the CF to locally buy replacement parts. Steering, throttle and shifting actuators were added. The roll bar system was replaced to allow the housing of the teleoperation electronics, antennas and cameras. A fold down portion reduced the vehicle's height for loading and unloading on the transport trailers and aircraft. Additional batteries enabled the electronics to operate at 24 volts while maintaining a 12 volt system for the basic Mule engine operation. Sensors were added to enable the operator to monitor vehicle health and speed.

Defence R&D Canada – Suffield personnel also developed other electronic subsystems:

- Relay box for computer to actuator control
- Navigation Module with sensors for an inertial navigation and a custom computer to integrate GPS position,
- Vehicle Control Processor (VCP) for vehicle control computations including conversion of transmitted high level commands to actuator level commands,

- Video Multiplexer which switches and transmits the various onboard video signals to the groundstation.
- A digital data link for vehicle commands, and an analog video link

These electronic modules function within the DRDC developed ANCÆUS robotic control architecture, which includes a command and control protocol and communication interfaces for a wide variety of robotic systems. It has been successful demonstrated on a wide variety of DRDC vehicles, including the CAT D6 and ILDP systems described earlier.

The conversion process occurred over a short time and relied heavily upon staff experience. It is noteworthy that the vehicle selection process began in August 2003 and a completed unit was delivered in November 2004. Furthermore, the Kawasaki unit was the first time that a robotic conversion had been done for an Ackermann steered vehicle at Defence R&D Canada – Suffield. The considerable expertise of the AISS project staff combined with the flexibility of the ANCÆUS architecture allowed for a complete conversion from initial selection to delivery to occur in just 14 months.

4.2 Primary Sensor Suite

An integrated enclosure on the rear deck of the vehicle houses most of the CBRN sensors (Figure 7). The nuclear detection sensor head is mounted in a ruggedized container in the trailer receiver at the rear of the vehicle. The enclosure provides environmental protection and vibration isolation for the more sensitive components. Additional space was left to account for possible future changes to the primary sensors.

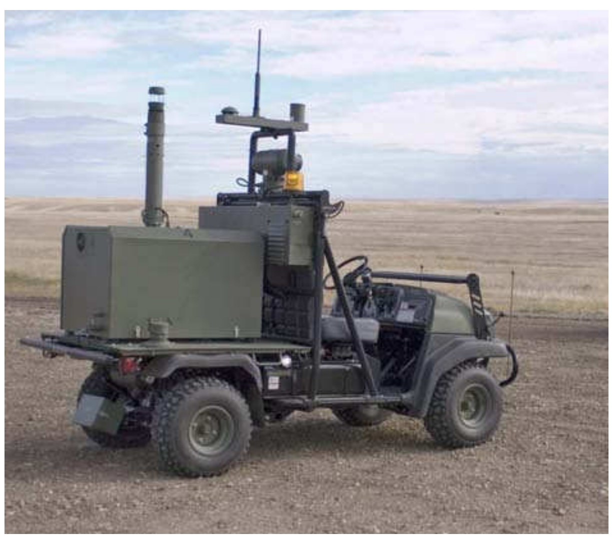


Figure 7: *The MATS sensor suite.*

The enclosure also contains necessary infrastructure components. A particle concentrator draws in external air, using virtual impactor techniques to mechanically filter the incoming airborne particles to test for biological agents. Air taps provide test points for the chemical agent sensors. Ceramic heaters in the air intake stack maintain an ice free intake. The milSpec weather station is mounted on top of the intake stack. A custom sensor suite computer collects all the sensor data. It receives commands from the Vehicle Control Processor, controlling all activity in the enclosure and returning collected data for serial transmission to the groundstation. The enclosure design allows removal from the vehicle for dismounted operations. The sensor suite can interpret, collect, and transmit all of the data relevant to the operations of the CBRN detection process.

4.3 Ancillary Subsystems

Although the primary sensor integration (i.e. data collection, display, and logging) is critical to system level performance, the overall performance is greatly enhanced by the inclusion of various ancillary subsystems.

Two TACMET milSpec weather stations, one on the command post and the other on the remote vehicle aid in characterizing the potential downwind threat and give insight into local anomalies such as building turbulance. Differences in meteorological conditions between the vehicle and command post allow the operators to provide a higher fidelity report of threat progress. This also helps in determining ingress and egress lanes to the hot zone when MATS is used in a first responder capacity.

GPS provides a rolling map display on the groundstation, which can record the position of CBRN detection events. A learned waypoint mode records GPS waypoints which can be automatically or manually created. Once a path is accumulated, the vehicle can retrace or loop on this path for "hands free" operation, substantially reducing operator workload, enabling extended duration operations. Two MATS systems patrolling in this mode are shown in Figure 8.

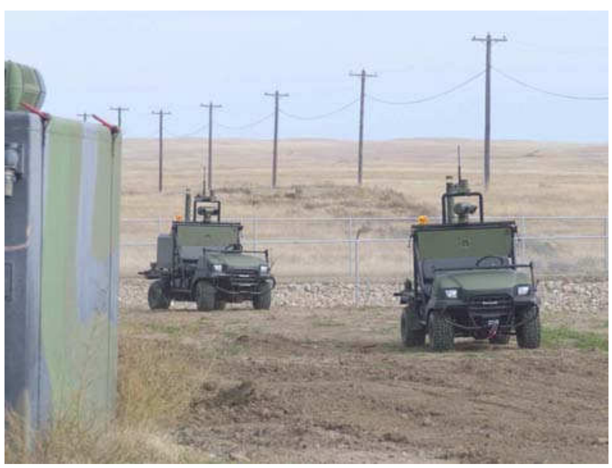
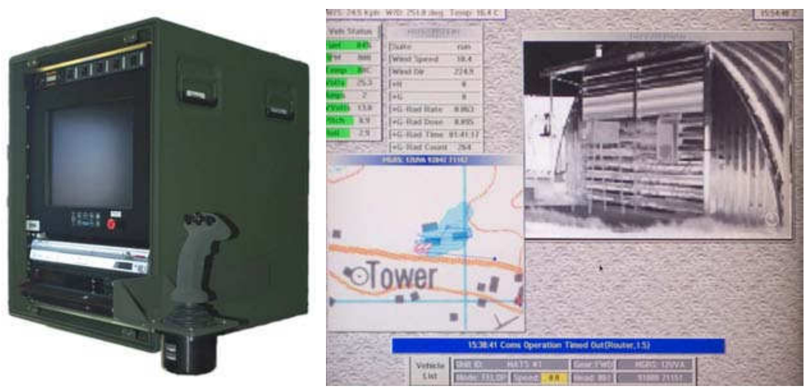


Figure 8: *MATS vehicles patrolling in "learned waypoint mode".*

The Digital Imaging Inc. DI-5000 video pan and tilt unit is the vehicle operator's primary input sensor. It contains visual and thermal cameras and a laser rangefinder. The thumb-stick of the joystick controls the pan / tilt motion and keyboard commands switch between thermal and standard video feeds. Customizable programmable viewpoints are also available from keyboard commands, used to switch between the forward driving view and the left, right, and rearward checkpoints. The camera is often used at its maximum optical zoom during operations when the operator attempts to gather information about a specific element in the threat environment. The operators typically turn the vehicle engine vehicle off if the camera's digital zoom is engaged, limiting the shake in the video signal.

4.4 Groundstation

Originally each remote vehicle was to have its own groundstation. Future designs may revise this model (e.g. a single groundstation might be used to control multiple remote vehicles) depending on operational requirements. The groundstation is contained in a hardened portable rackmount container. The 36 inch rack contains a high brightness LCD display, the rackmount computer / keyboard, a harddrive / DVD based digital video recording system, the processing portion of the analog video subsystem, and the operators joystick. The groundstation is shown in Figure 9(a) and a screenshot of the operator display is shown in Figure 9(b). The case has built-in tie down points to fix it to the working surface of the command post. As the groundstation is the only link between the human operator and the remote vehicle, its operational aspects define the success of the MATS project.



(a) MATS Groundstation (b) MATS Groundstation Display

Figure 9: *The MATS control station.*

5 System Integration

The previous section detailed the major components that constitute a MATS system. Some of the subsystems required extensive design, implementation, and testing effort to complete (e.g. the groundstation) and some only required basic design and manufacture (e.g. configuration of the vehicle mounted antenna array). However all of them required considerable integration effort to meet overall system expectations. Although not comprehensive, some of the efforts are detailed in this section.

5.1 Remote Vehicle

The control system implementation and architecture for remote operations required considerable design effort. The original SOR required that the vehicle be easily switched between remote and manned operations (Figure 10). Since the changeover would be done by military personnel who might be operating in adverse conditions (e.g. poor weather, while wearing full CBRN suits, etc) both the design and hardware required close scrutiny. Therefore, the change from manned to remote operations uses only a single, easy to access switch. All of the actuators (e.g. steering, gear shift, throttle) can be operated in both modes without any additional reconfiguration. The groundstation software does exert some control over the vehicle in the event that the driver has left the vehicle in an unexpected configuration. For example:

- The groundstation has an electronic speed governor if the driver leaves the vehicle in high gear.
- Warnings are issued if the 24V and 12V power system switches are left in the wrong positions (so as to prevent unnecessary battery drain).
- Warnings are issued if the auxiliary brake system is left in the wrong control position.

The vehicle brake system also required modification. Consider the process to park the vehicle in a fixed position: A human driver moves the vehicle to the location, turns off the ignition, and activates the emergency handbrake. A remotely controllable hydraulic brake booster accomplishes the same under remote operations and ensures that the vehicle will always “fail-safe”. The master brake cylinder was modified and the system was configured to activate the brake whenever the vehicle is powered down. A bypass valve allows for towing or in case of an electrical system failure.

Considerable design and testing was done during the development of the control architecture to ensure that the years of remote operations experience of DRDC personnel was adequately embodied. For example, while driving a curve a human driving the vehicle partially determines appropriate speed from steering wheel force feedback. This sensitivity is lost to a remote operator using a joystick. This problem is exacerbated by the fact that a local operator has peripheral vision to help measure vehicle attitude, whereas the remote operator only has the camera’s limited field of view. Therefore, the response curve of the joystick is modified in real time based on vehicle speed. This required extensive testing to create the appropriate feel to the adaptive response curve.

To capture and codify three decades experience, the remote vehicle design and its operational characteristics was a challenge for the design team, especially since the military operators would have received only minimal training.

5.2 Command Post

In the original SOR, the groundstations and associated operational infrastructure would be integrated into a portable command post. Current TTPs call for deployment of the

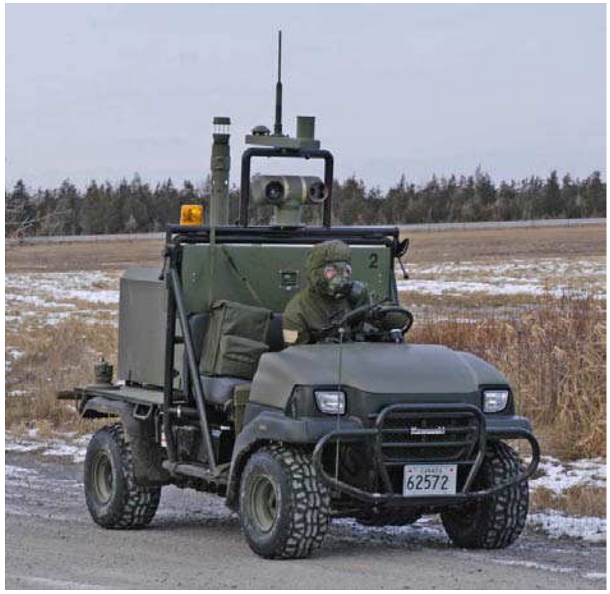
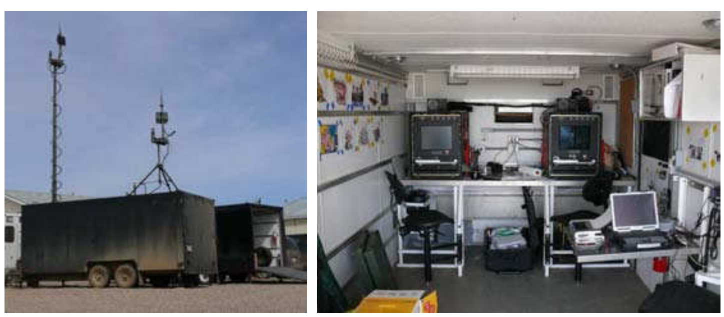


Figure 10: *Manned operation of the MATS system.*

MATS systems in pairs, with two groundstations installed adjacent to each other. The initial command post was installed in a variant of the CF LSVW truck, as shown in Figure 6.

A more spacious command post has now been developed based on an enclosed trailer. It also serves as transport for the MATS vehicles themselves. Two of these command posts are shown as deployed in Figure 11.



(a) (b)

Figure 11: *The command post with antennas deployed for controlling two MATS vehicles.*

Structural, electrical, and installation modifications were made to accommodate the groundstations, operators, network and radio. An external telescoping mast provides extended radio communications. The trailers have a rear drop down ramp so the MATS units can easily be driven into the trailer and strapped down. The trailers are certified for air transport via the C130 Hercules aircraft.

Besides the MATS vehicle drivers, a crew commander is situated in the CP in such a fashion that he can make operational decisions based on operator feedback. His laptop is also networked to the two groundstations, allowing him to control various aspects of the groundstaton operations and collect forensic data (e.g. sensor logs, screen captures, etc).

6 Ongoing MATS Development

Since the initial delivery of the MATS system, feedback from military users has resulted in a large number of additional features, broken down into the following categories:

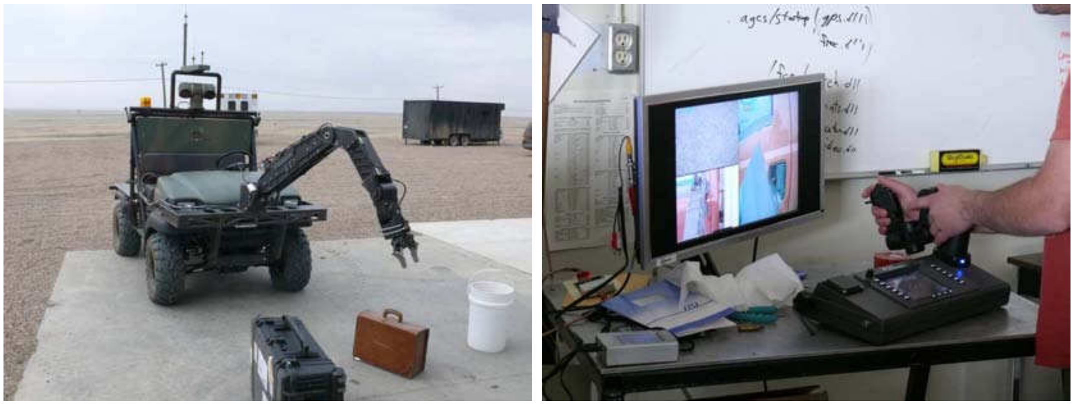
- Sensing (e.g. inertial navigation solution hardware / software and integration of GPS data).
- Man machine interface considerations (e.g. vehicle microphones).
- Remote operations amongst crowds (e.g. warning lights, emergency stop buttons).
- Operations in potentially hostile environments (e.g. hidden switches).
- Harsh operations (e.g. improved shock mountings, off-road protection hardware).
- Conversion of the operator from the "local" to the "remote" position (e.g. driving camera placement and performance to replicate the driving position, joystick fine tuning to create the appropriate "feel" of the brakes).

Various mechanical changes such as installation of visual driving cues and hard mounting points have also been made to the vehicle, while alarm states have been added to both the vehicle and groundstation software. The addition of simple color coding on the external ground control station wiring and antenna arrays reduced connection times by 75% and reduced connection errors by 100%.

Beyond minor changes, additional subsystems and/or capabilities have also been incorporated. Most notable is an onscreen display of laser rangefinder data when the operator triggers it from the groundstation. This gives operators a basic standoff capability from a vehicle platform that is itself remotely operated. This allows operators to better localize points of interest (e.g. a suspicious package) while maintaining a safe distance.

To help with the difficulty of driving using only video, an obstacle detection sensor is also being developed. It will use radar to warn the user of potentially damaging obstacles within a specified range of the vehicle. It will also be active during the semi-autonomous waypoint following mode, preventing collisions with obstacles moving into its path. This work is ongoing.

Besides day-to-day convenience and safety issues, DRDC staff are adding significant capabilities to the MATS system. A robotic arm has been mounted on the front of one of the development vehicles, as shown in Figure 12(a). It allows the system not just to sense its environment, but to interact with it. The powerful "Predator" arm from Kraft Telerobotics



(a) (b)

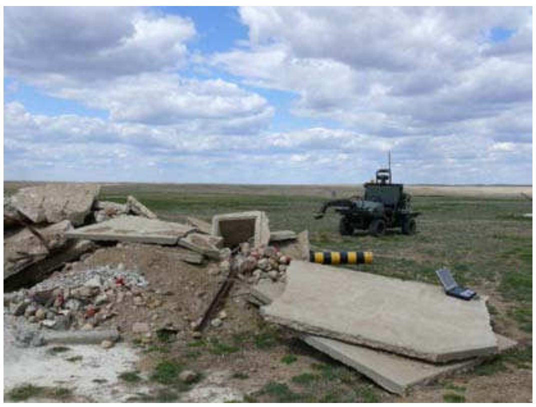
Figure 12: *The MATS vehicle with robotic arm and control station.*

has a reach of 72 inches with a load capacity of up to 200 lbs. A force-feedback joystick provides control, along with a video display from 3 cameras mounted on the wrist, arm and shoulder (Figure 12(b)).

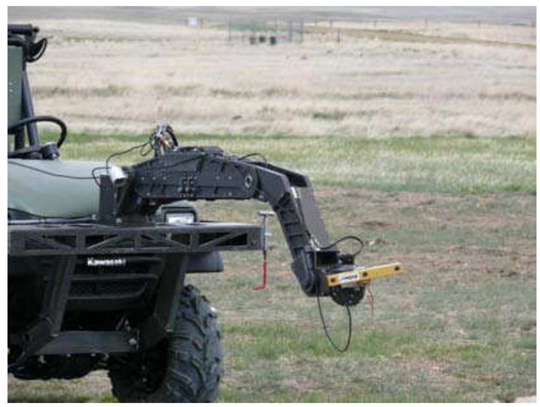
Figure 13: *A training scenario with MATS opening a vehicle door for inspection.*

The arm has undergone initial trials with the CF client. It is capable of smashing windows, inspecting under vehicles, moving heavy objects, opening fence gates, and even opening vehicle doors and buildings with the use of special tools (Figure 13).

The Mobile Scene Modeler from Macdonald, Detwiler and Assoc. has also been trialed on the vehicle. It builds 3D models of an environment using a combination of stereo cameras and image features. The system is normally held by a human operator, sweeping the scene with the cameras. A computer then generates both a wire-frame and photo-overlaid version of the 3D model, which may be used to measure distances and sizes of objects. In trials with the CF client, the manipulator arm operated the Mobile Scene Modeler, investigating suspicious scenes. The 3D model was sent back to the user control station for investigation.



(a) Vehicle



(b) Scene Modeler

(c) 3D Model

Figure 14: *MATS inspecting a rubble pile using the Mobile Scene Modeler*

One of these trials is shown in Figure 14.

It is expected that the MATS system will continue to be a technology on-ramp for a number of other robotic technologies being investigated at Defence R&D Canada – Suffield.

7 Lessons Learned: Designing and Delivering Robots for Military Clients

7.1 Client Interaction

The importance of client(CF) involvement in all stages of the project has been the most important lesson from the MATS project. Without the constant feedback from the end-user, the introduction of new technology would have had little chance of success. The CF end-users agree that "the most important thing was being involved with design and features as they were developed". This client contact must begin right from the initial concept phase and progress well past the delivery date. Although the Defence R&D Canada – Suffield personnel had a good grasp of the technical aspects of designing a robotic system, a large number of operational issues were discovered once soldiers began to use it. The project success hinged upon users "buying-in" and feeling that the equipment was useful and reliable. Constant interaction gives the client an appreciation of the system value, the design difficulties, and provides a transfer of the designers intentions to the users. On the other side, the military client provides a much improved final delivery through test and evaluation. It also prevents design effort on features which are of no value to the end user.

The members of the CJIRU continue come back with lists of questions and requests of the MATS project staff . Maintenance and feature development are ongoing efforts. There is a cyclic design process with TTPs and the product evolving at the same time. Furthermore, quarterly meetings have been held since the initial stages of the project with the CF project staff, which have been invaluable given the fluid nature of the project. These meetings will contionue as the stakeholders discover new technologies and new operational scenarios.

7.2 Useability and Operator Overload

Another set of important lessons has been the difficulty of making a complex robotic system user-friendly enough to be operationally practical.

Situational awareness for a tele-operated vehicle is particularly difficult. A video feed and a digital speedometer display give little tangible feedback for speed or object proximity. New users have difficulty orienting to a rolling map display of the vehicle and command post positions, and they can frequently be seen looking out of the back of the command post to see where the vehicle is. Indeed, part of the MATS training includes a driving course complete with pylons. One way of mitigating this was with the use of "shoulder check" hot keys, which allow the users to quickly pan the camera to see their surroundings. Also, visual cues have been added on the front of the vehicle to allow the operator to quickly know when the camera is facing forward.

Operator overload is also a major concern. The difficulty of remotely driving a vehicle should not be underestimated, especially as the user needs to control the vehicle steering, velocity, and pan/tilt/zoom camera while monitoring the sensor suite for CBRN information. New operators often miss sensor hits due to the concentration required for driving. This was mitigated by additional control station warning lights and sounds for CBRN sensor threshholds exceeding pre-set limits. Also, the on-board cruise control further reduces operator overload. Usability is a strong consideration when adding new features. For example, an automatic obstacle sensor is only useful if it has an extremely low false positive rate. Otherwise, it will just serve as a distraction to an already overloaded operator.

Useability is especially essential when designing for a military client. There is generally a lack of training time for the operators who come from a variety of backgrounds. One operator training group contained members from various combat arms trades, such as infantry, tankers, and firemen, with no-prior training in electronic systems. The multiple roles of most of the operators can create skill fade at times. Finally, there is a a tendency with the soldiers that unpopular equipment is not cared for and becomes damaged, while useful, user-friendly equipment is well cared for. For these reasons, it is important to carefully design the user interface with usability in mind, balancing system capabilities with ease of use. Adding too many capabilities may complicate the operator experience or even cause the base functionality of the system to be lost. In addition to the above challenges, if the system is too simple to use it will tend to get abused. Some of the new operators tended to treat the system like a video game without equating their actions to the consequences of driving a 1000kg vehicle down a road.

Procedures are kept as simple as possible. Initially, the control station software required two programs to be started: one for the user interface, and one for a GPS control program to co-locate the groundstation and vehicle. Many of the operators did not understand the significance of the second program, and simply wouldn't start it. This was remedied by incorporating both programs into one executable.

Finally, product reliability is paramount. The CF users have a job to do, and will use the equipment to the limit of its abilities. If a system is seen to be unreliable, any problems which arise, even ones due to operator error, are assumed to be system flaws. This can lead to the system being not used at all. Designing for robustness is important, but so is keeping spare parts on hand for rapid repair.

7.3 Training

Training aspects were not a Defence R&D Canada – Suffield expertise in the past, but have become important over the course of the MATS project. In addition to standard technical documentation, the designers and builders needed to produce training documentation to "train the trainers". Furthermore, they also have been continuously involved in creating realistic training scenarios, pushing the limits of the system and its operators. This is beneficial for CJIRU staff, but also for the designers as well, providing regular feedback on system useability and performance.

The adaptation of the operators to remote operations given limited training was a major concern. Therefore, particular attention was paid to the control station software and to the fine tuning of the vehicle operational parameters. In the end, the system was robust enough that the operators were able to learn the intricacies of remote operations while only having to perform minor repairs.

There are some training issues specific to training for a military client. Staff turnover is common among CF units, which means that the documentation must be especially good to make up for any shortfall in staff continuity and experience. Operational misconceptions are hard to remove once learned. For example, at one point the operators felt that they needed to hit all the emergency stop buttons when shutting down the vehicle, which was simply not necessary. Furthermore, routine maintenance tasks such as lubrication, etc. will get forgotten if not documented properly.

Skill fade is prevalent with even the highly skilled operators, as most of them have more duties than just using MATS, and operational constraints limit the amount of training time available. With a complex system such as this, training needs to balance the operators need for information without saturating them. This also can be helped by breaking up the training sessions. During instruction, it has been best to give only one procedure for accomplishing any task. For example, many system commands are available by menu items, or hot keys, and only one of these should be taught. Teaching both can lead to misconceptions that may lose the message. There is also an observed tendency among the operators to avoid excess information that does not help them do the job. An engineer may be curious about the system's inner workings, but most of the soldiers view the robot as a tool which helps them get their job done, and do not need to know about technical aspects of system functionality.

7.4 Operational Considerations

As described earlier, there were a number of system integration issues in delivering not just a robot to the CF, but an entire system. In doing so, a number of CJIRU operational considerations came to the forefront, considering the nature their work.

There is wealth of information coming back from the vehicles including visual and IR video, audio, and digital readouts from the vehicle sensors, weather sensors and CBRN sensors. There is more than enough information for one operator per robot. The addition of warning indicators for certain conditions helps this situation. DRDC has also added intelligent software to model chemical plumes to help the user understand the sensor data. However, today's technology simply cannot offer the same level of expertise and judgment in analyzing sensor data that humans can. The current procedures for operating MATS from the command post involves two vehicles each with their own groundstation. It was also necessary to add a third station for the commander, who's job it is to analyze the wealth of incoming information. He is able to view the sensor information from either vehicle, and to print camera captures, etc. A DVD recorder was also added to the system to record events as they occur for analysis later, as it is just too difficult for the operators to catch everything.

A map upload procedure for the control station was also developed. Soldiers are often given maps in paper form and would like to see the vehicle position on this map displayed on-screen. A user interface was developed whereby the user can scan a map into the computer, and after a simple two-point geographic calibration he can view the MATS vehicle's position overlaid on it.

Some of the most important lessons learned derive from the inventiveness of the operators. Since MATS was delivered very early in the development of the TTPs, the operators were given considerable latitude in accomplishing their tasks with the tools they had at hand. Different teams would use different elements of the system to address the task at hand. The best solutions were recorded and incorporated into the TTPs. The following example illustrates this process. In an exercise that took place in June 2005 on the Suffield EPG, a mockup of a terrorist chemical agent lab was created in a complex of buildings. One group of operators chose to map out possible locations of the lab by creating an upwind quartering pattern using the chemical detection sensors. After an initial survey to confirm that there was indeed a chemical source, the other group of operators chose to do final localization by searching for lab type hotspots using the thermal camera. Both methods were successful and the TTPs were updated to reflect the importance of using the thermal camera when gathering situational intelligence.

Numerous lessons have also been learned regarding the role of MATS in joint operations. Exercises have been done in which other agencies have actively interacted with the operators of the MATS systems. Other first responders (e.g. RCMP, highway patrol, and Health Canada) have been involved in exercises that simulate domestic scenarios. Other military groups have also been involved in both domestic and international scenarios. Encryption has been added to the video radio links to protect the information during sensitive operations. The doctrine, concept of operations, and TTPs for the CJIRU continue to develop with each exercise that involves MATS.

7.5 Technology Acceptance

It is important to analyze the MATS project to determine what characteristics enabled it to succeed where other robotic projects at DRDC have not. John Messamore from the United States Joint Ground Robotics Department has given some of the following criteria for technology to gain acceptance with the military. Each of them are examined with regards to the MATS project:

- *Trialability: It can be tested on a limited basis.* The MATS system already had a working prototype when the DNBC got involved, and the Joint Coy was able to trial it on exercise at CFB Wainright.
- *Observability: Results can be seen.* Again, with the Joint Coy involved in the early trials, the results were obvious. The synergy from combining disparate point sensors with a robotic vehicle was clear.
- *Advantage: It offers an advantage over the status quo.* With an application as dangerous as CBRN detection, it is easy for the end user to experience the advantage of

sitting in a safe command post rather than investigating hazardous scenes directly. It also reduced the time required to get intelligence down range as the robot does not require any safety systems in place in advance of deployment unlike humans.

- *Complexity: The system is not overly complex to employ.* Although the MATS vehicle itself is quite complex, the user experience has been relatively sheltered from this through a useful and intuitive control station interface. The robustness of the design of the other system components has also hidden system complexity from the end users.
- *Compatibility: It is compatible with existing practices and values.* This was particularly fortuitous with the Joint Coy, as they were in the process of forming up, and had not yet developed their TTPs, and did not have pre-existing notions of how their work should be done. The MATS system was able to be incorporated right from the beginning.

There also seems to be some other key components which enabled the success of the project. Given the reality that there is a sizable lag between R & D investment dollars and a realizable product, another requirement is a stable, long-term investment in a given technology. The history of Defence R&D Canada – Suffield had enabled robotics to mature to a reasonable point. Finally, having a champion within the client group who sees the potential of the project and develops the concepts within the CF is particularly important, which was the case with the MATS project.

The MATS project was a special case within the military: an especially hazardous occupation, a unit in the middle of formation, and world events motivating action. The challenge from here will be to get wider adoption of robotics within the CF, where not all of these conditions will typically be in place at any given time. Much like the longbow, the tank, and the atomic bomb, technology always outraces strategy and doctrine to control it. Ethical issues and fear of technology will hinder its adoptation. Now is a key time for ground robotics, as the technology is beginning to mature to the point of being practical, and it will be interesting to see how the military adopts robots over the coming years.

8 Conclusions

The Multi-Agent Tactical Sentry provides the Canadian Forces with a capability to perform vital point surveillance for CBRN threats, achieved by integrating a suite of CBRN sensors onto a teleoperated robotic vehicle. It is the first asset downrange during incident response, and is the eyes and ears of the Canadian Joint Incidence Response Unit. The unit now has four MATS systems used in numerous joint exercises designed to simulate both international and domestic CBRN threat scenarios. The systems have proven to be reliable and technically capable. Consequently the doctrine and TTPs for CBRN deployments continue to evolve with MATS functioning in a keystone role as intelligence gathering assets.

Rapid project development was possible due to the long term investment in robotic systems at Defence R&D Canada – Suffield over the last three decades. This project is an exemplar of how the military R&D / S&T community can react to an identified gap in military operational capability. A working relationship has developed and communication channels opened between researchers, project offices, end users, and Canadian industry that will continue to produce results that are relevant to Canadian military CBRN doctrine.

Many important lessons were learned over the course of this project, including the importance of CF client involvement through development process and well after. The importance of product usability and reliability, and the training aspects involved in delivering to the CF were also key. The project has been a boon to other research projects as well, providing a test and demonstration capability, as well as a technology on-ramp to the CF. Many previous robotic systems have been created at Defence R&D Canada – Suffield, but the unique success of this project has been in getting a robotic asset in regular operation with Canadian Forces.

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The Multi-Agent Tactical Sentry (MATS) represents one of the most advanced robotic systems in day-to-day military operation anywhere in the world. It addresses the Canadian Forces (CF) requirement to remotely detect Nuclear, Biological, and Chemical threats (NBC), integrating a suite of primary NBC sensors onto a remotely operated vehicle. The system was initially designed and built from the ground up at Defence R&D Canada – Suffield in under 30 months, and has become an operationally important component of the Canadian Joint Incidence Response Unit (CJIRU), and their continually evolving techniques, tactics, and procedures (TTPs). This paper describes the technology and development of the MATS system, but more importantly it examines the many lessons learned in designing and delivering a robotic vehicle to a military client.

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