Intelligent Autonomous Systems

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1 Overview

We look at the application of unmanned ground vehicles (UGVs), both teleoperated as well as autonomous, operating in real-world environments. This covers existing capabilities in autonomous systems, novel platforms, progressive automation of existing systems and examples of autonomous and semi-autonomous military vehicles currently in use around the world.

An autonomous system is capable of performing its mission critical tasks independently of this particular input from an operator. In the confines of a factory or other structured environment, this does not represent such a significant hurdle; however, in outdoor, dynamic and real-world environments, the task is substantially more complicated. In these environments, the autonomous system is required to sense, adapt and reason about its ever-changing environment, leading to the term "intelligent autonomous systems". We provide a brief overview of the history of ground-based intelligent autonomous systems, and more specifically their application within the military.

The use of autonomous military systems has several key advantages over their human counterparts - autonomous systems can operate in darkness, do not get tired or distracted during repetitive tasks, always function at peak performance and do not have a family that miss them while they are away. These autonomous systems also provide the advantage of removing personnel from hazardous environments and reduce the human workload of teleoperated or remote control vehicles, allowing fewer operators to control more vehicles.

Autonomous ground systems consist of three primary components: platform (with sensors and 3rd party payloads), intelligence and user-interface. We will focus on advances in technology centred on the platforms and the intelligence. Traditionally, much effort was invested into the comparatively easier task of platform design and construction resulting in many teleoperated platforms. As intelligent algorithms mature, we are slowly seeing the introduction of intelligent components and functions on these traditionally teleoperated systems. In recent years, further advances have permitted the first fully autonomous systems to be created. These systems are capable of operating independently for many hours, only occasionally requiring operator intervention.

2 DARPA and their Role in Developing Ground-Based Autonomous Systems

Many of the existing technologies and capabilities in ground-based autonomous systems were developed as a result of investments by the Defence Advanced Research Projects Agency or DARPA. Between 2004 and 2007, DARPA funded three competitions with the aim of developing capabilities in ground-based autonomous systems with the ultimate goal of making one-third of ground military forces autonomous by 2015. The three projects collectively known as the DARPA Grand Challenge, focussed on developing a driverless vehicle capable of navigating along a predefined route.

The 2004 Challenge required vehicles to complete a 240 km desert route in the United States. None of the entries managed to complete the route with the farthest distance travelled being only 11,78 km. In 2005, the competition was held again, where the results had improved since only one of the 23 finalists did not reach the maximum distance in 2004. Five entrants successfully completed the 240 km course, with the winning time posted by "Stanley", a modified Volkswagen Touareg, which completed the course in 6 hours 54 minutes – representing a pivotal point in the development of autonomous ground-based systems.

Following the success of the 2005 Challenge, the 2007 Challenge, also known as the "Urban Challenge", required autonomous vehicles to operate in a mock urban environment, while interacting with other vehicles and obeying traffic rules. While the 2004 and 2005 challenges were more physically demanding on the vehicles – the fact that they operated in isolation simplified the problem. The 2007 challenge required more "intelligent" decisions to successfully navigate the course while interacting with other human-controlled vehicles and competitors. Six teams successfully completed the course with the three top entries all finishing within 30 minutes of each other.

The technologies developed for this challenge form the foundation of many ground-breaking autonomous systems available today. The most noteworthy being that of the Google Autonomous Cars that have collectively covered more than 20 000 km in urban traffic scenarios in the United States. Examples of some technologies that emerged from these competitions included real-time obstacle detection, mapping and exploration algorithms and planning algorithms to create driveable paths in fractions of a second. These algorithms are key to creating unmanned ground vehicles.

3 From Teleoperation to Partial Autonomy

In the previous sections, we covered some advances and capabilities in ground-based robotics enabling fully autonomous systems. These capabilities however are only the fundamental building blocks and many of the high-level logic and reasoning components required for full and independent autonomy are still unreliable. As a result of this, most autonomous systems still require a human operator in the loop to assist in resolving complex scenarios and aid the UGV when it becomes necessary.

In the past, robotic systems were nothing more than remote controlled vehicles that could return information about their environments to the operator who would make decisions and provide commands to the system. These teleoperated systems allowed human controllers to command vehicles in dangerous or inaccessible environments without placing the operators in danger. The downside to these systems is the lack of “situational awareness” as a result of the limited information available to the operator. This makes teleoperation of a vehicle a cumbersome task with high cognitive load on the operator. The process is also complicated by the introduction of delays in the control loop due to the need to process and transport the data; as well as the limited information that is presented to the operator.

To overcome these issues, certain aspects of the teleoperation process can be automated leading to partially autonomous systems. This also has the benefit of reducing time-to-market and allowing autonomous sub-tasks to mature in a production environment while more capable algorithms are being developed. This progression is currently visible in the automobile market where partial autonomy is being introduced to handle difficult or laborious tasks in the form of anti-lock braking, electronic stability systems and cruise control. The remainder of this section will be devoted to examples of partial autonomy and assisted teleoperation systems.

3.1 Reduction of Operator Load

One application of partial autonomy is the reduction of operator load, usually through the form of some sort of autonomous tramming. Most common in the mining industry, these UGVs are capable of navigating between the work face and ore processing areas autonomously (Marshall, 2008).

One possible application of this form of technology in a military environment is in a search and rescue scenario. A single operator could operate multiple search and rescue or battlefield extraction systems if the simple task of navigating to and from the “disaster area” could be automated.

Convoy transport of equipment is another application that could benefit from autonomous tramming. Instead of continuously controlling each system in the convoy, UGVs could be equipped with automatic collision avoidance, and the ability to follow another UGV. In this manner, a single operator could control the entire convoy.

3.2 High-Speed Driving by Teleoperation using Virtual Environments

As mentioned in the introduction, one of the primary problems with teleoperated vehicles is the lack of situational awareness as a result of the limited field of view of the operating environment. In addition to this, any latency in the control of the vehicle manifests itself as a lack of manoeuvrability, and increases the effort required to control the vehicle.

To overcome this problem, a research group from Carnegie Mellon University created a teleoperated system that allowed operators to control a virtual vehicle in a virtual environment that resembles the actual environment surrounding the vehicle. Commands to the virtual vehicle are then executed with no latency in a simulation environment the operator’s computer and feedback is given to the operator immediately. The results of these movements are then transferred to the teleoperated vehicle that mimics the relative motion of the simulated vehicle with relation to the environment. The resulting system resembles a control environment similar to a computer game. By simulating the control actions locally, the latency usually present in teleoperated systems is overcome and the control performance is greatly improved. This results in an improvement in maximum operating speed of around 20% in studies that were conducted (Kelly, 2009).

Figure 1: Virtual Reality with Teleoperated Vehicle

Figure 2: BigDog Platform from Boston Dynamics

4 Novel Robotic Platforms for Ground-Based Autonomous Systems

Alongside the research into intelligent algorithms and partial autonomy for these systems, many groups have focussed on the more established field of mobility for the underlying platforms. Many such solutions incorporate multi-wheeled or tracked vehicles for example the Crusher autonomous platform (CMU Robotics Institute, 2006) or the Battlefield Extraction-Assist Robot (Vecna Robotics, 2010). Of more interest however, are the platforms that do not rely on these standard means of locomotion. One company that has been receiving increasing interest is that of Boston Dynamics. Primarily known for their legged platform BigDog, Boston Dynamics have also manufactured several other novel robotic platforms for various applications. This section will cover some of the more practical and novel platforms that are available. Novel platforms incorporating the necessary intelligence to make them stand-alone systems will be covered in the following section.

4.1 Boston Dynamics BigDog

The BigDog platform is the most well-known and mature UGV platform from the Boston Dynamics team. This legged platform is capable of traversing rough terrain while carrying large loads, which is the result of a design brief to create a system that can go anywhere people and animals can go. The platform with the size of a large dog (roughly 1m in length) is capable of moving at a top speed of 6.5 km/h, climb slopes of up to 35° and traverse various terrains including rubble, muddy trails, snow and water. The platform is capable of carrying a load of up to 150 kg and has an operating range of 20 km without stopping or refuelling (Boston Dynamics, 2012a). See Figure 2.

4.2 Boston Dynamics Cheetah

The Cheetah platform, also from Boston Dynamics, is a four footed UGV based on similar technology used in the BigDog platform; however, by articulating the body, the system is able to travel at much higher speeds. Although still in development, the Cheetah platform is capable of travelling at speeds of up to 30km/h on a treadmill. Boston Dynamics is currently in the process of making the platform stand-alone to allow field testing (Boston Dynamics, 2012b).

4.3 Vecna Robotics Battlefield Extraction-Assist Robot (BEAR)

The Battlefield Extraction-Assist Robot is a part humanoid, part tracked robot designed primarily as a search and rescue platform to assist in the recovery of injured personnel from the battlefield. The combination of a humanoid upper-body and tracked lower body provides the best of both worlds for environment interaction and locomotion. The robot has been designed to carry injured personnel or equipment with a total lifting capacity of around 230 kg. The arms and hands on the upper body give the platform the ability to sift through rubble looking for victims. The BEAR is primarily a teleoperated robot, however, it is benefitting from the inclusion of partial autonomy as described in a previous section. Autonomous tasks currently being included in the platform include autonomous navigation and load lifting (Vecna Robotics, 2010).

4.4 CMU Crusher Off-Road Ground Combat Vehicle

The Crusher Unmanned Ground Combat Vehicle is a six-wheeled teleoperated vehicle designed by Carnegie Mellon University (CMU This independent, six-wheel drive vehicle can also adjust its suspension by 75 cm and as a result it can turn on the spot and travel over rough terrain, slopes and riverbeds including over vertical walls of 120 cm. It can drive up slopes of 40° and with 30° of sideways tilt, carrying a combined load of up to 3600 kg comprising armour and cargo. Due to the complexity of control, the vehicle is teleoperated from a video game like interface while the vehicle autonomously attempts to satisfy the requirements of the computer operator (CMU Robotics Institute, 2006). See Figure 3.

Figure 3: Crusher Off-Road Vehicle

Figure 4: General Dynamics MDARS Patrolling

5 Military Applications of Ground-Based Autonomous Systems

This section provides a brief survey of existing applications. These systems can be roughly broken into two categories, teleoperated systems that essentially form an extension of existing ground forces and autonomous systems that operate independently and only require occasional supervision from an operator. The teleoperated systems are typically used for surveillance and exploration tasks or for tasks where human operators would be placed at risk (e.g. EOD, Explosive Ordinance Disposal). At present, the primary military applications for fully autonomous ground-based systems are in perimeter patrols and logistics.

5.1 iRobot Packbot and FirstLook

iRobot Corporation's Packbot 510 and FirstLook UGVs are battlefield tried and tested teleoperated UGVs. The Packbot 510 may be used for Explosive Ordinance Disposal, for surveillance or have a weapon mounted on it for combat applications.

The iRobot FirstLook platform is a smaller and more recent development from iRobot resembling a small Packbot 510 UGV. It was designed to be a small remote surveillance system with a hand-held controller and several cameras mounted in various directions. The platform measures only 0,25 m x 0,23 m x 0,1 m and weighing around 2 kg has a 6 hour battery life and a top speed of 5,5 km/h. The platform may also be equipped with a number of additional sensors including thermal imagers, chemical and radiation sensors and a two-way radio (iRobot Corporation, 2011).

5.2 General Dynamics Mobile Detection, Assessment and Response System (MDARS)

The General Dynamics Mobile Detection, Assessment and Response System (MDARS) is a wheeled patrol UGV designed to assist personnel in the task of patrolling secure areas. It has several sensors allowing it to detect the presence of intruders as well as a non-lethal weapon that can be remotely controlled by the operator. The system is capable of patrolling predefined areas autonomously while interacting with other people and vehicles on the site. When the MDARS detects an intruder, it alerts operators at the control centre and provides them with real-time video surveillance allowing the operator to decide on the plan of action. Operators are also able to remotely control the vehicle to resolve any issues that could arise during autonomous operation. The vehicle is capable of speeds of up to 30 km/h and can run for 16 hours without refuelling. The MDARS system is one of the older examples of an autonomous vehicle with development starting in 1993 and the first prototypes being deployed in active service since 2004 (General Dynamics, 2006). See Figure 4.

5.3 G-NIUS Guardium

The Guardium is the Israeli counterpart to the General Dynamics MDARS system. The platform can operate autonomously up to 50 km/h both on and off-road. The vehicle can host a multitude of sensors, armour and weaponry and can operate continuously for several days. The Guardium system is capable of autonomously patrolling pre-defined routes, identifying targets and reporting any incidents to human controllers (G-NIUS, 2012). See Figure 5 depicting the system on border patrol in Israel.

Figure 5: G-NIUS Guardium Platform

Figure 6: Lockheed Squad Mission Support System

5.4 Lockheed Squad Mission Support System (SMSS)

The Lockheed Squad Mission Support System or SMSS is one of the first autonomous UGVs that falls into the class of soldier support or mule vehicles focussing on transport logistics. The goal of these systems is to support foot-borne personnel by assisting in the carrying of heavy equipment. The six-wheeled platform is capable of carrying a load of up to 544 kg and is equipped with an amphibious capability for crossing rivers and marshes and can climb a vertical step of 0,55 m. The current range of the SMSS prototype is 200 km. The SMSS is fitted with a number of sensors that allow the platform to navigate independently while following a designated soldier on the battle field. The SMSS is currently undergoing field testing to test its efficacy in real world battle scenarios (Lockheed Martin, 2011). See Figure 6 depicting the SMSS in foot-soldier configuration.

5.5 Boston Dynamics Legged Squad Support System (LS3)

The Boston Dynamics Legged Squad Support System or LS3 is another soldier support system similar to the Lockheed SMSS, built around a larger version of the legged Boston Dynamics BigDog. The smaller LS3 is anticipated to be more agile that the SMSS however the load carrying capacity is not as large with a maximum load of around 180 kg. While the LS3 is somewhat smaller than the Lockheed SMSS, it is envisaged that several such platforms could accompany each troop of soldiers. The LS3 is currently in development with the first field-testing expected to commence in 2012 (Boston Dynamics, 2012c).

6 Future of Autonomous Systems

As autonomous systems become more robust and reliable, we can expect to see many advances and future applications of these systems in the military and other application areas. These systems will likely operate for days or even months without intervention, reducing the work load and increasing safety in what is currently a very hazardous environment.

Autonomous systems are still a relatively new field and DARPA are continually funding newer and more advanced applications of these systems in the US military. They had planned to have one third of their military vehicles autonomous by 2015, and while this seems optimistic with the present technology, this thrust will likely continue into the future.

7 Conclusions and Implications for SANDF

As autonomous UGVs become more robust and reliable, we can expect to see many advances and future applications of these systems in the military and other application areas, thereby reducing the work load and increasing safety in dangerous or hazardous environments. Autonomous systems are still a relatively new field and DARPA are continuously funding newer and more advanced applications of these systems in the military – it noted that the US planned to have a third of its military vehicles autonomous by 2015.

8 Glossary

DARPA : Defence Advanced Research Projects Agency
EO : Electro Optical
EOD : Explosive Ordinance Disposal
FIBUA : Fighting in Built Up Areas
GCS : Ground Control System
IR : Infrared
LIDAR : Light Detection and Ranging
MTI : Moving Target Indication
OPV : Optionally Piloted Vehicles
UGV : Unmanned Ground Vehicle

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