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Shape-shifting Tracked Robotic Vehicle for complex terrain navigation

Characteristics and architecture

I. Vincent and M. Trentini

Defence R&D Canada
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Abstract

Defence R&D Canada is extending its experience in teleoperated ground vehicles to the development of autonomous systems for the Canadian Forces. The Autonomous Intelligent Systems Section develops novel robotic platforms that autonomously generate useful locomotive behaviours. This paper is the outcome of two years of development effort combined with a two-year R&D contract. It summarizes the characteristics and architecture of the Shape-shifting Tracked Robotic Vehicle (STRV) demonstrating variable geometry abilities to adapt and traverse complex terrain.

Résumé

R&D pour la défense Canada élargit son expertise en véhicules terrestres téléopérés au développement de systèmes autonomes pour les Forces Canadiennes. La Section des Systèmes Autonomes Intelligents développe de nouvelles plate-formes robotiques qui génèrent de manière autonome des comportements locomoteurs utiles. Ce mémoire technique est le fruit de deux années d'effort de développement combiné à un contrat de recherche et développement de deux ans. Il synthétise les caractéristiques et l'architecture du "Shape-shifting Tracked Robotic Vehicle" (STRV). Celui-ci possède l'habileté de varier sa géométrie pour s'adapter et traverser des terrains complexes.

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Executive summary

Shape-shifting Tracked Robotic Vehicle for complex terrain navigation.

I. Vincent and M. Trentini; DRDC Suffield TM 2007-190; Defence R&D Canada – Suffield; December 2007.

Defence R&D Canada is extending its experience in teleoperated ground vehicles to the development of autonomous systems for the Canadian Forces. The Autonomous Intelligent Systems Section develops novel robotic platforms that autonomously generate useful locomotive behaviours. Research in mobile robot navigation has demonstrated some success navigating a flat world and avoiding obstacles. However, the challenge of analysing complex environments to traverse tridimensional obstacles has had very little success due to the complexity of the task.

This research work aims to define a methodology for the mobile robot Shape-shifting Tracked Robotic Vehicle (STRV) to learn to overcome obstacles. Novel research is possible taking advantage of the small size of the unmanned ground vehicle, its robustness, its few degrees-of-freedom and its inherent ability to change geometry. The prototype is retroffitted with perception sensors such as GPS, inertial measurement unit, laser range finder and optical encoders to sense its environment. This memorandum explains the selection of the sensors and hardware installed on the vehicle, and the controller architecture to perceive, analyze, make decisions and command the robotic platform. Furthermore, it lists improvements for the next generation of the STRV, including more space for hardware and battery power, a better communication system, and redesigned tracks for better traction and torque sensing.

The Autonomous Intelligent Systems Section uses the high fidelity simulator Vortex by CMLabs Simulations Inc. To fill the gap between the real-world and the controller, the simulator extracts relevant geometric features of the environment into a world representation, and passes their coordinates to the mathematical modeller. Then, it positions correctly a model of the robot, which includes its dynamics, into this world model. The controller calculates and makes corrections to the behaviour implementation for robust performance.

In order for the STRV to interact appropriately with its environment, it must recognize obstacles which may affect its behaviour. Sensing research presented in this paper aims at detecting physical characteristics, such as location, height, width and shape, useful for decision making. Object modelling is described using terrain mapping, image segmentation and shape detection.

A robot that adapts its behaviour based on experience is an attractive concept for robotics in a complex environment. Learning by reinforcement and progress estimation could facilitate robot control and navigation. This paper presents the learning architecture developed for safely traversing obstacles with the STRV by autonomously adapting the vehicle's geometric configuration.

Creation of intelligent mobility algorithms for robotic locomotion in complex terrain requires research in areas of control, sensing and learning. The objective is to produce improved Unmanned Ground Vehicle (UGV) locomotion for military relevant environments to better address the needs of the Canadian Forces in their future urban operations.

Sommaire

Shape-shifting Tracked Robotic Vehicle for complex terrain navigation.

I. Vincent and M. Trentini ; DRDC Suffield TM 2007-190 ; R & D pour la défense Canada – Suffield ; décembre 2007.

R&D pour la défense Canada élargit son expertise en véhicules terrestres téléopérés au dévelopement de systèmes autonomes pour les Forces Canadiennes. La Section des Systèmes Autonomes Intelligents développe de nouvelles plate-formes robotiques qui génèrent de manière autonome des comportements locomoteurs utiles. L'avancement scientifique en navigation des robots mobiles a démontré quelques succès en navigation 2D et au niveau de l'évitement d'obstacle. Cependant, le défi d'analyser des environnements complexes pour traverser des obstacles tridimensionnels a eu peu de succès vu la complexité de la tâche.

Ce travail de recherche a comme objectif de définir une méthodologie pour que le robot Shape-shifting Tracked Robotic Vehicle (STRV) apprenne à grimper des obstacles. Cette plate-forme robotique offre plusieurs avantages tels sa petite taille, sa robustesse, son nombre de degrés de liberté peu élevé, et son habileté intrinsèque à changer sa géométrie. Le prototype est équipé de capteurs tels un GPS, une unité de mesure inertielle, un télémètre à balayage laser et des encodeurs optiques pour percevoir son environnement. Ce mémoire technique explique la sélection des capteurs et du matériel installés sur le véhicule, ainsi que l'architecture des contrôleurs de perception, d'analyse, de prise de décision et de commande de la plate-forme robotique. De plus, il liste les améliorations à apporter à une prochaine génération de STRV, incluant plus d'espace pour le matériel et des batteries additionnelles, un meilleur système de communication, et une réingénierie des roues à chenilles afin d'obtenir une meilleure traction et de mesurer le torque des actuateurs.

La Section des Systèmes Autonomes Intelligents utilise le simulateur Vortex de CMLabs Simulations Inc. Le simulateur extrait les éléments géométriques pertinents dans une représentation du monde, et passe leurs coordonnées a un modeleur mathématique. Puis, il positionne correctement le modèle du robot, en tenant compte de sa dynamique, dans le modeleur. Le contrôleur calcule et corrige le comportement du robot pour obtenir une performance intéressante.

Afin que le STRV interagisse adéquatement avec son environnement, il doit reconnaître les obstacles qui peuvent affecter son comportement. La recherche en perception présentée dans ce document vise à détecter les caractéristiques physiques utiles pour la prise de décision, telles que la position, la hauteur, la largeur et la forme des obstacles. La modélisation des objets est décrite par la cartographie du terrain, la segmentation des images et la détection des formes.

Un robot qui adapte son comportement selon ses expériences est un concept très attrayant pour la navigation de véhicules robotisés traversant des environnements complexes. Apprendre par renforcement et estimation de sa progression pourrait faciliter le contrôle

et la navigation du robot. Ce mémoire technique présente l'architecture d'apprentissage développée pour que le STRV traverse sécuritairement les obstacles en adaptant de manière autonome sa configuration géométrique.

La création d'algorithmes en mobilité intelligente pour la locomotion en terrain complexe requiert l'avancement scientifique dans les aires de contrôle, de perception et d'apprentissage machine. L'objectif est de produire un véhicule terrestre sans pilote possédant une locomotion améliorée pertinente pour les environnements militaires, afin de mieux répondre aux besoins des Forces Canadiennes dans leurs futures opérations en milieux urbains.

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1 Introduction

Though research in mobile robot navigation has demonstrated some success navigating in a flat world and avoiding obstacles, the challenge of analysing complex and unstructured environments to traverse tridimensional obstacles has had very little success due to the complexity of the task. This research work aims at defining a method for a mobile robot to learn negotiation of obstacles. In this context, negotiating an obstacle means to clamber over, rather than avoiding, obstacles by adapting the vehicle configuration and behaviour. This requires a good understanding of the shape of the obstacles. In addition, the robotic vehicle needs geometric reconfiguration abilities to adapt to the obstacle shape and traverse it.

Previous publications presented the concept of the Shape-shifting Tracked Robotic Vehicle (STRV), the variable geometry paradigm and perception challenges to navigate with this platform [1–3]. This technical memorandum presents the STRV prototype that has been built and retrofitted with different sensors, systems and controllers. Moreover, it gives an overview of the architecture (perception, decision and control modules) that has been developed for this platform, and the dynamic modeler used to validate the perception and control algorithms.

2 Robot and equipments

This section presents the robotic vehicle used in the research project, and the different systems and sensors on the platform. Required improvements for the future generation of the STRV complete the section.

2.1 Robotic platform

RoboMotio Inc. designed the STRV for Defence R&D Canada. Figure 1 presents the robot in different geometric configurations. The platform consists of four independently driven tracks with two solid axles articulating the front and rear track pair. Novel research is possible taking advantage of the small size of the unmanned ground vehicle (UGV), its robustness, its few degrees of freedom and its inherent ability to change geometry. The small size of the vehicle permits driving through standard door frames and staircases, making it a good platform for indoor applications. In addition, its abilities to shift configuration provides an excellent platform to adapt to obstacle shapes. Finally, its few degrees of freedom allow simpler control algorithms than, for instance, would be required for a legged robot to cross obstacles.

2.2 Sensors

The STRV is retrofitted with perception sensors (see figure 2). This section describes each sensor chosen for the research project and the reasons for their selection.

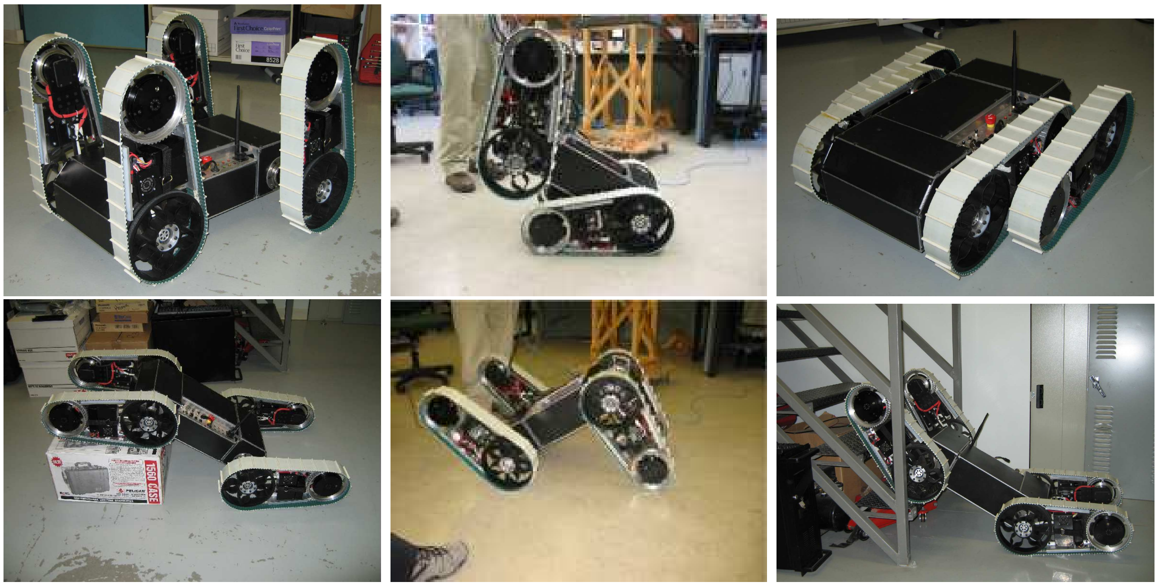


Figure 1: *STRV in different geometric configurations.*

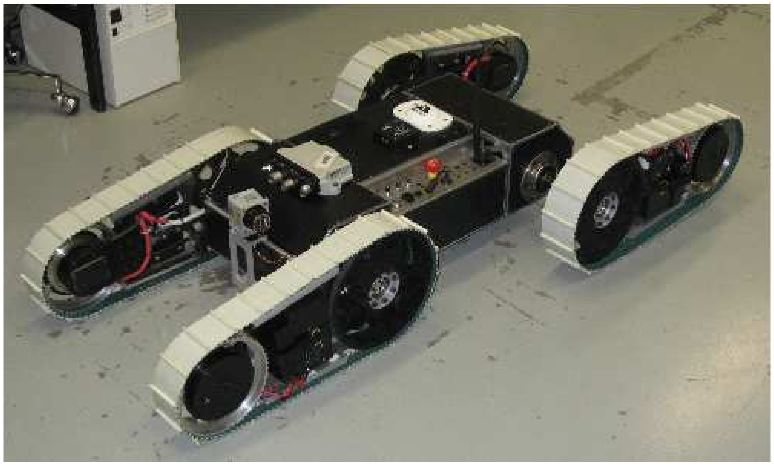


Figure 2: *STRV sensors: global positionning system (GPS), inertial measurement unit (IMU) and laser range finder.*

2.2.1 Vision

To traverse obstacles, the robot requires a good knowledge of the shape and location of obstacles. Different vision systems, to provide the robot with terrain shape detection, were investigated:

- The Digiclops and Bumblebee stereo vision cameras were eliminated because they have difficulty estimating distances to surfaces with little or no texture such as walls, floors, stairs and boxes.
- the large nodding SICK laser range finder, mainly used by the Autonomous Intelligent Systems Section personnel, does not fit on a small robot such as the STRV. However, nodding laser range finders provide 3D distance measurements. Thus, shape detection and control of the vehicle for terrain traverse are possible.
- An interesting alternative, the Hokuyo URG-04LX scanning laser range finder, provides a 240° scan line in the 785 nanometre light spectrum. This small and light laser is popular for simple indoor assumed 2D world navigation and obstacle avoidance. However, this project requires 3D world representation and a good detection of the obstacle shape.

A pan mechanism was designed and built at DRDC Suffield. It pans the Hokuyo sensor over 90° which, when combined with the 240° URG laser scan line, produces a 3D scan of the environment.

It was concluded that collecting vertical scan lines and panning the camera require simpler algorithms to determine the shape of the obstacles than scanning horizontally and nodding the camera. The URG laser makes 512 range measurements per scan line, and the pan mechanism makes 19 pan angles. For this reason, there is a better resolution vertically (along the scan line) than horizontally. Since good vertical shape detection is desired to cross the obstacles, with accurate height and depth measurements, the vertical scan line is more appropriate than the horizontal scan line. In fact, the horizontal scan perceives the obstacle width and the robot tolerates inaccuracy of the obstacle width measurement. Consequently, the URG laser range finder is mounted at the front of the vehicle, scanning vertically and panned by a servo controller mechanism.

2.2.2 Inertia

To orient the vehicle in the 3D world and evaluate its progress traversing the terrain, the robot needs inertial measurement information. A previous technical memorandum [4] presented an experimental comparison of different inertial measurement units (IMU) for autonomous vehicle guidance. Following this study, a good compromise between size and accuracy is the Microstrain 3DM-GX1. It gives triaxial acceleration, rotational rate and orientation with respect to the vehicle center of gravity and magnetic north. Experimentation has shown this unit is influenced by magnetic fields. In the presence of an interfering magnetic field, the algorithms must compensate for the bias.

2.2.3 Position

For a small robotic platform crossing outdoor obstacles instead of avoiding them, it is necessary to have the best possible position information. Furthermore, a complete GPS/antenna system must occupy the smallest volume and weight as little as possible. These criteria lead to the selection of a Novatel Flexpak enclosure with the OEMV-2 engine, combined with a Novatel GPS-532 L1/L2 antenna and a Pacific Crest PDL RVR radio. The system supplies differential global positioning of the vehicle. It provides 5 cm accuracy in real-time kinematics at an update rate of 4Hz.

In indoor environments where global positioning is not available, the robot makes decisions based on relative positioning.

2.2.4 Robot status

Finally, the robot internal sensors provide the track velocities and the axle positions. The optical sensors from the E4 series sold by US Digital provide 300 cycles per revolution, allowing slow speed control of the propulsion.

2.3 Systems

The robot was delivered by the contractor without any upper level control. To add intelligence to it, a motherboard was installed in the body, and all computers and controllers were networked. This subsection presents the systems added.

2.3.1 Motherboard

The robot has been retrofitted with a motherboard to acquire and process the sensory data, make decisions and control the robot locomotion. The Kontron 986LCD-M mini-ITX was selected for its 2.16 GHz processing speed, its 2 GB RAM memory, its Ethernet abilities and its different ports. It has eight USB, four serial RS-232 and two IEEE-1394 ports. The different sensors are plugged to these ports. Furthermore, size and power were important issues. The mini-ITX is the maximum size that fits in the body, while the motherboard is able to use the power provided by the robot batteries.

2.3.2 Network

The robotic system has been retrofitted with a wireless communication network. Several Pico-modules (controllers developed by RoboMotio Inc.) control the STRV power, sensors and actuators. Communication with the controllers is done via a Controller Area Network (CAN) communication network. To communicate with external computers, a transceiver bridges the CAN protocol and the Ethernet protocol. A wireless Ethernet network establishes the connection between the platform and a motherboard installed on the robot. The motherboard analyzes the data, makes decisions and commands the platform. A Virtual Network Computing (VNC) server allows administration of the motherboard from a desktop or laptop.

The current wireless system (802.11g) has a short operational range in indoor applications since walls block the signals. However, it is an inexpensive network for experimentation. Moreover, the research purpose is traversing obstacles and developing shaping behaviours rather than navigating through different rooms in a building. When navigation becomes an issue, better receivers and transmitters will be required. Alternatively, the robotic platform could be modified to incorporate a router. The robot transceiver could then communicate directly with the motherboard without requiring wireless communication. The only use of wireless would be to allow the user to remotely administer the motherboard and view the files.

2.3.3 Operating system and architecture

The UGV motherboard runs the Linux Fedora Core 5 operating system. The system architecture is the open source Miro middleware [5], a distributed object oriented framework for mobile robot control. Miro adheres to the common object request broker architecture (CORBA) standard and its components are developed in C++ programming language. The adaptive communications environment (ACE) provides object-oriented abstraction layers for many operating systems and The ACE Orb (TAO) is an implementation of the CORBA based on ACE.

2.4 Improvements for next STRV generation

While working with the STRV platform, scientists and technologists have noticed some deficiencies with the prototype. This subsection lists necessary improvements for the next STRV generation.

- The major disadvantage of working with small robotic platforms is the lack of space to retrofit the vehicle with computers, sensors, and other hardware. The STRV needs more internal space for motherboard, sensor hardware, power supplies and batteries to increase run time.

- As mention in section 2.3.2, the platform was not designed to have a direct communication between the motherboard and the CAN bus transceiver. Wireless communication is currently used, but this is not the best option. A future version of the STRV should integrate a router to connect the motherboard and the transceiver, having wireless communication only for external vizualisation and administration of the motherboard computer. Then, the robot could drive autonomously even if it loses communication with the operator.

- Another item to improve is the security level of the network. The robot Pico-module transceiver is not designed to accept encrypted Ethernet communications. In a defence research environment, all networks must be secured. Therefore, a security level must be added to the wireless system and the Pico-modules must be designed to accept encrypted messages.

- For further modelling of the robot interaction with the immediate environment, torque sensors should be added to the actuators. Currently, there is no sensory input providing any tactile feeling of the terrain. Torque sensors would give some idea of how much force each track applies to the ground. A closed-loop system could adjust the actuator command to obtain the desired torque on the axles or propulsive force on the tracks.

- Another very important modification to the vehicle would be continuous track rotation. The actual axles rotate 720°. This limits the possible behaviours that can be generated. In muddy or snowy terrains for instance, where slippage becomes an issue, it would be more appropriate to stop the propulsion and rotate the axle continuously , generating a "snowshoeing" behaviour. Similarly, if the robot reaches the rotation limit while crossing an obstacle, it will get stuck. Continuous axle rotation would avoid such undesirable situations.

- Trials demonstrated that the current track belts lose their treads when pushing on the edges of obstacles. A solution would be belts providing more grip and finer pitch. More rubbery belts would reduce the slippage of the robot between the grousers when attempting to climb an obstacle. Presently, the track slips with the weight of the robot until a tread hits the edge of the obstacle. This is repeated for every grouser during the ascent, resulting in tread wear and damage. *Sorbothane*® rubber sheets were added between the grousers to improve friction and reduce impact of slip on the grousers. Also, a new set of rubber belts were bought with shorter treads, spaced every 5 mm, which have not been tested yet.

- The prototype was delivered with four batteries for a maximum run of 20 minutes. It was then retrofitted with sensors, a motherboard and hardware which use energy from the same batteries, resulting in significant runtime reduction. The STRV needs more battery power for longer operating time.

- The body top is not designed for maintainability and CPU cooling. It should have a vent to cool the computers.

- The next generation should have attachment points to fix sensors and antennas.

- Finally, all controllers and the power supply delivered with the STRV are custom made boards. The next STRV generation should be built with commercially available and documented electronic components. This would reduce dependance on the contractor who designed the robot and simplify maintenance.

Other desirable improvements may be identified in the future. The next generation of STRV will probably have a more spacious body for component installation, a better communication system and redesigned tracks for better traction and torque sensing.

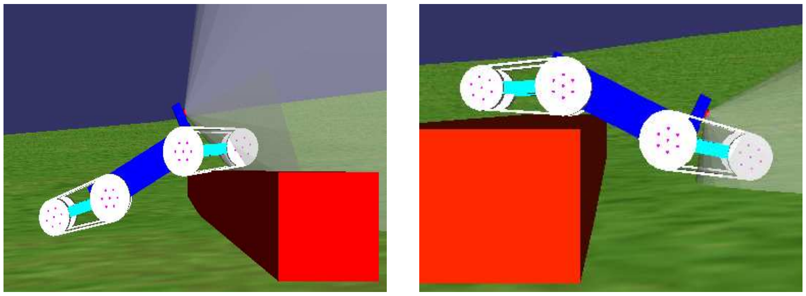


Figure 3: *Model of the STRV in a representation of its environment based on relevant geometric features and the actual platform.*

3 Sensing for Control to Produce Desired Locomotion in Complex Terrain

Algorithms to control vehicle dynamics and behaviours must be mated with relevant perceptual information of the environment to allow the UGV to interact intimately with its surroundings. For the most part, use of open-loop behaviours, which do not close the control loop with world representation information, are unable to meaningfully maneuver UGVs in the world. For a closed-loop system, perceptual information must be made available to the controller. However, there is a gap between the information provided by perception systems and that which is required by the locomotion system for controller synthesis. Mathematical models are essential in the analysis and design of traditional control systems and prove to be indispensable tools to the controls engineer. The next logical extension would be to embed a mathematical modeller in an autonomous system. In this context, the Autonomous Intelligent Systems Sesction at Defence R&D Canada is using the Vortex emulator by CMLabs Simulations Inc., a faster than real-time physics based engine, to act as an on-board modelling tool. To fill the gap between the real-world and the controller, relevant geometric features of the environment are extracted into a world representation, whose coordinates are passed to the mathematical modeller. A model of the UGV, which includes its dynamics, is then correctly positioned into this world model, as illustrated in Figure 3.

This model contains sufficient information represented in a meaningful mathematical framework that can be used by the intelligent mobility algorithms. The controller synthesis may be performed in faster than real-time, allowing for trials of candidate behaviours before implementation. The controller is able to formulate input/output relationships, calculate and make corrections to behaviour implementation for robust performance.

3.1 Measured Variables from Complex Environments for Locomotion

In the practical application of control theory, the control engineer must determine which variables should be controlled and which variables should be measured in an effort to make the system behave in a desired manner. The selection of measurement variables should be those that have strong relationships with the controlled outputs and are dependent on the control objective, which may be the stabilization of an unstable plant, rejection of disturbances and/or tracking reference changes. For traditional control problems such as temperature control, automobile cruise control or flight controls, these relationships are fairly intuitive. These relationships are also fairly intuitive in some of the inner control loops of a robotic platform that control motor torque for leg position or wheel speed. These control concepts become more abstract at higher levels where control is needed to produce desired robotic behaviours that yield improved mobility characteristics. Here, intelligent mobility algorithms must select what variables should be measured from the world in an effort to move the UGV successfully through its environment. As an example, perception algorithms may produce a 3D model of the environment. Intelligent mobility algorithms must then extract relevant information from this data to be useful. This information must be translated into a meaningful mathematical framework that can be used by the intelligent mobility algorithms. The variables measured from the environment will change depending on the specific UGV, and are complicated by vehicle speed, modes of locomotion, and mobility objectives. Specific examples of measured variables may include footfall distances for galloping, gap crossings for jumping, hill grades for energy management, or clearances for shape-shifting maneuvers. For example, during the course of its approach, the STRV must calculate the height of objects to successfully clear objects in its path. The capability of faster than real-time calculations allows for corrections to motion or selection of alternate behaviours due to disturbances such as uneven surfaces or variable surface frictions.

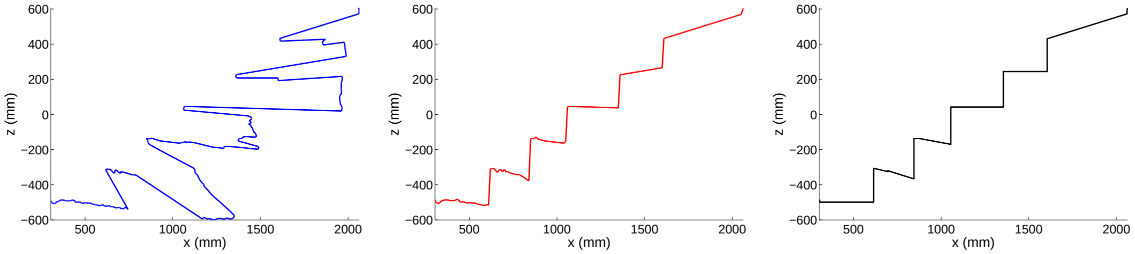
4 Terrain perception for learning robot navigation

In order for the STRV to interact appropriately with its environment, it must recognize obstacles that may affect its behaviour. The research project focuses on detecting physical characteristics such as location, height, width and shape useful for making control decisions rather than on obstacle identification.

4.1 Terrain mapping

To cross obstacles, the robot requires a good knowledge of the shape and location of the obstacles. The Autonomous Intelligent Systems Section is currently exploring object recognition and modelling for obstacle crossing using the laser range finder. The algorithm is based on image segmentation and shape detection. The shapes currently studied are staircases, ramps and boxes. The algorithm will be developed for more complex shapes later.

First, a terrain elevation map is built. The elevation contained in each grid cell is the highest



(a) Range data (b) Terrain map (c) Final image segmentation

Figure 4: *2D detection of a staircase without risers.*

elevation the laser detects at that specific grid location. This terrain map facilitates feature extraction as shown in figure 4 for a 2D detection of a staircase without risers. Without mapping the highest elevation per grid cell (central image), it is laborious to recognize the staircase from the raw data (left image).

To extract the structural information of each scan line elevation map, edges are located using 1D edge-based detectors; slopes and flat areas are detected using 1D region-based detectors looking for homogeneous regions. Finally, the detected segments are connected to generate the final image segmentation. Figure 4 shows the segmentation of the staircase (right image). The resulting segmentation provides more useful structural information for robot control navigation compared to the initial range data. Then, the distance between consecutive convexities gives step size and location.

In addition to elevation, the robot needs some knowledge about the obstacle width and orientation to complete the shape detection of an obstacle. To proceed, the commonly used Canny edge detector is applied to the 3D terrain map. The output image indicates the location of edges. Lines are fitted with the Hough transform. Figure 5 shows the edge detection output for the terrain map of a staircase and the lines generated by the Hough transform. The three steps are clearly detected. By comparing the edge length to the robot width, it is possible to determine if the vehicle is too wide to safely attempt traversing the obstacle. The bottom left image in figure 5 represents the robot width in cyan. Furthermore, the robot misalignment is rectified by computing the orientation of the vehicle with respect to the edges. For each edge, the algorithm computes the robot misalignment and the path to orient the robot and traverse safely the obstacle (in black in figure 5).

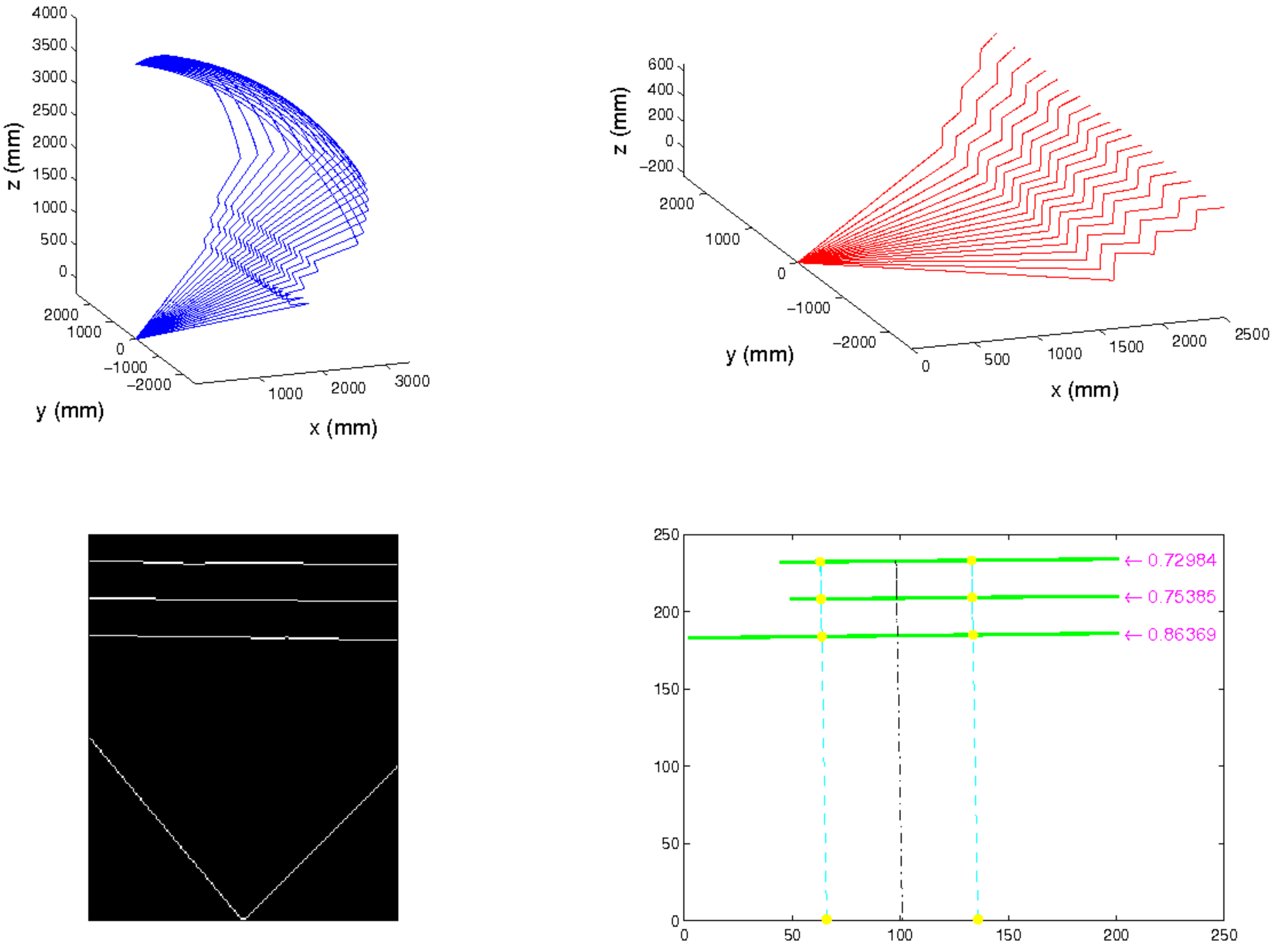


Figure 5: *Shape detection for a staircase: top left) laser range data, top right) terrain map, bottom left) Canny edge detector and bottom right) Hough Transform line-fitting for obstacle width detection (robot width in cyan) and robot misalignment (in degrees) (magenta)*

4.2 Behaviour learning

A robot learning how to behave in its complex environment is an attractive concept in robotics. Vincent published a literature review of reinforcement learning applied in robot navigation [6]. She explains why learning could facilitate robot control and the promising capabilities of reinforcement learning in robot navigation. This review has led the author to develop a learning architecture for traversing obstacles with the STRV.

A two stage reinforcement learning method is being developed, which will autonomously adapt the vehicle configuration as it crosses an obstacle. Figure 6 presents the main idea of the learning architecture. The first control layer inputs the terrain map into a reinforcement learning algorithm for the axle angular position computation. Each behaviour has a first layer reinforcement learning module trained individually. Reinforcements are provided based on vehicle motion progress and stability of the platform. Data collected during remotely controlled runs provide target commands to train the system by passive observation. Then online training converges quicker to adequate actions. A second layer selects behaviours based on obstacle recognition from image segmentation: step, ramp, staircase, etc. Figure 7 presents the overall control algorithm ensuring safe navigation.

Finally, an operator remotely controls the vehicle heading. The learning algorithm takes charge of mobility adaptation to the terrain complexity, reducing considerably the labor of the operator who just needs to plan the vehicle trajectory. This semi-autonomous characteristic of the robot simplifies the algorithm and adds safety to the navigation process, since the operator will naturally choose paths that seem feasible.

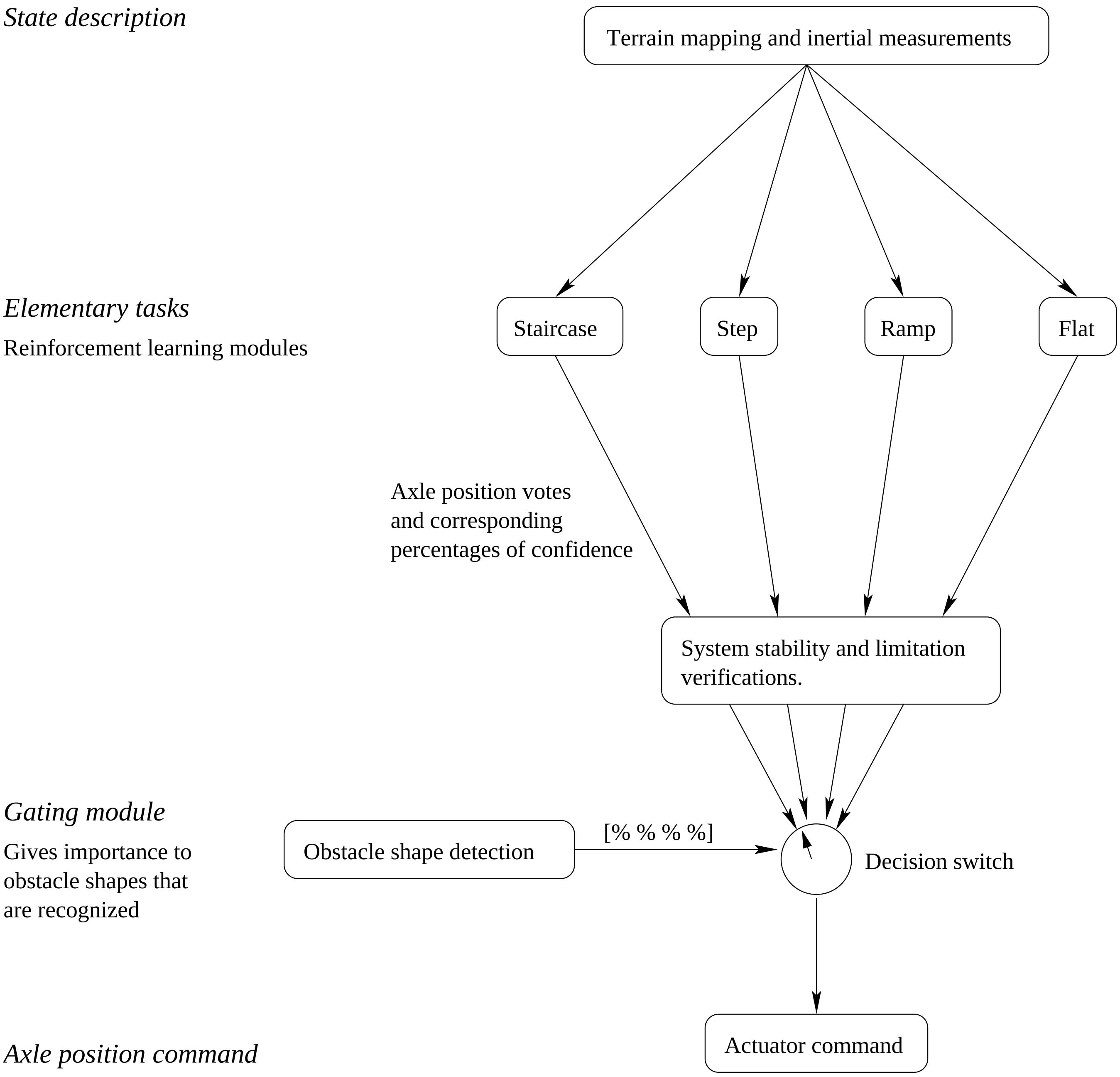


Figure 6: *STRV control system architecture - part 1.*

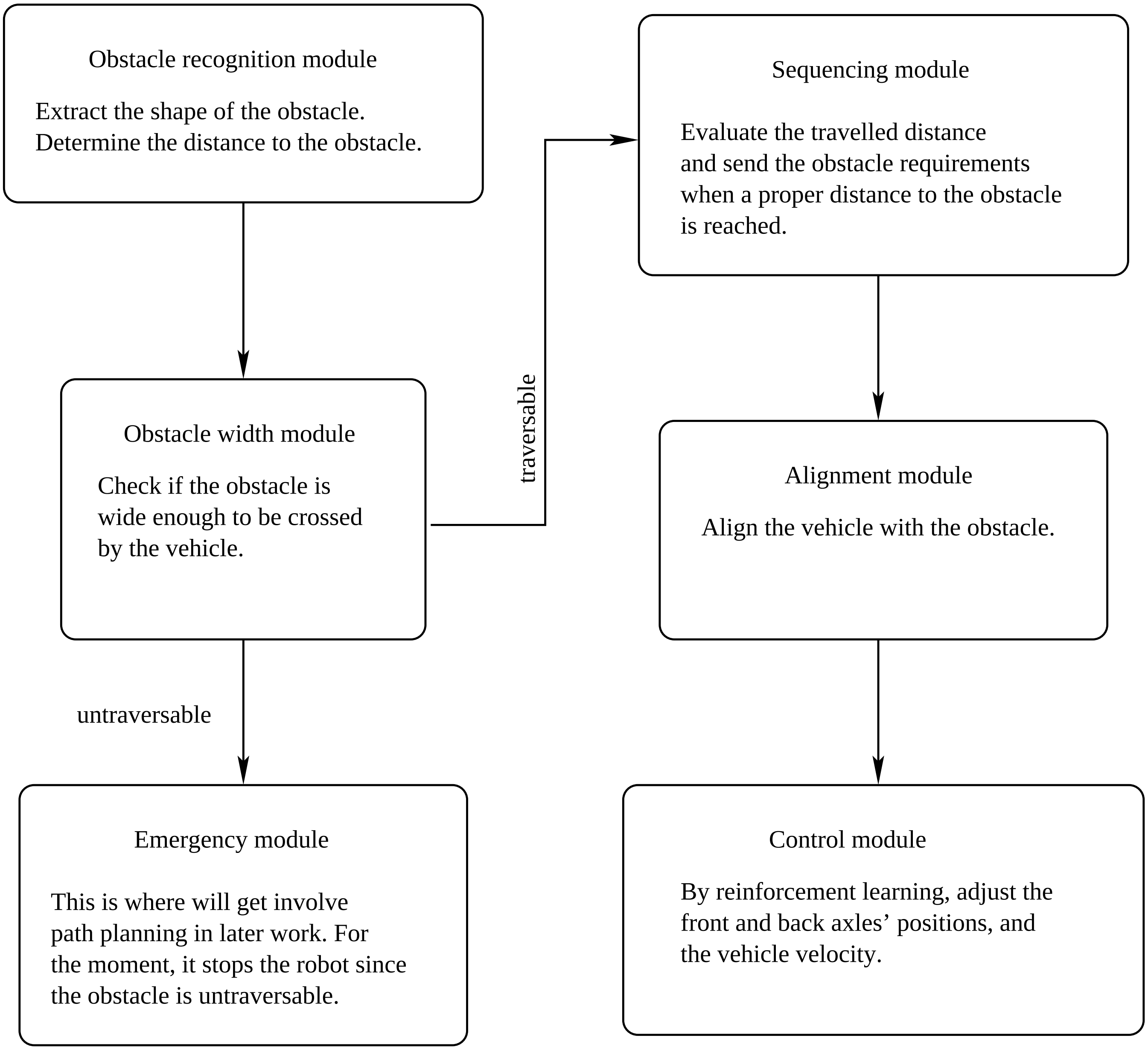


Figure 7: *STRV control system architecture - part 2.*

5 Conclusion

The STRV is an attractive robotic platform for traversing complex environments as a result of its inherent ability to vary its geometry. Researchers are investigating intelligent mobility controllers for adapting the vehicle configuration to obstacles. In order for the STRV to interact appropriately with its environment, it must recognize obstacles that may affect its behaviour. For simplification of the environment perception and navigational learning process, the project focuses on linear obstacles common in indoor environments. Once the methodology is established for simple linear obstacles, it will be adapted to more complex terrains. Sensing research presented in this paper aims at detecting physical characteristics such as location, height, width and shapes useful for making control decisions. Object modelling is described using terrain mapping, image segmentation and shape detection. This paper presented the learning architecture developed for safely traverse obstacles with the STRV by autonomously adapting the geometric configuration of the vehicle. Learning based on reinforcement and progress could simplify robot control and navigation.

Researchers envision shape-shifting robotic platforms being part of the future military teams in urban settings. Intelligent mobility algorithms aim to produce improved UGV locomotion for military relevant environment. That could support the Canadian Forces in surveillance and recognition missions, or scene investigations.

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Shape-shifting Tracked Robotic Vehicle for complex terrain navigation.

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