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Intelligent Mobility Algorithm Research & Development

Creating Intelligent Algorithms for Robotic Locomotion in Complex Terrains

M. Trentini, B. Beckman and I. Vincent
DRDC Suffield

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Abstract

The objective of the Autonomous Intelligent Systems Section of Defence R&D Canada – Suffield is best described by its mission statement, which is "to augment soldiers and combat systems by developing and demonstrating practical, cost effective, autonomous intelligent systems capable of completing military missions in complex operating environments." The mobility requirement for ground-based mobile systems operating in urban settings must increase significantly if robotic technology is to augment human efforts in these roles and environments. The intelligence required for autonomous systems to operate in complex environments demands advances in many fields of robotics. This has resulted in large bodies of research in areas of perception, world representation, and navigation, but the problem of locomotion in complex terrain has largely been ignored. In order to achieve its objective, the Autonomous Intelligent Systems Section is pursuing research that explores the use of intelligent mobility algorithms designed to improve robot mobility. Intelligent mobility uses sensing, control, and learning algorithms to extract measured variables from the world, control vehicle dynamics, and learn by experience. These algorithms seek to exploit available world representations of the environment and the inherent dexterity of the robot to allow the vehicle to interact with its surroundings and produce locomotion in complex terrain. The focus of the paper is to present the progress and future research that addresses the requirement to produce robotic locomotion in unknown highly complex terrain.

Résumé

L'objectif de la Section des Systèmes intelligents autonomes de R & D pour la défense Canada – Suffield est particulièrement bien décrit par son énoncé de mission qui consiste à « augmenter les systèmes d'hommes et de combat en mettant au point et en démontrant des systèmes intelligents autonomes peu coûteux et pratiques, capables de complémenter les missions militaires dans des contextes d'utilisation complexes. » Les besoins en mobilité des systèmes mobiles terrestres, opérant en milieu urbain, doivent augmenter de manière importante pour que la technologie robotique soit en mesure d'augmenter les efforts humains dans ces rôles et ces milieux. L'intelligence requise par les systèmes autonomes opérant dans des milieux complexes exige de réaliser des progrès dans beaucoup de domaines de la robotique. Ceci a résulté en des organismes de recherche importants dans les domaines de la perception, de la représentation du monde réel et de la navigation mais le problème de la locomotion sur un terrain complexe a été pour le moins négligé. Pour être en mesure d'atteindre cet objectif, la Section des Systèmes intelligents autonomes poursuit la recherche qui explore l'utilisation des algorithmes de mobilité intelligente conçus pour améliorer la mobilité d'un robot. La mobilité intelligente utilise les algorithmes de la détection, du contrôle et de l'apprentissage pour extraire des mesurandes provenant du monde réel, pour contrôler la dynamique d'un véhicule et acquérir des connaissances par expérience. Ces algorithmes cherchent à exploiter les représentations disponibles du monde réel d'un milieu ainsi que la dextérité inhérente du robot à permettre au véhicule d'interagir avec sa zone périphérique et de produire un mouvement de locomotion sur un terrain complexe. Cet article focalise sur la présentation des progrès et de la recherche future traitant des besoins de produire des mouvements de locomotion robotique sur un terrain inconnu très complexe.

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Executive summary

The autonomy of Unmanned Ground Vehicles (UGVs) operating in urban settings must increase significantly if robotic technology is to augment human efforts in military relevant roles and environments. Creating effective intelligence for these systems demands advances in perception, world representation, navigation, and learning. In the land environment, these scientific areas have garnered much attention. However the problem of locomotion in complex terrain has largely been ignored. The ability to develop robots that can operate in highly unstructured environments necessitates advances in visual processing and scene understanding, complex reasoning and learning, and dynamic motion planning and control. Moreover, a framework for reasoning and planning in these unstructured environments will likely require new mathematical concepts that combine dynamics, logic, and geometry in ways that are not currently available.

This undeveloped framework has resulted in a lack of control design tools for robotic locomotion and, as a result, practical applications have been limited. Advances have largely been confined to positioning and navigating within structured environments. To address the requirement for robotic locomotion in complex terrain, the Autonomous Intelligent Systems Section is pursuing research that explores the use of intelligent mobility algorithms designed to improve robot mobility. Intelligent mobility research investigates sensing, control, and learning algorithms to extract measured variables from the world, to control vehicle dynamics, and to enable robotic systems to learn by experience. The algorithms seek to exploit available world representations of the environment and the inherent dexterity of the UGV to interact with its surroundings and produce locomotion in complex terrain. The objective of this research is to create effective intelligence to improve the mobility of ground-based mobile systems operating in urban settings to assist the Canadian Forces in their future urban operations.

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Sommaire

L'autonomie des Véhicules terrestres sans pilote (UGV), opérant en milieu urbain, doit augmenter de manière importante pour que la technologie robotique soit en mesure d'augmenter les efforts humains dans des rôles et des milieux pertinents. La création d'une intelligence efficace pour ces systèmes exige de réaliser des progrès en matière de perception, de représentation du monde réel, de navigation et d'apprentissage. En milieu terrestre, ces domaines scientifiques ont beaucoup attiré l'attention mais le problème de la locomotion sur un terrain complexe a été pour le moins négligé. La capacité à mettre au point des robots pouvant opérer dans des milieux hautement non structurés exige de réaliser des progrès en matière de traitement visuel et de compréhension de scènes ainsi qu'en raisonnement et apprentissage complexes et planification et contrôle de la motion dynamique. Au demeurant, un cadre de travail pour le raisonnement et la planification de ces milieux non structurés exigera probablement de nouveaux concepts mathématiques qui combineront la dynamique, la logique et la géométrie avec des moyens qui ne sont actuellement pas disponibles.

Ce cadre de travail n'étant pas encore développé, il en résulte un manque d'outils de conception concernant le contrôle de la locomotion robotique et par conséquent, les applications pratiques demeurent limitées. Les progrès sont surtout confinés au positionnement et à la navigation à l'intérieur de milieux structurés. Pour aborder ces besoins en locomotion robotique sur terrains complexes, la Section des Systèmes intelligents autonomes poursuit une recherche qui explore l'utilisation d'algorithmes de mobilité intelligente conçus pour améliorer la mobilité des robots. La recherche en matière de mobilité intelligente examine des algorithmes de détection, de contrôle et d'apprentissage pour extraire des mesurandes à partir du monde réel qui visent à contrôler la dynamique du véhicule et à permettre aux systèmes robotiques d'apprendre par expérience. Les algorithmes cherchent à exploiter des représentations disponibles du monde réel d'un milieu ainsi que la dextérité inhérente des UGV à interagir avec leur zone périphérique et à produire des mouvements de locomotion sur un terrain complexe. L'objectif de cette recherche est de créer une intelligence efficace qui améliore la mobilité des systèmes mobiles terrestres opérant en milieu urbain et ceci dans le but d'aider les Forces canadiennes durant leurs opérations urbaines futures.

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1. Introduction

The mobility requirement for UGVs operating in urban settings must increase significantly if robotic technology is to augment human efforts in military relevant roles and environments. In order to achieve this objective, the Autonomous Intelligent Systems Section conducts research on intelligent mobility algorithms to enhance UGV mobility. The algorithms seek to exploit available world representations of the environment and the inherent dexterity of the UGV to interact with its surroundings and produce locomotion in complex terrain [4]. Intelligent mobility uses sensing, control, and learning algorithms to enable the UGV to extract measured variables from the world, control vehicle dynamics, and learn by experience [3]. The focus of the paper is to present current and future research within the framework of the research methodology, plan and direction defined at Defence R&D Canada – Suffield.

2. Background - Mobile Robotic Locomotion in Complex Terrain

Attaining the necessary intelligence for Unmanned Ground Vehicles (UGVs) to operate autonomously in complex environments will require advancements in many areas of robotics research including those of perception, world representation, navigation, and machine learning. While these areas have garnered much attention in robotics research, researchers have largely ignored the mobility requirement for UGVs operating in complex terrain. Despite the large body of research in the area of robotic locomotion, UGVs exhibit extremely simple behaviours. This is especially true when compared to the human ability to move in the world or to the numerous, very capable examples of locomotion found in nature. A large body of research has been developed to support robotics locomotion although the research has been focused on a particular set of assumptions or based on a specific morphology.

> *Most current mobile robot motion planning and control algorithms are not well suited to rough terrain environments, since they generally do not consider the physical interaction of the robot and terrain. This is likely due to the fact that terrain parameters are difficult to directly measure. Also, current planning and control algorithms often assume that the robot has perfect sensory knowledge of the environment, which is never the case for these applications[1].*

Thus, advances in robotic mobility have largely been confined to positioning and navigating within structured environments. Unlike traditional control problems, intuitive and systematic control tools for robotic locomotion do not readily exist thus limiting their practical application. A framework for reasoning and planning in these unstructured environments will require new mathematical concepts that combine dynamics, logic, and geometry in ways that are not currently available[2]. This is a critical gap in current robotics research, where sophisticated algorithms are needed to coordinate and control robotic locomotion in unknown, highly complex environments. Autonomous systems that have robust mobility characteristics in all terrains do not exist and few metrics have been developed to describe this type of UGV performance. To address this issue, mobility paradigms are introduced in the following section to facilitate research of intelligent mobility algorithms.

3. Distinct Mobility Paradigms

The Intelligent Mobility research methodology produces a depth of research in intelligent control algorithms with activity and linkages to research in areas of perception and world representation. Distinct vehicle paradigms have been formulated in an attempt to scope research that addresses the large complex space of relevant military UGVs. The intent is to facilitate research in UGV intelligence for mobility in complex terrain. Vehicles are configured that represent each of the distinct paradigm classes, allowing each vehicle to handle their environment in a different way with different capabilities. The paradigms which describe the general classes of desired robotic vehicle behaviours include, but are not limited to: deliberate dexterous, variable geometry, and dynamic reactive locomotion.

3.1 Deliberate Dexterous

The deliberate dexterous paradigm represents a class of UGVs that requires more advanced control strategies to control a large number of degrees-of-freedom. The UGVs operate by a deliberate placement of appendages that permit the UGV to traverse complex terrain with slow, confident maneuvers.

3.2 Variable Geometry

The variable geometry paradigm describes a class of UGVs that are capable of altering their geometry into more desirable positions for mobility. These UGVs use moderately complex control strategies to control a relatively low number of degrees-of-freedom.

3.3 Dynamic Reactive

The dynamic reactive paradigm describes the class of UGVs that exploits the inherent dynamic capabilities of the platform. These platforms use hybrid locomotive concepts such as wheels and compliant legs, which have the ability to store and release energy. They have the potential to yield dynamic behaviours that will outperform larger conventional vehicles in their ability to overcome obstacles. They will likely require more sophisticated control strategies to exploit these behaviours.

4. Intelligent Mobility Research Topics for Novel UGVs

Real-world testing of intelligent mobility algorithms is being conducted using representative UGVs defined by the mobility paradigms discussed in Section 3. Experimentation using these UGVs is key for the validation of simulation models, and investigation of robotic UGV behaviours. Their progress, research topics and preliminary results are discussed in the following section.

4.1 Deliberate Dexterous Locomotion

Interest in mobile robotics operating in complex environments and performing useful tasks is continuously expanding. Researchers in the mobile robotics community look towards biological systems for inspiration in design and control given their ability to maneuver in complex terrain. Mobile robots with increased dexterity that model biological systems have the potential to perform complex mobility tasks. The desire to create high degree-of-freedom UGVs, that start to mirror biological system complexity, result in an expectation of animal level performance. However, biological system performance creates an increased control requirement for the system. The UGV needs to be controlled both at the individual actuator and system level to achieve desired motion or position. The objective of research into high degree-of-freedom UGVs is to create a control theory that applies to a general class of mobile robotics. Research in deliberate dexterous mobility paradigm is being addressed by the 14 degree-of-freedom hybrid legged/wheeled Micro Hydraulics Toolkit (MHT) UGV.

4.1.1 Deliberate Dexterous UGV Description

The MHT derives from a necessity to experiment with advanced control algorithms on a reconfigurable UGV. To provide the highest utility for control algorithm development, it is designed to be a high degree-of-freedom robot that is readily configurable and controllable. The system depicted in Figure 1 is the completely assembled 14 degree-of-freedom version of the MHT. The main structure houses a rotary actuator, or ”hip”, that connects to another rotary actuator, or ”knee”, by means of a structural leg member. The rotary knee actuator connects to a rotary wheel, which can be actuated in yaw for steering. The entire toolkit is designed with 14 possible degrees-of-freedom that are actuated by 12 hydraulic motors and two electric motors. The hydraulic pump is powered by onboard batteries and an electric motor that is situated in the main body of the toolkit. The toolkit is equipped to control 14 actuators and is equipped with feedback sensors on all actuators. Dimensions in the standing position are approximately one meter in length, width and height.

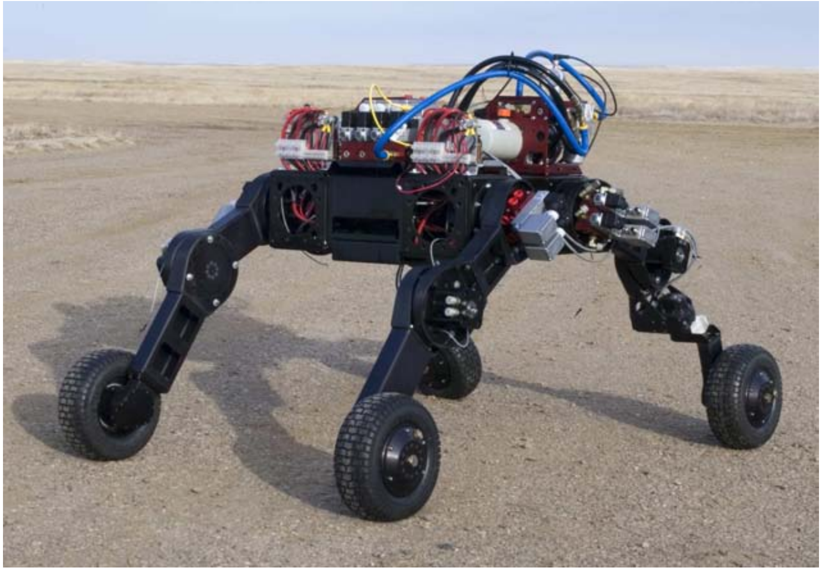

Figure 1: *MHT in its fully assembled configuration.*

4.1.2 Deliberate Dexterous UGV Research

The research intent is to understand system level control of high degree-of-freedom UGVs. The control community does not currently have the necessary tools available to produce robotic locomotion in complex terrain as discussed in Section 2. The Intelligent Mobility research being conducted by DRDC will generate an understanding of the control strategies required to produce locomotion in complex terrain for multiple degree-of-freedom UGVs.

The MHT UGV has achieved some level of development in simulation, however, this is a work in progress and the actual UGV is still being configured. A TopSolid 3D parametric model with material properties for the UGV has been developed to verify collisions and constraints of the toolkit. Further, a model of the vehicle has been developed under MSC.visualNastran Motion and is connected to MATLAB/Simulink for control algorithm development. Basic kinematic simulations that account for the appendage ranges of motion have been created to understand the capabilities of the robotic system. Future developments for the toolkit include solving the velocity kinematics, statics, and dynamics equations to completely define the theoretical capabilities of the system. A model of the system will then be used to develop advanced control algorithms for the novel series/parallel actuated robotic system in all its configurations.

4.2 Variable Geometry Locomotion

The focus of the Variable Geometry research is to investigate mobility behaviours that exploit the shape-shifting capabilities of the UGV to produce improved locomotion in complex terrain. Control of vehicle geometry via intelligent mobility algorithms can produce various modes of locomotion for the UGV (e.g. snow-shoeing, legged motion, tracked motion, etc ...) and conformance to its environment to provide improved mobility (e.g. duct crawling, bridging gaps, ducking under obstacles, etc ...). Research in the variable geometry mobility paradigm is being addressed by the UGV called the Shape-shifting Tracked Robotic Vehicle (STRV).

4.2.1 Variable Geometry UGV Description

The low degree-of-freedom STRV concept derives from the need for a simple system to initiate learning control algorithm research and development. The STRV consists of four independently driven tracks with solid axles articulating the front and rear pair of tracks, capable of 720 degrees of continuous rotation at a rate of 15 degrees per second. Novel research applicable to operations in complex environments will be possible, taking advantage of the small size of the UGV, its robustness, its few degrees-of-freedom and its inherent ability to change geometry. A visual representation of the global concept is depicted in Figure 2.

4.2.2 Variable Geometry UGV Research

The STRV benefits from a low number of degrees-of-freedom. Consequently, the basic control of the actuators is moderately simple to implement. Traditional control theory is used in the inner control loops of the robot to control the motors that pivot the track pair shoulders and the track belt. On the other hand, since just a few degrees-of-freedom are available, it is an arduous task to generate useful diversified and complex behaviours that close the loop with perception to interact with the world. The purpose of research is to create mobility behaviours with a low degree-of-freedom UGV using its shape-shifting capabilities to conquer complex terrain. By varying its geometry, the vehicle can generate various modes of locomotion by combining mobility behaviours to cross obstacles, adapt to the environment and improve the overall mobility performance.

Scripted behaviours is a good first step. However, human-scripted algorithms prove difficult and time consuming to understand, design, and tune for diverse UGVs that often possess multiple modes of locomotion. The production of mobility behaviours needs systematic control algorithms and flexibility to adapt to changing conditions. The ultimate goal is to mature the level of control from performance optimization based on metrics to an implementation which relies on learning. Learning algorithms may be used to exploit the

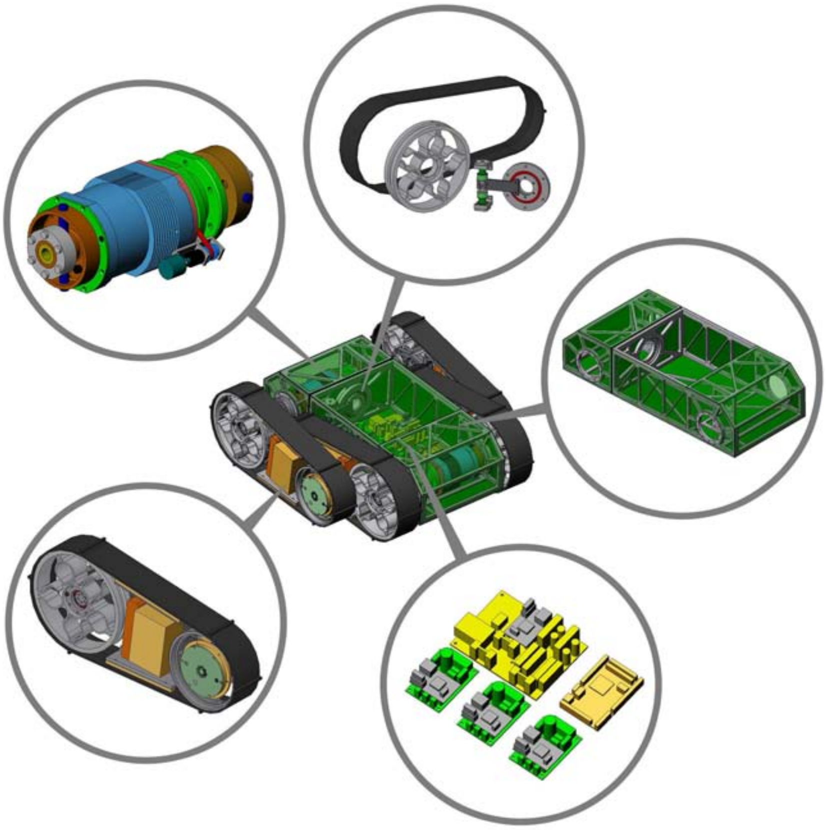

Figure 2: *Model of the STRV.*

available degrees-of-freedom to produce the appropriate shape-shifting behaviour and allow the UGV to navigate variable terrain conditions or circumstances. This implies that the UGV will have the necessary onboard intelligence to choose and create geometric configurations and manoeuvres to conquer unknown highly complex terrain that varies depending on the environment, obstacles, and terrain conditions. The development of intelligence to learn a behaviour and choose a geometric configuration will allow the UGV to interact with the world using previous experiences and adapt itself to new conditions.

4.3 Dynamic Reactive Locomotion

The paradigm of dynamic reactive behaviours has the potential to greatly enhance the mobility of UGVs. This paradigm includes UGVs that utilize hybrid concepts of compliant legs and wheels, which store and release energy. These UGVs have the potential to yield mobility behaviours that widen the scope of negotiable obstacles and generally increase UGV mobility, which would not otherwise be possible with conventional configurations. As such, a smaller robot with intrinsic dynamic capabilities may prove to outperform larger conventional vehicles. They will require advanced control strategies and have a high dependency for perception and world representation to intelligently negotiate obstacles that are much larger in size than is currently typical at that small scale. The Platform for Ambulating Wheels (PAW) robot will be used to investigate how the inherent dynamic capabilities of a UGV can be exploited to produce improved mobility characteristics.

4.3.1 Dynamic Reactive UGV Description

The PAW robot depicted in Figure 3 is an active research project between DRDC Suffield and the McGill Centre For Intelligent Machines at McGill University.

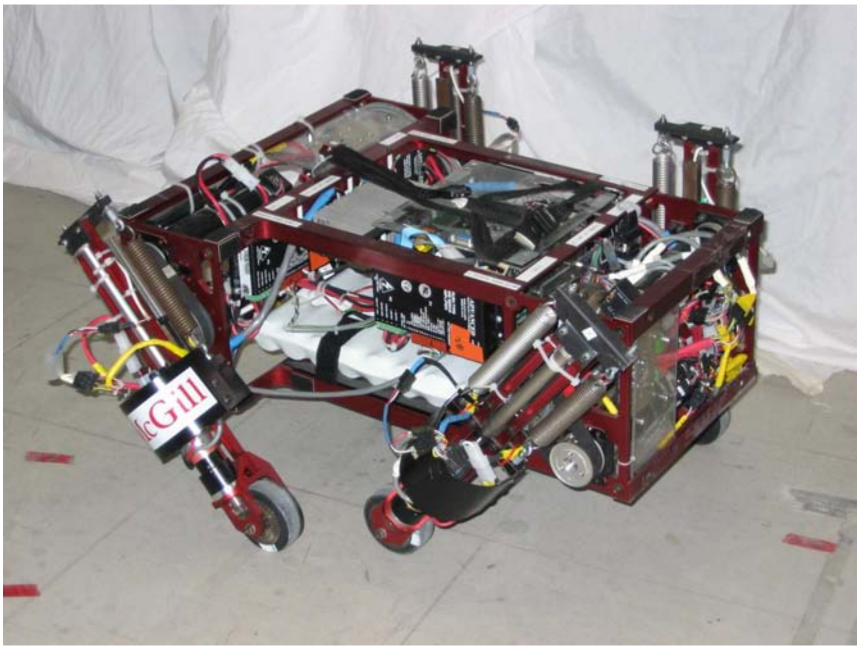

Figure 3: *PAW demonstrating a novel turning behaviour.*

The body of the robot consists of a T-shaped aluminum frame. The robot has four compliant legs and an active wheel placed at the foot of each leg. Thus, each leg has three degrees-of-freedom: an actuated joint at the hip, a passively compliant telescoping leg, and an actuated wheel joint. PAW is used in the study of both wheeled and dynamically stable legged modes of locomotion. Recent experimental results regarding current wheeled mobility behaviours for the PAW, including a novel turning behaviour for the vehicle have been presented [5]. UGV intelligence is created to exploit the hybrid nature of the UGV, to enhance the wheeled behaviour stability and locomotive performance of the robot.

4.3.2 Dynamic Reactive UGV Research

The PAW robot combines aspects of legged and wheeled locomotion in order to achieve greater overall mobility. In wheeled modes of operation, it takes advantage of locomotive efficiencies by ground traversal in conditions where the terrain is flat. In legged modes of operation, the dynamic behaviours of the robot include jumping and bounding to allow the robot to operate in increasingly complex terrains where conventional rolling is prohibitive. Thus, the PAW robot has the potential to outperform conventional vehicles of much larger geometric scale in its ability to overcome obstacles and negotiate unstructured terrain. While this research represents a potentially significant contribution to the state of the art, it alone does not fully solve the mobility problem for UGVs operating in unknown terrain. Existing PAW open-loop behaviours, which do not close the control loop with world representation information, are unable to meaningfully maneuver UGVs in the world. Any of the resulting mobility behaviours of the PAW must be mated with relevant world representation information of the environment so as to allow the UGV to interact intimately with its surroundings. Unlike traditional control problems, the tools necessary to produce robotic locomotion and close the loop with world representation and perception systems simply do not exist. New algorithms are necessary to coordinate and control complex vehicle motion. This has resulted in limited application of highly agile, mobile, autonomous systems that can operate in unknown highly complex environments.

For a closed-loop system, world representation information must be made available to the controller. However, there exists a disconnect between the information provided by world representation generators and that which is required by the locomotion system for controller synthesis. To address this need, DRDC Suffield is using Vortex 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 must be extracted into a world representation. This is a requirement of the intelligent mobility algorithms. With this information, a model of the UGV that includes its dynamics, is then correctly positioned into this world model. This model would now contain the sufficient information, represented in a meaningful mathematical framework, to be used by the intelligent mobility algorithms. This framework will assist scientists and facilitate research that addresses the mobility problem for unmanned ground vehicles maneuvering in unknown highly complex environments.

5. Conclusion

The intelligence required for autonomous systems to operate in complex environments demands advances in many fields of robotics. This has resulted in large bodies of research in areas of perception, world representation, navigation, while largely ignoring the problem of locomotion in complex terrain. Traditional control theory and tools are ill-equipped for new robotic demands for autonomous operation in unknown complex environments. Distinct vehicle paradigms are identified that address a spectrum of mobility issues, challenges and uncertainties that complicate UGV mobility. These paradigms facilitate research in creating sufficient vehicle intelligence for UGVs to maneuver in their environment by producing locomotion in different ways. The objective is to produce vehicle intelligence for UGVs capable of navigating autonomously in relevant military environments. This paper documents the current and future research that addresses the requirement to produce robotic locomotion in unknown highly complex terrains.

References

1. K. Iagnemma and S. Dobowsky. *Mobile Robots in Rough Terrain: Estimation, Motion Planning, and Control with Application to Planetary Rovers.* STAR (Springer Ttracts in Advanced Robotics), 2004. ISBN 3-540-21968-4.

2. R. Murray, editor. *Control in an Information Rich World.* SIAM, 2003.

3. M. Trentini, B. Beckman, and B. Digney. Control and learning for intelligent mobility of unmanned ground vehicles in complex terrains. In *Proceedings of SPIE Unmanned Ground Vehicle Technology VII*, Orlando, FL, March 2005.

4. M. Trentini, B. Beckman, B. Digney, and J. Collier. Novel mobility platforms utilizing intelligent algorithms. In *Proceedings of SPIE Unmanned Ground Vehicle Technology VI*, Orlando, FL, April 2004.

5. M. Trentini, J.A. Smith, and I. Sharf. Intelligent mobility for dynamic behaviours of paw, a hybrid wheeled-leg robot: Robot design and control algorithm development for wheeled mobility behaviours. DRDC Suffield TM 2005-203, Defence R&D Canada - Suffield, December 2005.

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The objective of the Autonomous Intelligent Systems Section of Defence R&D Canada – Suffield is best described by its mission statement, which is “to augment soldiers and combat systems by developing and demonstrating practical, cost effective, autonomous intelligent systems capable of completing military missions in complex operating environments.” The mobility requirement for ground-based mobile systems operating in urban settings must increase significantly if robotic technology is to augment human efforts in these roles and environments. The intelligence required for autonomous systems to operate in complex environments demands advances in many fields of robotics. This has resulted in large bodies of research in areas of perception, world representation, and navigation, but the problem of locomotion in complex terrain has largely been ignored. In order to achieve its objective, the Autonomous Intelligent Systems Section is pursuing research that explores the use of intelligent mobility algorithms designed to improve robot mobility. Intelligent mobility uses sensing, control, and learning algorithms to extract measured variables from the world, control vehicle dynamics, and learn by experience. These algorithms seek to exploit available world representations of the environment and the inherent dexterity of the robot to allow the vehicle to interact with its surroundings and produce locomotion in complex terrain. The focus of the paper is to present the progress and future research that addresses the requirement to produce robotic locomotion in unknown highly complex terrain.

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