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Intelligent Mobility Algorithm Research

Dependencies on Autonomous Systems Research

B. Beckman, M. Trentini, C. Brosinsky, S. Penzes
DRDC Suffield

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Abstract

The mission of the Autonomous Intelligent Systems Section at Defence R&D Canada – Suffield is to augment soldier and combat systems by developing and demonstrating practical, cost-effective autonomous intelligent systems capable of completing military missions in complex operating environments. Fulfilling this mission, in part, is current intelligent mobility research aimed at control algorithms that exploit an Unmanned Ground Vehicle's (UGV's) inherent dexterity and available world representation information to produce intelligent locomotion in complex urban terrains. Traditional UGV research has largely been applied to operations in unstructured, obstacle-free outdoor environments. The shift to the complexity of a highly unstructured, obstacle-rich, military urban environment requires dramatically improved mobility characteristics. Intelligent mobility algorithms will exploit learning and control theory to enhance UGV mobility in extremely cluttered environments. This paper defines intelligent mobility research and provides a framework for algorithm development, simulation capabilities and describes the inherent dependencies on other autonomous systems research.

Résumé

La mission de la Section des Systèmes intelligents autonomes de R & D pour la défense Canada – Suffield consiste à augmenter les systèmes pour les soldats et le combat en mettant au point et en démontrant des systèmes intelligents autonomes qui sont pratiques, économiques et capables de compléter des missions militaires dans des milieux opérationnels complexes. Cette mission est remplie en partie par la recherche actuelle sur la mobilité intelligente qui vise à contrôler les algorithmes exploitant la dextérité inhérente au Véhicule terrestre sans pilote ainsi que l'information disponible par la représentation du monde réel ceci dans le but de produire un moyen de locomotion intelligent circulant dans des terrains urbains complexes. La recherche traditionnelle sur les Véhicules terrestres sans pilote a surtout été appliquée à des opérations dans des milieux extérieurs, sans obstacles et non structurés. Le changement d'orientation vers un milieu urbain militaire, riche en obstacles et non structuré exige une amélioration importante des caractéristiques de mobilité. Les algorithmes de mobilité intelligente exploiteront la théorie de contrôle à apprentissage pour améliorer la mobilité des Véhicules terrestres sans pilote dans des milieux extrêmement encombrés. Cet article définit la recherche sur la mobilité intelligente et fournit un cadre de travail pour la mise au point des algorithmes et des capacités de simulation et décrit leur dépendance inhérente à d'autres recherches portant sur les systèmes autonomes.

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Executive summary

Traditional Unmanned Ground Vehicles (UGVs) have been used in open-terrain operations but the current operational need is in urban settings, which requires increased mobility. Intelligent mobility researchers with the Autonomous Intelligent Systems Section (AISS) at Defence R&D Canada – Suffield envision UGVs operating in complex urban environments. Urban environments are designed with human scale structures and, therefore UGVs must also be designed to be capable of operations in these spaces. Canadian Forces (CF) client groups continue to emphasize the need for UGVs capable of operations in urban areas as evidenced by ongoing sponsored research programs within Autonomous Intelligent Systems Section (AISS).

The Autonomous Intelligent Systems Section is addressing this urban requirement through intelligent mobility research. Intelligent mobility research investigates learning algorithms, extracting necessary variables from sensing systems and world representations to control UGV systems in unstructured environments. The objective of this research is to create intelligent mobility algorithms for UGVs which improve their mobility characteristics in urban terrains. This paper discusses the intelligent mobility research and provides a framework for algorithm development, simulation capabilities and describes the inherent dependencies on other autonomous systems research.

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Sommaire

Les Véhicules terrestres sans pilote traditionnels ont été utilisés durant des opérations en terrain découvert mais les besoins opérationnels actuels existent plutôt dans des milieux urbains ce qui demande une mobilité accrue. Les chercheurs en mobilité intelligente de la Section des Systèmes intelligents autonomes de R & D pour la défense Canada – Suffield travaillent à créer des véhicules opérant en milieux urbains complexes. Les milieux urbains sont conçus avec des structures à l'échelle humaine et par conséquent les Véhicules terrestres sans pilote doivent aussi être conçus avec la capacité d'opérer dans ces espaces. Le groupe client des Forces canadiennes (FC) continue à insister sur le besoin en véhicules terrestres sans pilote, capables d'opérer en zones urbaines, comme en sont témoins les programmes subventionnés de recherche continue au sein de la Section des Systèmes intelligents autonomes.

La Section des Systèmes intelligents autonomes répond actuellement à ce besoin urbain au moyen de la recherche portant sur la mobilité intelligente. Cette recherche étudie les algorithmes d'apprentissage par analogie en extrayant les variables nécessaires, provenant des systèmes détecteurs et de représentation du monde réel, pour contrôler les systèmes de Véhicules terrestres sans pilote dans des milieux non structurés. L'objectif de cette recherche consiste à créer des algorithmes de mobilité intelligente pour ces véhicules visant à améliorer leurs caractéristiques de mobilité dans les terrains urbains. Cet article discute de la recherche portant sur la mobilité intelligente et fournit un cadre de travail visant à mettre au point des algorithmes et des capacités de simulation et décrit leur dépendance inhérente à d'autres recherches portant sur les systèmes autonomes.

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1. Introduction

The mobility requirement for Unmanned Ground Vehicles (UGVs) is expected to increase significantly as military conflicts shift from open terrain operations to the increased complexity of urban and other complex environments. Urban environments are designed on a human scale with stairs, narrow hallways, tight corners and closets. There are also smaller than human scale spaces such as crawl spaces, ducts and sewer pipes. These tight confines can further be complicated by the addition of wire entanglements, booby traps, sand bags, furniture, rubble, and barricades. Operations in urban environments pose difficult problems to UGV mobility in that locomotive path selection is limited and operations are in tightly confined spaces. Canadian Forces (CF) client groups continue to emphasize the need for capable robotic systems for operations in these urban areas as evidenced by ongoing sponsored programs within AISS.

The conventional solution for UGVs operating in the open terrain has been to minimize the perception burden by using larger vehicles and brute force to overcome mobility challenges.[1] This solution presents limited options in negotiating obstacles that the platform has not been designed to overcome. The size constraint of UGVs operating in urban environments provides a vast array of research opportunities for smaller robotic systems capable of improved mobility. Intelligent mobility research addresses the shift in the battlespace environment and the need for UGVs to overcome the difficult transition from the open terrain into the urban setting. This will require the development of novel and intelligent robotic systems that exploit their inherent dexterity to move. For example, the result may be UGVs that exploit dynamic behaviours to outperform larger systems in overcoming obstacles or UGVs that change shape according to their environment so as to leverage themselves into more advantageous positions.

To achieve the required objective of UGVs operating in complex urban environments research must be initiated in various areas. Intelligent mobility research develops learning algorithms and control algorithms by extracting necessary variables from sensing systems and world representations. The objective of this research is to create intelligent mobility algorithms for UGVs which improve their mobility characteristics in urban terrains. The following sections address the research dependencies of intelligent mobility with other autonomous systems research.

2. Background

The objective of Defence Research and Development Canada (DRDC) is to explore emerging technologies which ensure the Canadian Forces (CF) remain technologically prepared and relevant. Autonomous Intelligent Systems (AIS) are recognized in the Technology Investment Strategy (TIS) as an emerging technology that will advance the capability of the CF. Autonomous Intelligent Systems are unmanned robotic systems that interact in complex terrain with minimal human intervention. The Autonomous

Intelligent Systems Section (AISS) at DRDC Suffield has active research programs in the key enabling technology areas which will create unmanned system autonomy. One component of AISS, namely intelligent mobility, is to improve the mobility of novel robotic systems so as to improve their mobility of UGVs in both open and urban terrain. This specific research area addresses the necessary algorithms to coordinate and control complex motion of these novel robotic systems in unstructured urban environments.

Intelligent mobility research has the potential to yield dramatic mobility capabilities for future UGVs operating in these complex unstructured environments. It is envisioned that the CF will operate in urban environments with combatants and thus, it is necessary to advance UGV mobility to enhance soldier performance, protection, and survival. The Future Security Environment 2025 report states:

> *The UN estimates that by 2030 approximately 60 percent of the worlds population will live in urban centres compared to the current level of 48 percent. Historically, urbanization has correlated to increased economic growth. However, this occurred in societies able to develop the social, political and legal institutions to manage the challenges of urbanization by implementing municipal programs such as effective waste and water management. In the developing world, generally weak governments and low incomes of urban dwellers have impeded the development of adequate systems to inure the population to the health, environmental and social effects of rapid urbanization. This will further exacerbate the problems of water distribution, infrastructure development and provision of health, economic, and social services thereby creating disgruntled citizens who might express their rage through violence and insurrection.* [2]

Given the growing trend towards urbanization and military operations in the urban setting it is necessary that intelligent mobility research continue to address control of novel robotic systems in complex environments. The objective of the AIS activity is to create unmanned robotic systems that interact in complex terrain with minimal human intervention.

> *Robotic systems will be fully exploited in the future battlespace (e.g., micro-robots for surveillance and target identification and robotic weapon systems). They can improve lethality, mobility, effectiveness and survivability both on the tactical battlefield, in peacekeeping and in urban operations. [3]*

However, the TIS also identifies that:

> *Operation in the land environment provides the greatest challenges to mobility and machine learning, and the greatest opportunities and requirements for*

automated, cooperative and collective intelligence gathering and information sharing among robotic systems. Throughout, the focus will be on data fusion and the development of cooperative, intelligent systems, for various platforms, rather than on the development of specific new platforms.[4]

Methods for AIS to interact with their environment: Develop algorithms, software and hardware to control the automated/robotic systems behaviour as it responds to a changing environment. [4]

The intelligent mobility research addresses the challenges stated in the TIS by creating novel robotic systems that are capable of operating in the complex urban environments. These robotic systems are expected to be of smaller scale, which would better allow them to interact dynamically and intimately with in urban unstructured environments.

3. Intelligent Mobility Research

Intelligent mobility research has the potential to yield large advancements in the coordination and control of complex robotic motion in unstructured environments. This would be a significant contribution by DRDC Suffield to the problem of UGVs operating in urban circumstances. This implies the use of small novel robotic systems executing slow, confident and deliberate maneuvers while other robotic systems have the potential to yield faster dynamic behaviors that exploit the intrinsic capabilities of the robotic system to negotiate obstacles. This research establishes a niche area for DRDC where innovation will address a difficult and challenging problem.

Intelligent mobility seeks to exploit the inherent dexterity of the robotic systems and available world representation of the environment using concepts and advances in planning, adaptation, learning and control theory so as to allow UGVs to engage extremely irregular and cluttered environments. The synergistic combination of these elements will allow UGVs to outperform larger conventional vehicles designed without these capabilities.

Intelligent mobility comprises several areas of research that must be addressed to produce UGVs capable of operating in highly complex unstructured environments. The research dependencies on creating intelligent mobility algorithms are comprised of the following: world representation, classification of the environment, Unmanned Ground Vehicles, and UGV metrics.

3.1 Intelligent Mobility Algorithm Development Process

Intelligent mobility algorithms coordinate and control complex robotic motion to allow UGVs to interact intimately with their surroundings and move through complex terrain. This interaction necessitates closing the loop between the motion control of the UGV with the various perception subsystems and world representation information to develop highly agile, mobile, and autonomous robots that can operate in unknown highly complex environments. Intelligent mobility researchers plan to incorporate simulated world representation data to advance the control algorithms until the data and sensor research has sufficiently matured to be used on small robotic systems in real-time. This will require advances in the many facets of robotic research. A report documenting the findings and recommendations of the Panel on Future Directions in Control, Dynamics, and Systems addresses the issue of control as a central element in robotics and intelligent machines. [5] The panel comprised key members of the control community from government agencies, universities, research organizations and industry. Together they discussed the state of the field and future opportunities, which included discussions and presentations at Defense Advanced Research Projects Agency (DARPA) and the Air Office of Scientific Research (AFSOR) to produce their report. Concerning the application, opportunities and challenges with respect to robotic and intelligent machines, the panel had the following comments on the subject.

> *It is interesting to note some of the history of the control community in robotics. The IEEE Robotics and Automation Society was jointly founded in the early 1980s by the Control Systems Society and the Computer Society, indicating the mutual interest in robotics by these two communities. Unfortunately, while many control researchers were active in robotics, the control community did not play a leading role in robotics research throughout much of the 1980s and 90s. This was a missed opportunity since robotics represents an important collection of applications that combines ideas from computer science, artificial intelligence, and control. New applications in (unmanned) flight control, underwater vehicles, and satellite systems are generating renewed interest in robotics and many control researchers are becoming active in this area.*

> *Finally, we note the need to develop robots that can operate in highly unstructured environments. This will require considerable advances in visual processing and understanding, complex reasoning and learning, and dynamic motion planning and control. Indeed, 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.*

It concluded that control of robotics and intelligent systems will become even more important than it is today. This research will provide the foundation for creating highly controllable novel unmanned ground systems. What follows is a description of key research areas explored in intelligent mobility.

3.1.1 World Representation

Creating a world representation is the process of developing a suitable representation of the environment in which the UGV is operating by extracting information from perception sensors. This world representation is required by the intelligent mobility algorithms of the UGV to coordinate complex robotic motion and behaviours to navigate through the environment.

Intelligent mobility researchers are not directly developing any of the world representation information for their algorithms, but are highly dependant on the success of this research. Simulated sensor data will be used by the intelligent mobility algorithms to control the complex robotic motion until acceptable world representation information and sensors have been developed for small UGVs.

3.1.2 Classification of the Environment

The design of a mobility system is highly application dependent, making it difficult to develop systems for mission requirements that have a high degree of variability. Fundamental to success in any mission scenario is the understanding of the environment within which the UGV is expected to operate. Urban operations are a primary focus of the AISS research and development activities and defining obstacles within these highly complex unstructured environments is essential to the design of capable UGVs. It is, however, unreasonable to assume that all of the mobility challenges presented by the urban environment can be foreseen in the design of an optimal UGV.

DRDC Suffield plans to commit to a better understanding of UGV operating environments. Currently, work is being done that classifies urban terrain for military missions but little work is being done to assign a UGV traversable factor to these classifications.[6] The intelligent mobility researchers plan to leverage research conducted in terrain classification and link the mobility characteristics of novel robotic systems to create a traversable value in a given locomotive path. This link will be the combined result of research conducted in terrain classification, done by external researchers, and research conducted in mobility characteristics of novel robotic systems done by the intelligent mobility program at DRDC Suffield.

3.1.3 Unmanned Ground Vehicles

In open terrain, large vehicles use size and power to overcome most mobility challenges presented by the environment. However, urban environments are designed on a human scale, therefore, mobility challenges cannot be addressed by simply increasing UGV's size or power. Smaller UGVs offer the obvious benefits of accessibility and stealth but are presented with increased mobility challenges because of their smaller size. The design of a novel mobility robotic systems will significantly affect the ability of a UGV to maneuver in the world. While highly configurable articulated robotic systems are typically best suited for unstructured terrain, the added degrees-of-freedom that typically provides this configurability must be controlled. Innovative robotic system design facilitates the use of intelligent control systems that exploit the inherent dexterity of the robotic system to overcome unforeseen mobility challenges.

The intelligent mobility researchers will focus their research toward novel robotic systems that use non-conventional modes of locomotion in order to advance control algorithm development. The research systems will primarily employ non-harmful emission types of propulsion. These robotic systems will be approximately under 150 kgs, have volumes of one m^3 or less, and be able to be tested in a large indoor lab environment. Occasionally, there will be tangential research activities that explore advanced development of ruggedized and fieldable systems. These tangential research directions will address short term aspects, such as soil traction-element interaction that will advance the knowledge of mobility in complex environments. The intelligent mobility researchers are limited in size in terms of people and resources, therefore, only a few research themes will be advanced at one particular time.

DRDC Suffield has distinct mobility paradigms to describe general classes of robotic locomotion. Representative UGVs of these paradigms are being developed for real-world testing of intelligent mobility algorithms, validation of simulation models, and investigation of mobility behaviours. These paradigms include dynamic reactive, variable geometry, and deliberate dexterous.

The dynamic reactive UGV paradigm includes novel robotic systems that store and release energy for locomotion. One of these systems resides at the Centre for Intelligent Machines at McGill University. McGill University is conducting research in dynamic behaviours of small robotic UGVs. This particular UGV utilizes actively controlled hips connected by compliant legs to actively controlled wheels. The contract has been conducted for approximately five years and it has been determined that a duplicate robotic system will be constructed at DRDC Suffield. This robotic system will be be used by DRDC Suffield staff to advance algorithm development.

The variable geometry UGV paradigm consists of robotic systems that are capable of changing their shape. The intelligent mobility researchers are in the preliminary design phase of the Shape-shifting Tracked Robotic Vehicle (STRV). This UGV is able to change its geometry to leverage itself into positions that allow it to better interact and move more efficiently through, its environment.

The deliberate dexterous UGV paradigm consists of robotic systems that are capable of fine accurate placement of appendages. The Micro Hydraulics Toolkit is an extensive toolkit that permits the user to easily create and investigate many UGV configurations. This toolkit is being developed from joint research activities by DRDC Suffield and Collineo Inc. and will provide the intelligent mobility researchers with the components for an advanced hydraulically powered UGVs with accurate appendage placement.

3.1.4 Unmanned Ground Vehicle Metrics

Many of the current metrics developed for larger traditional vehicles operating in open terrain do not apply to the smaller lighter UGVs intended for highly unstructured and complex urban environments. Some traditional metrics consider empirical data for large scale and weight vehicles with conventional track or wheel configurations that will not apply to smaller UGVs. Metrics for UGVs performance need to be developed for the quantification of small vehicle mobility. Moreover, the many modes of UGV locomotion including walking, hopping, rolling, galloping and sliding, complicate the analysis and determination of a general set of metrics for UGV performance. Thus, it is necessary to develop a general set of metrics that apply to all UGVs in order to facilitate system optimization. As an example, an energy management metric can be described as the power required to traverse a specified terrain within a given time frame. In this manner it is possible to develop mobility behaviours, including efficient gaits that optimize energy management to extend the UGVs operating range.

Novel UGV performance metrics and set of standard tests will be developed to allow comparison of novel robotic systems. The research will focus on determining the performance of a novel robotic system, in mobility and survivability, for a standard complex terrain.

3.2 Software for Intelligent Mobility Algorithm Development

The intelligent mobility researchers require a variety of software and hardware components to advance the capabilities of novel robotic systems operating in complex terrain. These resources will provide the ability to advance the control algorithm development, form a database for future vehicle UGV development, create measures of performance for novel UGVs, and create the ability to conduct experimentation in other venues.

The intelligent mobility researchers will need to operate with four different classes of software. It is typical to expect that these classes of software will have a high degree of interaction with each other, preferably from a common database. The software will allow novel robotic systems to be tested and controlled in a simulated environment prior to being committed to firmware.

3.2.1 Parametric Solid Modeling

This first class of software will provide 3D models, 2D drafting plans, and mechanical drawings for the novel UGV configurations. This software package takes into account moments of inertia, center of mass, collisions and material properties. While it is not a dynamic modeling tool, this software highlights the reality of mechanical construction.

3.2.2 Dynamic Simulator

A dynamic simulation tool that will model rigid bodies interacting with UGV terrain. This class of software also incorporates inertial, force, and mechanical characteristics but they typically have contact models with different terrains and tractive elements. They typically have libraries of many types of components such as hydraulics, internal combustion engines and suspensions systems. The system will provide the necessary information to control UGVs in simulation and aid in the development of control knowledge for use in the real environment.

3.2.3 Faster than real-time Physics Modeler

This software is a physics-based real-time behaviour modeling package that will be used to develop accurate motion models that operate in real-time simulations. The software will be used to combine a physical model of the robotic system and sensor information of the real world to create a world representation of the UGV in its environment. The resultant model will be of sufficient fidelity that coordination and control studies can be undertaken to produce meaningful locomotion in complex environments.

3.2.4 Control development software

Control development software interacts with the dynamic modeling software and the real-time physics modeler. This software is a powerful tool that will be used to develop the control algorithms for the novel UGV. The interaction will enable the researchers to determine how a UGV will behave in various terrains with various configurations and different intelligence algorithms.

3.3 Hardware Dependencies

Validation models and simulation of novel robotic robotic system in the distinct dynamic reactive, variable geometry, and deliberate dexterous mobility paradigms will reach a point of completion for a defined novel robotic system. Once this occurs, prototypes will need to be created of these novel robotic systems and conduct validation experiments to confirm the modeling and simulation results. The intelligent mobility researchers will not build these prototypes but contract the basic physical construction of them to various external organizations.

Infrastructure facility is needed for testing novel robotic systems. The large open floor plan of the research facility for the intelligent mobility researchers will include clean space for offices and trial preparation. The trial area will be a large rugged testing environment with reconfigurable obstacles and controllable environmental conditions such as lighting. The building must also be equipped with readily portable and configurable instrumentation (motion capture, transducers, data collection systems) to capture mobility experiments in real time. Data collection of the trial area is also an important component for post experimentation records. Once these robotic systems reach a level of capability additional testing will be required in a larger area. Outdoor testing in unstructured terrain will occur in the experimental proving ground at DRDC Suffield.

4. Conclusion

The objective of intelligent mobility research is to create intelligent mobility algorithms for Unmanned Ground Vehicles which improve their mobility characteristics in urban terrains. Intelligent mobility control algorithms exploit the inherent vehicle dexterity and any available world representation information to produce intelligent locomotion in complex urban terrains. The control algorithm research requires dependencies on other autonomous systems research. In particular world representation information is a limiting condition to real-time locomotion in complex terrain using intelligent mobility algorithms. The intelligent mobility researchers plan to use simulated sensor data until suitable world representations are available.

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The mission of the Autonomous Intelligent Systems Section at Defence R&D Canada – Suffield is to augment soldier and combat systems by developing and demonstrating practical, cost-effective autonomous intelligent systems capable of completing military missions in complex operating environments. Fulfilling this mission, in part, is current intelligent mobility research aimed at control algorithms that exploit an Unmanned Ground Vehicle's (UGV's) inherent dexterity and available world representation information to produce intelligent locomotion in complex urban terrains. Traditional UGV research has largely been applied to operations in unstructured, obstacle-free outdoor environments. The shift to the complexity of a highly unstructured, obstacle-rich, military urban environment requires dramatically improved mobility characteristics. Intelligent mobility algorithms will exploit learning and control theory to enhance UGV mobility in extremely cluttered environments. This paper defines intelligent mobility research and provides a framework for algorithm development, simulation capabilities and describes the inherent dependencies on other autonomous systems research.

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