Defence Research and Development Canada
Recherche et développement pour la défense Canada

Multirobot collaboration project

A collaborative effort between Defence R&D Canada – Suffield and the University of Alberta

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Technical Memorandum
DRDC Suffield TM 2006-163
October 2006

Canada

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Technical Memorandum

DRDC Suffield TM 2006-163

October 2006

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Abstract

Defence R&D Canada – Suffield and the University of Alberta have been collaborating on multirobot systems for the past two years. Initially efforts were combined on the RoboCup project and more recently in collective decision making and collective task allocation. This paper provides a short background on the two year project including the current research at the University of Alberta, the current research at Defence R&D Canada – Suffield, the collaborative efforts, and the future work including hardware modifications to the robots loaned to the University of Alberta by Defence R&D Canada – Suffield.

Résumé

R & D pour la défense Canada – Suffield et l'Université de l'Alberta collaborent depuis deux ans dans le domaine des systmes multirobot. Les efforts étaient initialement axés sur le projet RoboCup et plus récemment sur la prise de décision de groupe et l'allocation de tâches de groupe. Cet article explique brivement les antécédents de ce projet de deux années dont la recherche actuelle de l'Université de l'Alberta, la recherche actuelle de R & D pour la défense Canada – Suffield, les efforts de collaboration et les travaux futurs comprenant les modifications sur l'équipement des robots prêtés par R & D pour la défense Canada – Suffieldá l'Université de l'Alberta.

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Executive summary

Multirobot collaboration project

S. Verret, H. Zhang and C. Parker; DRDC Suffield TM 2006-163; Defence R&D Canada – Suffield; October 2006.

Introduction

Through considerable research and experience, Defence R&D Canada – Suffield has come to realize that teams of autonomous unmanned systems (or nUxVs) will be necessary to realize the much sought after “force magnification” long promised by battlefield robotics researchers and engineers.

The following sections briefly describe the efforts of a collaborative agreement with the University of Alberta and Defence R&D Canada – Suffield. The initials sections detail the research at the University of Alberta and Defence R&D Canada – Suffield and are followed by more specific details of the collaboration project.

Multirobot research

University of Alberta

Research activities in multirobot systems at the University of Alberta include the study of collective decision making, collective construction, collective sorting, and multirobot communication, using a biologically inspired approach. In addition, a RoboCup team has been organized, Team Canuck, and has represented the University of Alberta and Canada competing internationally since 2001.

Defence R&D Canada – Suffield

Research activities in multirobot systems at DRDC are in the beginning stages. While most of the recent work in the Autonomous Intelligent Systems Section (AISS) has been creating Architecture for Autonomy and developing and refining a couple of autonomous vehicles, some work has been done in understanding the multirobot problem by defining the specifications and requirements of the multirobot problem. More recently, Defence R&D Canada – Suffield has purchased a team of Pioneer 3 All-Terrain vehicles which will be used for multirobot research. Various areas of potential research include; communications relay, multirobot SLAM and multirobot task allocation.

Collaborative Efforts

Collaboration between Defence R&D Canada – Suffield and the University of Alberta in multirobot system research began in 2004 when Defence R&D Canada – Suffield purchased a set of six robots, at the cost of $28,350, from RedZone. These robots were provided to the University of Alberta on a long term loan in order for Team Canuck to participate in RoboCup 2004 in Portugal. The team involved six graduate students - mostly from the Department of Computing Science - and two faculty members, and competed well, advancing to the playoffs as one of the top eight teams.

The RoboCup project also led to the development of interesting research of which the communication infrastructure for a multirobot system is a good example. Some of the results were published in 2005 IEEE/RSJ International Conference on Robot and Intelligent Systems. This communication infrastructure, called Broker, is a novel implementation of the interprocess communication (IPC) technology, and was developed in support of the operation of a complex robot system.

Hardware Modifications

The Robotics Lab in the Department of Computing Science at the University of Alberta needs a set of general purpose mobile robots that can be utilized in multirobot systems research as well as in a classroom environment. Originally, the soccer-playing robots from RedZone were to be used for other research when they were not playing in soccer. In practice, however, these robots proved to be inadequate, both on and off of the soccer pitch. An effort is ongoing to retrofit the soccer playing robots to make them more generally useful.

Future Work

There are several areas of research in multirobot systems that can be explored. However, in the near future, research into the problem of high-level task planning for a MRS is a high priority. For instance, a MRS, which functions in a dynamic environment, an adversarial environment, and an unpredictable environment, and whose complexity prevents the naive application of traditional AI planning techniques. The research will focus on algorithms for determining the individual actions of the robots, based on the current and predicted future state of the world. Even under the generous assumption that the entire group of robots is under centralized control, i.e., with one brain, such as the case of RoboCup, it is not clear what is the best way to exploit this opportunity in the form of a centralized planner that computes coordinated team plays in terms of individual robot actions.

Sommaire

Multirobot collaboration project

S. Verret, H. Zhang and C. Parker; DRDC Suffield TM 2006-163; R & D pour la défense Canada – Suffield; octobre 2006.

Introduction

Après avoir effectué une recherche et accumulé une expérience toutes deux considérables, R & D pour la défense Canada – Suffield a fini par réaliser que des équipes de systèmes autonomes sans équipage (ou nUxVs) seront nécessaires pour réaliser l'amplification des forces tant prisée et depuis longtemps promise par les chercheurs et les ingénieurs de la robotique des champs de bataille.

Les sections suivantes décrivent brièvement les efforts d'un accord de collaboration entre l'Université de l'Alberta et R & D pour la défense Canada – Suffield. Les premières sections détaillent la recherche effectuée à l'Université de l'Alberta et R & D pour la défense Canada – Suffield et sont suivies par des détails plus spécifiques concernant ce projet de collaboration.

La recherche multirobot

l'Université de l'Alberta

Les activités de recherche des systèmes multirobot de l'Université de l'Alberta qui utilisent une méthode s'inspirant de la biologie comprennent l'étude de la prise de décision de groupe, la construction de groupe, le tri de groupe et la communication multirobot. De plus, une équipe de RoboCup, appelée Team Canuck a été organisée et représente, depuis 2001, l'Université de l'Alberta et le Canada lors de compétitions internationales.

R & D pour la défense Canada – Suffield

Les activités de recherche dans le domaine des systèmes multirobot à RDDC en sont à leurs débuts. Alors que la plupart des travaux récents de la Section des systèmes intelligents autonomes (SSIA) ont créé des architectures pour l'autonomie et ont mis au point et raffiné quelques véhicules autonomes, certains travaux ont cherché à comprendre le problème multirobot en définissant les spécifications et les exigences du problème multirobot. Plus récemment, R & D pour la défense Canada – Suffield a acheté Pioneer 3, une équipe de véhicules tout-terrain qui sera utilisée pour la recherche multirobot. La recherche comprend des domaines potentiels variés dont les

relais de communication, les microscopes ultrasoniques à balayage laser multirobot et l'allocation des tâches multirobot.

Les efforts de collaboration

Les efforts de collaboration entre R & D pour la défense Canada – Suffield et l'Université de l'Alberta dans le domaine de la recherche sur les systèmes multirobot ont commencé en 2004 quand R & D pour la défense Canada – Suffield a acheté à RedZone un ensemble de six robots, au coût de 28 350$. Ces robots ont été fournis à l'Université de l'Alberta en un prêt à long terme permettant à Team Canuck de participer à RoboCup 2004 au Portugal. L'équipe était comprise de six étudiants diplômés, la plupart provenant du Département en Science informatique, et de deux membres du corps professoral ; elle s'est bien défendue puisqu'elle est parvenue aux éliminatoires parmi les huit meilleures équipes.

Le projet RoboCup a aussi abouti à la mise au point d'une recherche intéressante et l'infrastructure des communications pour un système multirobot en est un bon exemple. Certains des résultats ont été publiés à la Conférence internationale IEEE/RSJ de 2005 au sujet des Robots et des systèmes intelligents. Cette infrastructure des communications, appelée Broker, est une implémentation nouvelle de la technologie de la communication interprocessus et a été développée en soutien à l'opération d'un système robot complexe.

Les modifications de l'équipement

Le laboratoire de robotique du Département en Science informatique de l'Université de l'Alberta requiert un ensemble de robots mobiles polyvalents pouvant être utilisés pour la recherche sur les systèmes multirobot ainsi que dans un milieu de salle de classe. À l'origine, les robots joueurs de soccer de RedZone devaient être utilisés pour la recherche quand ils ne jouaient pas au soccer. Les robots se sont cependant révélés être inadéquats en pratique sur le terrain de soccer comme en dehors. Un effort continu consiste à réadapter les robots joueurs de soccer en des robots plus utiles.

Les travaux futurs

On peut explorer plusieurs domaines de la recherche en matière de systèmes multirobot. Dans un avenir prochain, la recherche en matière de planification des tâches de haut niveau d'un système multirobot sera cependant une grande priorité. Il s'agira par exemple, d'un système multirobot qui fonctionne dans un milieu dynamique, un milieu adverse et un milieu imprévisible et dont la complexité ne permet pas d' appliquer les techniques de planification traditionnelles et naïves d'intelligence artificielle

(AI). La recherche se concentrera sur des algorithmes visant à déterminer les actions individuelles des robots, en se basant sur l'état actuel ainsi que l'état futur du monde tel qu'on l'envisage. Même si l'on fait l'hypothèse généreuse que le groupe entier des robots opère sous une commande centralisée comme par exemple un seul cerveau tel qu'en est le cas avec RoboCup, la meilleure faon d'exploiter cette opportunité sous la forme d'un planificateur centralisé qui calcule la coordination des jeux d'équipes en termes d'actions de robots individuels n'est pas encore évidente.

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1 Introduction

Defence R&D Canada's (DRDC) Autonomous Intelligent Systems Section (AISS) has embarked on autonomous systems development projects for the Canadian Forces. The first project, Autonomous Land Systems (ALS), sought to demonstrate basic autonomous multivehicle capabilities and establish the personnel base and technical foundations for future projects. The next project, Cohort, seeks to demonstrate intelligent behaviours amongst groups of vehicles in an urban environment (Figure 1).

Through considerable research and experience, DRDC has come to realize that teams of autonomous unmanned systems (or nUxVs) will be necessary to realize the much sought after "force magnification" long promised by battlefield robotics researchers and engineers. Through years of teleoperation research, DRDC recognized that human supervision of unmanned systems has firm limits, some physical, such as communication range and control latency and others physiological, such as operator awareness. In the more recent ALS Project, DRDC learned how carefully designed autonomy removes some of these by making the system more responsible for its own safety and navigation. These strides have made practical battlefield nUxV control an exciting prospect. While it is clear that multiple vehicles, through redundancy, can improve the reliability of autonomous forces and that through multiple vehicle types, operational scope can be widened, the methods necessary to practically achieve these ends are still evolving.

Figure 1: *Example future urban environment with multiple unmanned vehicle systems alongside manned systems.*

The following sections describe briefly the efforts of a collaborative agreement with the University of Alberta and DRDC. Sections detailing the research at the University of Alberta and the research at Defence R&D Canada – Suffield are followed by more specific details of the collaboration project.

2 Multirobot research

2.1 University of Alberta

Research activities in multirobot systems at the University of Alberta include the study of collective decision making, collective construction, collective sorting, and multirobot communication, using a biologically inspired approach. In addition, a RoboCup team has been organized, Team Canuck, and has represented the University of Alberta and Canada competing internationally since 2001.

The research into collective decision [1] making is concerned with the problem of making system-level decisions in a multirobot system (MRS) without centralized control. This problem becomes significant in MRSs because for the robots in a MRS to work together, the individuals must coordinate their individual decisions so that the group will be able to act as a single coherent entity. If it can be assumed that the individual robots in the group will base their decisions on a set of hard-coded rules and facts, the decision coordination problem becomes trivial, since all of the robots can be guaranteed to make the same decision when in the same situation. Hard-coded rules, however, are very inflexible. Instead, it is more interesting to find solutions for a MRS to adapt to its environment and the particular problem at hand based on past experiences.

The work in collective construction [2, 4] is motivated by the desire to understand the fundamental issues in building useful physical structures using a group of robots under decentralized control. The ant species, *L. albipennis*, was closely examined and it was found to be able to create well-defined new nests through the construction steps of templating, stigmergizing, and blind bulldozing. These steps have been duplicated first in simulation and then through experimental verification using real robots. This work represents the first time when robots have successfully duplicated the well-known blind bulldozing behavior in the construction of a circular structure. In parallel, research has begun in algorithmic collective construction using stigmergy and a basic algorithm for the construction of arbitrary 2D structures with robots capable of only local sensing has been developed.

Another area of research is concerned with the trade-off between communication and sensing [3] in a MRS, using collective sorting (clustering) as the context. The secondary objective of this project is to experimentally determine whether segregation

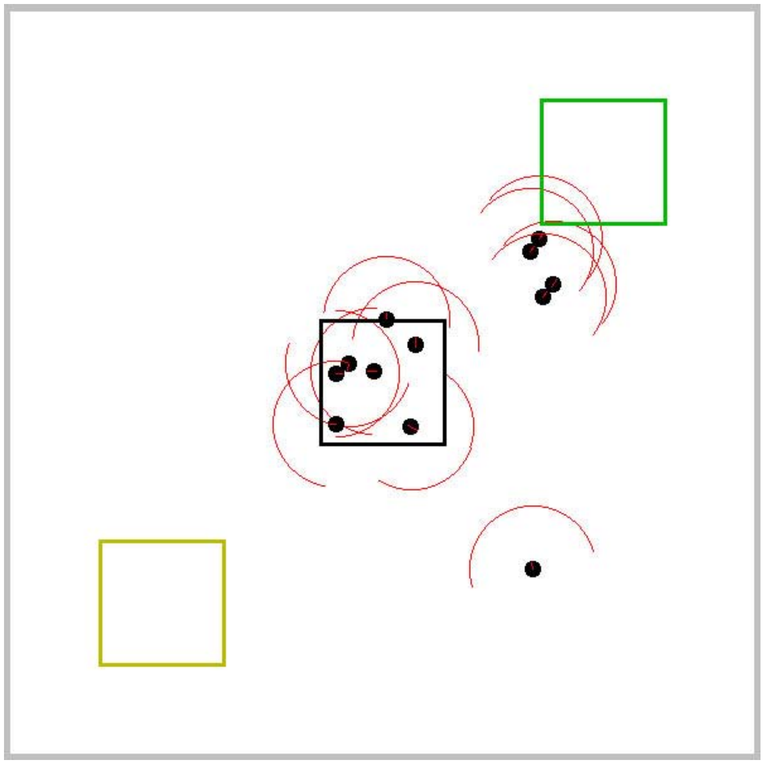


Figure 2: *Parker [1] has demonstrated, in simulation, a system of robot agents that recruit members to find a new "nest" after they must abandon their current "nest".*

sorting is possible with only local sensing and without centralized control [5]. For collective sorting, quantitative relationships were derived between the two important design variables: communication and sensing, and further verified the result qualitatively using the alternative task of multiple target tracking. An interesting extension of this work is an empirical study of a universal controller in which it was postulated that the external behavior of a robot group is determined as much by the design of the internal control as the environment in which the group is placed. The postulation is demonstrated with a robot controller capable of three seemingly different tasks: collective transport, foraging, and construction. This was accomplished with minor or no modification to the behavior-based controller in the robots.

Finally, the University of Alberta was actively involved in the small-size league (SSL) of the RoboCup international research initiative, for the purposes of stimulating interest in MRS research and building a common and reconfigurable testbed for experimental work in MRS. Team Canuck was the best Canadian team in SSL, qualified to compete in 2001-2005, with the best performance in 2004 when Team Canuck made the top eight in the world among approximately 60 teams. The success of this research project was well publicized nationally in the print, radio, and television media.

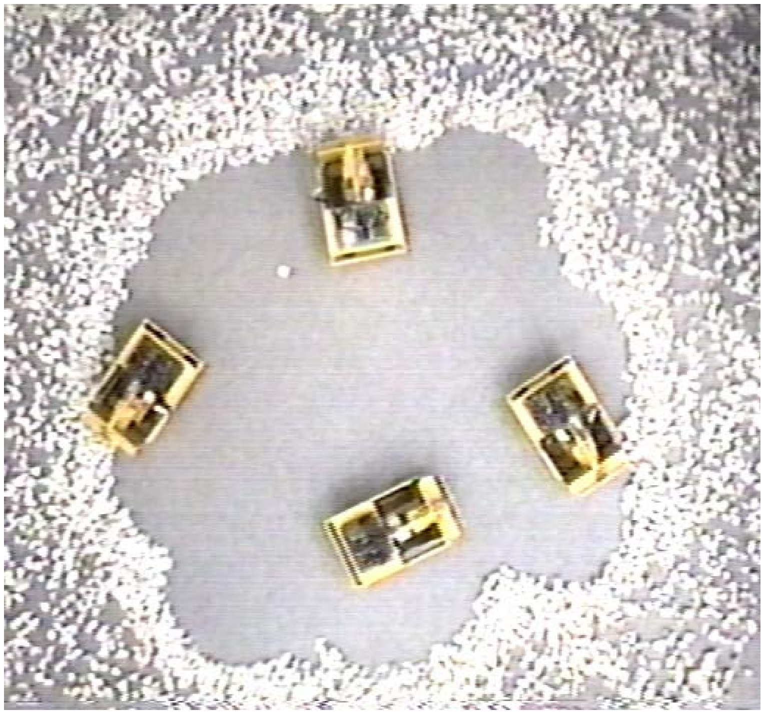


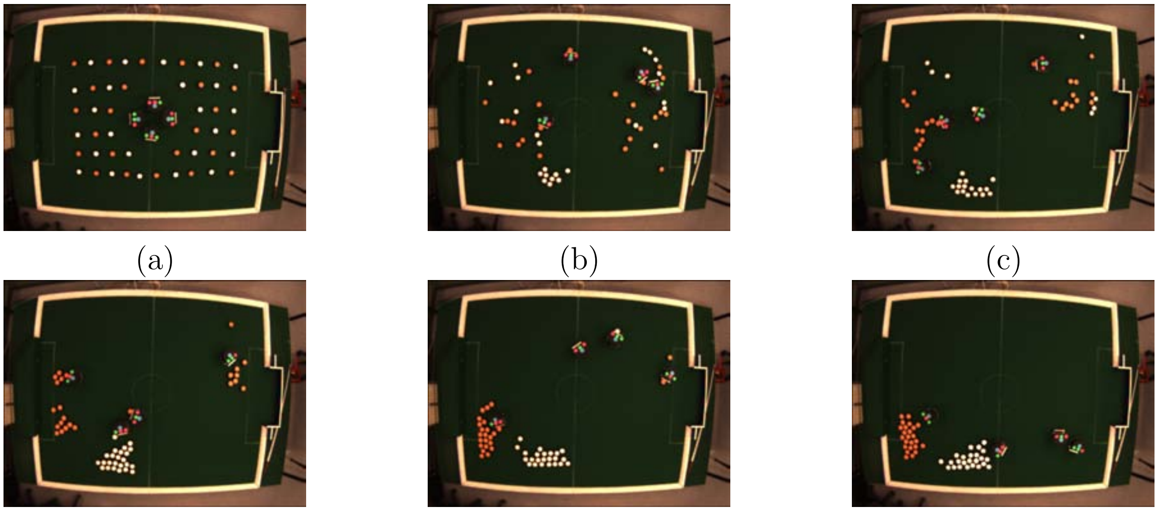
Figure 3: *Parker [2] demonstrated a system of robots with the ability to clear or build a nest of a size proportional to the number of robots in the nest.*

2.2 Multirobot research at Defence R&D Canada – Suffield

Research activities in multirobot systems at DRDC are in the beginning stages. While most of the recent work in the AISS has been creating Architecture for Autonomy [6] and developing and refining a couple of autonomous vehicles [7], some work has been done in understanding the multirobot problem [8] by defining the specifications and requirements of the multirobot problem [9]. More recently, DRDC has purchased a team of Pioneer 3 All-Terrain vehicles which will be used for multirobot research. Various areas of potential research include, communications relay, multirobot SLAM and multirobot task allocation.

3 Collaborative Efforts

Collaboration between Defence R&D Canada – Suffield and the University of Alberta in multirobot system research began in 2004 when Defence R&D Canada – Suffield purchased a set of six robots, at the cost of $28,350, from RedZone. These robots were provided to the University of Alberta on a long term loan in order for



(a) (b) (c)

(d) (e) (f)

Figure 4: *Verret [3] demonstrated a system of robots, each with a 50 cm sensing and communication range with the ability to sort two different colors of objects into two distinct piles. (a) shows the initial conditions (b) shows the experiment status after 8 minutes, (c) shows the experiment status after 15 minutes (d) shows the experiment status after 23 minutes (e) shows the experiment status after 30 minutes (f) shows the final results of the experiment.*

Team Canuck to participate in RoboCup [10] 2004 in Portugal. The team involved six graduate students - mostly from the Department of Computing Science - and two faculty members, and competed well, advancing to the playoffs as one of the top eight teams.

The RoboCup project also lead to the development of interesting research, of which the communication infrastructure for a MRS is a good example. Some of the results were published in 2005 IEEE/RSJ International Conference on Robot and Intelligent Systems. This communication infrastructure, called Broker [11], is a novel implementation of the interprocess communication (IPC) technology, and was developed in support of the operation of a complex robot system. A robot system is considered as a collection of processes that need to exchange information, e.g. motion commands and sensory data, in a flexible and convenient fashion, without affecting each others operations in case of a process' scheduled termination or unexpected failure. The IPC technology provides an ideal framework for this purpose, and the design decisions about its implementation were based on the needs of robotics applications. Broker is programming language, operating system, and hardware platform independent and has served its purpose well in a RoboCup project and collective robotics experiments, in both simulation and real-world environments.

4 Hardware Modifications

The Robotics Lab in the Department of Computing Science at the University of Alberta needs a set of general purpose mobile robots that can be utilized in multirobot systems research as well as in a classroom environment. Originally, the soccer-playing robots from RedZone were to be used for other research when they were not playing in soccer. In practice, however, these robots proved to be inadequate, both on and off of the soccer pitch. An effort is ongoing to retrofit the soccer playing robots to make them more generally useful.

The basic design of the robots is sound: three-wheeled holonomic drive platforms with onboard processing and radio communication to the outside world. It is only the implementation of the details that has caused the performance of these robots to suffer. The problems to overcome with this retrofit are: mechanical fragility, electronic hardware inflexibility and fragility and firmware inflexibility.

Mechanically, the robots have been completely disassembled and cleaned. The aluminum gears failed on several occasions. It was found that the aluminum gears had been mounted very inaccurately, contributing to this failure. Additionally, aluminum is not as flexible as steel; when an aluminum gear is subjected to abusive environment, it tends to grind itself to pieces, where as a steel gear is better able to adapt to such a situation, wearing just enough to break it in. Due to the nature of the robots' chassis, it is not possible to visually inspect the meshing of the robots' gears. Mounting accuracy must be achieved via accurate measurements of the components prior to assembly. The delicate aluminum gears were removed from the drive shafts and axles and replaced with stronger steel gears.

The robots' kickers were found to be completely inadequate. In order to increase the kick strength, the battery voltage of 7.2V was boosted to 25V to charge a large capacitor which would then be discharged to activate the kicker. However, the kicker would kick so hard that its own inertia would tear it apart in short order. This is a flaw in their mechanical design, as the kicking strength would have to be reduced to an inadequate level before the kickers could be deemed to be robust. As such, the kickers have been completely removed from the robots. There is no plan in the immediate future to replace the kickers unless these robots are to compete in robotic soccer again.

The most significant modification to the robots is related to their onboard controllers. The DSP based controllers that shipped with the robots were problematic in several ways. First, they were single purpose controllers which received and executed velocity commands sent over a wireless link. It was not possible (or at least convenient) to add more intelligent control to the robots themselves. Furthermore, because the robots' controllers were single purpose, the robots had no sensors installed (except for a crude ball detection sensor for use with the kicker), so using the robots required an external sensor system connected to offboard processing which would then relay commands to the robots over the wireless link. Furthermore, the firmware on the shipped controllers was fixed (e.g. it could not be modified) and the robots' IDs were fixed (commands were sent to the robots over an inefficient broadcast channel and each robot simply responded to the commands that were associated with its ID). The inability to change the firmware presented two problems. First, the closed loop controllers seemed to be tuned poorly, resulting in semi-erratic movement and excessive wear on their transmissions. Second, and more importantly, the controllers had a nasty habit of self-destructing. Occasionally, the controller would short out its H-Bridge motor driver (these were implemented discretely, rather than with ICs that include built in short circuit protection); this would burn out (literally) the driver components, and would also destroy the DSP that was the heart of the boards. The power connections, too, were found to be inadequate, using cables much too heavy for the application in conjunction with surface mount pads on the circuit board. These pads had a tendency to rip off of the board when batteries were changed, as no strain relief was included with the robots.

The solution to these problems has been to completely remove the original controller and replace it with a different controller. Rather than develop a single board controller, it was decided to go with a three board solution. The heart of the system is the motor driver board. This board is built around a Microchip PIC18F4431 microcontroller that implements four PID motor controllers. Three of these control a robot's drive motors. A fourth is implemented to allow for the addition of another motor for some future application. The motor driver board also implements an asynchronous serial bus that can interface to a standard RS232 serial port and an I2C synchronous serial bus. The motor driver receives commands over the RS232 line from a high level controller. For their immediate use, it was chosen to use the Gumstix platform, a miniature Linux system with a 802.11 compact flash wireless card. The I2C bus is used to connect to a sensor board. This board implements whatever sensors would be required by the project at hand. The high level controller would query a robot's sensors via the motor driver board. Thus a clean separation of high level control and low level control/sensor interfacing is provided. This separation will allow a researcher to modify the high level control software without having to worry about the code modifications negatively impacting the sensitive low level control processes. Additionally, by using modular sensor boards, robots can be switched quickly from one project to another simply by switching out the sensor suite.

For the research in the immediate future, the sensor board will include a modulated IR (infrared) transmitter/receiver, collision/bump sensors as well as IR range sensors. The modulated IR sensors will be used to eliminate the need for computer vision. Robots and objects of interest in the experimental environment will each carry a modulated IR transmitter outputting a beacon code similar to those used by home appliance remote controls. The robots will use their modulated IR sensors to see these objects and identify them. This approach is being taken because there is not a direct interest in the study of computer vision for this current project, however, there is an interest in the information that it would provide. There is no immediate reason why a blob tracking camera or other more complicated sensors could not be interfaced to the motor driver board. The limitation would be the speed of the I2C bus, which is about 400kb/s. Furthermore, high level controllers could be used that directly interface with sensors using their own ports.

5 Future Work

There are several areas of research in multirobot systems that can be explored. However, in the near future, research into the problem of high-level task planning for a MRS is a high priority. For instance, a MRS, which functions in a dynamic environment, an adversarial environment, and an unpredictable environment, and whose complexity prevents the naive application of traditional AI planning techniques. The research will focus on algorithms for determining the individual actions of the robots, based on the current and predicted future state of the world. Even under the generous assumption that the entire group of robots is under centralized control, i.e., with one brain, such as the case of RoboCup, it is not clear what is the best way to exploit this opportunity in the form of a centralized planner that computes coordinated team plays in terms of individual robot actions.

There is a fundamental flaw in the structure of the current AI employed in most MRSs which can be labelled the "hand-coded" approach. They do a static analysis of the world, looking at the location of all the robots, and check through a list of predicates to see if the state of the world resembles anything the programmer thought might happen. Once a match is found, it commands the robots to move according to what the programmer thought would be a good response to the situation. To reduce the complexity of the response, the programmer will naturally hand-code reusable behaviors that in turn are hand-coded to achieve their objectives by using lower-level behaviors. This instinct to reduce complexity by layering reusable behaviors is a good one, but is fraught with its own problems.

We plan to employ heuristic search as a way of constructing an AI planning system for a MRS, and develop search-based, real-time adaptive solution to the multirobot coordination problem in adversarial environments. By decomposing the global coordination task into a set of local search problems, efficient and effective solutions to subproblems can be found and combined into a global coordination strategy. In turn, each local search entails the use of a heuristic evaluation function together with state space pruning to make the search tractable and scalable, to overcome inadequacies in classical search algorithms designed for games like checkers; where the depth of the search is the key determinant of solution quality but which are infeasible in MRS where actions are not deterministic and branching factor immense.

6 Conclusion

This report outlined the past and current research activities of both DRDC and the University of Alberta. More importantly it outlined the collaborative efforts that occurred over the past two years and listed some efforts that will occur in the upcoming years. The University of Alberta and Defence R&D Canada – Suffield collaborated on several projects [5, 11] and expect to do so in the future.

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Multirobot collaboration project

4. AUTHORS (last name, first name, middle initial)

Verret, S. ; Zhang, H. ; Parker, C.

5. DATE OF PUBLICATION (month and year of publication of document) October 2006	6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc). 24	6b. NO. OF REFS (total cited in document) 11

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Defence R&D Canada – Suffield and the University of Alberta have been collaborating on multirobot systems for the past two years. Initially efforts were combined on the RoboCup project and more recently in collective decision making and collective task allocation. This paper provides a short background on the two year project including the current research at the University of Alberta, the current research at Defence R&D Canada – Suffield, the collaborative efforts, and the future work including hardware modifications to the robots loaned to the University of Alberta by Defence R&D Canada – Suffield.

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