Engineering Practical Work Report 2006

Practicum III

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Summary

Over the course of the 2005-2006 practicum I worked as a researcher with Dr Napoleon Reyes in the Institute of Information and Mathematical Sciences at Massey University. This meant that I was able to actively participate in the academic community at a level otherwise inaccessible to undergraduate students. It was my intention to pursue employment that would take full advantage of my abilities and propel my advancement into a scientific career in the fields of robotics and artificial intelligence. I aim to extend and continue this research throughout the year.

The research that I have contributed to has been an excellent opportunity for me to put a foot in the door of not only the scientific community at Massey University, but also internationally. During the course of my research I have assisted Dr Reyes with presentations and robotics demonstrations to a broad cross-section of the Massey community at the Alumni Society gathering in December and also to the wider community at Massey Open Day in November. Through such occasions I have sharpened my presentation skills and built beneficial relationships with key staff members and other scientists.

I have managed to prove my ability to rapidly develop successful new technology with the release of two research papers by Dr Reyes and myself detailing novel robot navigation systems. We were invited to present our first paper “A Novel Hybrid Fuzzy A* Robot Navigation System for Target Pursuit and Obstacle Avoidance” at the First Korean-New Zealand Joint Workshop on Advance of Computational Intelligence Methods and Application on Friday 17 November at AUT Technology Park. Dr Reyes asked me to conduct the presentation as I am the first writer on the paper, and suggested that it would be an excellent experience for me.

Presenting at the conference gave me a further opportunity to extend my involvement with the scientific community; gaining recognition and meeting important scientists in related fields from New Zealand and overseas. In attendance was Professor Se-Young Oh from the Department of Electrical Engineering at Pohang University of Science and Technology in South Korea. Professor Oh is regarded as one of the world's foremost robotics experts, and has been developing and researching intelligent vehicles for over thirty years. Being reviewed and recognised by peers such as Professor Oh has been a valuable first step into the scientific community.

We have submitted our second paper “Synthesizing Adaptive Navigational Robot Behaviours using a Hybrid Fuzzy A* Approach” for presentation at the 9th Fuzzy Days: International Conference on Computational Intelligence to be held in Dortmund, Germany this September. If accepted, this would provide me with an even greater opportunity to interact with the world's leading scientists in the field, and give my career opportunities an enormous boost.

Supplementing my research toward robot navigation, I am also the first student to have become involved with the new robot soccer program at Massey University. My involvement has been to adapt robot navigation systems and implement them into the game of robot soccer, research technologies employed by competing teams, conduct demonstrations of the current robot soccer equipment, build 3-D real-time simulations of the robot soccer game for research and demonstration of new robot control algorithms, and to generate interest to help recruit students to develop the necessary components as part of curriculum projects in 2006.

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1

2 Introduction

This is a final practical work report toward a Bachelor of Software Engineering with Honours degree at Massey University.

For this practicum I undertook a research project on robot navigation, targeted for the robot soccer system, but applicable to other robot systems. I was required to create novel hybrid robot navigation system that incorporate the behaviours of target pursuit and obstacle avoidance. This project was later extended to incorporate opponent-evasive behavior.

The hybrid navigation systems developed for the research project are described in detail in two research papers that I have attached to the end of this document: “A Novel Hybrid Fuzzy A* Robot Navigation System for Target Pursuit and Obstacle Avoidance” and “Synthesizing Adaptive Navigational Robot Behaviours using a Hybrid Fuzzy A* Approach”. Because of this, I have not explained the navigation systems and algorithms in detail in this document, but focused instead on the research processes taken during the development of the navigation systems. This report has been designed to be read *in conjunction* with the attached research papers. I recommend to the reader, for best overall appreciation, that he or she read the research papers immediately after reading the section 'Robotics and Science'.

This report begins with a background to robotics, covering all of the key technologies that I have worked with as part of the research project that I have completed, and that I talk about in detail in later sections. I convey to the reader my impressions of the current state of modern autonomous robots, and introduce the game of robot soccer. The information in the first section is drawn largely from my research of other robotics systems as part of my project, and introduces the reader to my individual definition and perception of *the robot*.

I have included sections discussing the academic and scientific communities that I have worked within during the period of my research project. I discuss the unique structures and processes supporting research within both of these communities.

Following the sections on the academic and scientific communities, there is a technical section covering the development of the research project. I describe the development of the simulation program in detail, and discuss the implementation of the hybrid system into the simulation. I discuss the possibilities of extensions to the simulation, and review the outcome of the project.

The conclusion of this report is designed to convey, in particular, my personal reflections on the practical work experience for this practicum, outline its benefits to my career development as an engineer, and present my future ambitions as an outcome of the practical work experience.

3 Robotics and Science

3.1 Introduction to Robots

The term *robot* was first coined by the Czech writer Karel Čapek in the 1920 play *R.U.R.* (Rossum's Universal Robots) and derives from the Czech word *robota*, meaning "the serf's obligatory work"[3]. The concept of an intelligent machine was cemented into science fiction long before it was able to be developed by science.

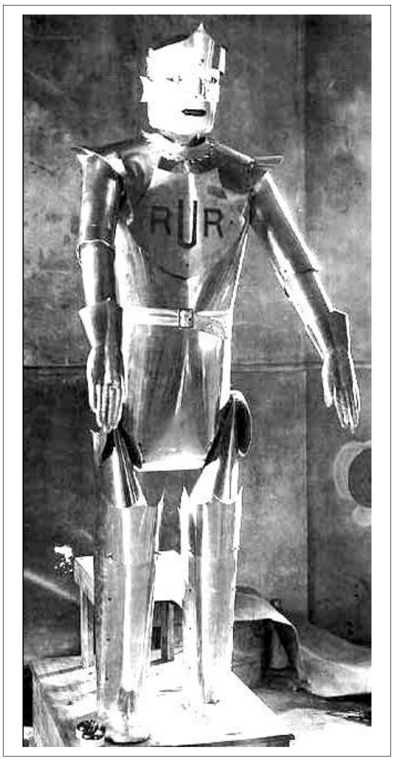

Figure 1: Robot costume from the 1922 production of R.U.R. Guild Theater, New York, 1922.

The robot of science fiction is typically a machine that can interact with the world in the same sense that people interact with the world; it can think, see, hear, communicate, move, and perform various other tasks. As characters of science fiction novels and films, robots frequently interact with people and other robots.

The term *robot* is used very broadly to describe any sort of machine that employs some form of computer-aided control mechanism. Unmanned vehicles that require human remote control or other assistance to operate are commonly referred to as robots. This report, however, will refer only to those machines that are truly autonomous as robots.

3.2 Contemporary Applications of Robots

Modern applications of robots are wide-ranging. Giant manufacturing robots are commonplace in industry. Industrial robots are commonly used to perform the laborious and heavy tasks of vehicle assembly (refer to *Figure 2*). Many CNC (Computer Numerical Control) cutting and manufacturing machines are considered robots.

Figure 2: KUKA Industrial Robots assembling a vehicle underbody

Several companies are now producing robot vacuum cleaners that can determine the layout of a floor and proceed to clean the carpet. Robotics is increasingly being introduced into toys. Sony's Aibo and irobot's Scooba and Roomba robots have all been marketed successfully. LEGO also produces a number of robot kits.

Fully autonomous robots are being designed to replace semi-remote-controlled moon-rover vehicles (*Figure 3*) which have been plagued by communication delays [4,5]. Humanoid robots are being developed by Honda and other research institutes to assist and entertain the elderly, or to help people with special needs [6,7,8]. Robots have been used to explore inaccessible tunnels in the pyramids of Egypt.

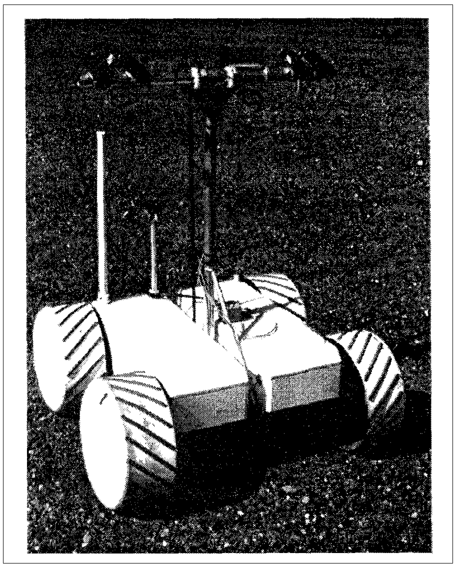

Figure 3: Carnegie Mellon University's Ratler Moon Rover

Inspired by science fiction and driven by modern technology, robots are being designed and developed for a variety of tasks where humans can not perform as effectively, or would prefer not to do.

3.3 Key Robot Components

The robot of modern science is an *intelligent agent* (refer to *Figure 4*) operating in the real world, that is, a machine that can *sense* its environment, make an intelligent decision, and then *act* on the environment [9]. To this end a robot has three key components:

- Sensors
- Actuators
- An Agent Program

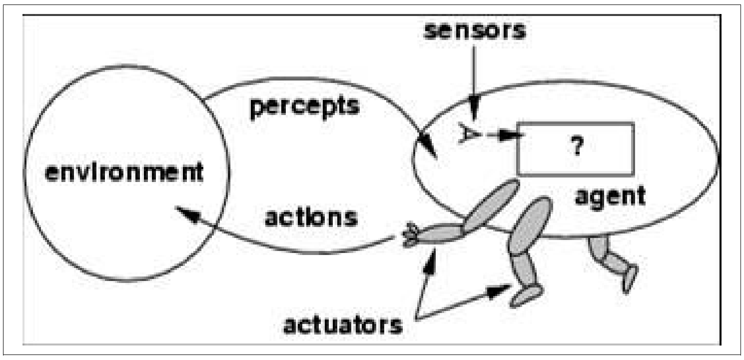

Figure 4: Components of an intelligent agent

Sensors are systems that provide a robot with the ability to perceive its environment. Sensors gather the *input* to the robot system. Sensors are commonly complex *machine vision* systems using video cameras to analyse the robot's physical environment, but a plethora of other systems are in use, including laser range-finders, microphones, sonar equipment, tactile *bump* switches or brushes and systems using GPS [10,11].

Actuators are moving, physical components of a robot's machinery, that, when controlled by a robot's intelligence system, allow the robot to manipulate its environment. Actuators provide the *output* from the robot system. Actuators are commonly the wheels, legs, or caterpillar tracks of a robot, allowing it to move, and any other robot-controlled devices, which allow the robot to perform other tasks.

The Agent Program is the brain of the robot; it processes information gathered by the robot's sensors (*percepts*), and makes a rational decision by matching percepts to actions to take by controlling the robot's actuators.

3.4 Core Technologies of Robotics

Robotics brings together a whole array of modern technologies and fields of development. The architecture of a robot requires systems that can support the key elements of the intelligent agent. Actuators generally require motors and mechanical components. A central processing unit is required to operate the agent program on the architecture. Robots are often required to communicate with a disembodied control computer, or other robots. Robotics therefore, generally involves the technologies of:

- Artificial Intelligence
- Electronics
- Mechatronics or Mechanics
- Machine Vision
- Signal Processing

The field of artificial intelligence is central to robotics, and can be further subdivided into specialised areas of artificial intelligence research related to robotics:

- Navigation Systems and Algorithms
- State-Based Behavioural Control
- Multiple-Agent Coordination Systems and Algorithms
- Machine Learning and Performance Measures
- Evolutionary Intelligence and Genetic Programming
- Object Recognition and Machine Vision algorithms

3.4.1 Navigation Systems and Algorithms

Navigation systems for robots operate on three different levels; *global navigation*, *local navigation*, and *personal navigation*. Generally, a robot's navigation system requires a separate algorithm to deal with each layer.

Global navigation algorithms, track a robot’s position in *absolute* or map-referenced coordinates, and plan long-distance paths to optimise future robot movement, often utilising GPS, digital environment maps, and other prepared navigational aids. Local navigation systems generally operate in real time, considering the current state of the environment in the robot's immediate vicinity, and make short-term, reactionary course corrections to the robot's path toward its goal. Personal navigation systems factor into robot path planning the physical space occupied by the shape and size of the robot, and ensure that any movement calculation also takes into account the space required by any individual moving parts (legs, arms etc.).

3.4.2 State-Based Behavioural Control

Many systems involving intelligent agents require the agent to behave differently in different scenarios. State-based behavioural controls attempt to give robots some kind of common sense. Robotic vacuum cleaners and similar systems are susceptible to the *magician's apprentice* syndrome, where the robot will continue to vacuum the carpet long after the last speck of dust has been removed. State-based systems attempt to identify the *scenario* the robot is in, and set the internal *state* of the robot, which in turn will determine the set of behaviours followed by the robot [12]. The vacuum cleaning robot, for example, may identify the scenario as '*The carpet is clean*' and set the robot's internal state to '*Wait until dirty*'. Most robots are required to perform more than one task, and so involve some form of state-based behavioural switching system to decide which task it should be performing at a particular time [13].

3.4.3 Multiple-Agent Coordination Systems and Algorithms

Some robots are required to operate in coordination with other robots. Algorithms are then necessary to determine the communication method and control hierarchy of the robots. Algorithms are also required for identification of a set of goals for the whole group, and then the delegation of those goals as tasks to individual robots, avoiding interference and collision.

Multi-agent coordination is a mostly unexplored area of robotics. Robot systems that involve multiple robots are at this stage mostly unintelligent, and are based on awarding roles to individual robots that minimise the possibility of conflict between robots. Researchers at Carnegie Mellon University, however have developed a multi-agent robot system, where several robots cooperate and share information to explore and map their environment [18].

3.4.4 Machine Learning and Performance Measures

Robot systems are beginning to employ Machine Learning [14,15], as a self-improvement technique for robots. Robots with a capacity for Machine Learning are supplied with a *performance measure* that allows the robot, as an intelligent agent, to evaluate its own performance of a task by comparing its measure against a history of performance measures. The robot can then determine which methods of task completion have been the most successful, and employ methods similar to those for future tasks.

3.4.5 Evolutionary Intelligence and Genetic Programming

It is sometimes hard for human scientists to create optimal algorithms for robot control. The field of Genetic Programming (GP) attempts to create programs that approach algorithm optimality by means of *evolution.* Genetic Programming is an attempt to automatically generate effective programs by continually making randomly modified copies of an initial algorithm set (the *gene pool*), and *selecting* only the best of those for the next generation by means of a *fitness function* that evaluates their optimality.

Researches with Genetic Programming for development of robot control algorithms [16,17] have seen moderately successful results, but suffer from enormous computational and time costs of development, and are at risk of the *black box* syndrome, that is, the methods employed by programs that are developed by Genetic Programming are not totally visible to scientists, may contain redundant code, and often manage to develop unorthodox solutions to problems.

3.4.6 Object Recognition and Machine Vision Algorithms

Machine Vision is the study of how a computer can be made to perceive the world using data acquired from an imaging device. Autonomous robots that are not supplied with comprehensive navigational data on environment elements are invariably required to scan their environment for obstacles and other elements using video cameras.

Machine Vision, as a sensory input device, is used to identify key elements in the environment, such as obstacles and other robots. This is known as *pattern recognition.* Machine Vision algorithms are also required to enhance the images captured by cameras, in particular to correct the '*barrel effect*' perception of the camera lense, and to apply various *filters* to adjust images captured under different levels of lighting.

Figure 5: The GDRS 'Demo III' autonomous robotic testbed with stereo-vision

Autonomous, mobile robot systems employing machine vision generally use cameras mounted on the robot in stereo-vision configuration to obtain a spatial perception of the environment (refer to *Figure 5).*

3.5 Importance of Simulation

Professor Se-Young Oh from the Department of Electrical Engineering at Pohang University of Science and Technology in South Korea has over thirty years experience in the research and application of robots, and has developed everything from robot vacuum cleaners to autonomous 'smart cars' that can travel in convoys on the open road. Conversing with Professor Oh, one of the most important points he underlined was the absolute importance of creating simulations for every robot system that is developed, before attempting any real implementation. For computer simulations to be useful as research tools, they need to be highly accurate; incorporating as many features and physics systems of the robot's environment as possible.

3.6 Modern Autonomous Robots

Robot navigation systems traditionally attempt to combine global, local, and personal navigation in a single navigation algorithm. These systems require enormous computational time to determine valid paths for robots to follow to a goal location, determining the exact movements of the robot. As such, these systems are not applicable to robots operating in real-time that need to continually reassess or recalculate their path during transit. Intelligent methods for *best-path* path-finding have largely been dropped by scientists developing navigational systems in favour of short-sighted, reactionary methods with comparatively small computational requirements.
Experiments with modern mobile autonomous robots using potential-fields and similar systems [22-25] have demonstrated moderately successful results at best. In real-time applications we often observe real-world cases where robots employing these navigational approaches blunder into situations that cause them to become trapped – a result of the short-term *greedy* planning algorithms used in these systems.

After decades of research, robot navigation is still largely in a stage of infancy. Scientists researching new methods often overlook the advantages of time-proven navigation methods and search algorithms used in computer games and other fields, and are instead trying to 're-invent the wheel'; struggling to find a balance between optimality of path creation, and the speed of its calculation. One reason for this, is that intelligent path finding requires extensive knowledge about the environment, not available to most autonomous vehicles. Very few attempts have been made to provide autonomous robots with digital *maps* of their environment that would facilitate long-term intelligent path planning.

General Dynamics Robotics Systems (GDRS), a subsidiary and research group of the General Motors Corporation, has been awarded the contract to develop Unmanned Ground Vehicle (UGV) robots for the US Army (*Figure 5*). GDRS has produced a large number of large-scale working autonomous robot platforms, but has largely forgone intelligent navigational algorithms in favour of computationally non-intensive, reactionary steering control systems. Up to this time, the 'robots' of GDRS have been mostly tele-operated (by human remote control), or robots that are only capable of navigating by following stripes painted onto the ground. GDRS states that its 'grand vision' is to produce a cooperating network of battlefield robots to support soldiers on the ground. GDRS also states on its website that is developing human-recognition Machine Vision algorithms for its Unmanned Ground Vehicles. Despite near-unlimited funding, GDRS has failed to produce anything more than the most ponderous of autonomous robots, that have demonstrated very little capacity for Artificial Intelligence.

NASAs Moon Rover robots have been largely developed out-of-house by university research groups. Modern Moon-Rover robots have borrowed the simple steering decision systems employed by GDRS.

The US Defense Agency's Research group (DARPA), recently sponsored the DARPA Challenge; a race across the desert by autonomous vehicles, competing for a US one million dollar prize. Teams from MIT, Carnegie Mellon, and various other leading universities competed. A variety of four-wheel drive vehicles using laser-sights, cameras, GPS systems and various other navigational aids attempted the trek, along with a robot motorcycle that could right itself up if tipped over. The success of the competition proved the very high level of robot research that has been achieved by many research institutes around the world.

The intelligent ASIMO robot, developed by the Honda Corporation, is the show pony of humanoid robots. Scientists at Honda have developed ASIMO to a level that allows it to walk, navigate simple stairs, receive and give objects, push trolleys, and even run. Other humanoid research platforms have not been shared this success. Bipedal soccer robots are still taking baby steps; they have not yet advanced to a level of navigational autonomy capable of seriously participating in the game, but every year an improved generation is unveiled at the FIRA and RoboCup events.

Interestingly there is a stark polarity between spheres of autonomous robot research. One sphere, largely the domain of US research institutes, is driven largely by DARPA and other US Government initiatives toward the production of autonomous vehicles for space exploration and military purposes. Autonomous flying drones, developed by GDRS and other military contractors, are already capable of firing cruise missiles at self-selected ground targets. The second sphere, originally the domain of Japanese and South Korean researchers, but now also greatly contributed to by the European scientific community and other Asian universities and technical institutes, is motivated to create robots to provide assistance and entertainment to the elderly, the disabled, and the general public.

3.7 Robot Soccer

Robot Soccer was created by Jong-Hwan Kim as a research initiative to foster the development of robotics technologies through the stimulation created by a competitive environment. Special to robot soccer is the requirement for a cooperating team of robots; research that is not directly driven by other research platforms.

Universities and research institutes are challenged to demonstrate their mastery of all of the key technologies of robotics by developing a robot soccer team that is not only capable, but is *better* than other teams. In this way research is driven towards continual improvement of existing technologies, and the assembly of a *complete* robot system.

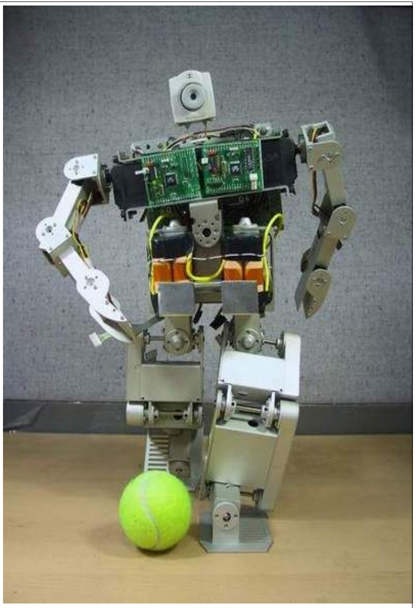

Figure 6: A humanoid soccer robot

There are two major international robot soccer organisations; FIRA (Federation of International Robot Soccer Association), the largest organisation, and the RoboCup, which is especially popular with European universities. Both organisations hold competitions in several events including teams of five miniature robots, teams of eleven miniature robots, and a humanoid league (refer to *Figure 6*).

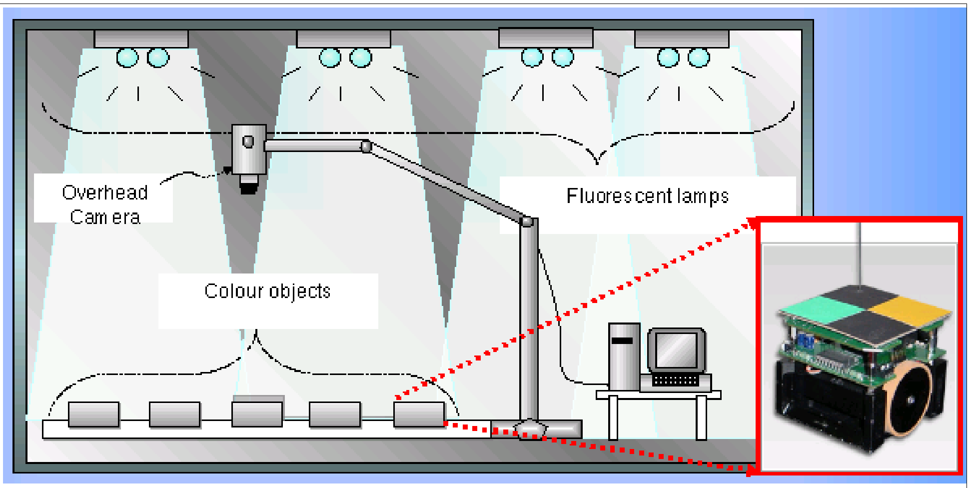

Figure 7: The standard robot soccer system

The standard game of robot soccer takes place on a playing field with dimensions similar to a table tennis table. Each team provides their own robots. *Figure 7* Illustrates the standard robot soccer system. A camera is suspended over the playing field, and a machine vision system can determine the angle, position, and team of all of the robots in play by analysing coloured patterns on the top of the robots (also pictured). Robots can contain on-board processing units, but due to the size of the miniature robots, most teams control the intelligence of their robots with a disembodied server. The team computer takes, as input, information from the machine vision system, makes all of the artificial intelligence processing, and then transmits instructions to all of the team's robots via remote control. The robot units themselves receive these instructions and translate them into voltages for motors controlling the port and starboard wheels of the robots.

The humanoid soccer robots (*Figure 6*) require a different system; each robot has an on-board camera, and must process machine vision and artificial intelligence with its internal microelectronics.

In order to compete in the demanding, competitive, fast-paced, dynamic, real-world environment of robot soccer, systems must process machine vision and all of their intelligence *for the entire team* within a window of time of 33ms. The speed of calculation required for robot soccer makes most existing robot research redundant, and calls for a new generation of machine vision and navigation algorithms that can quickly acquire environment information, and make efficient intelligent decisions that balance optimality with speed of calculation.

4 The Academic Community

4.1 Structure and Processes

Research that takes place within a university environment also has to fit into the structure and processes of the academic community. During the period of my practical work for this report I became involved with the academic community, not only as a student, but also on a different level as a *researcher*.

Firstly, it must be noted that within a university, the academic community also includes the administration framework that provides some of the funding for research within the university. This creates an interesting relationship of exchange between researchers and the academic community.

Researchers are required to represent and acknowledge the university when publishing or presenting research outputs. Researchers are also often called upon by the university to present to academic society meetings. In this way research outputs generate prestige for the university, which is a highly valuable commodity in the academic world.

The university remunerates research outputs by awarding research leaders higher levels of research funding, and possibly offering higher positions within the university hierarchy.

The broader academic community recognises academics based on the contributive quality of their research outputs. Higher levels of recognition in the broader academic community increase the researcher's reputation, and may allow the researcher to attract larger scholarships, contracts, or sources of external funding.

As part of the academic community, researchers working within universities are often required to participate in a formal research/lecturing/administration framework. In order to facilitate research, academics are commonly required by the university to lecture several papers to students, and supervise or referee research works by post-graduate students.

Through these processes the academic community is able to educate students, conduct research, sustain the community by supporting post-graduates, and maintain a healthy level of interchange of research.

4.2 Inter-Departmental Split of Robotics

Within universities, the broad range of technologies required for the research and development of robotics is spread across departments. Artificial Intelligence and Machine Vision typically fall into the domain of Computer Science. Electronics, Mechanics and Signal Processing are traditionally fields of study of Engineering.

Some universities have managed to establish inter-departmental robotics research groups, or have clearly defined robotics research groups as being the exclusive field of one department or the other, but it is not uncommon that universities have no formal plan of collaboration for research towards the emerging field of robotics.

In New Zealand the University of Canterbury's *Robotics, Control and Instrumentation Group* falls under the specialisation of Mechanical Engineering, at the University of Otago robotics is lead by the Department of Computer Science, however, the University of Waikato has established a robotics group linking Computer Science with Mechatronics.

The inter-departmental spread of the specialised areas of research comprising robotics presents itself as an interesting challenge to the collaborative strengths of a university.

5 The Scientific Community

The scientific community is intrinsically linked with the academic community, however it has separate processes and structures of recognition. Not all academics participate in the scientific community, and indeed not all researchers are scientists.

The scientific community has established its own frameworks and processes for recognition and of interchange of ideas. Traditionally, the scientific community is an international linking of scientists for the promotion of interchange of knowledge. Recent advances with the Internet have dramatically improved the ability of scientists to publish results, review papers and interact on an international level.

As an engineering student, it is also important to note that the engineering community is also linked to the scientific community, as many engineers are also at some stage scientists. The engineering community is a professional body with a self-governing code of ethics. The scientific community, however, is not a professional body, nor is it governed by any formal code of ethics.

5.1 Peer review

Central to the scientific community is the process of peer review. In order to gain prestige within the scientific community, scientists target prestigious publications or conferences in their area of research.

For acceptance to a conference, scientists must submit their paper to review by the conference organisers, who are generally experts in the field. After acceptance the scientist is required to justify his work by presenting his paper before peers.

To have research papers acknowledged in a journal, scientists submit their paper to scrutiny by journal reviewers, who are generally appointed experts from the scientific field.

Publishing or presenting a paper requires scientists to interact with their peers; to share knowledge, to gain prestige and to defend the integrity of their work.

6 My Research Project

6.1 Background to the Research Project

I volunteered for a project under Dr Napoleon Reyes in the Institute of Information and Mathematical Sciences at Massey University. The project I undertook was to create a hybrid robot navigation system, combining a Fuzzy Logic navigation system [19,20,21,22,31] that had already been developed by Dr Reyes, with the A* search algorithm. The navigation system was to be designed for the robot soccer system being developed at Massey University.

Dr Reyes and other computer scientists at Massey University aim to create the first robot soccer team from New Zealand to be taken to competition internationally. Computer scientists at Massey have already assembled a working robot soccer system, with playing field, several robots, cameras, controlling computers, and advanced Machine Vision algorithms.

Dr Reyes was invited to chair the previous FIRA games, held in Singapore. Because of this, the team has a large amount of information about the current state of the game, and the strategies employed by the leading teams. It has been discovered that the major weaknesses of competitive robot soccer teams lie in their lack of strategic (multi-agent) intelligence, as the robots on one team often conflict with each other, and the short-sightedness of their navigation algorithms, as robots often become trapped in avoidable situations.

It was proposed that the a new navigation system, incorporating the A* algorithm for its fast forward-planning ability [27-29] should out-perform systems employed by the leading universities at the recent FIRA robot soccer tournament.

6.2 Research Objectives

The creation of a successful navigation system for autonomous robots; that is a system that can take information about a robot's environment, processed in a meaningful way, and execute a planned path of pursuit towards a goal, avoiding obstacles, is one of the great challenges of modern robotics.

The primary objective of the research project I undertook with Dr Napoleon Reyes was to create an advanced, hybrid robot navigation system, designed for soccer robots, but applicable to other autonomous vehicles operating in real time.

If successful, the navigation system would replace the existing system in use by soccer robots at Massey University, and be taken to international competition at the next FIRA games in June of 2006.

The objectives of the navigation system were:

1. The navigation system must integrate two complementary navigation systems in order to combine strengths and eliminate weaknesses.

2. The navigation system must inculcate the behaviours of target pursuit and obstacle avoidance.

3. The navigation system must operate in real time, without any pre-processing of paths, within a calculation window of 33ms.

4. Should the algorithm prove successful, it will be extended to synthesise evasive robot behavior

6.3 Development of the Research Project

Initially the research project required me to gain a degree of familiarity with robot navigation systems, and to learn to Fuzzy Logic control system already developed for the robot soccer system. Specifically, the first phase of the project required:

- Investigating navigation systems in use by other robot soccer teams
- Researching scientific papers on the subject of robot navigation
- Investigating alternative navigation algorithms for applicability to robot control
- Communicating with scientists in the field working in related areas
- Learning Fuzzy Logic, especially relating to robot control
- Understanding of robot control programs and robots

Once my acclimatisation into robot navigation was achieved, I began to design the new, hybrid navigation system, relying heavily on my knowledge of Fuzzy Logic and the A* algorithm from papers that I has taken at university. I had to make modifications to the Fuzzy Logic and A* algorithms, and create new algorithms to support the hybrid system's implementation requirements.

Figure 8 illustrates the layered approach agreed upon by Dr Reyes and myself for the hybrid system. The A* algorithm would receive a map of the environment generated by a new *environment processor* layer, employing the new map-generating algorithm. Using the map as a search domain, where map indexes translate to nodes in the search graph, A* would plan a *shortest path*, to its target, avoiding obstacles. This path would be fed down to a cascade of Fuzzy systems, which would control steering and acceleration along the path. The Fuzzy layer would also react to any immediate obstacles by engaging an *obstacle avoidance* fuzzy system, that would temporarily take control of steering and acceleration of the robot to avoid collision. For a complete discussion of the navigation systems, please refer to the two research papers attached to the end of this document.

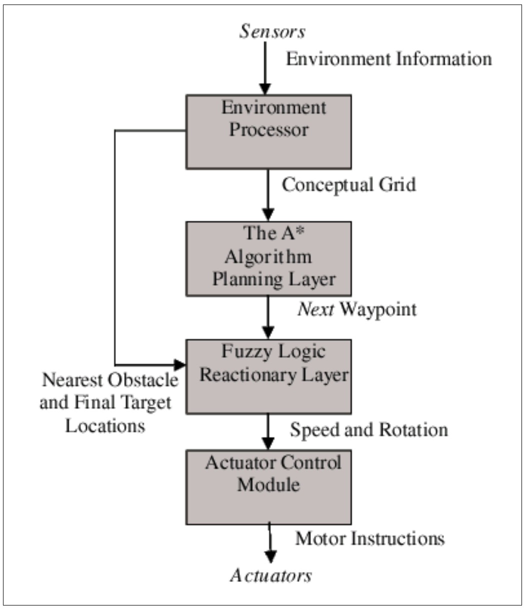

Figure 8: Layers of the Hybrid Navigation System

This second phase of the project comprised of porting an existing Fuzzy Logic robot control implementation from Visual Basic to C++, creating a real-time adaptation of the A* algorithm for dynamic path-finding operation, creating the algorithm for mapping the robot soccer environment, and extending the navigation system and algorithms for broader applicability.

After refining the hybrid system in a new 3-D computer simulation, Dr Reyes and I wrote a research paper on the successful hybrid navigation system [17] (*attachment 1*). This paper was submitted to the First New Zealand Korean Joint Workshop on Advance of Computational Intelligence Methods and Applications, to be held on February 17th, and was subsequently accepted.

I presented the paper at the conference, which gave me an excellent first opportunity to participate in the processes of the scientific community. I presented to an audience of New Zealand, Korean, and other international scientists, many of whom had more than three decades of experience with robot systems. I had to field questions, and answer criticisms to the work. I was also able to meet some of the most important scientists in the field from Korea and exchange ideas.

With an early success, the research project was extended to creating a new, modified A* algorithm for *evasive* robot behaviour. This involved extending the hybrid system with the new algorithm, implementing the new algorithm in simulation and writing a new research paper [2] on the new behaviours inculcated into the system. Dr Reyes and I have submitted our second research paper to the 9th Fuzzy Days conference, to be held in Dortmund, Germany, from the 18th to the 20th of September this year. We receive acceptance confirmation on the 18th of March.

Should our paper be accepted into the 9th Fuzzy Days conference, I will have the unique opportunity to interact with the world's leading computer scientists in the area of Fuzzy Logic, including Lofti A. Zadeh, the inventor of Fuzzy Logic.

6.4 Simulation Development

To experiment with and develop the hybrid algorithm, it was necessary to create a simulation of the robot soccer environment. This presented an excellent opportunity to create a new 3-D simulation. A 3-D simulation would provide the additional advantages of being able to be extended in future projects to model 3-D ball physics, and would be a very portable presentation piece, that could communicate research in an entertaining and visually appealing manner to any audience.

6.4.1 Graphical Environment

A 3-D simulation required the creation of a graphics engine able to take spatial information about the environment, project that information into a 3-D *scene* based on a perspective of the environment, and apply the appropriate mathematical *transformations* to flatten that scene into a 2-D picture that could be output to a monitor display. To produce a real-time effect, the graphics engine would have to make these transformations on a regular basis; at least 33 times per second on an average PC.

To support the creation of the 3-D graphics engine, there were several major programming libraries available:

- OpenGL
- DirectX
- Java3D

I decided to use DirectX for the graphics engine, based on the availability and reliability of documentation. I was also able to program with DirectX using C++, which I preferred based on my extensive experience from papers taken throughout my degree. By that token, the simulation program (illustrated in *Figure 9*) should then also be easier for other Massey students to interpret, should they choose to use it as a platform for future projects.

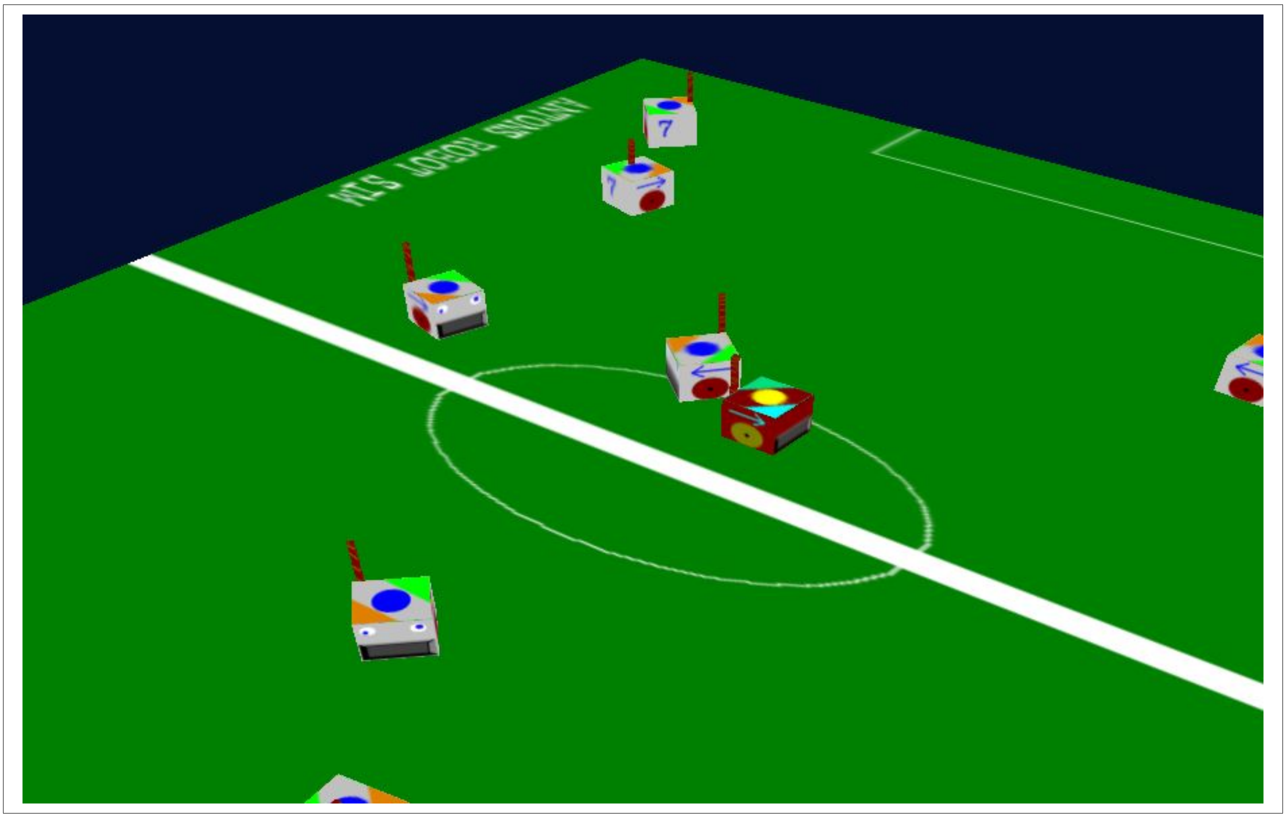

Figure 9: The robot soccer simulation

The entire simulation engine would bring together several different programs for controlling robot intelligence, and with this in mind I created the entire program in a modular fashion, conforming to the *Controller* design paradigm, which is studied as part of several Information Systems papers at Massey University. To conform to *Controller*, I created one controlling graphics class, that can be instantiated in *any* Windows program. The class provides a simple interface to the programmer, and hides all of the complex graphics transformations and other data structures.

For the demonstration version of the simulation, I developed and incorporated several modern graphical effects that make the rendered output more visually appealing:

- Alpha-Testing
- 32-bit Anti-Aliasing
- 1280x1024, 32-bit Texture Rendering
- MIP Mapping
- Improved Triangle Occlusion Culling
- Field-of-View Frustum

With the exception of MIP Mapping all of these effects are minor enhancements to the graphics engine. MIP Mapping, which is from the Latin “multim im parvo” means “*many things in a small space”*. MIP Mapping is a technique that reduces the grainy appearance of textured objects that are farther away from the viewpoint by scaling textures to a range of different resolutions. The textures then appear to 'blur into the distance' as they are farther away from the viewpoint. The Field of View *Frustum* is a performance-enhancer that calculates which objects are outside of the field of view of the viewpoint, and then excludes those objects from the rendering process.

Debugging graphical programs is exceedingly difficult, as they do not have the ability to print out simple error message text in the manner of common console applications. I found that it was beneficial to have a whole range of internal data printed out during simulation, and also created a system to write important debug outputs to a log file. To display data on screen during simulation I created an additional module to display text on special overlay panels.

Figure 10: Panel displaying internal variable values for selected robot

I created a panel to display various internal states and variables for a selected robot (*Figure 10*), including all of the special variables relating to the algorithms in the robot navigation system. I created another panel to display all of the general debug information to the screen, including the number of 3-D models successfully loaded, files in use, and other information.

6.4.2 3-D Models

In order to create a representation of the soccer robots for the 3-D space of the simulation environment it was necessary to create 3-D models using CAD (Computer Assisted Design) software. I had some experience with several CAD programs in design papers during the first year of my degree, so learning a new program was not a major obstacle. The challenge, I discovered, was to find a CAD package that was able to export 3-D models to the Direct-X-compatible format that I was using in the graphics engine of my simulation.

I was able to configure the CAD packages that I used so that metrics used by the packages to determine the dimensions of the robot models agreed with the metrics I was using in my simulation. Because of this I was able to create accurate scale models of the real robots, and thereby improve the accuracy of my simulated robot soccer environment.

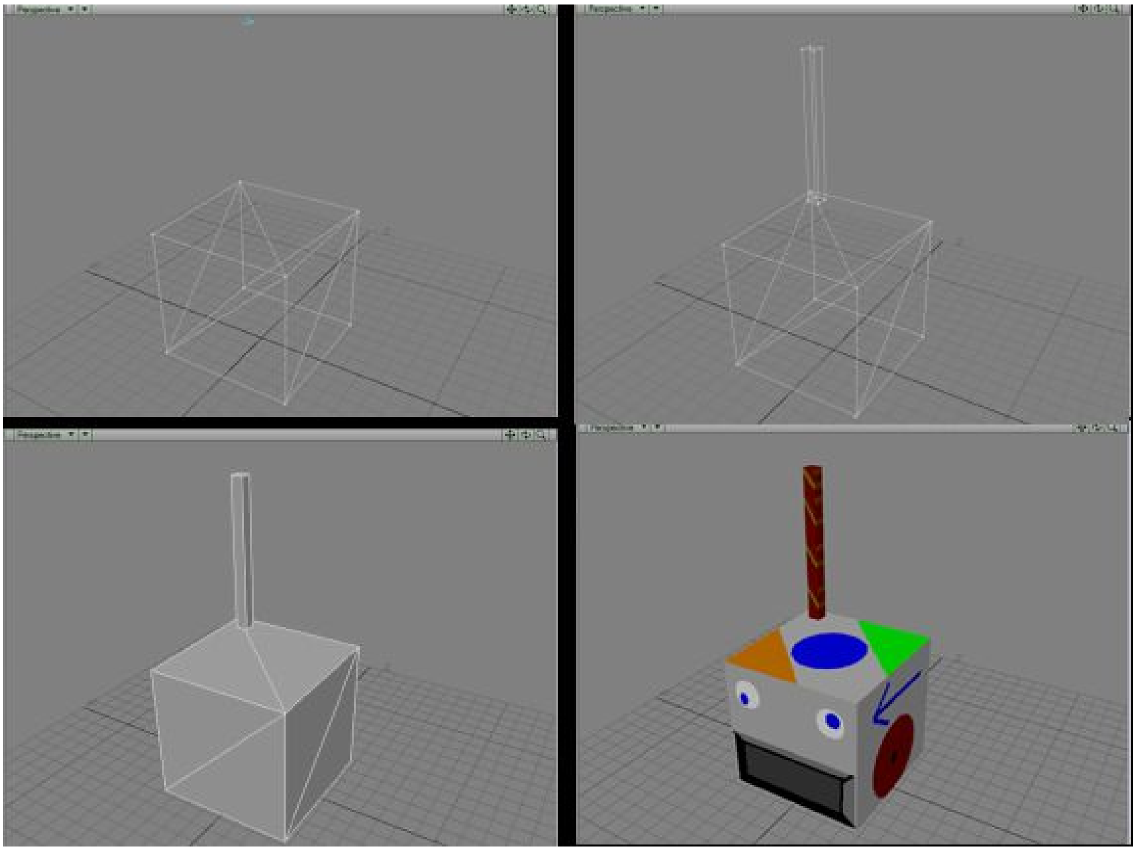

Figure 11: Constructing soccer robot models for simulation in a CAD program

Figure 11 illustrates the steps in the design process followed to create robot models. I wanted to keep the models as simple as possible to reduce the CPU requirements of the rendering engine. The simulation was also to be used to demonstrate the hybrid navigation system, so I wanted to make the models at least recognisable, if not highly visually appealing. You can see in *Figure 15* that I created a basic cube to represent the robot, added several more polygons to represent the antenna, and finally applied simple bitmaps to all of the surfaces to provide detail.

6.4.3 Algorithm Implementation

Implementing the hybrid navigation system within the 3-D simulation proved to be a considerable challenge. Implementing the Fuzzy Logic and A* navigation systems separately proved to be challenging, however combining the algorithms to form a hybrid system required extensive modification to both systems, and an enormous amount of testing and refinement.

The Fuzzy Logic reactive local navigation system required a port to C++ of a Visual Basic implementation. I was able to port and implement the Fuzzy Logic code as a module to the simulation program, but extensive modification was required in order to translate the metrics system used in the previous implementation into the metrics system of the 3-D simulation, which is based on real metric radians, meters, and seconds.

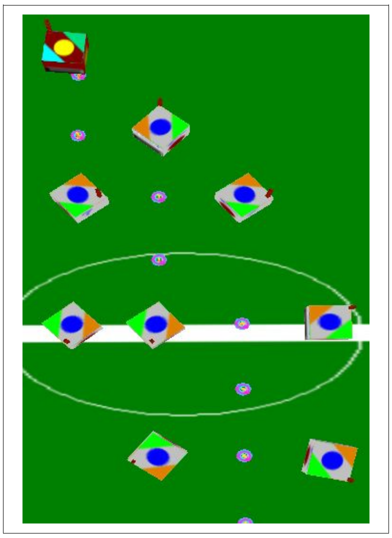

Figure 12: Path generated by the A algorithm*

In order for the A* algorithm to operate in a (simulated) real environment, I had to create a supplementary algorithm to generate a map of the robot soccer environment, based on the dimensions of the playing field, and the known sizes and positions of all of the robots in play (which would be identified by the machine vision system in the real game). The A* algorithm could then use the map grid as a large graph to search; generating paths for the robots. *Figure 12* illustrates an example of a path, as a series of points, generated by the dark robot which is trying to reach the area to the bottom of the picture, and avoid colliding with the other robots.

It was discovered after implementation, that the A* algorithm does not operate in real-time, and I had to create a specially modified *dynamic* A* algorithm to continually recalculate paths during transit for robots using the hybrid system.

Initially the two navigations systems conflicted over feasibility of calculated paths of movement. Extensive refinement was required to both systems in order to ensure that paths generated by the A* algorithm would be accepted as possible by the Fuzzy Logic system.

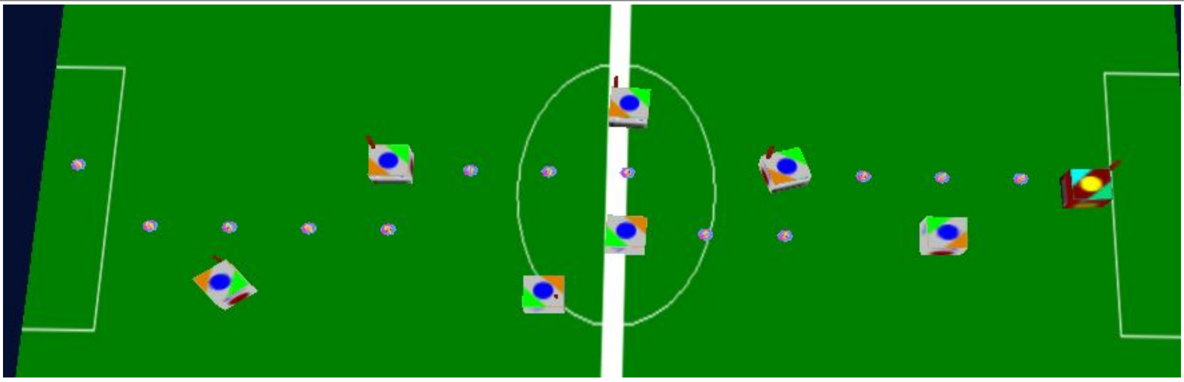

Figure 13: A path through hostile robots with only obstacle avoidance behaviour

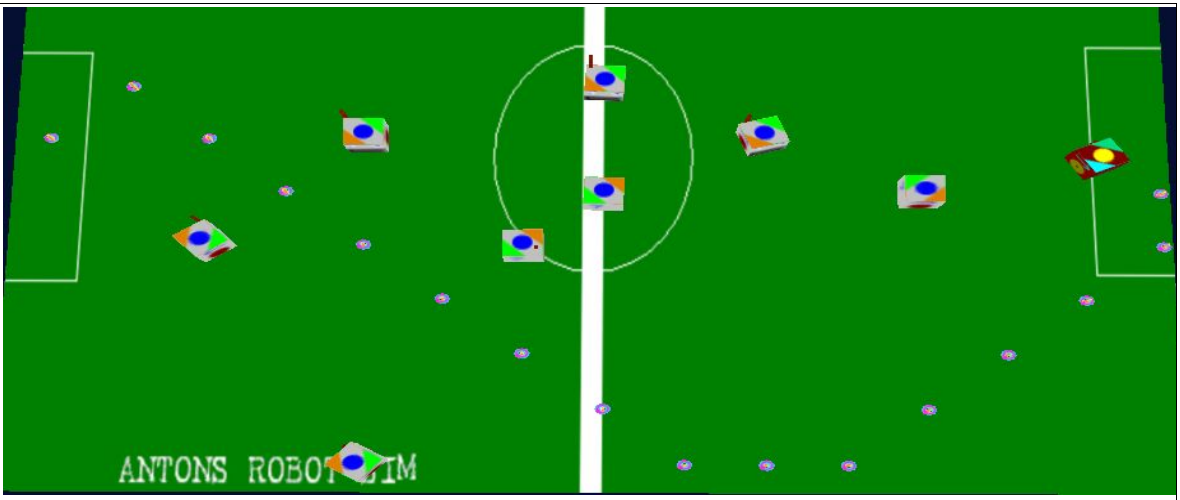

Figure 14: A path through hostile robots with evasive behaviour

Ball-carrying robots are more effective if they can steer clear of opponents, rather than simply avoid collision. Figure 13 and Figure 14 demonstrate the different path-planning behaviours of *obstacle avoidance* and *evasion*.

Implementing the algorithm for opponent *evasion* required additional infrastructure; another supplementary algorithm was required, to create a map of relative areas of *undesirability.* The opponent evasion algorithm inculcates into the navigation system a predictive ability; areas that opposing robots are more likely to move into, such as the area immediately in front of a moving hostile robot, are rated at a higher level of undesirability than those areas less likely to be moved into; reflecting the reduced threat to those areas. Robots planning paths with evasive behaviour can now make a prediction as to a *best* path balancing total path length with level of threat. Evasive robots continually re-assess the path to take into account the activities of opposing robots.

6.4.4 Extensions to the Simulation

It was my intention to create a robot soccer simulation that would be useful beyond the scope of the robot navigation research project that I undertook. I created the entire program in a modular fashion so that different modules could be added to or removed from the program. I managed to develop another implementation of the simulation, concurrently with the robot soccer implementation, to be used as an all-terrain autonomous robot navigation simulation, employing a similar navigation system (refer to Figure 15 and Figure 16).

It was also my intention to make the simulation program available to other students working on robot soccer research within Massey University, and so I made several additional modules to extend the usability of the simulation program:

- Graphical User Interface
- Scenario-loading system
- Model-loading system

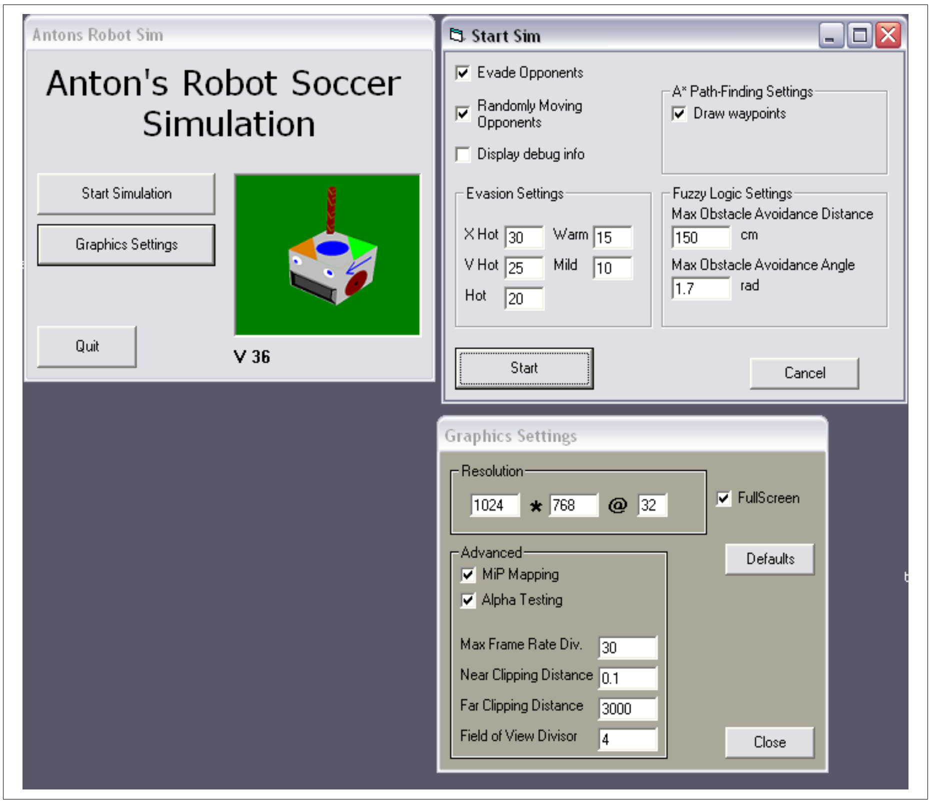

Figure 17: The Graphical User Interface for the robot soccer simulation

Because the simulation will be used by other students, or by other people for demonstration, I developed a Graphical User Interface (GUI) in Visual Basic (refer to *Figure 17)*, to allow very simple customisation of the graphical settings of the simulation and other variables. Prior to the creation of the GUI, all of the customisable variables and settings were entered into text files. The GUI program manipulates those text files, but provides the user with a much more user-friendly interface.

In order to accommodate repeated, comparative testing of the same situation, or demonstration of a particular scenario, I developed a small module to save and load specific soccer scenarios to and from simple ASCII text files. I have also created a similar module for loading sets of 3-D models into the simulation.

6.5 Outcomes of Research

The Hybrid Fuzzy A* algorithm has been tested to work well in a real-time simulation environment with a formidable army of opponents and obstacles. The algorithm developed is able to combine the strengths of the two intelligent techniques, as well as eliminate their weaknesses in one Hybrid

Fuzzy A* architecture.

The algorithm met all of the objectives of the research project; it was able to produce a hybrid of two navigation systems, combine their strengths, eliminate their weaknesses, and produce target seeking and obstacle avoidance behaviours. The hybrid algorithm was required to calculate paths for several robots simultaneously, at least 33 times per second. The final algorithm was able to calculate paths for *eleven* robots simultaneously, over 100 times per second; which is more than 33 times faster the speed requirement.

I have made a major contribution to the successful development of the Hybrid Fuzzy A* navigation system that inculcates two adaptive robot behaviours: Target Pursuit and Obstacle Avoidance. The system is able to take advantage of A*'s optimised path finding, as well as Fuzzy Logic's reactionary feature, allowing for a significant improvement in speed and adaptability to a harsh dynamic environment.

I have also developed an Improved Hybrid Fuzzy A* Algorithm that allows for Target Pursuit, Obstacle Avoidance and Opponent Evasion behaviours. A new predictive quality behaviour has been inculcated into the system with the addition of a new parameter in the A* formula.
In terms of speed and efficiency, where Fuzzy Logic alone, or the A* algorithm alone is used, the Hybrid Fuzzy A* algorithm can provide even better performance.

7 Conclusions

The project that I completed for practical work experience for my third practicum was a highly challenging, but rewarding experience.

I was able to make the most of my abilities as a Software Engineering student, and actively participate in the scientific community, co-writing two research papers. My programming and software development abilities have improved immensely as a result. I have sharpened my skills as a public speaker, learned methods of collecting and analysing existing research, learned how to interact with scientists and academics as peers, and become familiar with the scientific research and publication process.

I gained a much more intimate knowledge of the workings and processes of the scientific and academic communities, and was able to make presentations to and interact with a range of people from both communities. I was able to forge valuable relationships with key staff members within Massey University, and create a firm platform for a fourth-year engineering project.

The extremely high work demands of the research project meant that I had to make sacrifices to my social life, sport, and income, and I have developed improved project and personal management strategies as a result. I became familiar with the remuneration processes withing the university, and have used my successes to apply for several scholarships.

My experiences over the course of the practical work period have motivated me to continue research in exciting and challenging field of robotics, and I propose to develop an intelligent, role-independent multi-agent strategy system for the robot soccer system for my fourth-year project.

I will continue to contribute to the Massey robot soccer team, and if possible, help to launch the first competing New Zealand team for the next FIRA competition, in June of this year.

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9 Appendices

Research Papers:

1. A. Gerdelan, N. Reyes “A Novel Hybrid Fuzzy A* Robot Navigation System for Target Pursuit and Obstacle Avoidance”, from the proceedings of the *First New Zealand Korean Joint Workshop on Advance of Computational Intelligence Methods and Applications*, 2006, AUT University, Auckland, New Zealand.

2. A. Gerdelan, N. Reyes “Synthesizing Adaptive Navigational Robot Behaviours using a Hybrid Fuzzy A* Approach”, publication pending, 2006, Massey University, Auckland, New Zealand.