MAIN GROUP REPORT

Acknowledgements

Warwick Mobile Robotics has received a great deal of help and support throughout the course of the last academic year. The team would like to especially thank:

Project Supervisors; Dr. Peter Jones and Dr. Ken Young
WMG Staff; Adam Land, Neil Timms, Mick Carpenter, Roger Bull and Scott Haberton
School of Engineering Staff; Jonathan Meadows and Ian Griffith
Sponsors; Warwick IMRC, Warwick Manufacturing Group, Remotec and the School of Engineering
PhD Students; Michael Tandy, Sadiq Jaffer and John Oliver
WMG Finance team
RoboCup Rescue German Open Organisers
Nottingham University Robot Football Team
Project Assessors; Dr. Emma Rushforth and Dr. Marina Cole

CONTENTS

1.0 INTRODUCTION

The following Main Group Report provides a complete scenario of all the work achieved throughout the project in the 2007/08 academic year. All technical advancements and methods are introduced in relevant sections with more in depth discussion found in respective technical reports. The report outlines the methods employed derived from the specification, which was derived from the requirements, aims and objectives. A wide range of topics are addressed from health and safety, publicity and recommendations for the continuing team.

1.1 HISTORY OF ROBOT FOOTBALL

Initially run as a third year project at the University of Warwick in the year 2000, the work involved was mainly concerned with machine vision. The first generation of the Robot Football Team was sourced in from Merlin Systems. Since then the project has gained prominence within the School of Engineering and has become a fourth year group project. MEng teams in the past have developed their own hardware, strategies and communication systems to compete within the UK FIRA MiroSot Robot Football Championships. Success at a competitive level has helped the team gain sponsorship and has provided further interest in robotics amongst students.

The 2006/07 team produced a new generation of robots, the Evolution 4's, which involved a mechanical redesign and optimisation of existing strategies. Having hosted the UK championships, the team achieved second place in the MiroSot league and first place in the SimuroSot league, beating Oxford.

1.1.1 ABOUT ROBOT FOOTBALL

MiroSot Robot Football is an automated competition played between two teams of five cube-based robots, each 7.5cm Square, with no human interaction. Much like the traditional game, the aim of the competition is to score as many goals in the opposition's half as possible using pre-planned tactics and strategy, within a fixed time frame.

Played on a 220cm x 180cm pitch, each team uses an overhead vision system to accurately determine the location and orientation of the players based on colored ID barcodes positioned on the robots top. A computer system then runs a pre-written strategy to determine their next move and broadcasts the movement directions to the robots via wireless control.

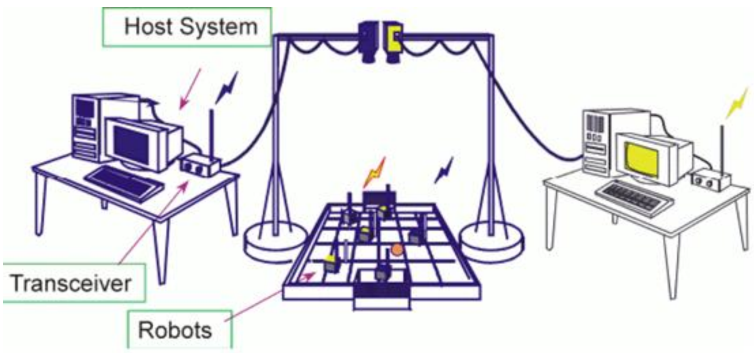

Figure 1 – FIRA Setup Diagram

1.2 RECOMMENDATIONS FROM THE 2006/07 TEAM

As with all fourth year projects, last year's team put forward a list of recommendations that they perceived would be in the futures team's best interests to follow. The team's recommendations left little scope for the physical mechanical and electronic development. Instead, large emphasis was placed on the advancement of the strategy, including facilitating passing between robots, obstacle avoidance methods and auto-positioning capabilities. In general the recommendations are highly focused on programming and limit opportunities for the new multi-disciplinary team.

1.3 THE NEW TEAM

This year's team consists of eight MEng undergraduate students from a wide range of streams, including electronics, manufacturing, mechanical and systems engineering. The project runs the duration of the academic year, with the final portfolio submission in April and an oral presentation in May.

Figure 2 [1] – From left to right: Edward Elbourne, Jonathan Holmes, Alex Smith, Mahan Ramachandra, Phil Smith, Redland Sanders, Alex Barnes, and Christopher Payne.

Name	Role
Alexander Barnes	Software development
Edward Elbourne	Finance and safety officer
Jonathan Holmes	Mechanical, publicity and web master
Christopher Payne	MiroSot Coordinator
Mahan Ramachandra	Project manager and secretary
Redland Sanders	Mechanical, CAD and sponsorship
Alex Smith	Technical director
Phil Smith	Electronics and communications

Figure 3 – Table of team members and assigned roles. The contact list is found in **Appendix 1**.

1.4 FUTURE OF ROBOT FOOTBALL

In recent years, interest from participating academic institutions in the UK FIRA MiroSot Robot Football Championships has been diminishing. The principal rival of past years, Plymouth University, has decided not to compete in the 2008 championships, raising doubts about the feasibility of the project's future.

Interest does continue to exist globally, albeit at a higher level. Outside the UK, teams are generally much larger and often include several full-time PhD candidates, leaving an unlevel field of competitors.

Due to the uncertain future of the sport, the team came to the mutual conclusion that Robot Football could not continue to be the sole focus of the 2007/08 project. The team was reluctant to end its participation in the sport all together, as it is still an excellent opportunity to gain publicity and promote other areas the team pursues. Furthermore, Robot Football is still a familiar point of reference amongst interested parties within and external to the University, allowing access to a wide audience concerned with robotics.

Therefore, the decision has been made to keep running the sport, but with limited assigned resources. Attention will only be focused on two key objectives:

1. To redevelop both attacking and defensive strategies.
2. To compete in the UK Championships.

This allows the team to concentrate on a new project that is a logical progression from Robot Football, building on the technological developments already achieved.

An analogy can be made between the cycle of Robot Football and that of a product. The Product Life Cycle refers to the sequence of phases a product goes through and in management these phases are part of the basis of strategic decisions.

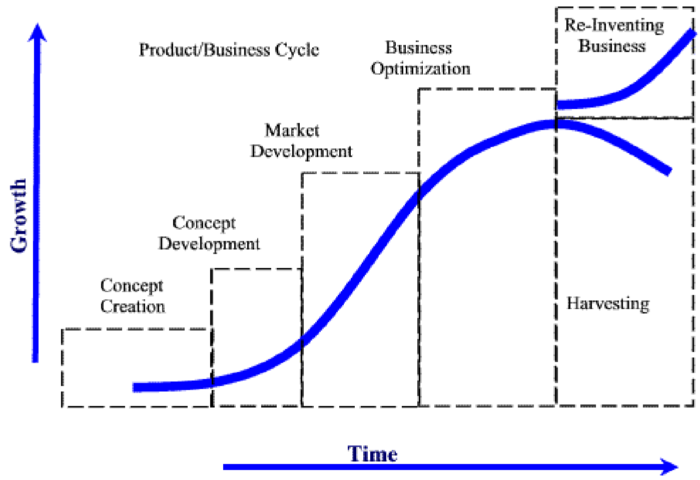

Figure 4 – Product Life Cycle [2]

With regards to the Product Life Cycle, in order for the team to 're-invent the business' a new product (project) must be developed.

1.5 PROJECT SELECTION

One of the primary factors affecting project selection was the extensive knowledge base that has been developed over the projects life so far. It would be prudent to implement and exploit certain technologies, including machine vision, image post processing and wireless control systems initially developed for Robot Football, but have wider applications in robotics. This reasoning led to the conclusion that some form of autonomous mobile robot development would be most appropriate.

1.5.1 OBJECTIVE ANALYSIS

From past experience, the team understands the value and advantage that competition brings to the project. As well as a level of excitement (providing motivation for the team), participating in established events provides exposure and access to a number of industrial and academic contacts. From this, a list of prominent prospective competitions was identified:

- DARPA Urban Challenge
- ESCO-UAS
- Trinity Fire Fighting
- MoD Grand Challenge
- RoboSot Robot Football Competition
- RoboCup Rescue
- ELROB

Subsequently, a score based objective analysis was undertaken to incorporate a number of factors influencing the decision to pursue each competition. These factors are as follows:

- *The competition deadline* – viability with respect to the academic timetable
- *Project expense* – estimated level of funding required
- *Funding prospects* – the possibility of generating the required funds
- *Regulation feasibility* – limiting factors in the regulations that would compromise the team's ability to compete successfully in the competition
- *Location* – feasibility of the competition location based on travel expenses and accessibility
- *Eligibility* – any non-technical barriers to entry, for example nationality
- *Team motivation* – the general consensus of the team's enthusiasm
- *Viability* – the ability of the team to succeed within the competition
- *Technological requirements*- how advanced the required technology is compared to what is feasible at the University of Warwick.
- *Future prospects*- the scope of further development within the project
- *Time scale* – the minimum time estimated to fully develop a successful entry

Each team member was assigned a competition to thoroughly research in order to discern the required information. MiroSot was also included in this process not only to provide a benchmark, but to demonstrate the team's reasoning for selecting a new project was objective. The Prospective Projects Analysis, found in **Appendix 2**, was used to select the four most favourable competitions for SWOT analysis. SWOT (strengths, weaknesses, opportunities and threats) analysis, is a popular strategic planning tool for quickly identifying internal and external factors, which have a heavy influence on the aims and objectives of an organisation or project.

The four qualifying competitions were; ESCO-UAS, Trinity Fire Fighting, MiroSot UK and RoboCup Rescue. A full SWOT analysis can be found in **Appendix 3**.

ESCO-UAS had a high level of enthusiasm from the team and a realistic technological requirement, however the use of flying drone brought up health and safety issues that could not be overcome on University premises.

Trinity Fire Fighting appeared the most achievable and is held in association with the IEEE, but unfortunately the location of the competition proved a prohibitive factor

MiroSot UK was deemed to be an insufficient challenge for the entire team, but for the reasons explained above, it was concluded it would still run in addition to the new project.

RoboCup Rescue, although possessing demanding goals, demonstrated a realistic and attractive opportunity. Through the inclusion of progressive technology, the project selection requirements were met adequately.

1.5.2 ROBOCUP RESCUE

RoboCup Rescue aims to simulate the scenario of a natural disaster, such as an earthquake, to drive the development of search and rescue technologies through competition. Participants are required to demonstrate capabilities in mobility, sensory perception, planning, mapping and operator interfaces whilst searching for simulated victims, in a recreated earthquake setting.

The competition is particularly well suited to the team because of the adopted structure; providing increasing levels of task difficulty in various arenas, allowing competition at different stages of development..

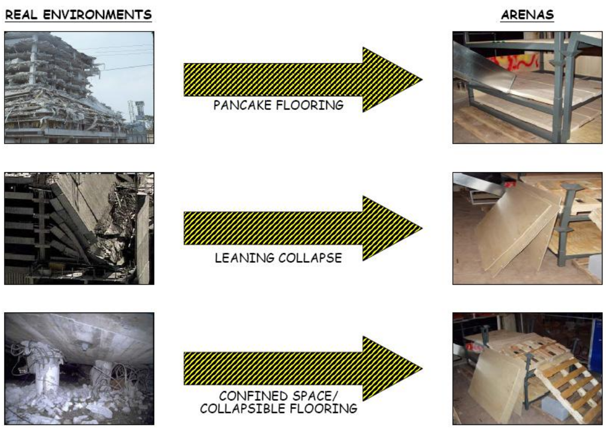

Figure 5 –Examples of typical RoboCup Rescue competition obstacles: collapse types [3]

The competition, held on 21-25 April during the Hannover Messe[4] engineering fair in Germany, hosts over 200,000 visitors, which provides an excellent opportunity to promote sponsors, the University of Warwick and the team.

1.6 REQUIREMENTS AND SPECIFICATIONS

The scope for different design approaches for such a competition is obviously vast. The team discovered the most efficient way of developing a basic design approach was to focus on the individual requirements of the competition. This was achieved by thoroughly examining all regulations set by the governing body. A list of physical requirements was drawn up, narrowing the range of design solutions.

A regulation of successfully competing in a RoboCup Rescue tournament is that the participating teams must publish a full technical report, detailing designs. The team found it useful to analyse some of the more successful entrants through their documentation. This aided decision making when approaching certain requirements.

Similar to the project selection process, a simple scoring system was developed to evaluate the different design approaches of previous entrants (**Appendix 4**). Aspects explored include; autonomous capabilities, locomotion, communications, mapping abilities, sensors used and cost.

This was used to compile a list of hardware, software and control specifications from which to base initial design concepts. Details of which can be found in **Appendix 5**.

In order to implement these requirements it became apparent that a number of changes to the approach of the project would have to be made.

1.7 ADAPTING TO CHANGE

One of the first changes that needed to be made was to avoid the two aspects of the project (Robot Football and RoboCup Rescue) from interfering with one another. To address the situation, a coordinator was established (Christopher Payne) to be responsible for the progress made on Robot Football. To limit the impact efforts on Robot Football would have on the progress of the RoboCup Rescue work, appropriate allocation of resources were planned in advanced.

1.7.1 LABORATORY REFURBISHMENTS

Before any other activities were commenced it was deemed necessary to refurbish the team's working space. The laboratory is in an ideal location within the IMC, lending itself to demonstrations and any open days that may be held for potential students or industrial visitors. It was therefore necessary to make sure the laboratory was clean and presentable. In addition to this, several changes were made to increase the laboratory's visual appeal. Refurbishments include: Spotlight fittings, window displays, posters, widescreen LCD display, storage cabinets, whiteboards etc.

Figure 6 – The refurbished laboratory

1.7.2 CORPORATE IDENTITY

The previous identity of the project no longer represented all interests of the team. In addition to this, to facilitate the appropriation of funding and improve scope for promotion a new identity was required. To demonstrate professionalism and attract serious attention from industrial and academic institutions, the new corporate identity of Warwick Mobile Robotics was adopted.

At the heart of this identity change was a new logo that would be used in all formal documentation, letter heads, presentations and publicity produced by the team. To help create awareness of this new identity the project website was completely redeveloped.

1.7.3 A NEW WEBSITE

A new website was created within the main University website structure, providing a more professional appearance. After creating the new design, the content was written to achieve three primary targets; firstly to regularly update stakeholders of the team's progress, to provide a useful source of information for new visitors and finally, to use the website as a tool within the team.

Through the acquisition of the domain name www.mobilerobotics.warwick.ac.uk, the identity change was complete.

1.8 AIMS AND OBJECTIVES

1.8.1 AIMS

- Redesign the project's corporate identity and image
- Optimise our MiroSot strategy for national championships
- Design and build a RoboCup Rescue certified robot

1.8.2 OBJECTIVES

- Develop a new marketing strategy to attract sponsors and raise the profile of the School of Engineering
- Develop a robot chassis capable of navigating the scenario terrain
- Build a test environment for the robot
- Produce a sensor array capable of mapping the environment
- Provide support for tele-operation and autonomous navigation
- Investigate the implementation of victim identification using thermal imaging, motion, sound and CO_2 sensors
- Compile a handbook detailing the rules and regulations of the challenge as well as the learning experiences of the team for the benefit of the next team
- Create a new website to generate interest in the project
- Renovate the existing laboratory facilities to project a more professional image
- Compete at the European RoboCup Rescue league within 3 years

2.0 PUBLICITY AND SPONSORSHIP

2.1 PUBLICITY

2.1.1 EVENTS

Warwick Mobile Robotics has been host to a number of highly acclaimed individuals, organisations, staff, students, schools and visitors from industry. Events have ranged from presentations to demonstrations and tours. Holding such events has allowed the promotion of sponsors, the creation of industrial links and increased credibility to stakeholders, internal and external to the University. A few of the more prominent events are outlined below:

- Dr Abdul Kalam, President of India (06.2002 – 06.2007), visited WMG on Sunday 21st October to meet staff and students, and to talk on the subject of 'The Future of India's Space Programme'. WMR was fortunate enough to be given the opportunity to give Dr Abdul Kalam a presentation outlining the project, as well as a live demonstration of the MiroSot Evo3 and Evo4 robots.

Figure 7 – Dr Abdul Kalam with Alex Smith, Mahan Ramachandra, Redland Sanders and Alex Barnes (left to right) holding the MiroSot Evolution Team

- The team presented the poster formally to the two assessors, Dr. Emma Rushforth and Dr. Marina Cole on 16 January 2008. The poster was displayed among other fourth year engineering project posters in the foyer of the School of Engineering.

- On Wednesday 30 January 2008 WMR held an open day, during the School of Engineering's open day. Visitors ranged from school groups, industry visitors, lecturers and University students. The day included regular presentations and demonstrations of the team's progress. Promotional material for the event can be found in **Appendix 6**.

Figure 8 – Alex Smith presenting during the open day

- The MiroSot and SimuroSot UK robot football championships were also held by WMR in the International Manufacturing Centre, on Saturday 8 March 2008. During the event, WMR were able to provide presentations to several tour parties (of prospective students, parents and staff members).

2.1.2 WEBSITE

To facilitate a professional image, a website was created with the new domain name www.mobilerobotics.warwick.ac.uk. The website has proved highly useful, with a number of interested individuals enquiring about Warwick Mobile Robotics prior to visiting the website. Since the launch of the new site, it has received an average of approximately 2000 hits per month (statistics courtesy of the web counter, BBClone).

The website provides information on aims and objects, details about the team and laboratory, an updated news page (including a newsletter archive), information on both robot football and the RoboCup Rescue competition, sponsor information, links, videos, a webcam and a Members Area. The image gallery provides updated photographs of the WMR robot manufacture and assembly, events and promotional material such as logos.

A Members Area within the website was used as a tool for the management of the project. The page consists of all administration documents (for example, headed paper and the purchase order requisition form), a chronological documents database, finance information, the project plan and weekly meeting information.

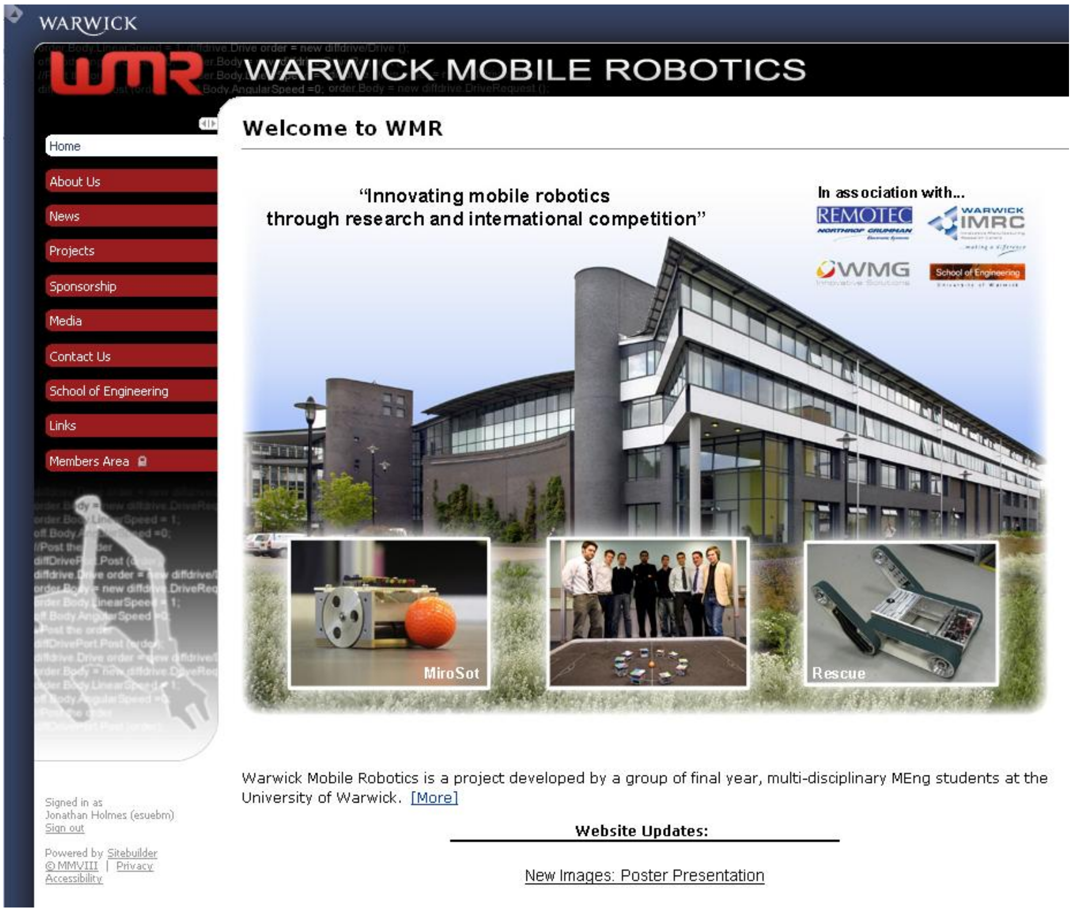

Figure 9 – Screenshot of the WMR homepage (www.mobilerobotics.warwick.ac.uk)

2.1.3 NEWSLETTERS

In order to keep project stakeholders informed of progress and major events, from December 2007 onwards, monthly newsletters where produced. The newsletters were posted on the WMR website, sent to a mailing list and posted on the WMR notice board in the School of Engineering. All newsletters to date can be found in **Appendix 7**.

2.1.4 EXTRA PUBLICITY

The team also acquired a notice board in the School of Engineering to display the WMR development poster. The board was also used for advertising 'up and coming' events and used to display the newsletters.

Furthermore, a short presentation about the project is displayed on the plasma television in the School of Engineering foyer. This is of particular use in attracting visitors from the School to the laboratory in the International Manufacturing Centre.

2.2 SPONSORSHIP

A key part of achieving the set aims and objectives was the need for sponsorship. The team composed a detailed sponsorship package, available in **Appendix ???**, and through contacting various organisations and obtaining details of the relevant personnel, the package was sent out. Due to the large number of organisations that were contacted, it was necessary to compile a Microsoft Excel spreadsheet of e-mail addresses and telephone numbers with a colour scheme employed to show sponsorship status.

The aim of the sponsorship package was to portray a highly professional image and present a two tiered approach to financial and technological support. Though, the team was keen to be flexible in receiving contributions of various levels.

Promotion of the WMR sponsorship package was also supplemented with a dedicated page on the WMR website, in which the sponsorship package is available for download in pdf format. Additionally links and information on current sponsors is included.

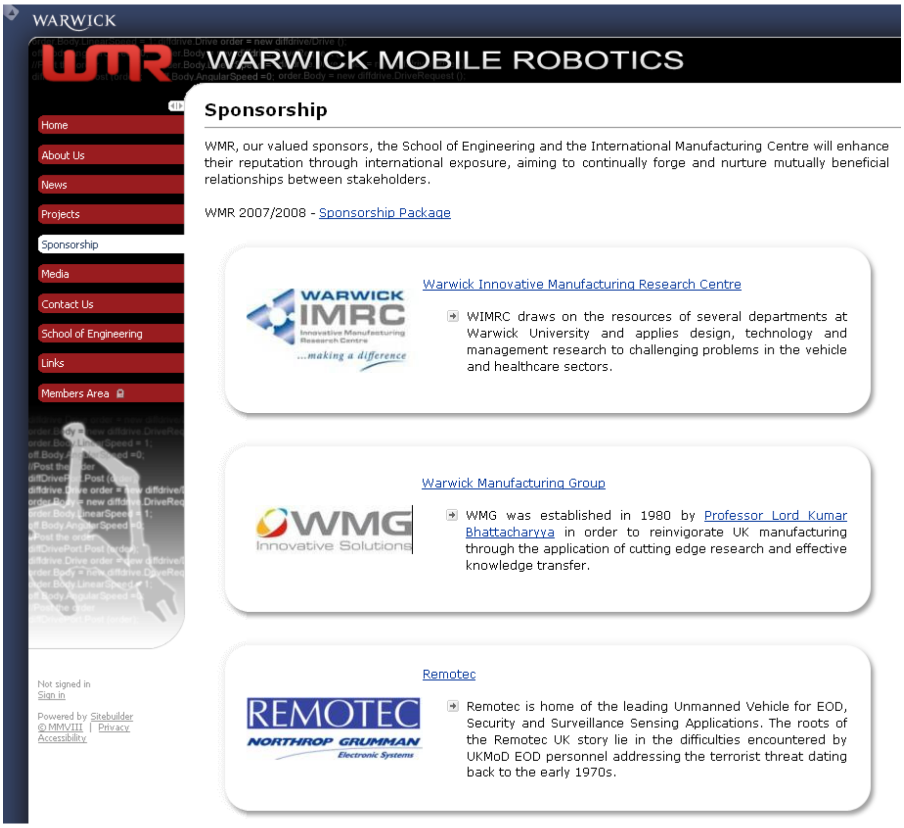

Figure 10 – Screenshot of the WMR sponsorship webpage (www.mobilerobotics.warwick.ac.uk/sponsorship)

Principle sponsorship received includes £4,000 from the Warwick IMRC, £3,500 from the Warwick Manufacturing Group, £1,200 from the School of Engineering and a long-term partnership with Remotec, who also donated hardware. Full details of sponsorship received can be found in the finance section of the **Business, Finance and Management Report**.

3.0 HEALTH AND SAFETY

The health and safety of everyone involved in the project was considered highly important, especially since a large number of visitors would often be given tours of the laboratory. The new direction of the project introduced new research procedures and subsequently, new potential risks. It was clear that new health and safety guidelines were required from the beginning of the project, however at this stage it was unknown what the procedures and potential risks would be. Hence a generic *safe working procedure* was drafted, and this can be found in **Appendix 8**.

This document contained guidelines for working safely with standard laboratory equipment such as computers and soldering irons. It also contained risk assessments for some standard hazards such as flying parts in a MiroSot match, or a collision of the automated rescue robot. The risk assessments determined who was at risk, a quantitative score of the likelihood and severity of the risk, measures to reduce the risk, and a modified quantitative score.

Most importantly, the safe working procedure requested that for any new research activity, a new risk assessment should be carried out. This proved a useful method to ensure any unforeseen risks could be accounted for. For example, when the search and rescue robot was taken to the School of Engineering for the poster presentation it had to ascend a steep staircase. A new risk assessment was written to objectively account for any risk inherent in this procedure. Another risk assessment was written for the use of the search and rescue robot in Germany, and this is shown in **Appendix 9.**

Only two COSHH assessments were made over the course of the project; these both assessed the use of lubricating oil on the rescue robot. The members of the group using the substance filled in these forms, which were then filed for future reference.

Health and safety recommendations provided by the Health and Safety Executive (HSE) were also used when determining requirements for the rescue robot. The *Manual Handling Assessment Chart (MAC) Tool* (http://www.hse.gov.uk/pubns/indg383.pdf) was used to determine the ideal weight for the robot. This tool gives a quantitative score representing the risk to operators of lifting equipment, in this case the rescue robot.

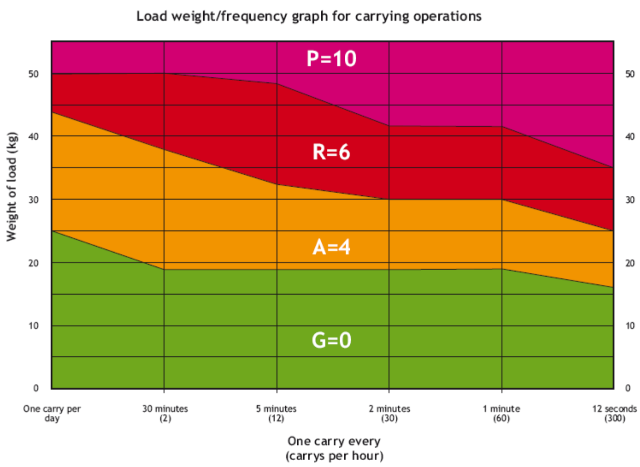

Figure 11 - The MAC Tool, used to specify the ideal weight of the rescue robot. Taken from http://www.hse.gov.uk/pubns/indg383.pdf

The rescue robot would ideally be in the green or yellow band, limiting the weight to 19kg or 38kg respectively. To be in the green or yellow band, the robot also required a method of easy conveyance, such as a handle that requires no upper-body twisting of the user. The full assessment of ideal robot weight can be found in **Appendix 10**.

In developing safety requirements for the rescue robot, other sources consulted included the School of Engineering health and safety recommendations (http://www2.warwick.ac.uk/fac/sci/eng/local/hands/), the RoboCup Rescue rules (http://robotarenas.nist.gov/rules.htm), the *Supply of Machinery (Safety) Regulations 1992* act (http://www.opsi.gov.uk/SI/si1992/Uksi_19923073_en_1.htm) and the *Health and Safety at Work Etc Act 1974*. Of these, the most specific requirements were given by the *Supply of Machinery (Safety) Regulations 1992* act *(*http://www.berr.gov.uk/files/file11274.pdf*)*. The other sources gave only the requirement that the product should be 'safe and without risks to health'.

4.0 MIROSOT ROBOT FOOTBALL

4.1 INTRODUCTION

MiroSot Robot Football is managed by the FIRA (Federation of International Robot-soccer Association) and was founded in 1995 with the goal of offering a challenging arena for researchers working in the field of autonomous mobile robotic systems. FIRA describes the game as a competition of advanced robot technology within a confined space.

Warwick has been entering the competition each year for the last four years as part of an annual MEng Group Project. Every year the team has designed a new set of robots, improving on the characteristics of previous designs whilst working in parallel with developing an enhanced playing strategy.

This year, Warwick Mobile Robotics is continuing to evolve and develop computer strategies for MiroSot however is halting major mechanical hardware development. This decision was taken due to a multitude of reasons, the key factors being a lack of national based competition this year and limited scope for hardware improvement above that of last year's team.

WMR's goal for the forthcoming year is to create a playing strategy that can surpass the previous evolution and win on a national level at the UK championships.

A lot of the skills, knowledge, software code and lessons learnt from the development of MiroSot over the past five years can be applied and transferred to WMR's newly commencing project, RoboCup: Rescue.

4.2 REQUIREMENTS

- Familiarisation with MiroSot concept, official rules and documentation.
- Understanding of RSS (Robot Soccer System), pitch calibration, operation of robots and use of strategy to control both movement and tactics.
- Study of previous games via video footage and practise matches to recognise weaknesses and areas for improvement.
- To investigate new sources of batteries for the MiroSot's to extend playing time and perform overall maintenance on the current Evo4 robots.
- Iterate and improve upon last years work to create a strategy that is competitive and capable of winning against all previous strategies developed at Warwick.
- To compete at and win the UK National MiroSot Championships.

4.3 APPROACH TO DEVELOPMENT

Due to the very practical nature of programming strategy for MiroSot robotics, an iterative design approach was taken, as opposed to a waterfall model for example.

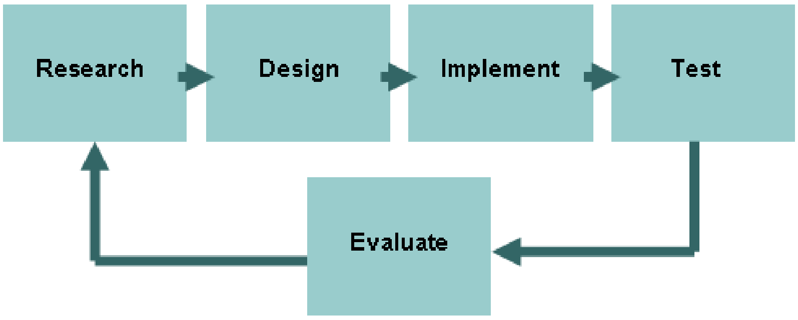

Figure 12 – Agile approach to development

Programming in this environment often requires testing and evaluation after every few added lines of code as the theoretical behaviour and simulated models do not often represent the true movement of the robots.

In addition to this, code added later in the strategy will often directly impact and will be impacted on by earlier movement algorithms. As a result of this close interaction, evaluation of the performance as a whole must continually be ongoing and therefore doesn't lead itself to a design approach that requires "signing" off and perfection on a particular section before moving onto the next.

This approach, as the report will demonstrate, proved successful and over a familiarisation and development period of six months a strong national award winning strategy was built upon these techniques.

4.4 HARDWARE AND SYSTEMS

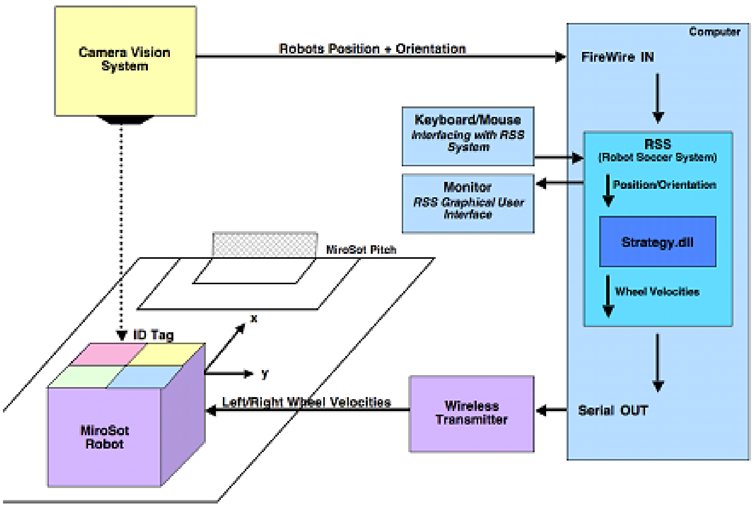

Figure 13 - MiroSot Systems Overview

MiroSot Robot Football is played at the University of Warwick using the following equipment:

- A Basler Firewire camera acts as the vision system to monitor the play area and is connected via FireWire400 to the computer.
- The strategy computer runs RSS (Robot Soccer System) software, developed by John Oliver, a PhD student, at the University of Warwick.
- RSS reads the data from the vision system and calculates the location coordinates and angular data from all of the robots and the ball within the play area.
- This data is then passed through the strategy.dll file. This is the file that forms the majority of this year's work as the instructions contained within it process the location information and pass back to RSS wheel velocities. The .dll essentially contains both the low-level movement algorithms as well as the high-level strategy control.
- The wheel velocities are then passed back to RSS, which interfaces over RS232 to the wireless transmitter.
- The wheel velocities are then sent to the robots, which adjust their wheel speeds accordingly.

4.5 LOW LEVEL STRATEGY

4.5.1 MOVEMENT ALGORITHMS

The movement algorithms are one of the fundamentals of a good strategy as they underpin everything else. If the robots can't move between defined points in a quick, efficient manner then it almost doesn't matter how good the higher level strategy is. It is essential therefore that time and effort was applied to enhancing these areas before assigning roles to various players.

Analysing the strategy used at the championships last year it became apparent that only one movement algorithm named "PID" was being applied across all the various different roles.

Studying the performance, despite being called "PID" only proportional control was in operation. However, the algorithm was excellent at quickly getting to a desired location and was generally efficient in the movement that it took. Despite this however, it was important to note that "PID" moved the robot from point A to point B without any care to the movement that it took to get there. (i.e. the robot would turn whilst moving to save time, often sometimes going slightly in the wrong direction before heading in the right direction).

As a result, while proving excellent for some applications, namely strikers and robots that need to rapidly cover the length of the whole pitch, it lacked the control and refinement needed for various defensive roles.

Defence often relies on preventing the ball from crossing defined lines within the play area. The most effective way of patrolling in these situations is by moving in a straight line. Since the robot can travel backwards and forwards along this trajectory, this can also eliminate much of the need for turning, increasing the overall speed and efficiency at stopping balls.

An effective straight-line movement algorithm was developed that proved fast and reliable and eliminated the need for turning when defending along a line. The development of this movement algorithm is demonstrated in the technical report.

4.6 HIGH LEVEL STRATEGY

4.6.1 CONCEPT

One of the most notable failures of previous strategies was the concept of having a separate defensive and attacking sub-strategy that would switch depending on whether the ball was in the home or away section of the play area. This often resulted in most of the robots holding back if the goal was under attack, or most of the robots striking if the ball was in the opposing half. This not only led to a very indecisive appearance, but also left potential vulnerabilities:

- The constant switch of defenders to become attackers often resulted in many clashes and robots being delayed getting to their destination whilst they became “unstuck” from their fellow players.
- By using attacking robots in defensive roles, when the time comes to strike the robots are not ready to do so and need to waste time positioning.

It was this year’s goal to develop a new high-level strategy that wouldn’t resort to dramatic team switching based on whether the ball has crossed the half way line or not.

4.6.1.1 ATTACK

- The two primary attackers would remain so throughout and attack the ball when sufficiently outside of our penalty box. When not chasing the ball they will remain ready and angled in the correct direction, ready to strike at the first opportunity.
- These robots will not take any defensive roles at all. Whilst this could be seen as a potential weakness and a risky move, it is in fact one of the greatest successes. Games are won on the number of goals scored as opposed to simply defence. By allocating these robots away from the defence zone, not only does this prevent constant collisions due to overcrowding in the home area, but allows a much stronger offense when the time comes.

4.6.1.2 DEFENCE

- Two robots would be allocated to providing linear defence along key lines, the goal line and the top of the penalty box. These are the two locations that are critical to defend to prevent line of sight at the goal for the majority of the ball locations.
- These robots will only defend along the specified linear lines and not move under any circumstance.
- Some of the greatest vulnerabilities were caused in the past from goalkeepers/defenders moving away from their specified location to attempt to kick the ball and either: leave the goal exposed or kick it in to score an own goal.

4.6.1.3 BALL CLEARANCE/EXTRA DEFENCE.

- Since the attack and defence are fixed in their specified roles, it was required to use an additional robot to fill the void of ball clearance during defence as well as an additional kicker for offense.
- The role of this multitasker can be found explained in depth later in the report, however is critical to the success of the entire team. Since the defence robots are “locked” to their specified lines, the multitasker clears the ball, passes it to the offense and provides additional backup.

4.7 ROBOT FOOTBALL COMPETITION

At the beginning of the project contacts from previous Robot Football championships were contacted to determine if any championships were to be held in 2008, and if so, where. By the beginning of term 2 it became clear that much of the interest from universities that had previously participated in the competition had decreased, with Oxford, Plymouth and the Open University suspending their robot football research programmes.

Interest in participating in a competition was expressed by undergraduate students at Nottingham University. These students were researching the simulation side of robot football, however they were keen to test their strategy against other teams with physical robots. It was agreed that the championships would involve both a MiroSot competition and a SimuroSot competition, to allow both teams to exhibit their strategies on the most suitable platform. The expectation was that WMR would win the MiroSot competition and Nottingham the SimuroSot.

Additional interest was expressed by PhD students in the WMG, who had previously worked on the robot football project. These students formed a third team, termed *Warwick X*, who used a strategy developed by the 2006-2007 robot football project students. Thus the results of the competition could be used to determine the success of one of the project goals: to develop a MiroSot strategy able to beat the previous strategy.

The fourth competing team was represented by Khairul Zainol-Ariffin, a third-year engineering student at the University of Warwick. Khairul’s third-year project was to develop a new strategy for SimuroSot, and this would be the strategy entered into the competition.

It was agreed to once again host the competition at Warwick, since advantage could be taken of the extensive equipment and experience held at the WMG. The competition was scheduled for Saturday 8th March 2008, a date convenient to all teams. This date would allow the group to publish and analyse the results in the project report. Previous championships had taken place over a whole weekend; however it was agreed that due to a reduced number in participants the competition could be held in a day, dramatically reducing the costs of accommodation and food. The proposed schedule for the day is shown below.

Time	MiroSot	SimuroSot
10.00	Arrival and welcome coffee at Warwick Manufacturing Group	
10.30	WMR MiroSot test run	SimuroSot setup
11.00	Nottingham MiroSot test run	
11.30	**Team A vs Team B**	**Team C vs Team D**
12.00		
	Team B vs Team C	**Team D vs Team A**
12.30		
13.00	Lunch	
13.30		
14.00	**Team C vs Team D**	**Team A vs Team B**
14.40		
	Team D vs Team A	**Team B vs Team C**
15.00		
15.30	**Team A vs Team C**	**Team C vs Team D**
16.00		
	Team B vs Team D	**Team A vs Team C**
16.30		
17.00	Trophy presentations	

In preparing for the championships the guidelines given by FIRA were well regarded. This included allowing 1 hour per game, and giving each team 1 hour to set up their system at the start of the competition. It was decided to run the competition in league rather that knock-out format since only a few teams were competing, and the results from a league are more tolerant to anomalous results. In the case that two or more teams had equal points by the end of the competition, the winners were to be decided by a rematch between the two teams. In the case that this was a draw, the winners were to be decided by the following criteria:

Goal difference in all group matches.
Greatest number of goals scored in all group matches.
Greatest number of points obtained in the group matches between the teams concerned.

Goal difference resulting from the group matches between the teams concerned.
Greater number of goals scored in all group matches between the teams concerned.
A tossing of a coin by the organizers.

On the day of the competition the team from Nottingham could not execute their robot strategy on either the SimuroSot or MiroSot platforms. The reason given by the team was that their strategy files relied on '.dll' extension files for which they did not have access. Hence the team resigned from the competition.

This left just two teams in each of the two competitions; WMR and Warwick X in the MiroSot league, and WMR and Khairul in the SimuroSot league. The result of the first match of the MiroSot league was a draw with a score of 5-5, and hence a rematch was held. This match was won by WMR with a score of **?-?**. The SimuroSot league was won by WMR. Hence the winners of the competitions were as follows:

	MiroSot	SimuroSot
Champions	WMR	WMR
Runners-Up	Warwick X	Khairul Zainol-Ariffin

The competition was a successful event, due to the favourable results of the team. The competition was also attended, in total, by an estimated 50 spectators. It is hoped that this has given the project significant publicity, and will encourage sponsors to help with future generations of the project.

4.8 CONCLUSIONS

The past 20 weeks of development have produced a final strategy that, as the results indicate, excels above all those that have come before it.

The first number of weeks showed an initial steep learning curve of familiarisation, a fact that wasn't aided by previous years poor documentation of code and the pitch coordinate system. We hope that the work left by the current team will prove well documented and hope elevate some of the initial stress at the beginning of the project for future teams.

Taking forward our success in practice situations and test games, the team went on to win at the National Championships in both MiroSot and Simulation leagues, fulfilling our key objective we stipulated at the start of the year.

The team has made recommendations for future years working on this project, however following WMR's victory at the National Championships, the future of MiroSot development at Warwick needs to be carefully considered.

It is our belief that the hardware is at the top of its field and further development improving an excellent design would be a misuse of time and resources. As a result our main goal this year was to achieve the best strategy developed at Warwick that could win at the National Competition and therefore be the best in the country.

Having met this goal, it must be asked, what's next? The team has made recommendations if it is decided that this project has enough merit to continue for another year, however it is our opinion that, unless taken abroad to compete on a higher level, that this should be the last year of MiroSot development at Warwick.

MiroSot in the UK seems to be a contest that is ever more undersubscribed to, with fellow research institutes and universities moving onto more advanced projects that utilise new and exciting technologies. It is of the teams opinion that this should be the direction of WMR and that next years team focus entirely upon competing internationally at the Robot Rescue league.

It is WMR's thoughts that it would be a shame not to utilise the MiroSot technology as many years of funding and research have been invested in their designs. The robots could be linked into the Rescue Robot and be used as a test bed for technologies such as swarm control. The main robot could deploy such mobile devices and perhaps act as a platform for wireless repeaters to increase the range of the main unit.

If however MiroSot robot football is to continue in its current form, it is of our recommendation that significant focus is put on competing at an international level and play in the European Championships. Competition in the UK is sparse and the only significant future for MiroSot development as part of WMR is international. If this is the route chosen by future teams then a list of robot football recommendations follows overleaf.

4.9 MIROSOT RECOMMENDATIONS TO FUTURE TEAMS

4.9.1 HARDWARE

- Focus on maintenance and upkeep of the current series of Evo4 robots rather than constructing a new design. The current models are highly competitive and some of the best MiroSot designs in country.
- Investigate a more durable, matte surface that could be attached to the top of the Evo4's to act as the ID card. Be careful ordering materials until their reflection characteristics have been tested as may cause calibration issues.
- Investigate replacement wheel rubbers for the Evo4 designs. Maintenance of the robots is essential if they are to be used over the course of another academic year. It is highly likely that over this time span the tyres will need to be replaced. Previous reports have suggested investigating Table Tennis rubber as a possible replacement.
- While the batteries have been refreshed this year, there is still significant potential for increasing the capacity. The main limitation is the dimensions of the compartment they have to be located within. Whilst we had to settle for 350mAh capacity, it was noted that batteries up to 500mAh

could be found that fitted the specification. Unfortunately for this years team they were found to be out of stock in all locations.

4.9.2 STRATEGY

- Investigate more advanced methods of clearing the ball from the home half. At the moment, defence is very strong however the main weakness is that certain situations can cause the team to be vulnerable. This generally occurs as the main defenders are linearly moving along a fixed trajectory and the lone multitasker, assigned to clear the ball, is stuck. These situations the ball can be left dangerously close to our goal with no robot attempting clearance.
- Investigate the strengths and weaknesses of the “Robot in Control” expert system and see if it can be applied to future versions of the strategy. The decision making process was found to be highly successful within testing, however didn’t apply well when combined with the old attack algorithm. With further work the team believes this method of dynamic allocation could be highly successful.
- Implement collision detection to avoid hitting both friendly and opposition robots. This will ultimately try to prevent deadlocked situations.
- Test strategy development throughout the year as early as possible in real game scenarios. What performs well in testing may not perform as well in a game situation and may give away fowls. To this extent become proficient in the official FIRA rules document as early as possible.
- Take note that the simulator is not a substitute for playing a real match. To the same extent note that playing SimuroSot games based on MiroSot strategies won’t work exactly as intended either. Both areas require optimisation in different places. Learn the differences between the two environments so that they can be used to your advantage.

5.0 ROBOCUP RESCUE

5.1 INTRODUCTION

The RoboCup rescue competition is an international competition to build a robot that aims to encourage the development of robots that are capable of traversing terrain that simulates an earthquake-struck building and finding trapped victims. This task can be undertaken autonomously by the robot or by an operator driving tele-operated. Points are scored for locating and identifying victims (with additional multiplier effects if performed autonomously), traversing increasingly difficult terrain and producing a map of the arena which conforms to international standards.

This is the first year the WMR has entered this competition, the aims of competing this year is to double-check and finalise our requirements as well as ensuring that our development is on track, generating any recommendations for modification to the design that may be required. In addition, it is a good to chance to learn lessons from other teams at a point in the development cycle where scope exists for designs to be modified.

This competition has obvious (and not so obvious) real world applications, so during the course of development we will be using the competition to guide the design, but will also be trying to take into consideration any requirements that may assist in making the robot more appropriate for these alternative applications.

The next few sections give a brief overview of the work undertaken this year, for a lot more detail, please see the two technical reports entitled “RoboCup Rescue Hardware Section” and “RoboCup Rescue Software Section”.

5.2 REQUIREMENTS

Here are the requirements that have been captured for each part of the design.

5.2.1 VICTIM IDENTIFICATION REQUIREMENTS

- Simulated victims will be placed in cardboard boxes with at least three signs of life:
    - Human form and Heat, Sound, motion, and/or CO2
- Multi-level box stacks provide searchable voids that may contain victims at various heights (45cm/18in boxes, up to three levels high)
- "Void" victims will be contained in box stacks with open box faces and tops
- "Entombed" victims will be contained in boxes with 15cm holes requiring sensor placement directly in front of the holes to identify sensory targets inside (eye charts and/or hazmat labels inside count as "form" points)
    - Variable illumination near the camera is required victim identification

5.2.2 HARDWARE REQUIREMENTS

The relevant robot hardware requirements as specified by the competition are as follows:

- Capable of operating for 15 minutes in Preliminary rounds and 25 minutes in the Final rounds
- Negotiate through a random maze consisting of;
    - 1.2m wide hallways, defined by 1.2m square walls and corners
    - Non-flat flooring with increasing complexity, 10˚ and 15˚slopes
    - Stepfield pallets (Orange: half-cubic, Red: full-cubic)
    - Confined spaces (ceiling blocks under elevated floors)
    - Stairs (40°, 20cm riser, 25cm tread depth, 5 in total)
    - Ramp with carpet for traction (inclined at 45° to test torque and center of gravity)
    - 20cm step/pipe combination to challenge robots reliant on the sharpness of step edges for traction
    - Acoustic tiles used for soundproofing; generally made from sound absorbing foam
    - Reflective surfaces present in most buildings in the form of glass, plastics etc
    - Excessively dark light absorptive materials such as felt

5.2.3 SOFTWARE REQUIREMENTS

- Software must allow Tele-Operation of the robot
    - Must be capable of being controlled by a single operator
    - Must present sufficient sensory data to allow remote operation
    - Must supply as much information as possible (the more detailed information they supply, the more confident the incident commander will be)
    - Must provide a means of communication between operator station and robot
    - Must allow control of all actuators on the robot
- Software should produce a map (not a focus for this year)
    - Map must be in the GeoTiff map format
    - Map must indicate the locations of each victim
    - Must not have prior knowledge of the arena
- Software should allow autonomous operation in the simpler areas of the arena (not a focus for this year)
    - Should autonomously identify victims
    - Should be capable of navigating through uneven terrain
    - Does not need to be capable of navigating steep slopes, stairs or step fields

- Software should ensure the robot is under control (safe) at all times
- Software should be reliable enough to minimise the number of resets that are required during operation
- Software should be secure enough to only permit authorised persons to control the robot
- Sufficient documentation must be in place to permit future teams to expand, fix and maintain the software
- The software should be designed to aid future extension of its functionality

5.3 REMOTEC CHASSIS

Remotec is home of the leading Unmanned Vehicle for EOD, Security and Surveillance Sensing Applications. The roots of the Remotec UK story lie in the difficulties encountered by UKMoD EOD personnel addressing the terrorist threat dating back to the early 1970s[5]. The company was kind enough to donate a bomb disposal chassis. This allowed the team to work concurrently on both hardware and software aspects of development. Having this platform to work from, the team was able to develop sensor arrays, control and communication systems parallel to the design, production and assembly of the RoboCup Rescue search and rescue robot. This vastly reduced the lead time for completion of the robot.

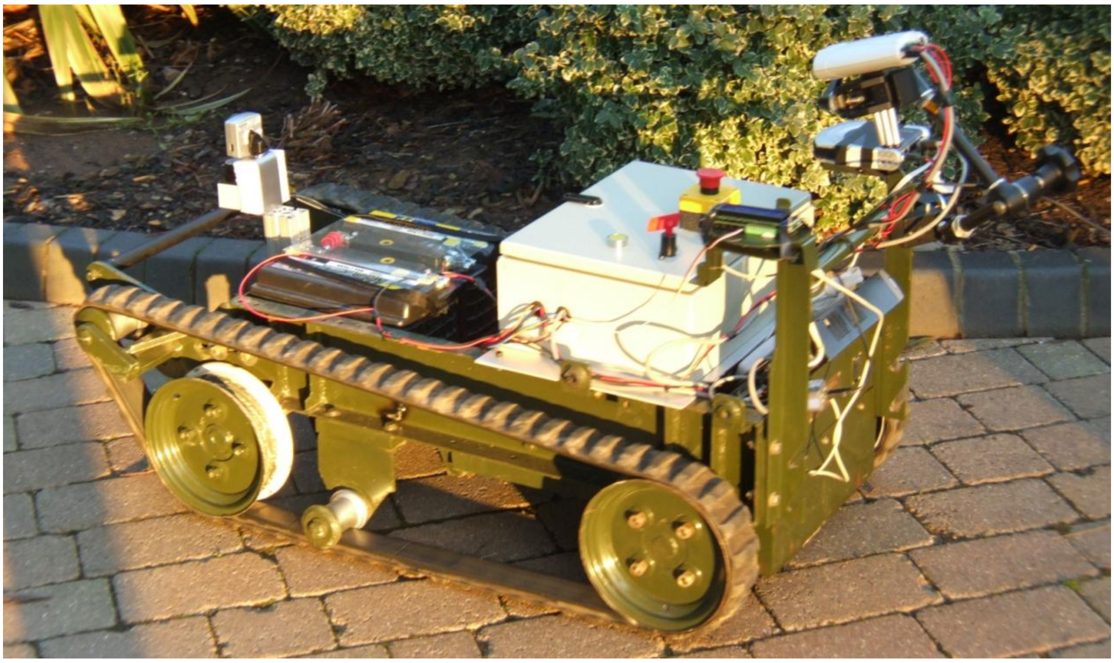

Figure 14 – Remotec bomb disposal chassis

The company has kept in contact with the team on a regular basis and expressed interest in both what the team has developed and the potential of a strategic partnership in the future.

5.4 SOFTWARE

The Software for this project has been developed using an agile methodology to allow to rapidly adapt to the changing circumstances that are inherent from the parallel development of the software and hardware. A robust server program has been produced which allows multiple remote clients to connect to the robot and control it or view information from its sensors. A client program has also been built to allow the optimum display of information to an operator. This software packages meets the large majority of requirements that were placed on it (see the "RoboCup Rescue: Software Technical Report" for further details).

The groundwork has been laid to allow autonomous navigation and mapping to be implemented in the future. A lot of this year's focus has been based on building a platform that is safe and robust that can be extended easily. This has been achieved with a platform being produced that allows different A.I.'s to be 'plugged in' to the software, in much the same way that different strategies can be run on the MiroSot system.

5.5 HARDWARE

The hardware has been developed using waterfall methodology reflected by the structure of the hardware technical report, beginning with initial concepts right through to the RoboCup Rescue competition. The main focus of the project this year was to develop a mechanical platform to support the sensor arrays required, to identify victims in the arena.

5.5.1 MECHANICAL

This year a fully working prototype robot chassis has been conceptualised, designed, manufactured and assembled. The final prototype design uses a differential drive, caterpillar tracked design to allow the robot to turn within its own length. One of the design targets was to make the chassis as small and compact as possible, this was achieved successfully by keeping the majority of components within the height of the tracks. The problem with such a compact design is how to navigate over tall obstacles, this was achieved using a pair of flipper arms pivoted around the front of the chassis which allows the robot to climb obstacles significantly taller than itself.

The competition requires ascending and descending of a 45° slope which requires a significant amount of power, this was met using custom wound DC motors with Neoyidium magnets to give a high power to weight ratio.

5.5.1 ELECTRONICS

5.5.1.1 OBJECTIVE ANALYSIS

The robot has a 24 V input from both a mains and battery supply, which is required to power all the components, sensors and motors on the robot. The alternatives were to either use wires to connect the outputs, or to use a main control PCB. It was decided that the PCB would be a better option. The principle reason for this was space, as PCB components are a lot smaller. Using a PCB also makes maintenance and repairs a lot easier as the components are all on one board. If the other option were used, having lots of wires everywhere would severely restrict access to components and make replacing them a lot more difficult.

The aims of the control circuit are to:

- Regulate the voltage input down to suitable output levels (18 V, 16 V, 12 V and 5 V)
- Provide a way of switching between mains and battery without losing power
- Provide both hardware and software safety features to stop the robot motors if necessary
- Provide a serial interface to communicate with the PC.
- Use LED indicators to show the system is functioning correctly
- Incorporate fuses to minimise damage to components, should a problem occur

5.5.1.2 SPECIFY NEEDS FROM REQUIREMENTS

It is important that all the electronics in the robot satisfy the requirements that were created in the planning stage of development. The relevant parts of the requirements document are displayed below; these were taken into consideration when designing the PCB:

> *A mobile robot will fall under the category portable equipment taken off site. This means that approval must be given for each occasion on which the robot is to be taken off site, and will require a visual inspection (for mechanical parts) and electrical inspection on each occasion.* ***Hence the robot must be easy to visually and electrically test***

As a result of the above requirement, a number of indicator LEDs were incorporated into the main PCB. These switch on when the robot is powered up and running normally without faults. The LEDs are placed at strategic points, such as at fuses, at the switching regulators, and at the MOSFETS. When an LED switches off, its location makes it very easy to tell which part of the circuit contains a fault. This enables a quick visual inspection of the electronics to be carried out, thus satisfying the requirement.

> *No rules on the safety of robots could be found on the Robocup Rescue website[6]. There are, however, 'bumping penalties' if the robot causes damage to the arena through a collision.* ***Hence it is a good idea for the robot to have an emergency failsafe brake when in close proximity to a wall***

The PCB design contains a "heartbeat PIC", which is a microcontroller capable of switching off power to the robot motors. The onboard computer is programmed to send a signal to the PIC every 500ms. As a failsafe, the PIC shuts the motors off if it does not receive this signal, which means the robot stops moving if communication with the PC is lost. This can also be linked to the output from the Ladar and sonar sensors so that the PC sends a signal to make the PIC stop the robot moving if it is in close proximity to a wall. This failsafe braking system satisfies the requirement above.

5.5.2 SENSORS

The sensors are a key requirement to the whole chassis as they provide the feedback from the hardware platform to the operator and AI layer. The competition requires a minimum of 3 signs of life to confirm a victim's health status. Thus several video cameras were included in the array to determine form and motion as well as a Thermal Imaging Camera capable of detecting body heat.

To allow the sensor array to be positioned in line with the victims position, which may be hidden within box which only has a 6 " visible opening, it is attached to a 4 axis robot arm. The robot arm is discussed in detail in the mechanical section but forms the basis for the mounting of the victim identification sensors.

Additionally a laser scanner and multiple sonar ranging sensors are positioned around the chassis to allow the operator and AI layer to localise the robot within the terrain. This map type data is much faster to process autonomously as each piece of data is a discrete distance.

5.6 CONCLUSIONS

This year's efforts have produced a good outcome in terms of the overall system. The rate of progress has been astounding, impressing most visitors that we have engaged with, both in our lab and at the competition at Hannover in April 2008. A lot of the feedback that we have received about our design is that it appears very strong for real world application and not just designed for the competition (we have been invited to try it at the National Fire Training Center, Moreton-on-the-Marsh). Our competition entry confirms the mobility advantages of our design, being the only team to get to the toughest-to-reach point in the arena. A strong chassis had been designed and produced, multiple sensors have been researched, purchased and integrated into the chassis design and a suite of robot software has been produced allowing for remote control and sensory feedback from the robot.

This venture has had a very successful start, helping to support the WMR project business plan. It has also generated a lot of interest from various visitors interested in it's real-world applications, ranging from bomb-disposal, search and rescue in hazardous environments to potential use on the railway lines to drive along the edge of the track finding faults. The documentation, road map and recommendations that have been produced this year should enable future teams to take this venture to success.

5.7 RECOMMENDATIONS

As a result of competing in the competition for the first time this year and due to the infantile nature of this new project, there are a lot of suggestions for improvements that can be made to the various aspects of the robot's design. These recommendations are detailed in full in the two technical reports; however here is a selection of the more pertinent ones:

- It would be beneficial to monitor the signal strength, bandwidth and latency properties of the communications channel; these can be displayed in the client window to alert the operator to any potential problems with the communications.

- A major issue experienced in the competition was not the ability to see the terrain to the front of the robot, but to try and work out what configuration the robot was in. This problem had been foreseen and lots of sensors are in place, such as the Inertial Measurement Unit (IMU), that will provide sufficient data for this purpose. The initial concept was to create a 3D model of the robot to display the position of the flippers and the arm and use the IMU data to tilt it to give the operator feedback, the compass heading could also be displayed. Implementing this would be a great help to the operator.

6.0 CONCLUSIONS AND FUTURE DEVELOPMENT

6.1 ROADMAP

A provisional schedule has been laid out for major development milestones for the next three years. The roadmap sets out, within a three year timeframe the required development that would be adequate to compete with the best teams in Europe. Future teams may however decide to take the project in another direction, perhaps entering a different tournament. This may require focus to be put on different areas.

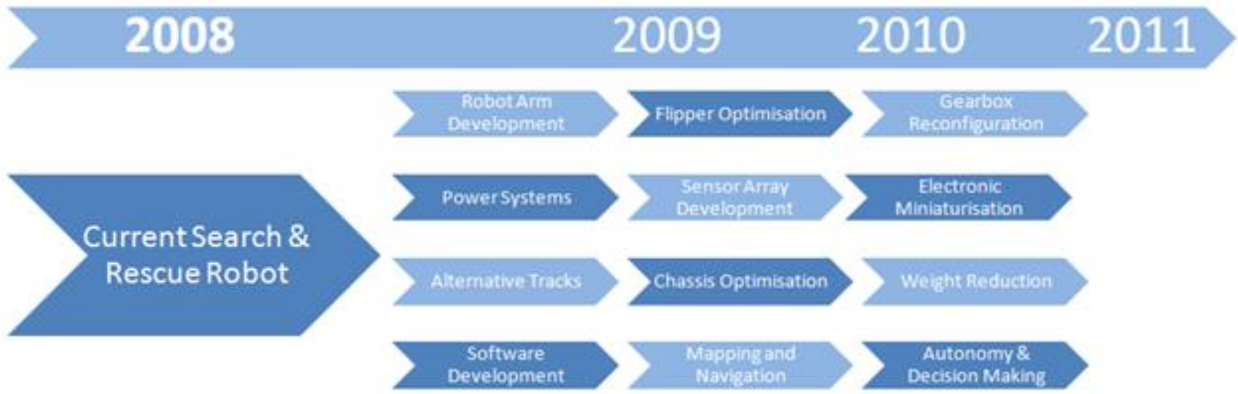

Figure 15 – Future road map for development

6.1.1 MAPPING

This academic year the focus of WMR has been on creating a tele-operated robot capable of international competition. Despite this, future expandability has been considered at every stage of the design process. For this project to successfully continue in subsequent years, teams will have to pay significant consideration on creating a versatile mapping solution.

For the rescue robot to exhibit true autonomy and fulfill some of the more advanced goals of the competition, it must be able to localise its position, retrace its steps and produce a detailed map of its environment including the locations of any survivors.

This is a highly advanced topic; no one single solution exists to solve this challenge. Future teams will have to investigate mathematical studies, cutting edge research as well as the efforts of the WIMRC work in this field.

The current team has investigated the area and selected some topics that would prove advantageous as a starting point for future teams.

6.1.2 SLAM

SLAM is an acronym for *Simultaneous Localisation and Mapping.* Localisation involves identifying one's position within a known mapped environment. Using data from various sensory devices, landmarks can be identified and compared to the environment in the provided map.

Mapping involves building a map of the unknown local environment using data from various noisy sensory devices.

The theory behind SLAM combines these two disciplines and involves creating a map of an unknown environment whilst simultaneously keeping track of the current position within that environment. Many consider the solution of this problem the pre-requisite for “true autonomy”.

SLAM uses probabilistic techniques to tackle the problem of noisy signals generated from real world data sensing units. A combination of active, passive, relative and absolute sensors work alongside each other and the outputs are processed together. SLAM can utilise various different methods to process this information, one of which can involve a Kalman filter. The goal is to provide an estimation of the current location state in a dynamic environment from a sequence of noisy data.

This is a highly advanced topic, with significant research being conducted worldwide. One of the more reported examples of SLAM in action is in the annual DARPA challenge competitions. The theory underpins the cars navigation systems, allowing them to map, localise and traverse a course in real time, solely based on the inputs from the on-board sensors.

SLAM is essentially the overall concept that future teams should be striving to implement over the next number of years.

Since this is quite a wide field, some starting point suggestions include researching Hausdorff distance and image correlation.

6.2 INTERDEPARTMENTAL LINKS

Throughout the course of the project the team has received support from Sadiq Jaffer, a PhD student at the WMG and former member of robot football. He has drafted a proposal to the Department of Computer Science to effectively outsource/collaborate over the software development at WMR. These links will bring additional expertise to fields such as autonomous mapping and control. This should hopefully improve both the speed and quality of research towards a competitive search and rescue robot. The proposal can be found in **Appendix 11**.

6.3 POTENTIAL FOR THIRD YEAR PROJECTS

In addition to links with other departments, WMR have proposed a number of smaller aspects of development that have the potential to be structured as a third year engineering project. For example, the robot arm, kinematics and control system is a self contained aspect of the search and rescue robot. The project would be defined by requirements of WMR, dictating budget, power supply, physical size and capabilities etc. It would provide an excellent challenge to a capable student and would be a good introduction to joining the fourth year team.

7.0 APPENDIX 1

Warwick Mobile Robotics

2007/08 Contact List

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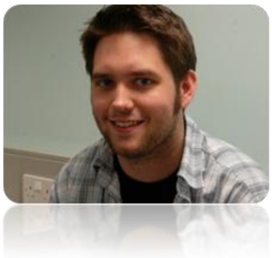

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8.0 APPENDIX 2

Prospective Projects Analysis

Scaled 1-5 (Lowest Total - Most Feasible)

	Darpa URBAN Challenge	ESCO-UAS	Trinity Fire Fighting	MoD Grand Challenge	MiroSot - UK Continuation	RoboSot	RoboCup Rescue	ELROB
Deadline:	5	2	1	5	1	3	1	1
Application Date Event Date	25 May 2007 03 November 2007	31 October 2007 June/July 2007 - TBA	24 March 2008 12 April 2008	Submit Proposals: 15 May 2007 July 2008 - TBA	TBA TBA	TBA 22-25 July 2008	01 January 2008 Open	01 December 2008 30 June - 3 July 2008
Funding:	5	2	2	4	1	3	2	4
Ability to obtain estimated required funds	$2 Million minimum. Insurmountable	Raised similar funds previously. Likely to raise 100% of required fund	Sponsored by IEEE, better opportunities. Possibly Chubb?	Difficult for individual company. Fraction of total funds available compared to total cost needed. In excess of £100,000 required	Approximately £10,000 available from summed University funding. Plus private sponsors	Greater potential, since International exposure. Not of great use for UK based companies	Larger amount than MiroSot required. Commercially attractive though sponsor perseverance needed	Fairly Open
Regulation Feasibility:	5	3	1	3	1	4	2	2
Ability to adhere to rules of competition	Impossible since highway code. Incredibly challenging	Problems could emerge when reducing kit parts to 30% by mass	None. E.g. No regulation on weight, materials & team size	Flexible, but has to be usable. Few regulations	Perfectly feasible. Accomplished previously to the 2007/08 team	20cm x 20cm (No height regulations) More constraint	Feasible, but posses challenges	Feasible. Flexible regulations. E.g. maximum weight - 3 tons.
Location:	5	1	4	1	1	3	2	3
Accessibility of competition location	Victorville, California, U.S.	Parc Aberporth, West Wales	Connecticut, U.S.	Copehill Down, Wiltshire, UK	University of Warwick (last year)	Qingdao, China	Global	Hammelburg, Germany
Expense:	5	3	2	4	1	4	3	4
Estimated expenditure for total project	Full scale car required. Drive by wire car	Limited to €15,000	Initial assessment revealed lower associated costs. Cheaper than Aircraft	Miniaturisation difficult	Within budget. In the region of £2,000 for a new set from scratch	Estimated at £8,000 per robot	Expenses directly linked to functionality. E.g. sensors, thermal imaging equipment	Multiple sensors and vision needed. Costly
Eligibility:	5	1	1	2	1	1	1	2
Teams suitability to enter the competition	U.S. entrants only	Eligible	Eligible	Eligibility is a barrier to entry	Eligible	Eligible	Eligible	European leadership only, so eligible

Motivation:	4	3	2	3	2	3	1	3
Consensus of team's enthusiasm	Too big, unobtainable goals	Feasible but challenges didn't appear too inspiring	Goals within reach. Practical applications	Much more experienced team competition	High probability of winning for the first time	Only 4 teams in competition. International	Practical uses, multi-disciplinary requirements matched. Good team sentiment	Well organised competition event. MoD preferable over German MoD
Viability:	5	4	2	4	1	4	2	4
General applicability of competition	Not practical for the team to enter	UAV (Unmanned Arial Vehicle). Vision and intelligence complex	Physically smaller	Not particularly viable	Viable. Achieved before	1-3 Robots. 2.6m x 2.2m pitch	Viable, but completion not possible within one year	Not viable
Technology:	5	3	3	4	1	4	3	5
Relative level of technical requirements	Forefront of hardware and software technology	Flying expertise in team	Current Technology. Ground better than flight. Plan view from air view difficult	Most of MoD sponsored teams offer UAV advanced technology	Within budget. Current Technology	Fully Independent/ Autonomous Robots. Motoring methods self-contained. No global vision system allowed	Using current technology. Limited only by budget and team capability	Mobility and RSTA (Reconnaissance, Surveillance and Target Acquisition)
Future:	1	2	1	2	4	2	1	2
Long-term scope of project for other teams	Once initially developed, multiple areas of research. Predicted a substantial future area of research	New competition - will probably expand in future years. E.g. new scenarios and missions	Great expandable potential for future undergraduate students.	Long-term competition, constant development possible. Plenty of scope	Extensive development limited. Mainly software engineering. Less mechanical development	Continual development possible. Plenty of complex areas to re-engineer	Open-ended, continual development encouraged. Multi-tiered tournament allowing for challenging competition	Long-term competition, constant development possible. Plenty of scope
Time Scale:	5	2	2	4	1	4	2	4
Estimated required time for completion	Minimum of 3 years for the project	Between 1-2 years	For entry next year. Working model obtainable by the end of current year	Large project. Smaller progressive goals needed	Within 1 year	Goals limited to 1 robot due to funding, but achievable within 1 year	Approximately more than 1 year	Between 1-2 years
TOTAL	**50**	**26**	**21**	**36**	**15**	**35**	**20**	**34**

Wednesday 10 October 2007

Green denotes the selected competitions for SWOT analysis

9.0 APPENDIX 3

Prospective Projects: Full SWOT Analysis

MiroSot Competition	
Strengths	**Opportunities**
· Existing resources in place: · Hardware, Software, Sponsorship · Achievable timeframe · Current testing facilities adequate · Knowledge base and recommendations from previous years · Other Universities taking part · Competitive environment · PR – exciting to watch · UK-based	· High probability of victory · Potential for Europe/world cups · Chance for greater/renewed sponsorship · Time to spend developing a better strategy · Only fine tuning of hardware needed · Completion of recommendations from last year possible
Weaknesses	**Threats**
· Not much of a challenge · Mostly software based work · Not enough scope for whole team to prove themselves · Not a whole years work – mostly completed · Lack of competition – less drive · No real practical application	· Threat of new emerging teams · Lack of teams – no competition · Unequal competition · Loss of sponsor interest · Termination of league · Poor use of budget and resources

ESCO-UAS	
Strengths	**Opportunities**
· High level of interest within team · Design for Universities within UK · High media exposure · Progressive technology involved · Multi-disciplinary project · Variable goals · Team members have flying experience · Budget limited to €15,000	· Real life applications · Attractive cash price · Recognition and exposure for University · Diverse sponsorship opportunities · Open-ended project · Visually impressive · Possibility of integration with other challenges
Weaknesses	**Threats**
· Flying prohibited on-campus · Avionics complicated · High damage risks and expenses · 30% kit-build only	· Health and safety regulations prohibitive · Future of competition uncertain · Knowledge-base incomplete

RoboCup: Rescue	
Strengths	**Opportunities**
· High level of interest within team · High media exposure, international recognition · Multi-disciplinary project · Inclusion of progressive technology possible · Scope for extension of project · Draws on MiroSot knowledge-base · European arenas situated in Germany	· Attractive cash price · Large scope for real-life applications · Good PR for University · Attractive for commercial developers · Possibilities of attracting International sponsors
Weaknesses	**Threats**
· Lengthy qualifying process · Two year development phase · Much higher difficulty than MiroSot · Construction of testing facilities required	· Demanding goals · High levels of competition · Completion dependent on next team's enthusiasm

Trinity Fire Fighting	
Strengths	**Opportunities**
· Real world applications · Held in association with IEEE · Uses emerging technology · Team interest present · Obtainable goals · Tiered competition · Existing laboratory facilities adequate · High level of progress possible in a year · Multi-disciplinary project	· International recognition and exposure for University · Attractive for commercial developers · Long term project potential and expandability · Attractive cash price · Develop future technology for Warwick · Knowledge-base transferable
Weaknesses	**Threats**
· High travel and accommodation expenses · Complex scoring method, difficulty judging competition · Construction of testing facilities required	· Risk of fire hazard · Knowledge-base incomplete · Sponsorship appeal unknown · Timescale uncertain, may miss competition

10.0 APPENDIX 4

Previous RoboCup Rescue Entrants Analysis Scale 1 - 5 (1 = optimal, 5 = undesirable)									
	Nationality	**Members**	**Autonomy**	**Locomotion**	**Communications**	**Mapping**	**Sensors**	**Cost**	**Total Points**
Keystone	N/A	N/A	1	5	5	3	3	3	**20**
	Canadian	Five full time members	Fully autonomous	Two-wheeled - poor design	None	2D occupancy grid	Visual CMOS camera and blob detection	Undisclosed	
Mantes Explorer	N/A	N/A	5	4	3	5	2	2	**21**
	French	Seven full time members	Two human operators	Basic four wheel system	Wireless LAN	None	Accelerometer, ultrasonic and infrared proximity, microphone and passive IR	£4,000	
IUB	N/A	N/A	2	3	3	2	2	5	**17**
	German	Seven full time members	Semi-autonomic parent robots, fully autonomous drones	Various wheeled	Glass fibre cable network, RF LAN backup	Probabilistic occupancy grid	Digital compass, thermal camera, CO2 detection and microphone	£34,900	
Kurt 3D	N/A	N/A	4	3	3	1	3	5	**19**
	German	Seven full time members	User operator - has potential for autonomy	Four wheel indoor and outdoor configuration	Wireless LAN	6D SLAM	3D laser scanning and video	£20,242	

BAM	N/A	N/A	5	2	2	2	3	4	**18**
	Iranian	Six full time members	User operated	Four wheel track system	Wireless LAN and RF	Odometry and GPS	Sonar, CO2 detection, thermometer, microphones and motion detectors	£7,238	
Resquake	N/A	N/A	5	2	3	5	3	1	**19**
	Iranian	Eight full time membes	User operated	Double tracked system	Wireless LAN	Proposed sonar system - currently user generated	Wireless camera with LED lighting array and thermal detector	£1,191	
Alcor	N/A	N/A	3	3	3	3	2	3	**17**
	Italian	Four full time members	Semi-autonomous	Two-wheeled differential drive	Wireless LAN	Automatic - unspecified	Eight sonar range detectors and a camera	£5,950	
SPQR	N/A	N/A	3	3	3	1	1	3	**14**
	Italian	Seven full time members	Semi-autonomous	Two-wheeled system	Wireless LAN	Fully passive and autonomous	Stereo video system, laser and IR range finders, ultrasonics, gas sensor, CO2 detection and microphone	£12,000	
NuTech	N/A	N/A	5	1	4	5	2	1	**18**
	Japanese	Seven full time members	User operated	Multiple tracked system	Tethered connection to laptop	Manually inputted	Laser range finder, camera, tilt sensor and thermometer	£2,000	
Shinobi	N/A	N/A	5	2	2	5	3	5	**22**
	Japanese	Eight full time members	User operated	Various systems including tracked snake, wheeled and treaded	Wireless and RF	Manually inputted	CCD Cameras, laser range finder, microphone and thermal sensors	£33,300	

ToinPelican	N/A	N/A	1	1	2	1	1	3	**9**
	Japanese	Four full time members	Autonomous	Triple tracked system	Wireless and Ethernet cable	SLAM and DEM (digital elevation mapping)	Laser ranger finder, rotary encoder, gyro, inclination sensors, stereophonic vision, thermal detections, microphone and CO2 detection	Undisclosed	
UMRS-V	N/A	N/A	3	2	2	2	1	3	**13**
	Japanese	Seven full time members	Semi-autonomous	Double tracked system	Wireless LAN and ad-hoc	IR range finder with panoramic head	Video camera, encoder, gyroscope, acceleration and geometric sensors, pyroelectric IR and CO2 detection	£6,979	
RFC Uppsala	N/A	N/A	1	4	2	3	1	3	**14**
	Swedish	Fifteen full time members	Fully autonomous	Three wheeled system	Wireless LAN and ad-hoc	DEM	Ultrasonic range finders, IR range finders, pyroelectric sensor, directional microphone and webcam	3 x £1950	
Scarabs	N/A	N/A	5	1	4	5	3	2	**20**
	American	Thirteen full time members	User operated	Invertible track	150ft umbilical Ethernet and power	Manually inputted	Modular, camera and passive IR	£2,500	
TOTAL									

11.0 APPENDIX 5

Specifications Research

The Traction System

From studying the requirements and the analysis of previous competition entrants it is apparent that there are two plausible methods of locomotion for a robot to navigate the specified terrain. The first and easiest to implement would be a wheeled system, however wheeled systems have proven to have stability issues when traversing more challenging terrain, such as stairs and the full cubic stepfields present in the red arena. Furthermore manipulation of a wheeled system to manoeuvre stairs would require actuated armatures, raising both the mechanical complexity and the total system expense. This precludes the further investigation of any wheeled systems, at this point.

Alternatively one of the most popular and successful methods of locomotion is the use of a tracked system. It not only provides greater traction (through an increased surface area) than a wheeled system but simplifies the mechanical requirements of climbing over various obstacles. Additionally terrain displacement is kept to a minimum by the greater weight distribution which may be critical in conditions where terrain is unstable and possibilities of further collapse.

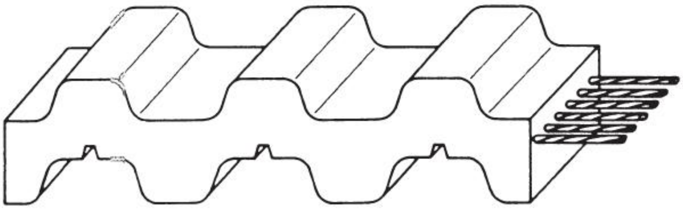
<u>Tracked system options:</u>

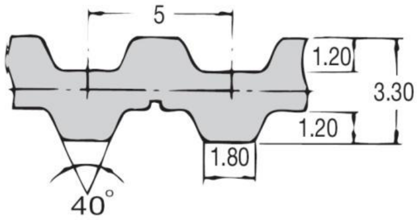
In-house manufacture		**Prefabricated track purchase**		**Timing belt**	
Positive	Negative	Positive	Negative	Positive	Negative
Flexibility to customise design allowing exact specification of: - dimensions - tread pattern - grip - material	Expensive	Shorter lead time	Limited width, tread and linkage options	Cheap	Pre-specified width options (in inches)
	Time consumptive	Design from existing knowledge base	Expensive	Widely available	Assembly will require gluing, comprising structural integrity
	Unique parts make servicing difficult	Customisable track length	Lead time for spare parts	Designed for traction and durability	
	Shifts priority from other manufacturing requirements i.e. chassis		Design will have to conform to track specification	Wide range of track options	
				Single piece part means low maintenance	
				Wide range of materials available	

Having considered the various advantages and draw backs of the available options it is evident that the use of timing belts would be most beneficial when considering the flexibility of design they offer in terms of price and ease of implementation. Furthermore, the short lead time associated with timing belts allows a grace period before deciding to implement other options, if the requirements cannot be met.

Timing belt options:

Commonly, timing belts are manufactured from the three materials; Neoprene Fibreglass Kevlar, Pitch Urethane Polyester or Urethane with Steel cord tension members. There are also multiple configurations; single sided, double sided and double sided alternately spaced. Additionally there are different teeth profiles, such as rounded, rhomboid etc. Each teeth profile provides varying traction abilities.





Pricing

For a 5mm pitch, double sided timing belt with steel cord tension members that has minimal stretch and is oil resistant average prices can be seen in the table below. Source: HPC Gears.

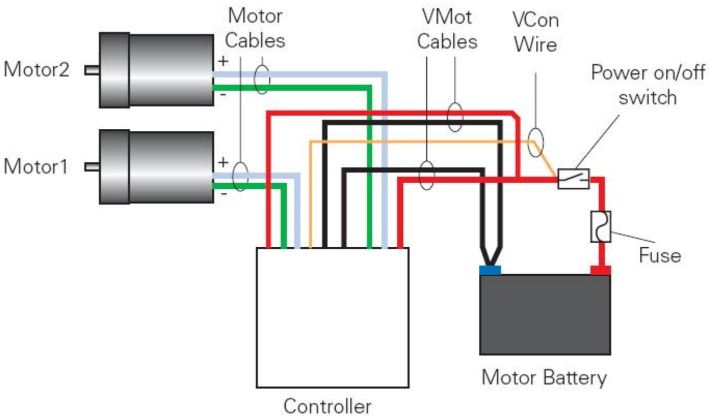
PITCH LENGTH	No. of TEETH	PRICE EACH 1-5								
		6mm	8mm	10mm	12mm	16mm	20mm	25mm	32mm	50mm
300	60	£5.72	£7.32	£8.93	£10.52	£13.72	£16.95	£20.97	£26.58	£40.99
350	70	£5.80	£7.45	£9.01	£10.75	£25.63	£17.30	£21.72	£27.15	£41.94
400	80	£5.95	£7.49	£9.29	£11.00	£14.34	£17.72	£21.88	£27.75	£42.88
410	82	£6.12	£7.94	£9.92	£12.43	£16.70	£19.91	£24.89	£35.02	£52.41
460	92	£7.24	£9.38	£11.72	£14.67	£19.72	£23.52	£29.38	£41.28	£61.85
480	96	£7.54	£9.76	£12.19	£15.24	£20.47	£24.38	£30.55	£42.95	£64.29
500	100	£7.68	£9.94	£12.45	£15.58	£20.90	£24.94	£31.18	£43.80	£65.66
515	103	£7.72	£10.54	£12.52	£15.68	£21.05	£25.13	£32.36	£44.09	£66.04
550	110	£8.00	£10.75	£13.02	£16.25	£21.88	£26.12	£32.65	£45.85	£68.37
590	118	£8.35	£10.83	£13.49	£16.91	£22.72	£27.11	£33.90	£47.59	£71.30
600	120	£9.00	£12.08	£14.17	£17.64	£23.94	£29.48	£35.19	£49.13	£73.86
620	124	£9.02	£12.22	£14.59	£18.21	£24.53	£29.61	£36.58	£51.33	£76.89
650	130	£9.13	£12.37	£14.74	£18.42	£24.81	£29.77	£36.99	£51.88	£77.74
700	140	£9.21	£12.54	£14.91	£19.12	£24.98	£29.87	£37.33	£52.41	£78.49
750	150	£9.29	£12.80	£15.07	£19.47	£25.28	£30.18	£37.73	£52.96	£79.35
800	160	£12.01	£15.63	£19.40	£24.28	£32.62	£38.90	£48.63	£68.29	£102.27
815	163	£12.23	£15.92	£19.76	£24.71	£33.23	£39.67	£49.52	£69.56	£104.18
850	170	£12.51	£16.21	£21.10	£26.47	£35.45	£42.79	£53.11	£70.69	£104.97
860	172	£12.56	£16.95	£21.22	£26.53	£35.64	£44.03	£53.35	£71.39	£106.98
900	180	£13.15	£17.64	£21.29	£26.63	£35.78	£44.93	£55.78	£74.91	£112.20
940	188	£13.70	£18.32	£22.16	£29.14	£37.24	£45.51	£58.25	£77.94	£116.62
1030	206	£14.74	£18.92	£23.58	£29.57	£38.26	£45.79	£58.88	£79.41	£117.22
1100	220	£14.99	£19.40	£24.26	£30.31	£38.68	£46.14	£60.71	£81.00	£127.27

It is also possible to have timing belts fully custom sized and profiled, one such company that offers this service is Gates Mectrol who specialise in timing belts and conveyors. Although this maybe an idea solution, price must be negotiated to make it a viable option. A solution could be to order a customised length, but to a generic profile. The main problem is that manufacturers generally deal with large volume runs and may not be interested in a one of, low profit job order. Initial designs suggest a main track width of 80mm with the flipper tracks width of 60mm.

Electronic Speed Controllers

The rescue nature of the competition dictates that there are heavy penalties incurred for failing to navigate the course without collisions with the victims and certain parts of the terrain. From this it is obvious that a robot competing must be able to manoeuvre itself smoothly, requiring the drive motor's speed and acceleration to be regulated. This can be achieved through the implementation of Electronic Speed Controllers used in conjunction with the motors. There are various configurations of ESC's for the different types of motors, including brushless, brushed, stepper etc.

One of the options available is to manufacture in-house the required ESC's. This would allow the team to tailor the properties of the controller to meet the exact requirements of the motors used. Acquiring and assembling the required components could prove to be a much more economic course of action than procuring existing ESC configurations, on the market. When considering the complexity involved in designing, fabricating and testing needed to approve the controllers, it becomes a far more logical option to purchase controllers that are readily available on the market.



<u>Options</u>

RoboteQ AX500 Dual Channel Digital Motor Controller - £126.90

- 2 x 15A Brushed DC Motor Controller
- Fully digital microcontroller-based design
- Multiple command modes
- Automatic joystick command corrections
- Max 100mA idle consumption
- Data logging capabilities

The AX500 is ideal for R/C radio, analogue joystick, W-LAN or microcomputer control of up to two high voltage, high current DC motors.

RoboteQ AX1500 Intelligent Digital Motor Controller (Dual Channel) - £261.10

The AX1500 has similar properties as the AX500, but with some additional features including an open or closed feedback loop and further safety precautions. These precautions ensure the secure power-on start, automatic stop and protection against overheating. Both speed controllers come with a fully programmable PC utility and allow configurations to be stored on the non-volatile memory.

Power Source

The power source of the robot is one of the most crucial components to the performance. One of the most popular methods of power systems used by previous entrants has been the use of a cable tether. This has the additional benefit of providing reliable, direct control of the robot and lower risk due to ratio interference. However, as the robot is intended to be used for autonomous operations, the control system becomes redundant. Furthermore, a tether greatly inhibits the range and some of the manoeuvrability of the robot. Moreover a tether implies there must be a user and a fixed power point available in an emergency situation which may not be obtainable or practical. For this reason a tethered system will not be initially implemented. However, the required hardware is easily installed and is a consideration for a later date, especially with regards to testing.

The alternative option is to use an onboard power source, such as batteries.

<u>Critical Features</u>

Weight - the robot is being designed with a maximum weight restriction in mind considering it will have to be carried by emergency personnel in critical situations, therefore making portability of paramount importance. In terms of manoeuvrability and balance of the robot, the centre of mass requires to be positioned at the front end of the chassis. Therefore the placement of the batteries (of which can be a considerable proportion of the total unit weight) becomes an issue.

Energy Density - the relative energy stored within a given battery per unit mass is directly linked to performance criteria such as power to weight ratios and the general efficiency of the robots locomotion.

Price - working on a budget limits some of the possibilities that can be considered as some battery configurations can quickly become very expensive considering spares and redundancy maybe required.

Charge Speed - Taking into account that the team intends eventually to participate in the RoboCup: Rescue competition, it may be required that the robot competes several times in a single event. If spare batteries are not a viable option then the charge speed must be kept within a maximum of 30 minutes.

Battery life - In terms of servicing the robot it must be appreciated that the battery performance will run down over time. When considering the expense of some of the battery systems available, it is a requirement that the team encounter no performance issues within at least one year.

<u>Further Concerns</u>

Another point of importance is the implementation of separate power systems for the mechanics and electronics.
There are three main reasons why:
- Interference and noise between electronic and mechanical systems.
- Variable consumption from different components
- Charging patterns

Battery Profiles

	Lead Acid 	Nickel Metal Hydride 	Lithium Polymer 
Battery	Sealed gel lead acid battery	Uniross RB D cell	Exceed RC Fusion 22.2V
Weight	2.7 kg each, total 5.4 kg	0.154kg, total 3.08kg	0.3kg, total 1.8kg
Energy Density	180 W/kg	250 - 1000 W/kg	Up to 2800W/kg
Size	150 x 97 x 95mm	Standard D-cells + housing	150 x 40 x 50mm
Price	£25	£6 per cell, total £120	£55 per cell, total £330
Advantages	• Reliable • Robust • Tolerant to overcharging • Low internal impedance • High currents deliverable • Indefinite shelf life minus electrolyte • Can be float charged • Widely available • World's most recycled product	• Less prone memory loss • Lower exercise cycle requirements • More 'environmentally friendly' • Standard cell configuration	• Low self discharge • Low maintenance • Can provide high current • Light weight • High energy density • No prolonged priming • Higher capacities • Low profile • Flexible form • Resistant to overcharge
Disadvantages	• Bulky • Low charge efficiency • Danger of overheating • Slow charge • Limited life cycle • Must be kept charged after an electrolyte has been introduced	• Limited service life • Limited discharge current • Complex charge algorithm • High self-discharge • Low performance at high temperatures • High maintenance	• Requires protective safety circuits • Require cool storage • Subject to ageing • Legislative transport restrictions • Expensive to manufacture • Developing product • Limited standard sizes

Communication System

The Requirement

Communications methods must have a bandwidth capable of delivering the relevant information from the robot to the operator

Robots must be able to cope with RF interference

- Poses a threat to most wireless control mechanisms
- The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit. The source may be any object, artificial or natural, that carries rapidly changing electrical currents.
- Any digital radio systems, such as Wi-Fi, error-correction techniques can be used. Spread-spectrum and frequency-hopping techniques can be used with both analogue and digital signalling to improve resistance to interference. A highly directional receiver such as a parabolic antenna, or a diversity receiver, can be used to select one signal in space to the exclusion of others.

Robots can plant transmitters in an arena (but not by hand) to aid victim identification and positional data

The rules do not state that hardwired backup communications is needed

Solutions

None (download all information when robot is recovered at end of mission)

Advantages:

- Don't need to worry about communication problems
- Bandwidth not an issue
- Interference not an issue
- Low cost

Disadvantages:

- No information received until robot returns
- No knowledge of where robot is / what it is doing

Wired Ethernet Cable

Advantages:

- High speed (10Mbps)
- Works over long distance (up to 2.5km)
- Easy to integrate
- Reliable
- Low cost
- Not affected by RF interference
- A second wired cable could be used for power source to robot

Disadvantages:

- Could get caught on debris when feeding out behind the robot, causing it to have movement problems
- If any part of the cable breaks, all communications will be lost

***Wireless Communication* (802.11A)**

Advantages:

- No cables to worry about
- Fairly high bandwidth (83.5MHz; not as high as cabled)

Disadvantages:

- Susceptible to RF interference
- Relatively expensive; requires router

Both Wireless and Wired

Advantages:

- Failsafe
- There is a backup if one fails

Disadvantages:

- More costly

Options

Condition	None	Wired	Wireless	Both
Ease of communication	No communication until end of mission; 0	Very easy to transfer data over LAN; 4	Requires setting up a router and wireless network; 3	Requires integration of wireless and wired setup; 2
Bandwidth	Bandwidth not an issue; 5	100Mbps; 4	83.5MHz; 3	up to 100Mbps; 4
Resilience to Interference	Interference not an issue; 5	Only interference is if cable gets caught; 3	very susceptible to RF interference; 2	Very resilient; backup present if one fails; 4
Distance	Infinite; 5	2500m; 4	Approx. 30m before significant reduction in bandwidth; 3	Up to 2500m; 4
Reliability	Highly unreliable, state and condition of robot is unknown until it reappears; 0	Very reliable; 4	signal easily blocked by walls / interference; 2	Backup present so very reliable; 5
Cost	Very cheap; 5	Cheap; 4	Moderate; 3	Most expensive option; 2
Total Score	20	23	16	21

Solution with highest score (more desirable) = Wired

Mapping and Vision

The Requirement

Robots must be able to cope with acoustic tiles.

- Used for sound proofing, they are generally made from sound absorbing foam
- They could provide blind spots in any sonar mapping techniques similar to rounded corners that create a reflective effect
- Victim identification by noise could also be hindered
- Laser range imaging techniques could be used to overcome the effects on the sonar system

Robots must be able to cope with reflective surfaces.

- Present in most buildings in the form of glass, plastics etc
- Presence could interfere with mapping techniques using laser range imaging techniques
- Reflection from various light sources could also cause difficulties with visual feedback
- Again use in combination with a sonar system would allow a more accurate mapping system
- Excessively dark light absorptive materials such as felt, could also create blind spots for light based systems

Solutions

Sonar Rangers

Advantages:

- Short to medium range
- Can cope with reflective surfaces
- Relatively cheap

Disadvantages:

- Susceptible to acoustic tiles
- Not good over long distances

Lasers / IR

Advantages:

- Accurate over longer distances
- Can cope with acoustic tiles
- Very fast lock on time
- Very narrow beam spread
- Few sources of interference

Disadvantages:

- Problems with mirrors / shiny / transparent objects
- High levels of dust can limit range
- Not very good on very short distances
- Expensive

Webcam

Advantages:

- Gives clear image back to the team
- The team can control all decisions made by the robot
- Very cheap

Disadvantages:

- The robot cannot use the images obtained
- Smaller field of view (unless it is rotated)
- Only a picture obtained; no distance measurement

Options

Condition	Sonar	Laser	Webcam	Combination
Distance	Short distance (0.04-0.34m); 3	Long distance (up to 32m); 3	Distance measurements have to be guessed by user; 1	Good over short and long distance, with visual image; 5
Ability to cope with interference	Poor with acoustic tiles; 2	Poor with reflective surfaces; 2	The only interference is reduced vision from dust / smoke; 3	Able to cope with majority of interference; 4
Accuracy	Fairly good, reduces over large distances; 3	Very good, to within a few mm; 4	No distance / accuracy measurements; 1	Accuracy depends on distance; 4
Cost	Moderate; 4	Very expensive; 3	Very cheap; 5	Very expensive; 1
Total Score	12	12	10	14

Solution with highest score (more desirable) = combination of mapping sensors and vision system (sonar, laser, webcam)

ZCO301PL - £16.95

- Built In microphone
- 307,200 pixels (640 x 480) optical lens
- Full software and manuals
- Multi-lingual support; English, German, French, Dutch, Greek / EMEA
- Measures 5.3 cm x 5.3 cm x 6.5 cm

Soyntec Joinsee 100 Mini VGA Webcam - £12.95

- Complete with Webcam, Software and manual
- Specification: USB 2.0/1.1/1.0 connection, compatible with Windows XP/2000/98SE/ME
- Automatic exposure and gain control
- Still image resolution: VGA 640X480
- Video resolution: CIF 352X288
- Includes button for taking pictures
- LED status indicator
- USB connection

PBS-03JN - £822.50

- Low cost infrared range finder
- Angular Resolution 1.8°
- Response time 180msec or less
- Angular scanning range 217.8°
- Range 200 to 3000mm
- Power consumption 24Vdc @250mA
- RS232 interface
- Size 75 x 70 x 60mm
- Weight 500g

SICK LMS 200 Laser Rangefinder

- Construction: anodized, CNC fabricated, and painted aluminium case
- Range: max. 150m
- Minimum reflectivity 1.8%: 4m
- Resolution: 1 mm at 32 meters
- Accuracy: +/- 7.5 mm
- Angular Resolution: 100° Scan: 0.25°/0.5°/1.°, 180° Scan: 0.5°/1.° configuration using software
- Interface: RS-232 Serial Interface
- Data Transfer: 38.4 Kbaud
- Dimensions: 155 x 185 156 mm (WxHxD)
- Weight: 4.5 kg
- Power Consumed: max. 17.5 W

Devantech SRF10 Ultrasonic Rangefinder - £37.48

- Size: 1.25" W x 0.59" D x 0.39" H (32mm W x 15mm D x 10mm H)
- Voltage: 5V
- Current: 15mA typical 3mA Standby
- Frequency: 40KHz
- Minimum Range: 3cm (1.18")
- Maximum Range: 6m (19.7')
- Maximum analogue gain variable 40 to 700 in 16 steps
- Connection: Standard IIC bus
- Timing: Fully timed echo, freeing host computer of task
- Range units: reported in µS, mm or inches

Devantech SRF235 "Pencil Beam" Ultrasonic Rangefinder - £66.50

- Ranges from 10cm to 1.2m
- I2C bus interface
- Very narrow 15° beam width
- 3-4cm Resolution
- Dimensions: 34mm x 20mm x 19mm

Tilt and Accelerometer Sensors

The Requirement

Robots must be able to negotiate 10-degree pitch/roll ramps filling the hallways between the walls.

Robots must be able to negotiate continuous 15-degree pitch/roll ramps.

Robots must be able to negotiate elevated floors.

- Accessible by stairs (40 degree incline, 20cm step heights, 25cm tread depth, 5 steps total)
- Accessible by steep ramp (35-45 degree incline with carpet for traction) to challenge power and centre of gravity
- Each elevated floor section will be separated by a 20cm step/pipe combination to challenge robots reliant on the sharpness of step edges for traction and reward robots that can change their shape to reliably surmount curbs of any condition.

Solutions

For purely measuring tilt with respect to an artificial horizon, tilt sensors/inclinometers would provide the best choice. Unlike accelerometers, which often require significant post processing to decode the tilt measurements, tilt sensors provide a simple voltage/degree measurement out.

Various types of sensors, listed in increasing price order:

- Switch, mercury trigger based.
- Limited range detection.
- Full range detection (0 → 90°) with high resolution based on either Single Axis/Dual Axis.

Full range detection is the most likely to be utilised as a solution. The following three options for range detection are:

- Single Axis, analogue voltage out
- Dual Axis, analogue voltage out
- Dual Axis, digital voltage out.

Options

ETS90XA – ASSEMTECH - £115.80

- Sensor, Tilt Electronic from Farnell Electronics
- Angle, detection 90°
- Weight – 0.065 kg
- Current, supply: 25mA

Dual Axis Assembly with Signal Processing (analogue)

- The Fredericks Company
- Accurate tilt information in the range needed for the competition.
- Can measure in both X and Y axis +/- 45°

AT3510 Atmodule – Dual Axis DIGITAL

The Atmodule AT3510 series are two axis precision digital-output angle sensors. The module incorporates a two-axis electrolytic tilt sensor, sensor interface electronics, and a sensor signal processor. Smart drive techniques are used to eliminate warm-up drift and long term drift which are normally seen with electrolytic sensors.

Operating from a standard five-volt power supply, the module is designed for board mounting with 6-pin header connection. An acrylic coating protects the electronic circuitry. The module is intended for cost sensitive OEM applications that require good null accuracy and repeatability.

- Digital design with very high resolution in two axes.

12.0 APPENDIX 6

13.0 APPENDIX 7

www.mobilerobotics.warwick.ac.uk

WMR Newsletter

Issue 1 - December 2007

Ed, Jonathan, Alex, Mahan, Phil, Redland, Alex and Chris (left to right).

Welcome!

Warwick Mobile Robotics is the revamped fourth year, group MEng project. The focus of the project will be to enter a competition that stretches the level of undergraduate research, in the field of robotics. Recent publicity for the team has involved a visit from the President of India (2002 – 07) and the opening of the WMR laboratory for the Deckel Maho open day, with Siemens, Dormer, Seco and other firms also attending.

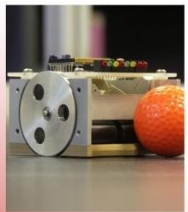
The team would like to thank the School of Engineering and WMG for hosting the project, along with our current sponsors for their highly valued support.

RoboCup Rescue

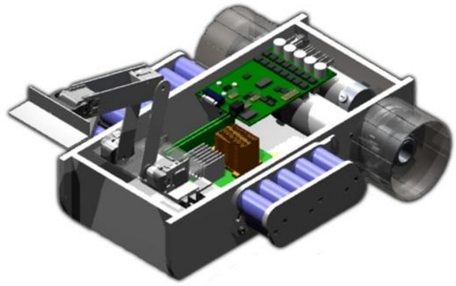
The team will enter the RoboCup Rescue competition, requiring the development of an autonomous search and rescue robot. This involves the navigation of various hazards, arena mapping and victim ID through a level of different sensors (including thermal, laser etc)

FIRA MiroSot: Robot Football

This year, WMR aims to host the championship again, near the end of term two. The main focus of development will be on the strategy; the defensive capabilities have been expanded this term and next term aims to strengthen the attacking algorithm.



WMR Robot



The creation of the search and rescue robot is well underway! A full requirement and specification has been completed and an extensive CAD model is in progress, whilst sensor procurement has commenced.

Additionally, the basic architecture for the control system is in place.

A brand new website!

www.mobilerobotics.warwick.ac.uk

WMR, our valued sponsors, the School of Engineering and the IMC will enhance their reputation through international exposure, aiming to continually forge and nurture mutually beneficial relationships between stakeholders.

JOIN WMR!

www.mobilerobotics.warwick.ac.uk/sponsorship

WMR Laboratory Refurbishments

New LCD display, wall sized posters, white boards, lighting and cabinets

in association with...

WARWICK IMRC

WMG Innovative Solutions

School of Engineering University of Warwick

REMOTEC Unmanned Vehicle Systems

www.mobilerobotics.warwick.ac.uk

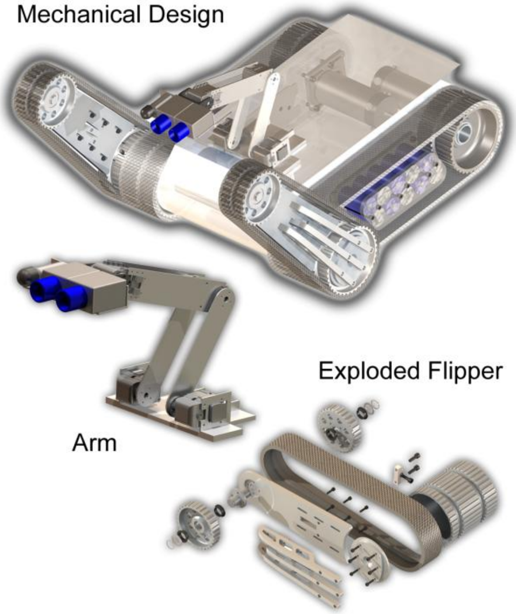
WMR Newsletter

Issue 2 - January 2008

Happy New Year from the WMR team!

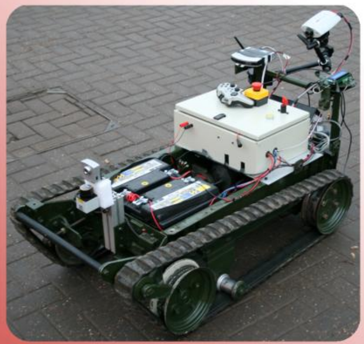
The team wishes all our sponsors and stakeholders an exciting and prosperous new year. After a very busy Christmas period the team is making great progress and is looking forward to the development in the New Year.

At present the team is in the process of planning the trip to the German RoboCup Rescue Open at the end of April. The competition takes place during the Hannover Messe, the world's biggest industrial fair, with over 200,000 visitors; a great opportunity to publicise the project and sponsors.



An earthquake scenario presents some very challenging terrain for the robot to navigate; above are some of the CAD designs that satisfy the specific requirements. Currently parts are arriving and designs are being manufactured.

Bomb Disposal Chassis



WMR would like thank Jamie Strachan (embedded software engineer) and Paul Foster of Remotec for their donation of a bomb disposal chassis. This has allowed the team to develop the control, communication and safety systems whilst fabrication of the WMR robot chassis is in progress. These systems are now capable of tele-operation. Videos of the team's progress can be found on the website.

MiroSot Robot Football Update

A strong defensive strategy has been implemented and development of the offensive strategy is now underway. WMR will be hosting the UK Championships for the third consecutive year at the end of the Spring term. Specific information on the event will be available shortly.

WMR Poster

As part of the team's formal submission, a detailed poster outlining the progress to date and goals is required. On 16 January the team will be presenting the poster to assessors and answering questions on the project. A copy of the poster is available online at

www.mobilerobotics.warwick.ac.uk/media/igallery

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School of Engineering University of Warwick

NORTHROP GRUMMAN REMOTEC

www.mobilerobotics.warwick.ac.uk

WMR Newsletter

Issue 3 - February 2008

Project Management

A critical path analysis is used to identify the key activities required to enable the completion of the robot, for the April RoboCup Rescue competition in Germany. The manufacturing schedule is updated every week, using project management software, Microsoft Project.

Image: Manufacturing schedule, present - April 2008

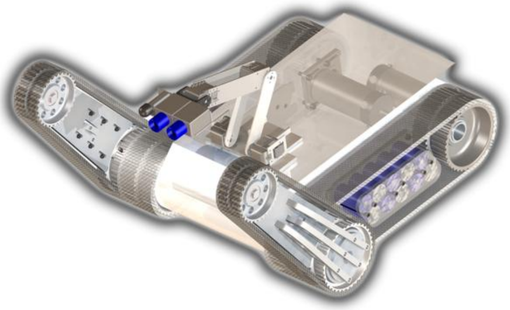
Robot Machining

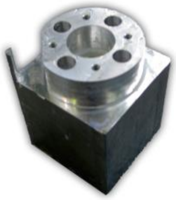
The continual design and manufacture of components has enabled the team to make great progress in the production of the WMR robot. Developments include customised tracks, main drive and flipper motors, gearbox, ITX motherboard, flipper speed controller, pulleys, shafts, bearings and recently the rear drive case plates.

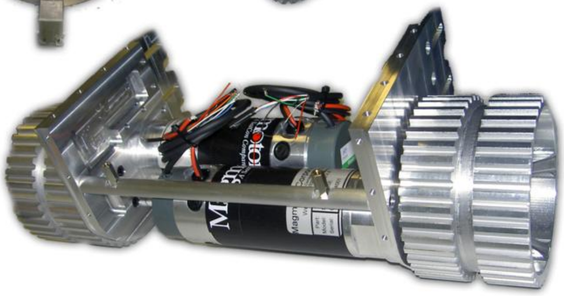
Photograph: DMU eVo, 5 Axis Mill machining the rear drive pulleys

Robot Manufacture

Images of some of the manufacturing achieved to date. From left to right: CAD render of the robot, rear pulley during machining, front pulley, spacing ring and the rear drive assembly.







Open Day

On Wednesday 30 January 2008 WMR held an open day, during the School of Engineering's open day. Visitors ranged from school groups, industry visitors, lecturers and University students. The day included regular presentations and demonstrations of robot football and the Remotec sensor development chassis. To view more photos please visit www.mobilerobotics.warwick.ac.uk/media/igallery

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WMR Newsletter

Issue 4- March 2008

UK MiroSot & SimuroSot Robot Football Championships

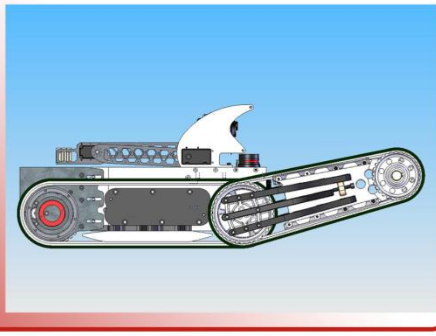
The UK Robot Football Championships took place on Saturday 8 March 2008, held by WMR, at the University of Warwick's IMC. After a successful day of competition and visitors, Warwick Mobile Robotics took both the MiroSot and SimuroSot titles. Further images of the event are avaliable online at www.mobilerobotics.warwick.ac.uk.

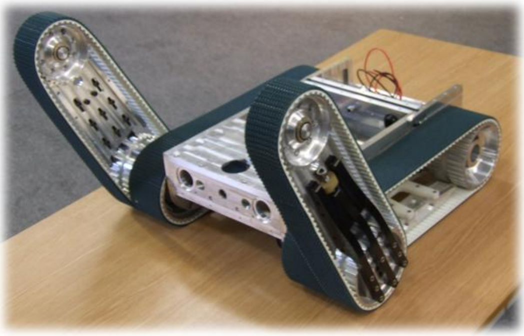
UK MiroSot & SimuroSot Robot Football Championships

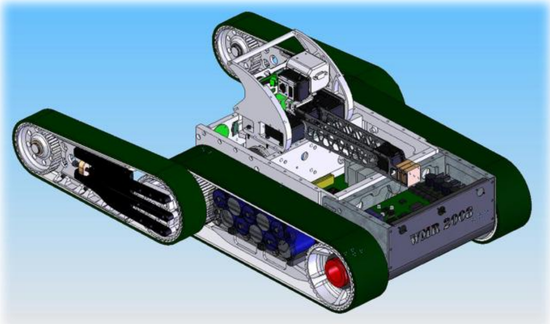
The two images below show the latest CAD model of the robot and the actual rolling chassis assembly to date. Machining of the chassis, battery casings and robot arm etc has been completed with a LED array completed and final PCB under construction. Furthermore other progess includes a fully operational digital compass and an Inertial Measurement Unit (IMU) interface to process logged data to create a historical map.

Additionally, sponsorship advertisements will be visible on the exterior of the WMR Robot.

www.mobilerobotics.warwick.ac.uk/projects/rescue







RoboCup Rescue 2008 German Open

Warwick Mobile Robotics will be competing in the RoboCup German 2008 Open, held during the Hannover Messe (the world's biggest industrial fair). More information about the competition is avaliable at www.robocup-german-open.de. The team is taking the ferry from Harwich Port to Hook of Holland and driving to Hannover in two vehicles (an approximate total driving time of 19 hours). WMR are staying in Minden, approximately one hour from Hannover, from 21-23 April 2008. At present there has been more than 120 pre-registrations across all the RoboCup competitions.

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WMG Innovative Solutions
School of Engineering University of Warwick
NORTHROP GRUMMAN REMOTEC

14.0 APPENDIX 8

General Safe Working Procedure

Risk Assessment

- A risk assessment has been carried out for work on the MiroSot robots and the RoboCup Rescue robot. If you are undertaking work that does not fall into either category, first assess the hazards present and then decide the best methods to reduce the risk posed by these hazards.

Computer Use

- Take a short break at least once every hour when working at a computer. If any signs of Repetitive Strain Injury appear (such as aching arms/fingers), stop use immediately.

Soldering

- Take care when using a soldering iron. Use a soldering iron only if you are confident in doing so.
- Do not lean directly over a component when being soldered, to avoid inhaling fumes.
- Use the fume extractor provided when soldering.

MiroSot and RoboCup Rescue Safe Working Procedure

Risk Assessment

- Read and understand the MiroSot and RoboCup Rescue risk assessments. If there are any parts of the assessments you do not understand, or you think there are changes that should be made, please consult the authors of the assessments.
- Since work on the MiroSot robots and RoboCup Rescue robot is research-based, there may be new activities to be undertaken that have not been risk assessed. Under these circumstances first identify any hazards present, and then decide the best methods by which to reduce the risk posed by these hazards.

MiroSot Risk Assessment

Risk assessment carried out by: Edward Elbourne   Date: 6th November 2007

Hazard and effect	Risk to whom:	Initial risk			Minimise risk by:	Managed risk		
		Hazard index	**Likelihood index**	**Risk product**		**Hazard index**	**Likelihood index**	**Risk Product**
Electrocution by chargers.	All	2	2	**4**	Using only 12V chargers.	0	0	**0**
Being hit by automated MiroSot.	All	2	6	**12**	System designed so MiroSots work only on pitch. When in action, persons to be off the pitch.	2	1	**2**
Injury due to flying parts (e.g. due to MiroSot collision).	All	6	4	**24**	MiroSots designed for durability. Each robot to be visually checked for any loose parts prior to any automation.	6	1	**2**
Repetitive strain due to prolonged use of computers.	Students	2	4	**8**	Computers to be used for no more than one hour by one person in one sitting. Any user with symptoms of repetitive strain injuries to stop immediately.	2	2	**4**
Burns due to soldering.	Students	2	8	**16**	Care to be taken when using soldering iron. Experienced users to use soldering iron only.	2	4	**8**
Inhalation of fumes when soldering	Students	2	8	**16**	User to avoid leaning over iron when in use. Fume extractor to be used.	2	1	**2**

Severity	Multiple Deaths **(10)**	Single Death **(8)**	Major Injury **(6)**	**Minor Injury (2)**
Certain **(10)**	100	80	60	**20**
Very Likely **(8)**	80	64	48	**16**
Probable **(6)**	60	48	36	**12**
Possible **(4)**	40	32	24	**8**
Unlikely **(2)**	20	16	12	**4**
Very Unlikely (1)	**10**	**8**	**6**	**2**

100 – 48: Unacceptable
40 – 32: Risk reduction necessary
24 – 16: Control measures essential
12 – 4: Monitor

RoboCup Rescue Risk Assessment

Risk assessment carried out by: Edward Elbourne **Date: 30th December 2007**

Hazard and effect	Risk to whom:	Initial risk			Minimise risk by:	Managed risk		
		Hazard index	Likelihood index	Risk product		Hazard index	Likelihood index	Risk Product
Repetitive strain due to prolonged use of computers.	Students	2	4	**8**	Computers to be used for no more than one hour by one person in one sitting. Any user with symptoms of repetitive strain injuries to stop immediately.	2	2	**4**
Burns due to soldering.	Students	2	8	**16**	Care to be taken when using soldering iron. Experienced users to use soldering iron only.	2	4	**8**
Inhalation of fumes when soldering	Students	2	8	**16**	User to avoid leaning over iron when in use. Fume extractor to be used.	2	1	**2**
Injury due to robot/human collision	All	6	4	**24**	A minimum of two users must be present when the robot is automated. Robot to be fitted with an emergency stop. Onboard safety-system installed to monitor the response of the robot; if the software fails, power to the motors is cut.	2	2	**4**
Electrocution by on-board circuitry	Students	6	6	**36**	Maximum on-board voltage limited to 24V. Power rails to be located to reduce chances of accidental contact. The batteries are to be disconnected (via a kill switch) when connecting components to the power rails to avoid arcing.	2	4	**8**

Injury due to lifting and carrying the robot	Students	6	4	**24**	Robot weight to be kept low (ideally below 25kg). Robot designed so it can be safely lifted. Lifter must be aware of the safest way in which to lift and carry the robot	6	2	**12**
Fire caused by overheating of components on robot	All	10	4	**40**	The heat emitted by components in the robot to be carefully considered at the design stage. Testing of the robot will determine if extra cooling systems are needed. A CO_2 fire extinguisher is to be available nearby the lab.	6	2	**12**

Severity	Multiple Deaths **(10)**	Single Death **(8)**	Major Injury **(6)**	**Minor Injury (2)**
Certain **(10)**	100	80	60	**20**
Very Likely **(8)**	80	64	48	**16**
Probable **(6)**	60	48	36	**12**
Possible **(4)**	40	32	24	**8**
Unlikely **(2)**	20	16	12	**4**
Very Unlikely (1)	**10**	**8**	**6**	**2**

100 – 48: Unacceptable

40 – 32: Risk reduction necessary

24 – 16: Control measures essential

12 – 2: Monitor

12.0 APPENDIX 9

RoboCup Rescue Competition Safety RIsk Assessment

Risk assessment carried out by: Edward Elbourne **Date: 17th April 2008**

Hazard and effect	**Risk to whom:**	**Initial risk**			**Minimise risk by:**	**Managed risk**		
		Hazard index	**Likelihood index**	**Risk product**		**Hazard index**	**Likelihood index**	**Risk Product**
Injury due to robot/human collision during competition	WMR	6	6	**36**	Robot controller is installed with a dead-man's handle. Robot software includes a 'heartbeat' to cut power in case of motor failure. Motors to be turned off when not necessary. Robot speed limited to 1m/s. The competition will be under supervision of the organisers, and any rules (such as no entry to the robot arena) should be strictly followed.	2	2	**4**
Injury due to robot/human collision outside of competition	WMR, General public.	6	8	**48**	Robot controller is installed with a dead-man's handle. Robot software includes a 'heartbeat' to cut power in case of motor failure. Motors to be turned off when not necessary. Robot speed limited to 1m/s. Before turning the robot on the surrounding area must be assessed. If the surrounding area is deemed too busy/unsuitable the robot should not be activated.	2	4	**8**
Electrocution by on-board circuitry at	WMR, General	6	6	**36**	Maximum on-board voltage limited to 24V. Power rails are located to reduce chances of accidental contact.	2	4	**8**

any time.	public.							
Injury due to lifting and carrying the robot at any time.	WMR.	6	4	**24**	Robot is designed to be carried easily by one person. Prior to lifting, an assessment must be made of the local terrain, and possible hazards noted. Lifter must be aware of the safest way in which to lift and carry the robot. There should be no need, under normal circumstances, to lift the robot.	6	2	**12**
Fire caused by overheating of components on robot at any time.	All	10	4	**40**	Motors to be kept turned off when not needed to reduce heat output. CO_2 extinguisher to be made available when testing. Current testing shows robot is unlikely to overheat.	6	2	**12**
Injury or loss of life due to robot not meeting safety specifications	All	8	6	**48**	Robot to be tested against *Test Methods and Cases* (See additional document.) The robot should not be used until it passes all these tests.	8	1	**8**

Severity	Multiple Deaths **(10)**	Single Death **(8)**	Major Injury **(6)**	**Minor Injury (2)**
Certain **(10)**	100	80	60	**20**
Very Likely **(8)**	80	64	48	**16**
Probable **(6)**	60	48	36	**12**
Possible **(4)**	40	32	24	**8**
Unlikely **(2)**	20	16	12	**4**
Very Unlikely (1)	**10**	**8**	**6**	**2**

100 – 48: Unacceptable

40 – 32: Risk reduction necessary

24 – 16: Control measures essential

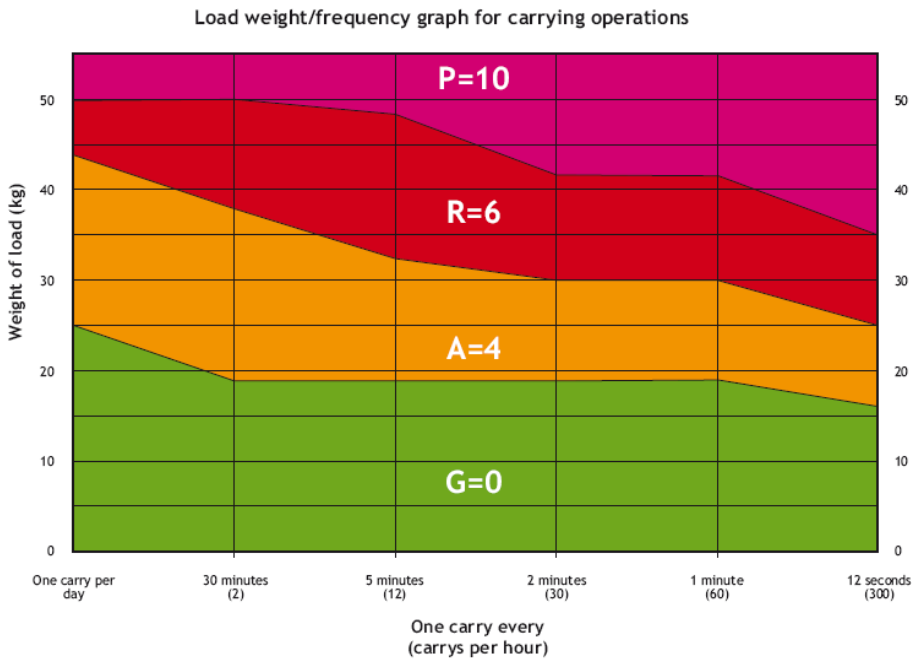
12 – 2: Monitor

13.0 APPENDIX 10

RoboCup Rescue: Ideal Weight

A robot system will be produced capable of being carried by one person. As with all guidelines written on the HSE website[1], there is a degree of ambiguity in what constitutes a safe lifting and carrying weight.

The executive have produced the *Manual Handling Assessment Chart (MAC) Tool*, a series of assessments that determines the risk involved in a lifting and carrying procedure. These assessments are compiled as a flow chart, which culminates in an (apparently meaningless) numerical score. Of these assessments, one is the weight of the object against the frequency of lifts. A graph to determine the risk of this is shown in the figure below.



Load weight/frequency graph available from HSE

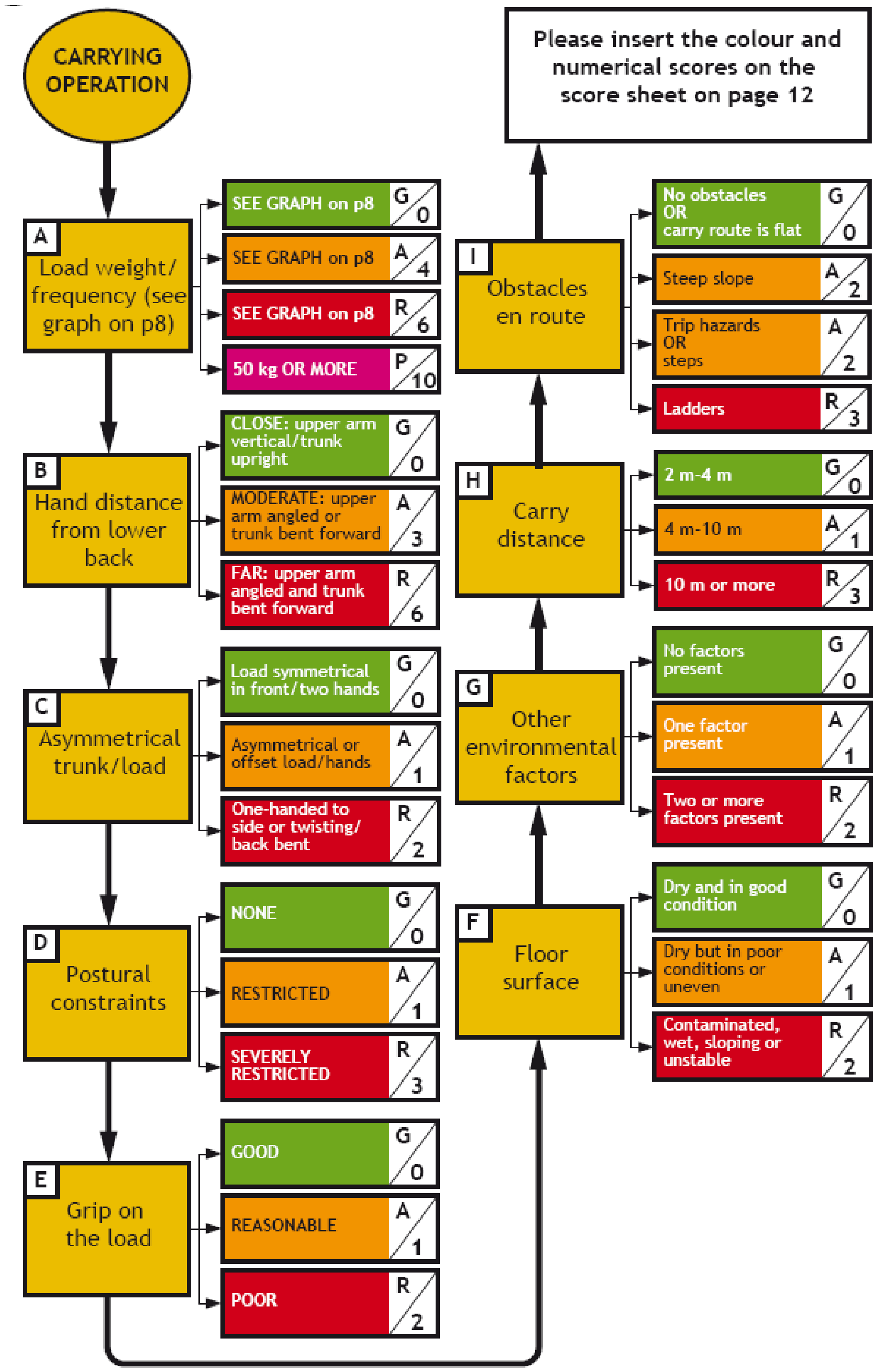
It can be reasonably assumed that the carrying of our robot will not occur more than once every thirty minutes. At this frequency, the green band allows a robot weight of up to 19kg and the amber band a robot up to 38kg.

Other assessments that apply to the design of the robot system include the hand distance from lower back, symmetry of the trunk/load and the grip on the load. Further assessments are included in the MAC, on the following page; however these depend on the environment in which the object is lifted.

[1] http://www.hse.gov.uk/msd/mac/index.htm, last accessed: 10 November 2007

A handle on the robot enabling the robot to be carried with a straight arm gives the best score in the *hand distance form lower back* assessment; however this will lead to a one-handed lift, giving the worst score in the *asymmetrical trunk/load* assessment. The weighting of the MAC scoring gives precedence to the former of these assessments, and hence this handled system is recommended.

If the handle provided is 'good' (i.e. enables good grip, does not dig in), the best score in the *grip on the load* assessment will be achieved.



Carrying MAC from HSE

14.0 APPENDIX 11

<u>Department of Computer Science Proposal</u>

1) Autonomous robotic search and rescue

This year's 4th year Engineering robotics team have put together a neat robotics platform for the RoboCup Search and Rescue competition. The platform has a slew of embedded sensors (cameras, thermal imaging, laser scanners, ultrasonic sensors and others) and an embedded dual-core Linux PC. It's currently controlled remotely with laptops, over wireless but we'd really like to enter a joint Computer Science and Engineering team in to next year's competition.

We're looking for a Computer Science group project who can work on the autonomous mapping and control aspects of the team. There's plenty of scope for different ideas and approaches to the problems, it's all Java-based so getting up to scratch with the existing codebase shouldn't take too long.

The current team have just returned from Hanover after taking part in the European championships and if anyone has any questions regarding the competition itself, I can put them in touch.

You can see the current team's robot and adventures at:

http://www2.warwick.ac.uk/fac/sci/eng/meng/wmr, they ought to have some photos up from their recent trip at some point soon.

2) Robot football strategy

Previous 4th year Engineering robotics teams have competed in the FIRA Robot Football league. It involves 5, 7.5cm cube robots and an overhead camera, on each team and is completely autonomous after play starts. The current limitation on progress at European and International tournaments is the sophistication of the autonomous strategies we have developed. A good 4th year Computer Science group project dedicated to the development of strategies ought to be able to take things much further. Strategies are written in C++ and Java, there's a freely available simulator and two working sets of physical robots available in the lab.

You can find photos and other information on the robot football team at the same URL as above. Videos from the World cup final two years ago are definitely worth watching:

http://www.robotfootball.uwcs.co.uk/video/11v11.mpg

If anyone has any questions or ideas about either project, don't hesitate to drop me an email.

REFERENCES

[1] Team photograph, courtesy of Robert Gilbert

[2] Product Life Cycle diagram, http://www.arundelstreet.com/case_studies_life_cycle.htm, last accessed: 18 January 2008

[3] Collapse Types: Examples, Reference Test Arenas for USRR, pp. 28

[4] Hannover Messe2008, www.hannovermesse.de, last accessed: 19 January 2008

[5] Remotec Website, www.remotec.co.uk, last accessed: 14 March 2008.

[6] http://robotarenas.nist.gov/rules.htm, last accessed: 29 October 2007.