Executive Summary

Warwick Mobile Robotics: Urban Search and Rescue Robot

ES410 Group Project

3rd May 2012

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Abstract

The field of Urban Search and Rescue Robotics is an area of continuing progression, with many institutions at the forefront of current advancements in research and development. The ultimate goal of Urban Search and Rescue Robot's is to aid the speed and safety at which searching for survivors is carried out in response to disaster sites of all types. This subject area has largely formed the foundations for the specific project undertaken, the development of the Warwick Mobile Robotics (WMR) Tele-Operated Robot.

This paper summarises and formally evaluates the efforts of the 2011/2012 WMR Tele-Operated Robot development from both a technical and business perspective. Principally, the Tele-Operated Robot is designed to enter a disaster area and search for any surviving victims. The robot is controlled remotely by a human operator and demonstrates capabilities such as advanced locomotion and sensory perception to carry out this procedure quickly and effectively. Research and advancements in this subject area aim to impact the future direction and application of technology.

The WMR Team of 2011/2012 analysed the previous successes and failures of preceding WMR robots to devise significant improvements which would contribute to a greater level of performance at the RoboCup Rescue Competition. Roboticists from across Europe compete in a simulated earthquake environment where the main aim is to detect human life. The competition aims to raise awareness of Search and Rescue Robots whilst allowing knowledge to be shared amongst participants.

The major development pursued was a redesign and construction of a new mechanical arm which could move sensory devices into unique positions for human detection. The concept was based on a worm and worm wheel gearing mechanism which had been used previously but suffered from a range of complications.

Successful design and implementation of the mechanical arm was demonstrated at the competition where Warwick Mobile Robotics won the accolade of 'The Best in Class Manipulation'. The 2011/2012

robot developments also contributed to a 2nd place finish in the overall Rescue Robot League competition and a further award for 'The Best in Class Mobility'.

An operating budget of £11,500 required meticulous planning and was allocated to ensure we could achieve our project aims. The account at the end of the project has a £400 surplus, illustrating the tight financial control taken. A substantial amount of publicity and media coverage was gained from attendance at the London Science Museum and our participation in the RoboCup Competition along with numerous local school visits. This has raised the profile of Urban Search and Rescue Robots as a subject, but more directly the success and competence of the WMR Search and Rescue group.

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1.0 Introduction

The WMR Search and Rescue Robot project is an evolutionary venture which was first initiated in October 2007. Each year, a team of multi-disciplinary engineering students aim to improve the robot with new and innovative solutions, adding to the research and application capability conducted worldwide by the Search and Rescue Robot community.

The WMR team of 2011/2012 derived a series of challenges and objectives which intended to satisfy the two high level aims stated below:

- To re-engineer the 2010/2011 robot to deliver a greater level of performance in terms of functionality and reliability
- To successfully compete in the 2012 German Open RoboCup Rescue Competition and the associated mobility and manipulation challenges

This Executive Summary provides a detailed analysis and review of the entire project scope, including coverage of the fundamental technical and business aspects embarked upon. An array of subject matters needed to be considered in order to meet the objectives set and contribute to raising the awareness of the undertaking to society. This summary follows a simple structure, firstly defining the pursued project approach before leading into describing the main technical improvements and participation at the German RoboCup Competition. Business principles such as project management, sponsorship, financial control and publicity are then commented upon, before the main conclusions are outlined and future recommendations are expressed.

2.0 Project Approach

2.1 Initiation

Understanding the project direction was the first and arguably the most important task in beginning to drive the project forward. This could be described both in terms of identifying the technical improvements that would develop the Tele-Operated Robot and meet the high level objectives set, and categorising the supporting business aspects which would form the required structure to ensure delivery within key constraints.

The formulation of determining which technical characteristics of the robot could be advanced to improve its overall functionality and reliability were recognised by conducting a SWOT Analysis of the 2010/2011 robot. This analysis provided a breakdown of which aspects of the robot could be improved, and therefore initiated the next stage of the projects progression; establishing how they could be improved to meet the objectives set.

However, the scope of the project meant that it was only feasible to engage in a small number of the robotic features identified. By analysing the proposed areas of improvement and the corresponding design ideas and solutions, a list of priorities could be compiled. Each recognised feature was chosen based upon consideration of a range of factors including time, cost, and skill of the human resource available.

Once the technical considerations had largely been constructed, with lower level objectives and specifications set for each corresponding work area, the necessary business aspects of the project could be evaluated in more detail. Individual tasks were formed at separate stages of the development process and were aligned to the known timescale of the project. This amounted to approximately 25 weeks from the first team meeting to the first day of the German Open RoboCup Competition.

Estimates of the required financial budget were also made from an initial expenditure summary which considered the prioritised technical improvements and the cost associated with attending the RoboCup

Competition. A series of different scenarios were considered and a minimum budgetary requirement was deduced, hence sponsorship was raised with this target value as a platform. A series of publicity events were also planned and carried out to deliver value to sponsors and raise awareness of the subject area and more widely, the field of engineering.

2.2 Lower Level Targets

The lower level objectives, outlined below, relate to the specific technical improvements devised to meet the high level objectives, as gained from the SWOT Analysis of the 2010/2011 Tele-Operated Robot.

- **PRIORITY:** To re-engineer the mechanical arm, based on the worm and worm wheel gear configuration used in previous iterations, into a fully operative mechanism which can manoeuvre sensors into a range of positions dependably
- To re-design the head for efficient sensor incorporation and weight loss
- To remove the chain 'slack' in the flipper mechanism and apply encoders to inform the driver of their position
- To implement inverse kinematics for the mechanical arm hardware
- To improve the electronic network by re-wiring the stack using suitable connectors and fitting the batteries with warning sensors
- To progress towards a robot which is fully Tele-Operational, improving the human interface by incorporating 3D visual representation and centre of gravity analysis
- To meet the new rules of the competition which included QR code reading and mapping capability

The points highlighted briefly summarise the goal of the tasks which were progressed, and form an overall statement which each specification emulated. A broad overview of the technical solutions which contributed to delivering these objectives is given concisely in section 3.0, Technical Improvements.

2.3 Team Structure

Figure 1 diagrammatically shows the team organisation, where individual responsibilities were assigned, and skills matched to the respective tasks where possible. A suitable team dynamic was critical to achieving technical and business success.

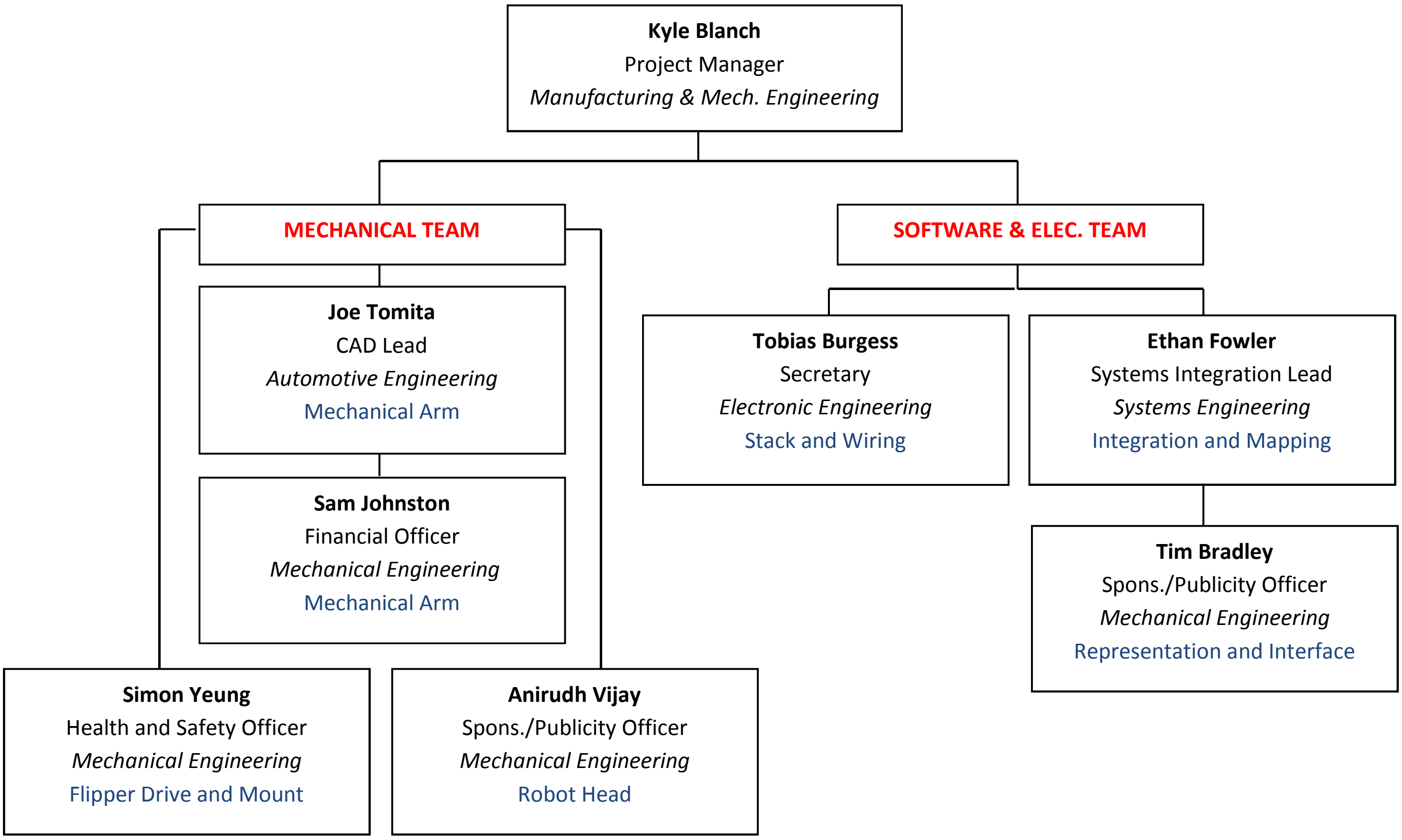

Figure 1: Warwick Mobile Robotics Team Structure 2011/2012

3.0 Technical Improvements

3.1 Mechanical Arm

The mechanical arm was re-engineered to meet the aim described in section 2.2. This was designed to complement the high level objective of constructing a robot which had a greater level of performance in terms of functionality and reliability. Achievement of this aim would also permit our participation in the RoboCup Manipulation Challenge.

The arm was based on the worm and worm wheel gear configuration used in the previous WMR designs, and consisted of five revolute joints to allow the head and end-effector gripper to move in five independent motions as shown in Figure 2.

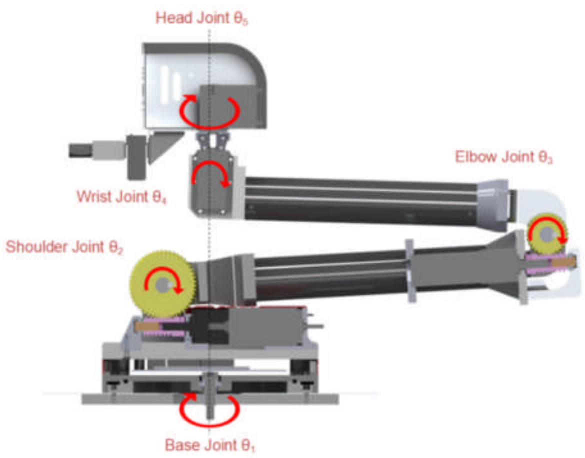

Figure 2: CAD Design of Mechanical Arm Structure

The mechanical arm from the previous year suffered from several major issues, as shown below.

Problem 1

There was a significant level of backlash in the joints of the arm, leading to large instability during robot motion

Problem 2

The arm was also very unstable due to higher inertia of the arm from the head and wrist joints being too heavy

Problem 3

Overloading of motors caused failure in the system with motor and motor control board burn outs

3.1.1 Design Solutions

In order to meet the aim of increasing the functionality and reliability of the arm, it was important to improve weight distribution and reduce backlash in the arm joints. Whilst a full breakdown of design changes is provided in Appendix A, a brief summary is provided in Figure 3 and Table 1 below:

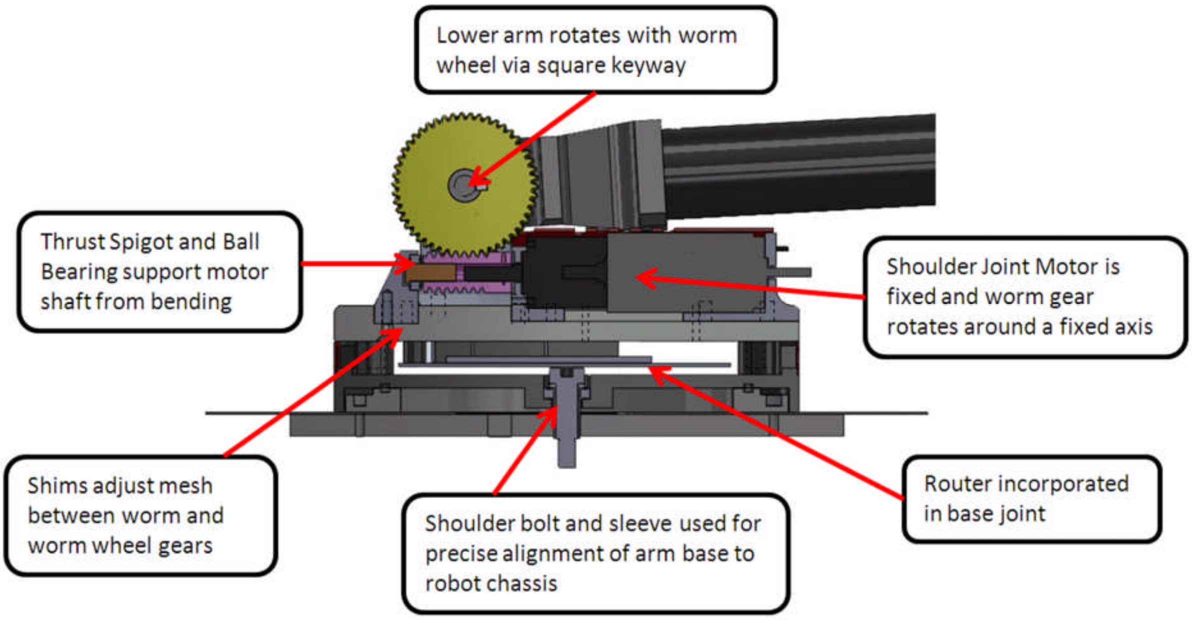

Figure 3: Design Changes in the Mechanical Arm

Design Intent	Reasoning
Reconfiguration of the shoulder joint gearing	The shoulder joint has been reconfigured to reduce the load on the motor and control boards. The Maxon motor has moved to a static position to drive the worm gear about a fixed axis. The joint must rotate 180 degrees and form a horizontal position for the manipulation challenge in the RoboCup competition.
Thrust spigot and ball bearing support	This has been implemented to prevent bending of the motor shafts that increases backlash due to inaccurate meshing of teeth in the worm transmission. The support is provided by ball bearings and mechanically connected to the worm gear through a thrust spigot.
Modular design	Shims are used to control the centre distance between the worm and worm wheel gears for accurate meshing and adjustable levels of backlash. Modular parts can be changed with ease and parts have been designed for specific manufacturing processes.
Reducing the inertial load of the arm	The arm features a significant redistribution of weight, relocating mass towards the base of the arm to lower the centre of gravity. Maxon motors and worm transmission has been removed in the wrist joint and replaced with an RX-64 Servomotor. Parts of the elbow and wrist joints have been rapid prototyped using low-density PA2200. As a result, the mass of the mechanical arm was reduced by 45%, with a 1kg mass relocation from the end effector position to the base joint.

Table 1: Design intent for the new Mechanical Arm

Figure 4 shows the completed Mechanical Arm which incorporated these design changes.

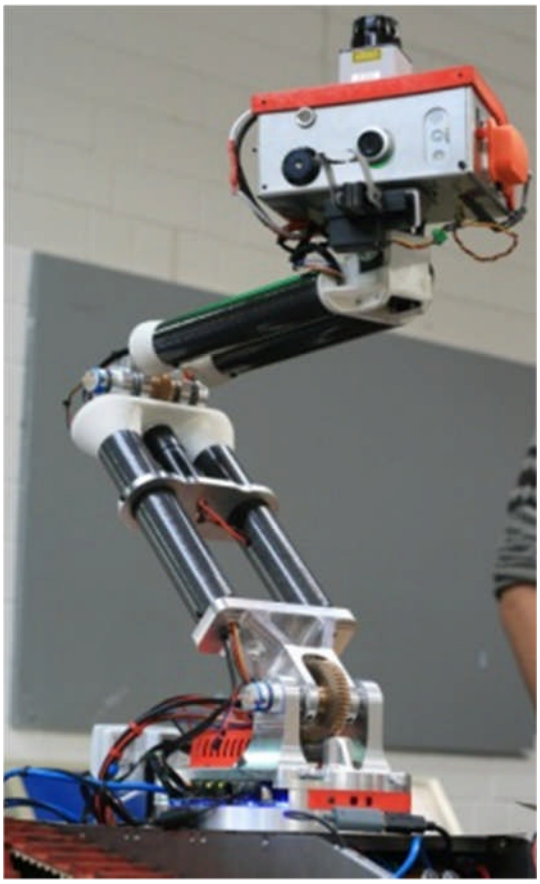

Figure 4: Mechanical Arm at the RoboCup Rescue Competition

3.2 Electronics and Software

The following flowchart (Figure 5) summarises the original objectives and actions taken with reference to the Electronics and Software systems of the robot. The level of progress made is illustrated from left to right. Further details can be found in Appendix B.

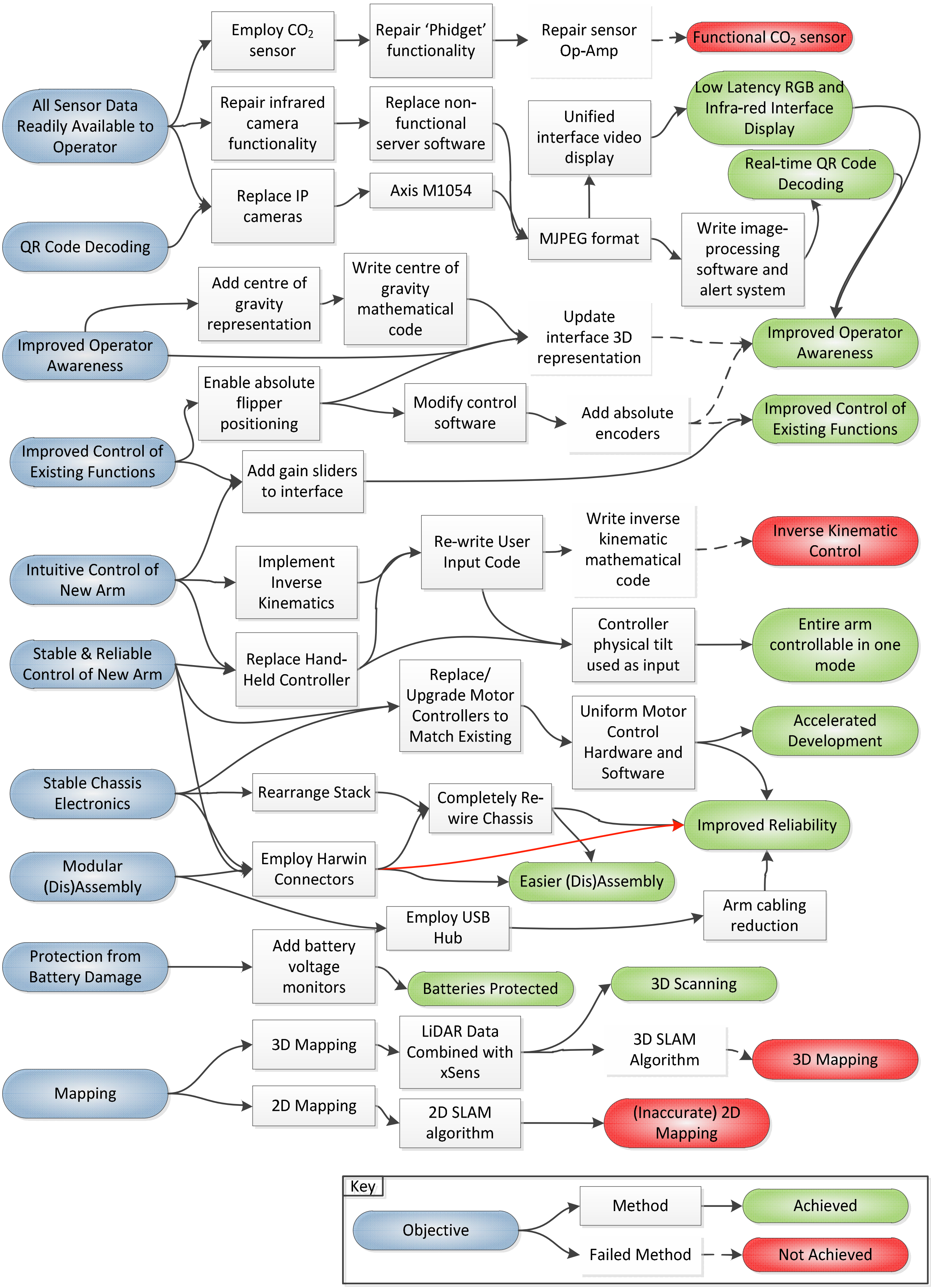

Figure 5: Software and Electronics Flowchart

4.0 RoboCup Rescue Competition

4.1 Main Results

The overriding objective of our entrance to the RoboCup Competition was to test our fundamental improvements made to the robot platform. These changes were proven to be largely successful and culminated in the award of three titles.

WMR was accredited with:

2nd Place in the Overall Competition

The Best in Class **Mobility** Performance

The Best in Class **Manipulation** Performance

In the competition points were scored by identifying victims, reading QR codes and mapping the course, with extra points added for marking points of interest onto the maps. Autonomous capabilities were awarded additional credit in the arena.

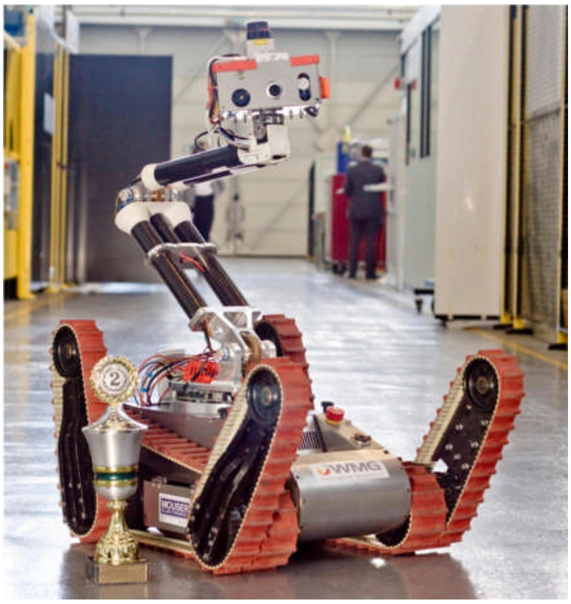

Figure 6: Tele-Operated Robot with Trophy

Achieving second place in the overall competition was a great success. In addition to this, the title of 'Best in Class Manipulation' was a great accomplishment as it proved our new mechanical arm was successful. The arm functionality coupled with the Axis (M-1054) cameras allowed the robot to attain a near maximum score during the manipulation challenge (as shown in Figure 7). Maintaining the title of 'Best in Class Mobility' for the third consecutive year highlights the continued excellent locomotive capabilities of the robot. Figures 8 and 9 are photos taken from the competition.

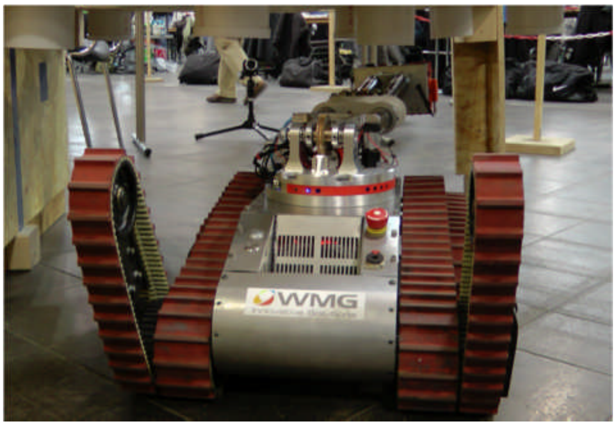

Figure 7: Manipulation Challenge

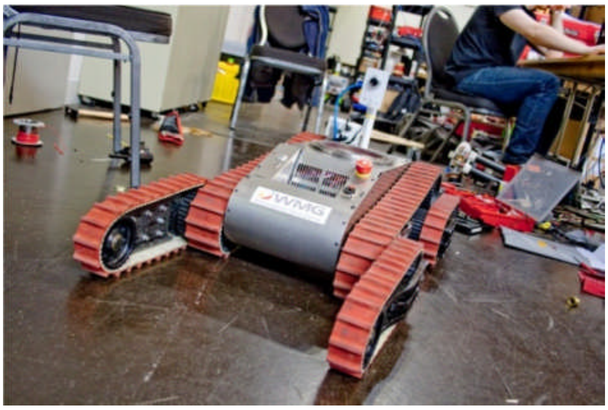

Figure 8: Robot stripped down for the Mobility Run

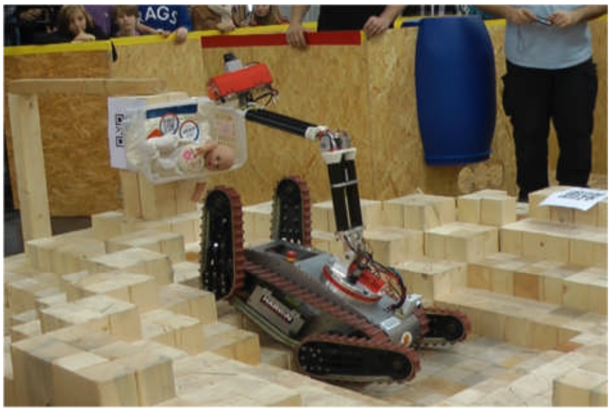

Figure 9: Robot during the Final Competition Run

4.2 Competition Problems

The areas outlined below (shown in Table 2, Table 4 and Table 3) highlight the observed issues during the competition which hampered overall reliability.

Software Problems	
Feedback	Feedback was the one of the main issues with the current software as it did not provide enough information to the remote operator. On several occasions the robot was situated in precarious positions as shown in Figure 10. Successful implementation of centre of mass and visual representation codes would have been beneficial along with absolute flipper encoders
Inverse Kinematics	Direct control of the end effector allows the operator to perform quick and precise movements. Unfortunately a working inverse kinematic solution was not able to be implemented due to limiting time constraints and mathematical errors

Table 2: Software Problems

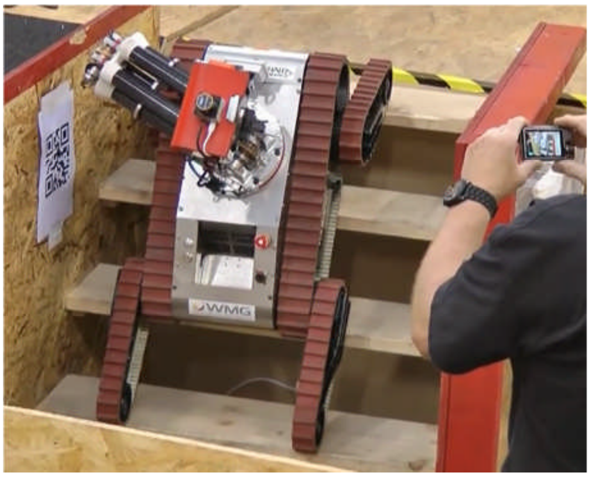

Figure 10: Precarious robot positioning due to inability to identify position of flippers

Mechanical Problems	
Drive	A loss of power in the drive on the right side of the robot was caused by an unsecure split pin that fixes the drive sprocket to the motor shaft. The pin had loosened from constant loading, resulting in material being removed from the chassis during rotation
Camera	Camera position limited driving accuracy and performance. A stationary camera at a higher position would allow the driver to observe the robot relative to its surroundings with precision. A front and rear view is an essential condition

Table 3: Mechanical Problems

Electronic Problems	
Flippers	Initial runs in the competition were hampered by the drop-out of the five volt rail during the rear flipper usage. As a result, the motor speed was restricted to increase driver accuracy and reduce the likelihood of such failure, which could have been due to high instantaneous power draw
Head	The head contained a large number of sensors and connectors which generated substantial levels of heat. The addition of a fan provided adequate cooling to prevent component failure due to over heating
Serial Converter	The current serial convertor uses TI chips. As a result, the motor control boards would only be recognised if a certain start up procedure was carried out. This problem could be solved by purchasing a serial converter that uses FTDI chips

Table 4: Electronic Problems

Limited operator experience was one of the most underestimated factors in the competition and contributed to some difficulties (see Figure 11). Driving with little feedback was challenging in a time period which was very short, highlighting the necessity to test regularly in competition conditions.

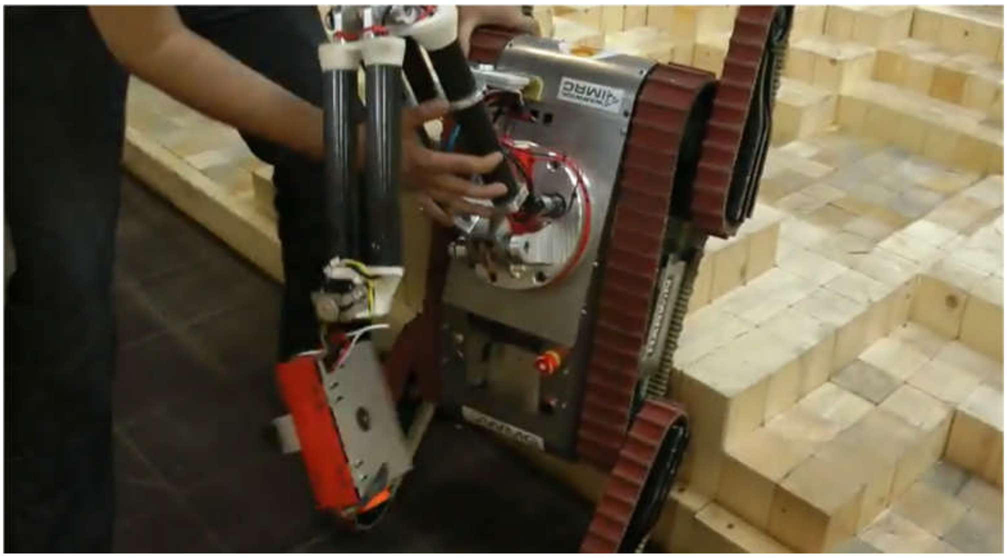

Figure 11: Driver Inexperience caused the robot to fall out of the arena

4.3 Competitors

This year saw an increase in the number of robots competing in the competition; a total of 11 teams entered the main competition. However, many teams encountered reliability issues that meant their performance was hindered.

Mechanically, the WMR robot was one of the most reliable and functional platforms. However, this mechanical advantage was rivalled by the superior coding experience of other teams who had greater capability in autonomy and mapping. Many teams utilised a pre-fabricated chassis with bolted sub-assemblies (as shown in Figure 12 below).

Team Darmstadt was the competition's overall winner and proved that a capable robot doesn't necessarily require high levels of mechanical aptitude to score highly in the competition. An in house mapping capability called Hektor SLAM was truly advantageous in gaining a greater accumulated points total.

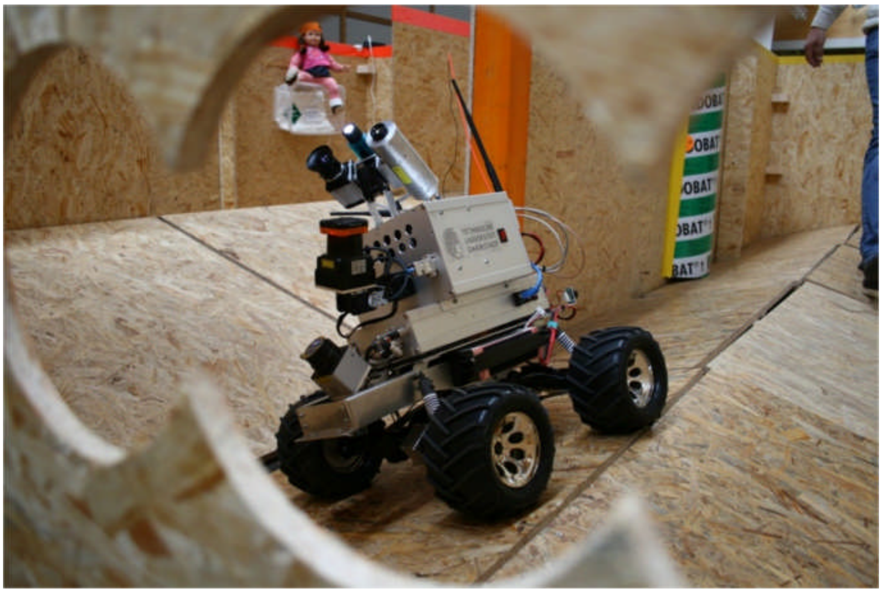

Figure 12: Team Darmstadt Rescue Robot

4.3.1 SWOT Analysis of Competition Robots

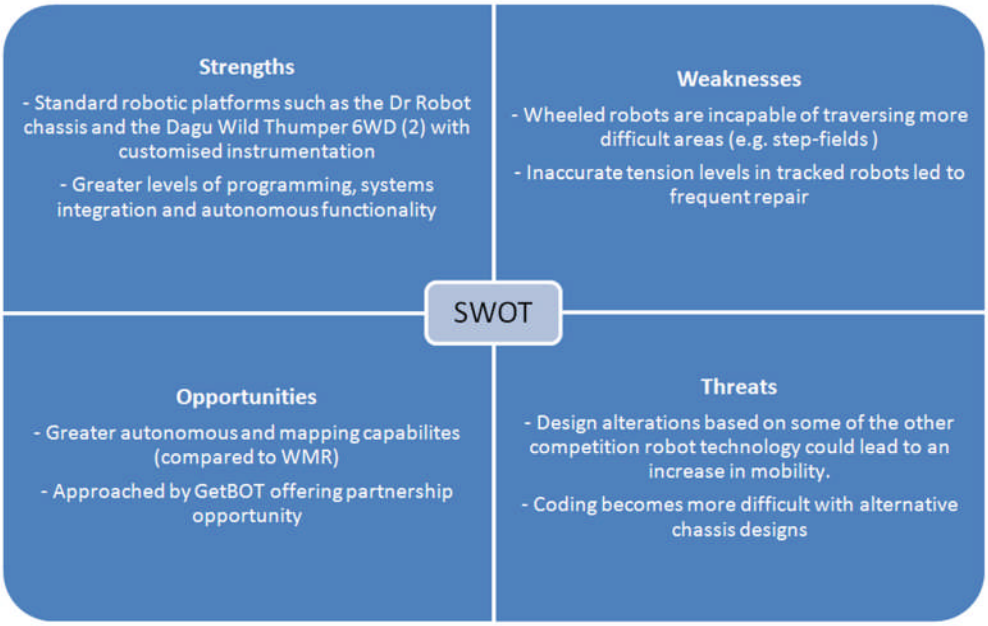

Figure 13: SWOT Analysis of Competition Robots

5.0 Sponsorship

Financial support is a key contributing factor to the development of the WMR robot. A lack of finance directly affects the project scope and how well objectives can be achieved. A total of £11,500 was raised during 2011/2012 through commercial and academic sponsorship.

This year the sponsorship approach targeted previous sponsors and further interest afield. A newly designed sponsorship pack was distributed to previous sponsors and other contacts. Table 5 outlines the commercial and academic sources of sponsorship gained.

Sponsor	Cash Sponsorship(£)
WMG	3950
Vice Chancellor	1000
Mouser	3000
School Of Engineering	1050
IMRC Money received in parts	2529.14
Total	**11529.17**

Table 5: Monetary Contributions from Sponsors in 2011/12

Axis Securities and Deloitte were two contacts that were made by sending out specialised emails and attending career's events. Both companies were highly impressed with the project and were keen to sponsor, however as the budget for the current year was already allocated, WMR was asked to contact them early next year for this to be a possibility.

Relationship with past and present sponsors was of great importance to the team. In order to keep them up to date with the progress of the project, email contact was maintained throughout the year. In addition, a newsletter was produced at the end of each term and a report on the competition achievements.

6.0 Finance

An initial estimate of £16,000 was budgeted for based on the costs of the WMR improvements made in 2010/2011. This took our initial design concepts into account, along with our expected costs throughout the year, such as the entrance and travel to the competition.

Figure 14, displays our initial allocation to each area of the project against our actual expenditure in each area at the end of the project. The total budget was below the targeted £16,000 (as shown in section 5.0). However, diligent planning and allocation of the budget ensured we could achieve our project aims.

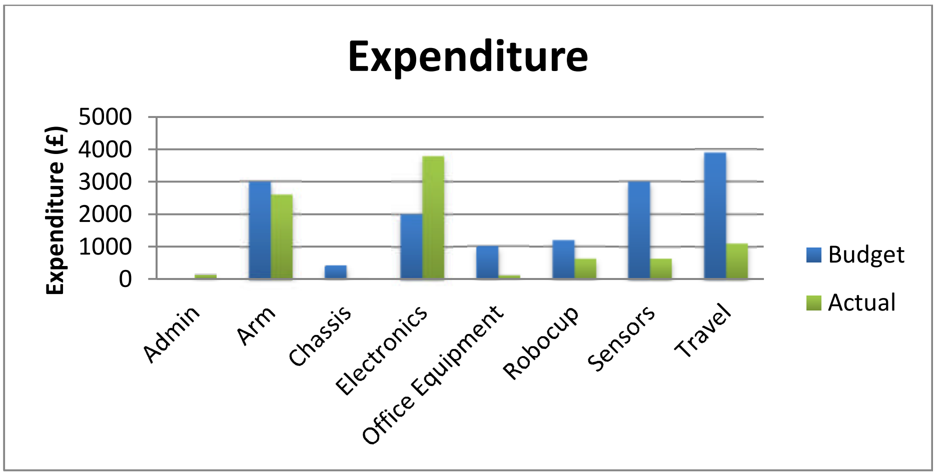

Figure 14: Graph to show the budgeted amount along with the actual expenditure

Table 5 highlights the 'cash' sponsorship gained. It should be noted that Harwin provided technical support and products throughout the project as a means of sponsorship. The product value totalled approximately £1500.

The total 'cash' budget for the project was reduced by a deficit carried over from the WMR team in 2011/2012. This reduced our real budget from £11,500 to £10,000 as the debt was cleared.

6.1 Expenditure

As the project progressed, designs evolved and financial priorities were affected. For example, initially there was no plan to outsource manufacture of the mechanical arm. However, due to strict limitations with staffing and time schedules with in-house technicians it was necessary to use external machining companies to complete the manufacture of components within the tight timeframe. In addition, the decision to reduce the number of team members who travelled to the competition was made to ensure necessary funds would be available for the actual robot improvements and that the project account remained in credit.

Figure 15 shows the breakdown of actual expenditure on each area.

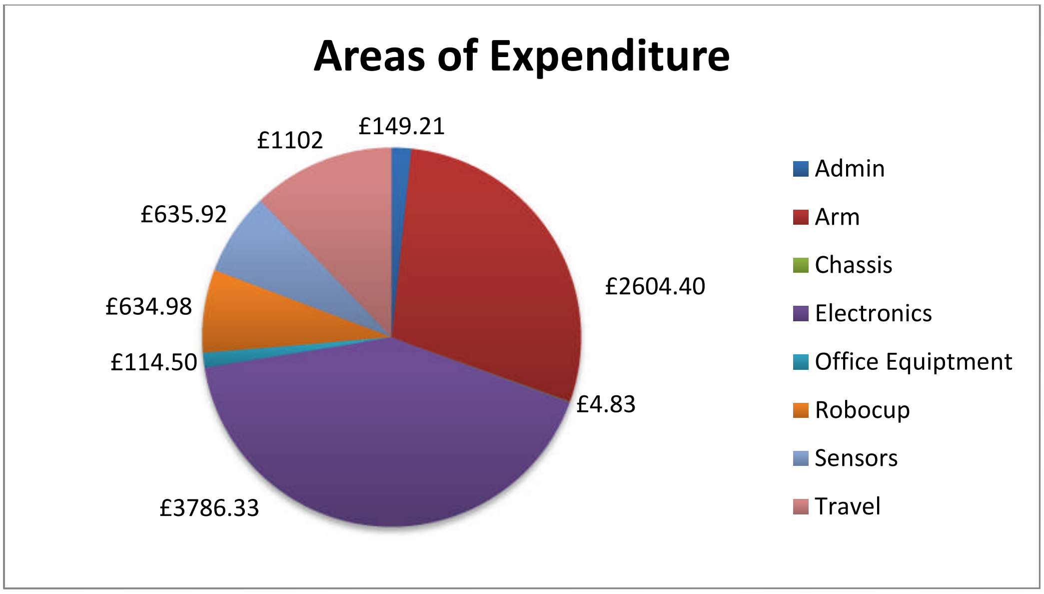

Figure 15: Pie chart showing the areas of expenditure

Finances were accurately controlled by recording each purchase made into a global spreadsheet. The spreadsheet contained supplier information and highlighted the remaining balance after each purchase to prevent overspending. Receipts and invoices were all filed for consistency and organisation, and used to validate purchases in collaboration with the finance department. The account at the end of the project has a £400 surplus, illustrating the tight financial control taken.

The following Table (Table 6) outlines the total cost of the project, including the cost of individual project members, technical staff, project directors and purchases made.

Personnel	Hours Worked	Hourly Rate	Total Cost
8 x WMR Team Members	2400	£15	£36000
WMG Technical Staff	171	£20	£3420
Project Director Peter Jones	25	£50	£1250
Project Director Emma Rushforth	25	£50	£1250
Purchases on Dissemination money			£2529.17
Purchases on WMR cost codes			£7009.13
		Total	£51458.3

Table 6: Total cost of the project

7.0 Publicity

This year the WMR team has made a special effort to increase the public profile of rescue robotics through the participation in the WIMRC's Outreach Program, the Science Museum's Antenna Live Exhibition and newspaper articles.

7.1 Outreach

The Outreach Program aims to raise schoolchildren's awareness of Science, Technology, Engineering and Maths (STEM) through real life examples of engineering projects. Figure 16 shows the Tele-Operated Robot in demonstration at a local school.

Figure 16: Robot during the Outreach program

During the course of the project, the team have visited a number of local schools (shown in Table 7) to talk about the project and give demonstrations of the robot's capabilities.

School Visited	Location
North Leamington School	Leamington
Till Hill Wood Sixth Form	Coventry
Whitley Academy	Coventry
Stratford Grammar School for Girls	Stratford
Caludon Castle School	Coventry

Table 7: Schools Visited

In February 2012 the WMR team participated in the Antenna Live Exhibition for four days. Members of the team gave talks and demonstrations about rescue robotics over this period. The setup is displayed in Figure 17.

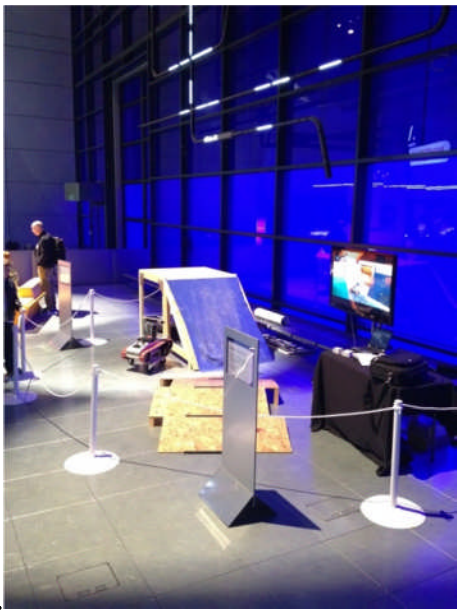

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Figure 17: Setup during the Antenna Live Exhibition

Jessica Bradford a member of the Exhibitions Team at the science museum provided the following feedback from the event:

> *"Warwick Mobile Robotics engaged over two thousand visitors during a record-breaking Half Term at London's Science Museum. As well as showing off the skills of their autonomous rescue robot, the team answered questions from museum visitors and staff. Our younger visitors were especially thrilled to see the robot in action. The team's energy and enthusiasm contributed to a lively event- one which I'm sure has inspired many budding roboticists."*

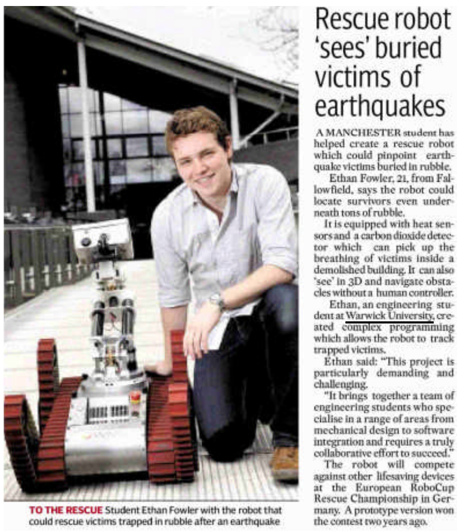
7.2 Media

A substantial amount of media coverage was gained from attendance at the Science Museum and our participation in the RoboCup Competition. A series of media articles released during 2011/2012 are summarised in Table 8.

Media	Name	Date
Newspaper	Coventry Telegraph	Mar-12
	Manchester Evening News	Mar-12
	Liverpool Echo	Apr-12
	Coventry Telegraph	Apr-12
	Evesham Observer & Evesham Journal	Apr-12
	The Boar (University Newspaper)	Apr-12
Websites	Warwick university	Mar-12
	Culture 24	Feb-12
	Talk Science, Science Museum Learning	Feb-12
	View London	Feb-12
	Referenced in a BBC article titled 'Kinect for Windows gesture sensor launched by Microsoft.'	Feb-12
	Rex Press Agency	Feb-12
	London Mums	Feb-12
	Science Business	Mar-12
Others	BBC Focus magazine (with a reach of 66,445 readers.)	Nov-11
	Facebook and Twitter	

Table 8: Media coverage

Figure 18 is a sample media publication taken from the Manchester Evening News. The piece focused on a team member's participation in the RoboCup Competition and their contribution to the project. Other sample articles are displayed in Appendix C.



TO THE RESCUE Student Ethan Fowler with the robot that could rescue victims trapped in rubble after an earthquake

Rescue robot 'sees' buried victims of earthquakes

A MANCHESTER student has helped create a rescue robot which could pinpoint earthquake victims buried in rubble.

Ethan Fowler, 21, from Fallowfield, says the robot could locate survivors even underneath tons of rubble.

It is equipped with heat sensors and a carbon dioxide detector which can pick up the breathing of victims inside a demolished building. It can also 'see' in 3D and navigate obstacles without a human controller.

Ethan, an engineering student at Warwick University, created complex programming which allows the robot to track trapped victims.

Ethan said: "This project is particularly demanding and challenging.

"It brings together a team of engineering students who specialise in a range of areas from mechanical design to software integration and requires a truly collaborative effort to succeed."

The robot will compete against other lifesaving devices at the European RoboCup Rescue Championship in Germany. A prototype version won the contest two years ago.

Figure 18: Media publication from the Manchester Evening Standard

Media efforts have evidently aimed to increase the awareness of and enhance the profile of Warwick Mobile Robotics and the development of Search and Rescue Robots. Engagement in media activities shares our knowledge with the public and aims to acquire further expertise and finance to continue the progress which has been achieved. With sufficient support WMR can continue to strengthen the robotics research and application community.

8.0 Project Management

8.1 Tools

All engineering projects require effective planning, functioning communication methods and 'buy in' from all participants to gain project success. A robotics project is relatively unique, and poses a particular challenge because of the combined engineering disciplines it entails. This project required the integration of Mechanical, Electronic and Software functions to deliver a truly capable system, hence planning of tasks and cross discipline communication was of high importance.

Several project management techniques were employed throughout the project in order to meet the aims and objectives set.

8.1.1 Team Building

Initiating a team ethic and creating a culture which worked towards a common goal was of high initial importance. The relatively short timescale of the project meant that the team needed to function as a whole from the start of the project and grow throughout its duration.

A notable factor which contributed to the team's early success and aimed to generate a collaborative culture for the whole period was the initial team building exercises executed. These included a range of social events; such as dining out and participation in sporting activities.

8.1.2 Specifications

A series of specifications were established for the technical parts of the project. Without formally initiating the project in this manner, judging progress and direction is made difficult because objectives and requirements are unknown. A project cannot be managed without knowing what it is trying to achieve. Hence, formulating specifications was completed as a prerequisite to the project management approach.

8.1.3 Gantt chart

Project goals, partially derived from the specifications, were constructed in a Gantt chart to associate their undertaking with time. Several project plans were made throughout the year, all of which marked the major deadlines and milestones required for the reward deliverables and a breakdown of the tasks which needed to be completed in order to deliver both the technical and business propositions (for example, the manufacture of the arm components and the Science Museum visit). Viewing tasks and respective deadlines in tandem allowed for simple evaluation of the duties which corresponded to maintaining progress and critically identified the risks to project delivery. Hence, risk could be alleviated by making informed decisions where activities were in danger of, or actually surpassing, their deadline. An example plan from the project is shown in Figure 19.

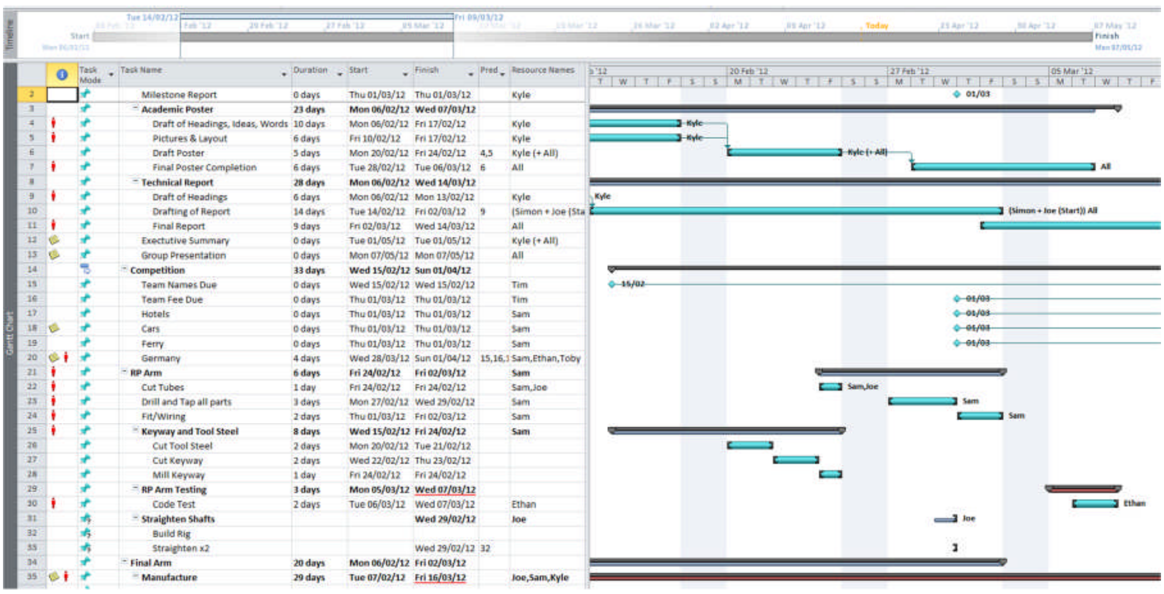
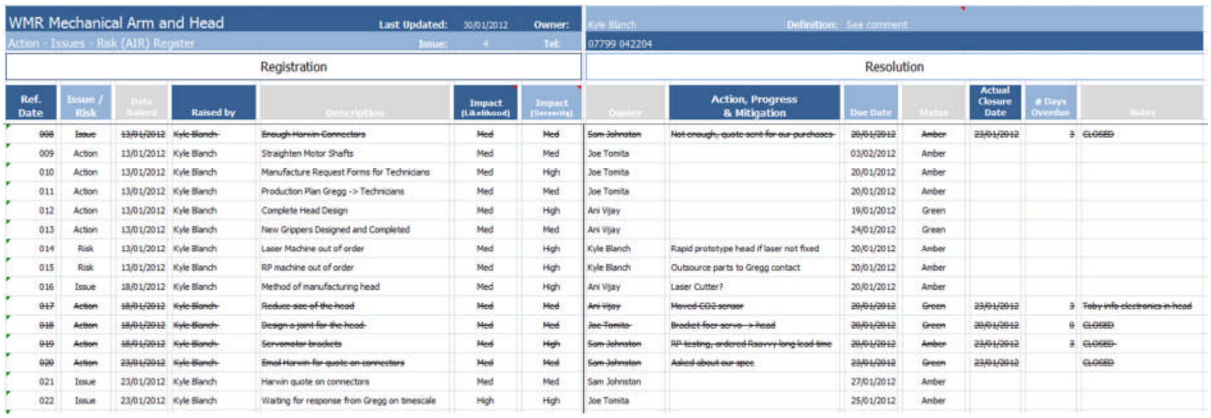


Figure 19: Sample Section of Project Plan (in MS Project)

Many difficulties surrounded the planning of tasks, with forever changing demands (such as school visits and manufacturing requirements), made creating a detailed plan which was consistently accurate, an unfeasible requirement. Instead, the project plan was constructed such that high level tasks were only displayed, yet the lack of experience in assigning time scales to tasks made mitigation a common principle in practice.

8.1.4 Management of Task Delegation

At a more detailed level, individual tasks were managed using a different project management tool, an AIR (Actions, Issues and Risks) register. This assigned all actions, issues and risks to a specific individual for progression, resolution or mitigation. Tasks were assigned based upon current project workload, specific role within the team and skills required to complete the task and complete it. A separate AIR register was developed for particular parts of the project (e.g. Mechanical Arm, Software etc.). The AIR also included a short description of the task, the date it was raised, the date it was scheduled to be completed, its criticality to the project and its current RAG status. This was displayed in the laboratory and regularly updated and distributed to the team when changes were made. An example register from the project, created using Excel, is shown below in Figure 20.



WMR Mechanical Arm and Head — Last Updated: 30/01/2012 — Owner: Kyle Blanch — Definition: See comment

Action - Issues - Risk (AIR) Register — Issue: 4 — Tel: 07799 042204

Registration							Resolution						
Ref. Date	Issue / Risk	Date Raised	Raised by	Description	Impact (Likelihood)	Impact (Severity)	Owner	Action, Progress & Mitigation	Due Date	Status	Actual Closure Date	# Days Overdue	Notes
008	Issue	13/01/2012	Kyle Blanch	Enough Harwin Connectors	Med	Med	Sam Johnston	Not enough, quote sent for our purchases	20/01/2012	Amber	23/01/2012	3	CLOSED
009	Action	13/01/2012	Kyle Blanch	Straighten Motor Shafts	Med	Med	Joe Tomita		03/02/2012	Amber			
010	Action	13/01/2012	Kyle Blanch	Manufacture Request Forms for Technicians	Med	High	Joe Tomita		20/01/2012	Amber			
011	Action	13/01/2012	Kyle Blanch	Production Plan Gregg -> Technicians	Med	Med	Joe Tomita		20/01/2012	Amber			
012	Action	13/01/2012	Kyle Blanch	Complete Head Design	Med	High	Ani Vijay		19/01/2012	Green			
013	Action	13/01/2012	Kyle Blanch	New Grippers Designed and Completed	Med	Med	Ani Vijay		24/01/2012	Green			
014	Risk	13/01/2012	Kyle Blanch	Laser Machine out of order	Med	High	Kyle Blanch	Rapid prototype head if laser not fixed	20/01/2012	Amber			
015	Risk	13/01/2012	Kyle Blanch	RP machine out of order	Med	High	Kyle Blanch	Outsource parts to Gregg contact	20/01/2012	Amber			
016	Issue	18/01/2012	Kyle Blanch	Method of manufacturing head	Med	High	Ani Vijay	Laser Cutter?	20/01/2012	Amber			
017	Action	18/01/2012	Kyle Blanch	Reduce size of the head	Med	Med	Ani Vijay	Moved CO2 sensor	20/01/2012	Green	23/01/2012	3	Toby info electronics in head
018	Action	18/01/2012	Kyle Blanch	Design a joint for the head	Med	Med	Joe Tomita	Bracket for servo -> head	20/01/2012	Green	20/01/2012	0	CLOSED
019	Action	18/01/2012	Kyle Blanch	Servomotor brackets	Med	High	Sam Johnston	RP testing, ordered Raswy long lead time	20/01/2012	Amber	23/01/2012	3	CLOSED
020	Action	23/01/2012	Kyle Blanch	Email Harwin for quote on connectors	Med	Med	Sam Johnston	Asked about our spec	23/01/2012	Green	23/01/2012		CLOSED
021	Issue	23/01/2012	Kyle Blanch	Harwin quote on connectors	Med	Med	Sam Johnston		27/01/2012	Amber			
022	Issue	23/01/2012	Kyle Blanch	Waiting for response from Gregg on timescale	High	High	Joe Tomita		25/01/2012	Amber			

Figure 20: Sample AIR Register from the Project (Mechanical Arm and Head)

8.1.5 Communication

Several means of communication were exploited during the project, including meetings, emails, document sharing resources and social media applications (such as Facebook and Skype). The nature of the project often required communication across the team, either to understand tasks in greater detail, to share knowledge or to make decisions which had an impact on a range of functions.

A Project Directors meeting was held weekly to discuss the progress and challenges which were being faced. These were highlighted in a formal meeting chaired by the project manager and structured with an Agenda and subsequent reporting of the meeting Minutes. A secondary team meeting was held weekly, where topics were largely focussed on the project details and active work plans, again structured with an Agenda to conduct a worthwhile meeting.

9.0 Conclusions

The redesign of a new mechanical arm was the biggest improvement of this year's robot. The title of 'Best in Class Manipulation' at the RoboCup Competition supports this statement. The reliability and functionality of the arm was improved considerably; the shoulder joint was able to rotate and lie horizontally without problems to the motors and control boards. Motor shafts were supported and bending was prevented. Backlash was also controlled and adjusted to suit.

The exclusive use of AX-3500 motor control boards has improved the communication within the software system. Improvements to the electronic stack and wiring have increased the levels of reliability and ease of maintenance. The reliability of the electronics system continues to be the critical feature of the robot, as small issues will lead to decreased performance (as described in section 4.2).

The greatest challenge overcome in terms of software systems is the successful integration of hardware on the new mechanical arm, as demonstrated by the achievements in the competition. Conversely, the competition also highlighted an area of weakness; a lack of remote operator feedback and awareness.

Finishing 2nd Place Overall in the RoboCup Rescue 2012 German Open and winning two additional titles was a great achievement. Unfortunately, driver error and a culmination of a number of small issues (as described in section 4.2) prevented the team from winning the overall competition.

A clear chain of communication was vital for the team to integrate successfully. Mechanical, Software and Electronic systems must be successfully incorporated before progress with the robot platform can be observed. It was vital to have regular team meetings to update all members on the work and progress of each area. Visibility of the whole project was available to all team members through regular communication and successful use of project management tools including an Actions, Issues and Risks (AIR) register which successful documented tasks and logged progress.

Despite operating on a budget of £11,500 that was lower than previous years, meticulous planning and allocation of the budget ensured we could achieve our project aims. The account at the end of the project has a £400 surplus, illustrating the tight financial control taken. A substantial amount of publicity and media coverage was gained from attendance at the Science Museum and our participation in the RoboCup competition along with numerous local school visits. This has raised the profile of Urban Search and Rescue Robots as a subject, but more directly the success and competence of the WMR group.

10.0 Recommendations for Future Work

Despite the knowledge of the importance of software integration and testing time, delays in the manufacture and delivery of the arm resulted in the inability to implement a fully working inverse kinematics solution in time for the competition. For example, calibration errors in Rapid Prototype parts caused delays due to the necessity to manufacture more critical parts from aluminium billets. More efficient planning and the knowledge of in-house resources in terms of personnel and machinery are critical if successful modifications are made to the robot platform in future years.

One problem that contributed to driver error in the RoboCup Competition was the lack of a camera mounted high enough to provide an accurate view of the robot and its surroundings. An additional improvement to the mechanical arm would be an additional degree of freedom, such as rotation in the x-axis. This would allow the head to remain horizontal even when the robot is positioned on an angled ramp or step field.

A redesigned robot chassis could further enhance the robot's locomotion and allow WMR to remain ahead of the competition. Areas of improvement include incorporating drive tracks to run directly under the robot chassis to reduce the likelihood of the robot 'bottoming-out' over steep step fields. Further developments beyond this would include designing the chassis to be waterproof and dust tight, with the inclusion of a lightweight space frame structure to provide the ultimate levels of rigidity and performance.

Any future WMR team would benefit from having a greater number of personnel with a strong interest and expertise in the areas of software and coding. There is a real need to provide a better balance to the team in terms of resource allocated to the mechanical, electronic and software aspects. One possible route for the project is to form a partnership with an established institution to collaborate and share knowledge. The team was approached by Team GetBot at the RoboCup Competition, who were interested in a joint collaboration to further develop the WMR platform through their superior proficiency in programming.

Continued levels of attentive planning of the financial budget and increased levels of sponsorship are critical to the success of the WMR project in the future. Future improvements to the robot platform will necessitate continued levels of funding, from both internal and external institutions and companies.

Appendices

A Mechanical Arm Design

The following design changes are aimed at removing delivering the project objectives of making the mechanical arm functional and reliable.

A.1.1 Shoulder Joint Configuration

The motor powering the shoulder joint is under the highest load as it accounts for the movement of mass in the whole structure. Figure 21 below highlights the configuration of the gearing mechanism where the motor has been placed in a static position to drive the worm gear about a fixed axis. The shoulder joint mechanics has been designed to enable rotation of the worm and the worm wheel about their own rotational axes.

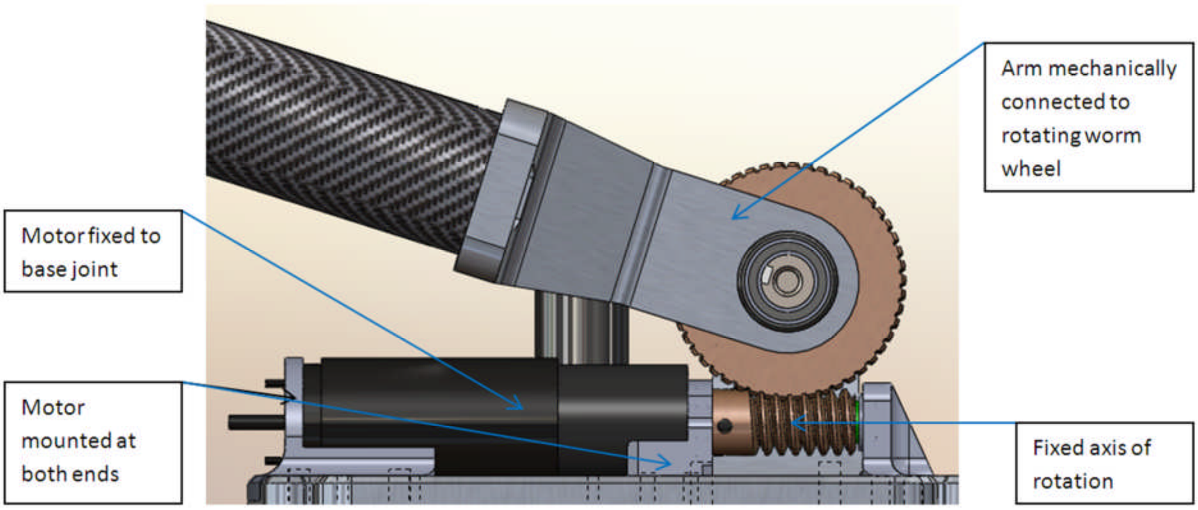


Figure 21: Shoulder Joint Motor Positioning and Accurate Meshing of Teeth

A.1.2 Fully Supported Motor Shaft

The motor shaft support mechanism is highlighted in Figure 22 below. A ball-bearing is encased in a support housing to fully support the worm gear and Maxon planetary gearbox shafts during operation. A thrust spigot is used to mechanically connect the worm gear to the ball bearing. The beam is supported at both ends to reduce deflection, improving the reliability of meshing and reduction in backlash which is critical when the joint is subjected to load and vibration.

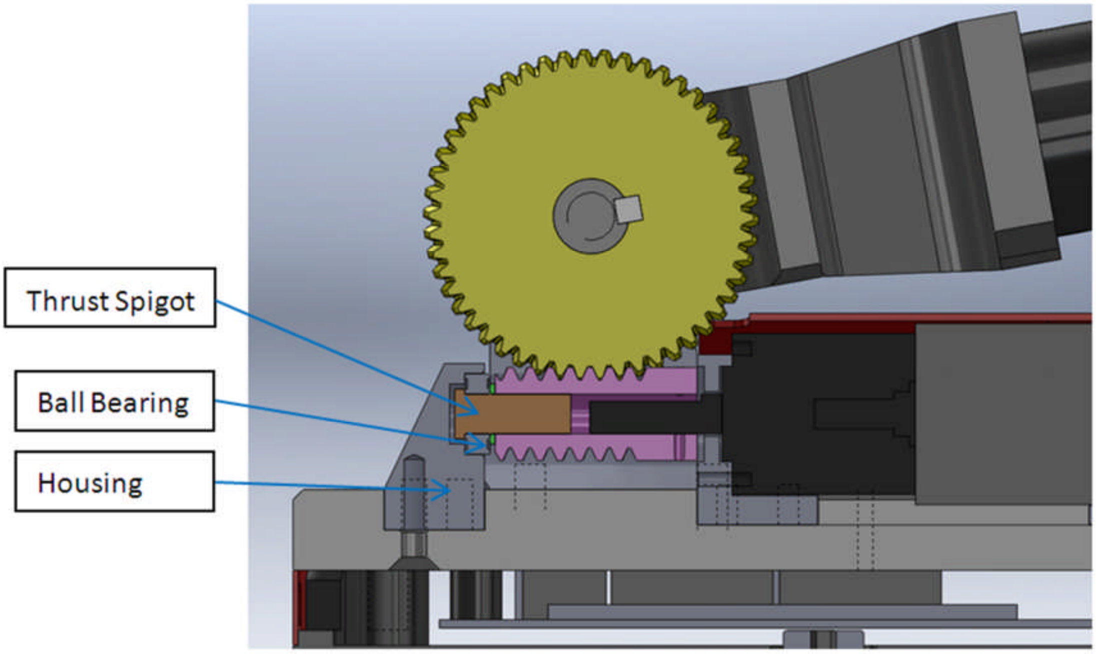


Figure 22: Thrust Spigot and Ball Bearing

A.1.3 Modular Design of Joints

The new joint structures were developed with significant consideration of the manufacturing processes. Parts assigned for machining processes have been designed to meet the specific geometry conditions for the use of 3-axis milling and reduce the number of machine set-ups required. This has simplified the manufacture of components in terms of equipment and skilled resource needed. Modular design of joints has also allowed the centre distance between the worm and worm wheel to be easily modified by using shims as shown in Figure 23 below. This mechanism therefore contributes to the objective of having a stable Mechanical Arm by ensuring accurate meshing of teeth. An additional benefit of using simple parts concerns the ease and speed of modification and replacement of small pieces rather than large blocks, essential for a bespoke design.

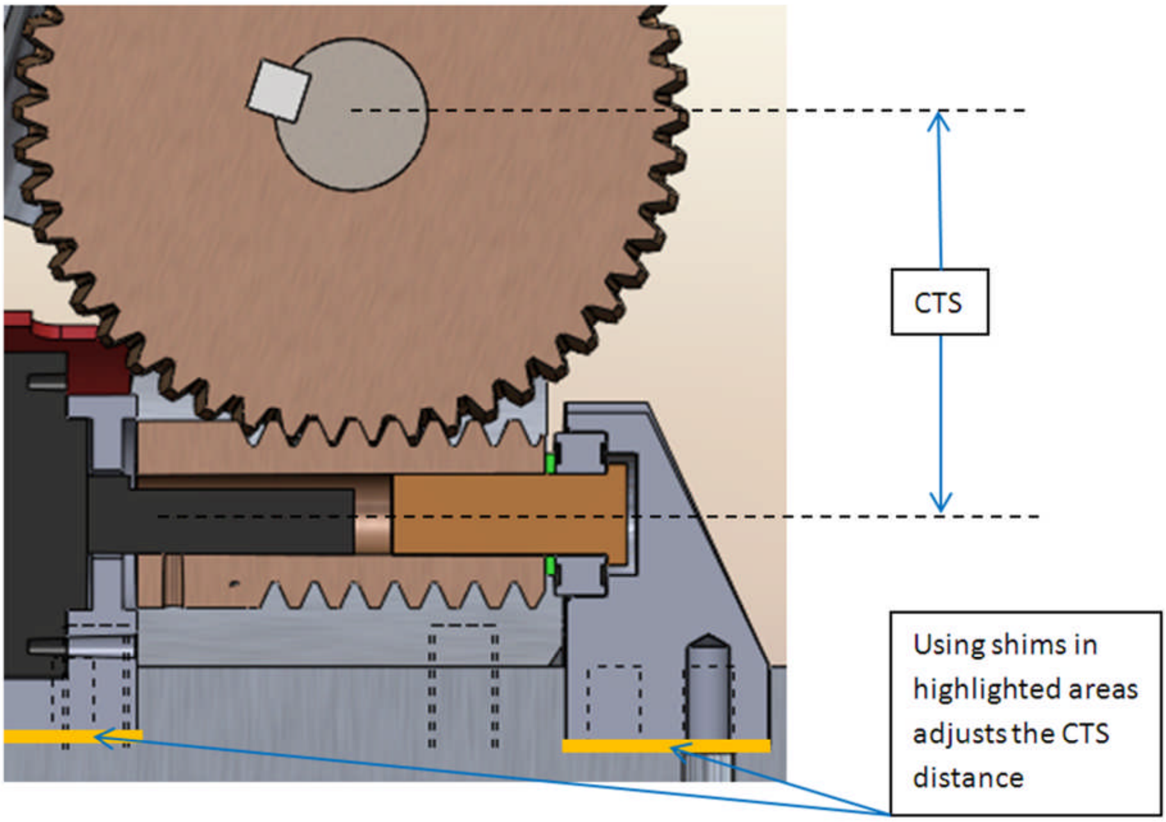


Figure 23: Centre Distance altered by adding and removing shims

A.1.4 Mass Re-distribution

A critical design objective was to relocate mass nearer to the body of the robot to keep overall centre of mass as low as possible.

Moving mass closer to the base of the arm reduces the total moment of inertia around the shoulder joint axis and will reduce the likelihood of the robot toppling. The arms resistance to changes in motion is therefore lowered, reducing backlash susceptibility.

Amalgamation of the router into the base joint, as shown in Figure 24 is one mass re-distribution measure applied.

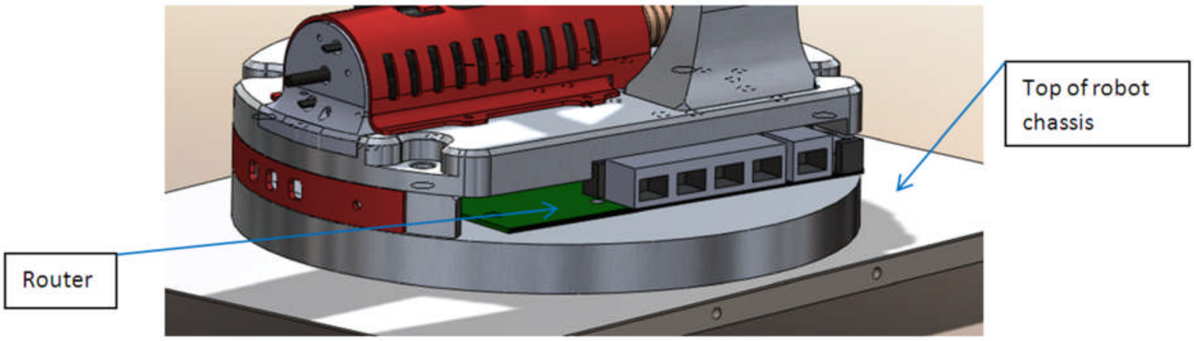


Figure 24: Router in the Base Joint

Components of the wrist and elbow joint have used rapid prototyped parts from Selective Laser Sintering Technology. This has reduced total joint mass and reduced the stress on the motors in the arm.

A.1.5 Concentric Mounting of Base Rotation

Concentricity of the connection between the Mechanical Arm and the robot body simply increases the functionality and reliability of the system because the spur gear used for base rotation can be accurately and consistently meshed with the annulus ring. Figure 25 below displays the precise alignment of the connection using a shoulder bolt and sleeve to eradicate movement.

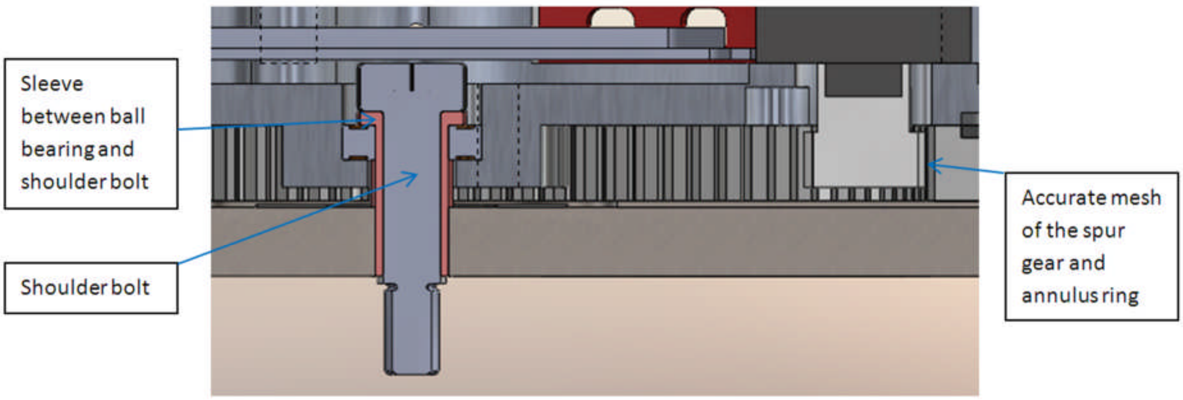


Figure 25: Cross-section of sleeve and Shoulder Bolt with Teeth Mesh

B Software and Systems

B.1.1 Arm Control

The foremost objective was to facilitate effective usage of the new arm design; that is to say that the user should be able to manoeuvre sensors and manipulator to the fullest mechanically possible extent. An implied objective was ease of use; a counter-intuitive or unreliable method of control would limit the speed and accuracy of arm usage, to the detriment of robot effectiveness and competition performance.

1. **Motor Controllers –** Roboteq AX500 motor controller boards that had previous powered some arm joints were replaced with AX3500 boards, making all motor control hardware identical. Existing AX3500 interface software had to be diversified to accept the differing feedback mechanisms/hardware attached to motors; the track use none, the flippers relative digital positional, and the arm joints absolute analogue positional.
2. **Hand-held Controller –** The existing controller was replaced by a model with more analogue control methods; by using physical controller tilt as an input, all arm joint control can be controlled from a single controller without changing mode.
3. **Inverse Kinematics** – The direct and intuitive control of end-effector position was expected to increase the speed and accuracy of movement. Prototype software was developed to accept operator commands, determine desired effector position, calculate possible joint solutions, choose the best and enact it. Due to manufacturing delays, the calculation portion of the software could not be properly debugged in time for competition runs, and joint control was used.

B.1.2 Wiring, Connections and the Stack

1. **Harwin Connectors** – Previous teams have used Harwin connectors, though use of hot-glue suggest improperly. Existing connectors were replaced with the latest types, and the arm wiring

loom was made modular using connectors. The connectors made disassembly easy, and locked securely, but were prone to failure despite proper crimping technique.

2. **Chassis and Stack** – All wires within the chassis were replaced, colour coded and properly restrained. The stack was similarly improved, removing excess cabling, colour-coding, and rearranging board positions for easier connection.
3. **USB Hub** – The inclusion of a USB hub within the head reduced the number of USB cables running through the arm from 5 to 1, and allowed single-connector access to all USB sensors.
4. **Battery Voltage Monitors** – Without under-voltage warning circuitry, there is risk of permanently damaging Lithium Polymer batteries when discharging. Past attempt at in-house circuitry have failed. Off-the-shelf LiPO battery monitors were found, capable of warning of individual cell under-voltage; the batteries are now protected from discharge damage.

B.1.3 Sensors

The second major objective was that sensors and manipulator should then able to carry out their designed purpose, i.e. return information to the user, or allow the user to interact via the robot. An implied objective was that the flow of data be reliable and low-latency.

1. **Axis M1054 IP Camera –** This model offered high resolution and low latency, as well as full duplex audio, although duplex audio is susceptible to feedback without gain tweaking. The camera's MJPEG stream provided a low-bandwidth video solution, independent of computer on-state. The built-in illumination LED also helped point-scoring during the manipulation test.
2. **Infrared Camera –** The deprecated and non-functional custom-written video server previously used for infrared video streaming was replaced by a short script, controlling commonly-used open-source software. The stream produced is an adjustable-bandwidth low-latency MJPEG stream, allowing similar code for interface display of both RGB camera and infrared camera feeds.

3. **CO_2 sensor –** Testing of the sensor was low priority, as unchanged hardware and software implied that the sensor would still be functional; at the competition it was found to be non-functional, and could not be repaired in time for competition runs.
4. **Gripper –** The gripper was of low priority as it was found to be of no competitive advantage, and therefore was brought to functionality.
5. **Flipper positioning –** Existing flipper encoders provide relative encoding, resulting in a lack of operator awareness. Due to mechanical and space constraints, the proposed solution was to mount absolute Hall Effect rotary sensors between the chassis and gearbox shaft. Due a single-digit error in order code, un-programmed sensors were ordered in place of pre-programmed, and the mistake could not be rectified in time for the competition. The software and host circuitry are ready for next year's team.

B.1.4 Interface

Another objective was that sensor information should be readily accessible to the operator, for speed of operation and maximum competition and real-world performance. To this end, the user interface was regularly re-structured to incorporate newly functional sensor data.

1. **QR Code Reading** – Competition points were available for detection and decoding of QR codes placed in the arena. Software was written to extract a still frame from IP camera feeds, convert it to binary (black and white), and supply it to an existing decoding library. The result is displayed on the user interface as an alert, and recorded.
2. **Control gain sliders** – Since different scenarios required different track or arm movement speeds, a slider interface was added to the interface, capable of real-time control gain adjustment.

Figure 26: Interface of the Tele-Operated Robot

3. **Centre of Gravity** – A visual representation of the robot's tilt and centre of gravity would help prevent overturning. The trigonometric code that would underpin such a system was developed, but not implemented into any kind of display, and so could not be employed.
4. **3D Representation** – A visual representation of robot limb positioning would improve operator awareness, and speed/accuracy of control. Some progress was made in creating a representation from scratch, but it was found to be complex; instead, the existing representation was to be updated. These updates were not completed.

B.1.5 Mapping

The ability to produce a representation of explored areas is key to both a search and rescue robot's functionality, and success at the competition. The implementation of 2D mapping was set as an objective, with 3D mapping being a potential addition. Trigonometric software was written capable of producing a Cartesian point-cloud of points in the plane of the module scan. With the addition of an xSens tilt sensor and the writing of 3D trigonometric software, 3D scans such as that in Figure 27 were produced.

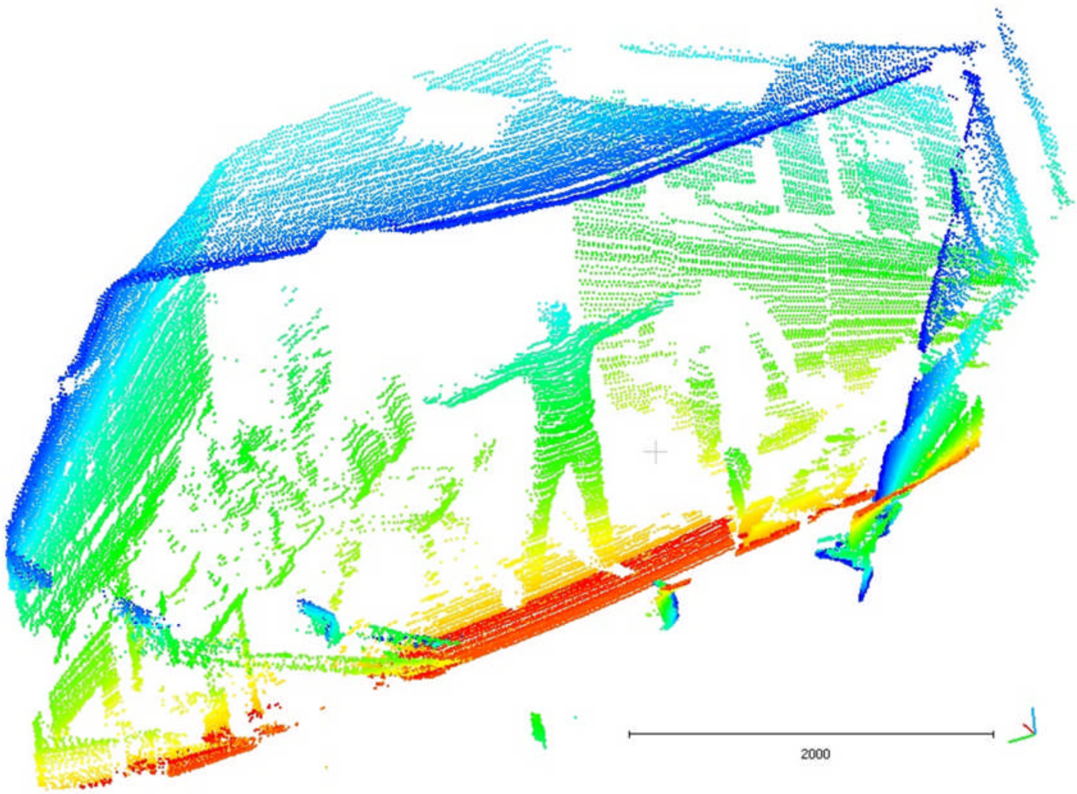


Figure 27: 3D LiDAR and xSens scanning

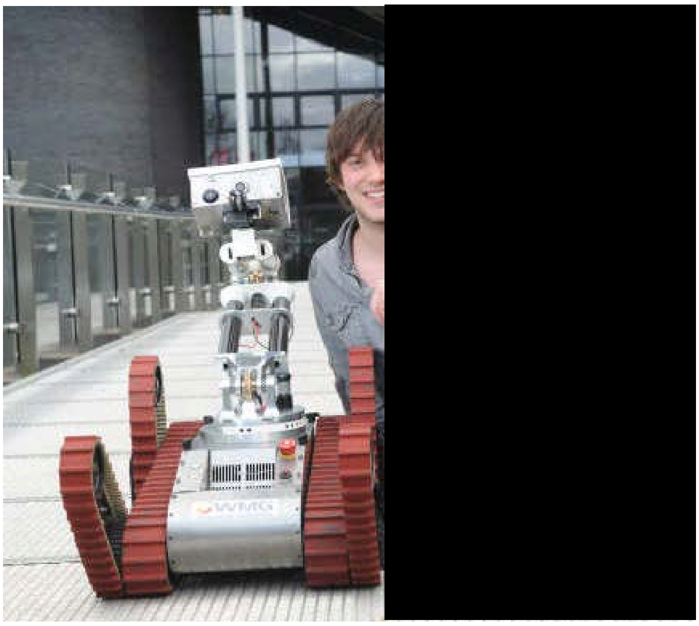
The process of SLAM mapping requires the calculation of the spatial offset between consecutive (2D or 3D) scans. Many 2D SLAM algorithms were examined and attempted, but with the competition approaching, the best results were still inaccurate: a human being could interpret the shapes being displayed, but the resulting map was too noisy to score points, or be any use to an automated navigation system.

During the competition, Stefan Winkvist adapted the 3D SLAM software that was the result of his PhD and ran it alongside the robot software, using the LiDAR and xSens combination already mounted on the head. The resulting 3D maps are proof of both the concept, and Stefan's software, but could not be considered a result of the WMR project.

C Publicity- Newspaper Articles

Vale student in robotics success

By Gary Smee 12/04 Updated: 12/04 12:10 Like



Buy photos » **Sam Johnston was part of the University of Warwick's winning Mobile Robotics team. (s)**

A BRIGHT spark from Ashton-under-Hill has scooped a pair of awards at a prestigious robotics competition.

Sam Johnston was part of the University of Warwick's Mobile Robotics team which recently competed at the European RoboCup Rescue Championship.

The eight strong team's tele-operated robot had to navigate through a simulated earthquake disaster area, searching, locating and helping victims who were trapped.

The robot used a series of human detection devices including a web-camera, CO2 sensor and infra-red camera to search for survivors.

The team eventually came away with special awards for Best in Class for Mobility and Best in Class for Manipulation at the four day competition in Germany.

Mechanical engineer Sam said: "We are all delighted to have achieved second place and been handed awards for the Best in Mobility and Best in Manipulation.

"All of us have really enjoyed the project and are immensely proud that we have done so well at a highly fought international event."

The team was backed by WMG academic, Dr Emma Rushforth, and Dr Peter Jones, from the University's Engineering department, who were equally pleased with the students achievements.

STUDENT'S SUCCESS

A LIVERPOOL student's creation came second in the European RoboCup Rescue Championship.

Simon Yeung, who studies at Warwick University, was part of a team which helped created a tele-operated robot to navigate and search a simulated earthquake disaster area as part of their final year academic project.

University's disaster rescue robot delivers awards success

A TEAM of engineering students from Warwick University have come second in an international robotics competition.

The eight students designed a robot which would be capable of rescuing people after disasters such as earthquakes and explosions.

They took their machine to the European Robocup Rescue Championships in Germany to compete with others from around the globe.

As well as second place overall, their robot won best in class for mobility and best in class for manipulation at the four-day contest.

It has a web camera, a carbon dioxide sensor and an infra red camera to search for survivors in disaster zones too dangerous for people to enter.

Project manager Kyle Branch said: "We are all delighted to have achieved second place and been handed awards.

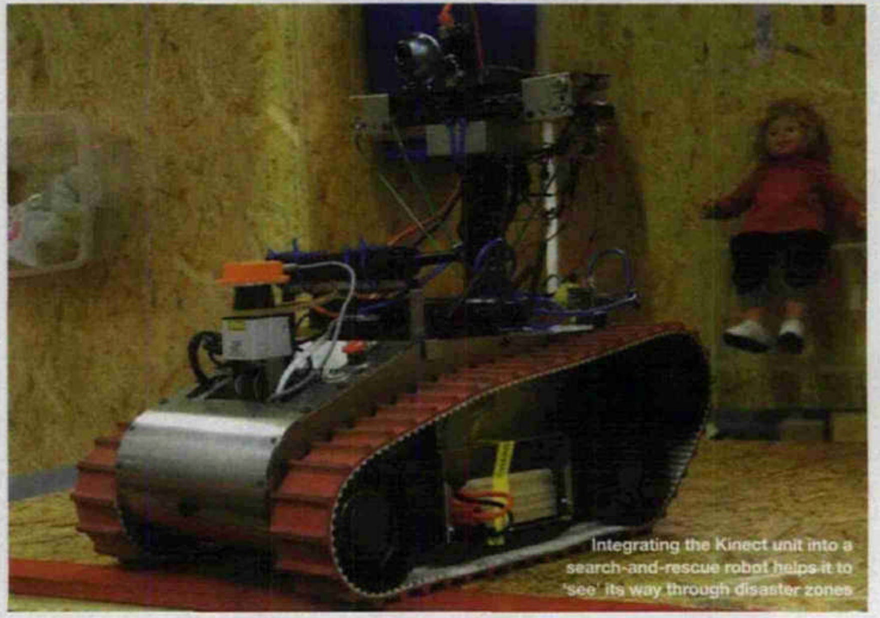
"All of us have really enjoyed the project and are immensely proud that we have done so well at a highly fought international event."

Dr Emma Rushforth, the academic backing the team, said: "It is fantastic that the Warwick Mobile Robotics team has picked up two awards and been placed second overall.

"The competition in Germany is tough but this group developed and built an excellent robot which is deserving of the accolades."

ROBOTICS

Search-and-rescue robots need precise information about their surroundings in order to navigate their way to disaster survivors without getting stuck. Roboticists at the University of Warwick have realised that Kinect is just as good at this as sensors that cost 10 times as much. They've hacked the device and used it as the 'head' of their latest rescue 'bot. Aesthetically speaking, the end result bears a passing resemblance to Johnny 5 from the *Short Circuit* films. But in technical terms, the infrared projector and sensor allow it to actively model its surroundings, while the camera sends a live feed to its operator. This feed can then be recorded, so rescue workers have a working map if the robot finds a survivor.



Integrating the Kinect unit into a search-and-rescue robot helps it to 'see' its way through disaster zones

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Busy 'bots

Posted by Micol, Talk Science Project Developer on February 15, 2012; This entry is filed under powerful questions, Robots.

Tags: earthquake, engineering, robotics, robots, search and rescue

SO! It's half-term. Many of you are busy taking a well-deserved rest (STOP WORKING!) and some of you might even be thinking of visiting the museum.

If you do, make sure you head to the **Antenna** gallery, on the ground floor, to check out *Robots to the Rescue*, a live event featuring an incredible robot that will do incredible things, and meet the University of Warwick engineers who've developed it.

The future of seach and rescue?

This hardy little 'bot is designed to navigate rough terrain and hunt for signs of life - searching dangerous disaster zones such as collapsed buildings, making it easier and safer for rescuers to find their way to survivors.

They are only here until tomorrow so make haste!

If you can't make it to see them, **Futurecade's Robo-Lobster** game might make you feel better. Control your mine-seeking robots to keep the harbour safe from attack! The game is based around the idea of robots doing dangerous jobs so humans don't have to, just like University of Warwick's rescue robot will do one day.

So will robots just keep improving our lives? What kind of tasks are you happy for robots to take on?

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Chilean Rescue Capsule at Science Museum

Like | Be the first of your friends to like this.

See the Chilean rescue capsule at Science Museum and relive the dramatic moments when the 33 miners trapped in the San Jose mine were finally freed, after 69 days underground.

When
11 February 2012 - 13 May 2012

10am - 6pm

Where
Science Museum

Cost
Free

Age Restrictions
n/a

Fenix 2
Named Fenix 2, the 460kg, 3.9m high and 54 cm wide rescue capsule was designed and built by the Chilean Navy in order to rescue the 33 miners trapped 700 metres underground following the collapse of the San Jose mine in August 2010. See the Chilean rescue capsule at Science Museum and learn more about the huge technical and engineering obstacles that the rescue team had to overcome in order to recover the trapped miners.

Engineering feat
Painted in the red, white and blue colours of the Chilean flag, the miners' rescue capsule was fitted with enough oxygen enriched air to last the 20 minute journey to ground level, as well as an emergency release mechanism to guard against the capsule becoming stuck. The display of the Chilean rescue capsule at Science Museum gives you the chance to see one of the most iconic artefacts from the unprecedented rescue, which involved hundreds of scientists, technicians and engineers.

Rescue robot
Alongside the display of the Chilean rescue capsule at Science Museum, a rescue robot will also be on display during February half term. Nicknamed Pinky, the remote controlled robot has been designed to look for victims and map out challenging terrains. Pinky's design team will be on hand to demonstrate the robot's skills and features, which include sensors for search and navigation as well as flippers that enable it to climb stairs, ramps and uneven ground.

The Chilean rescue capsule at Science Museum can be seen from Saturday 11th February - Sunday 13th May 2012. Admission is free.

Pinky the rescue robot is on show from

venue infomation
venue map
user reviews (2)
image gallery (7)
what's on

What's near Science Museum?

Below are the nearest 5 venues within 500 metres of Science Museum.

Restaurants near Science Museum (5)
Pubs & Bars near Science Museum (5)
Clubs near Science Museum (5)
Cinemas near Science Museum (2)
Hotels near Science Museum (5)
Shopping near Science Museum (5)

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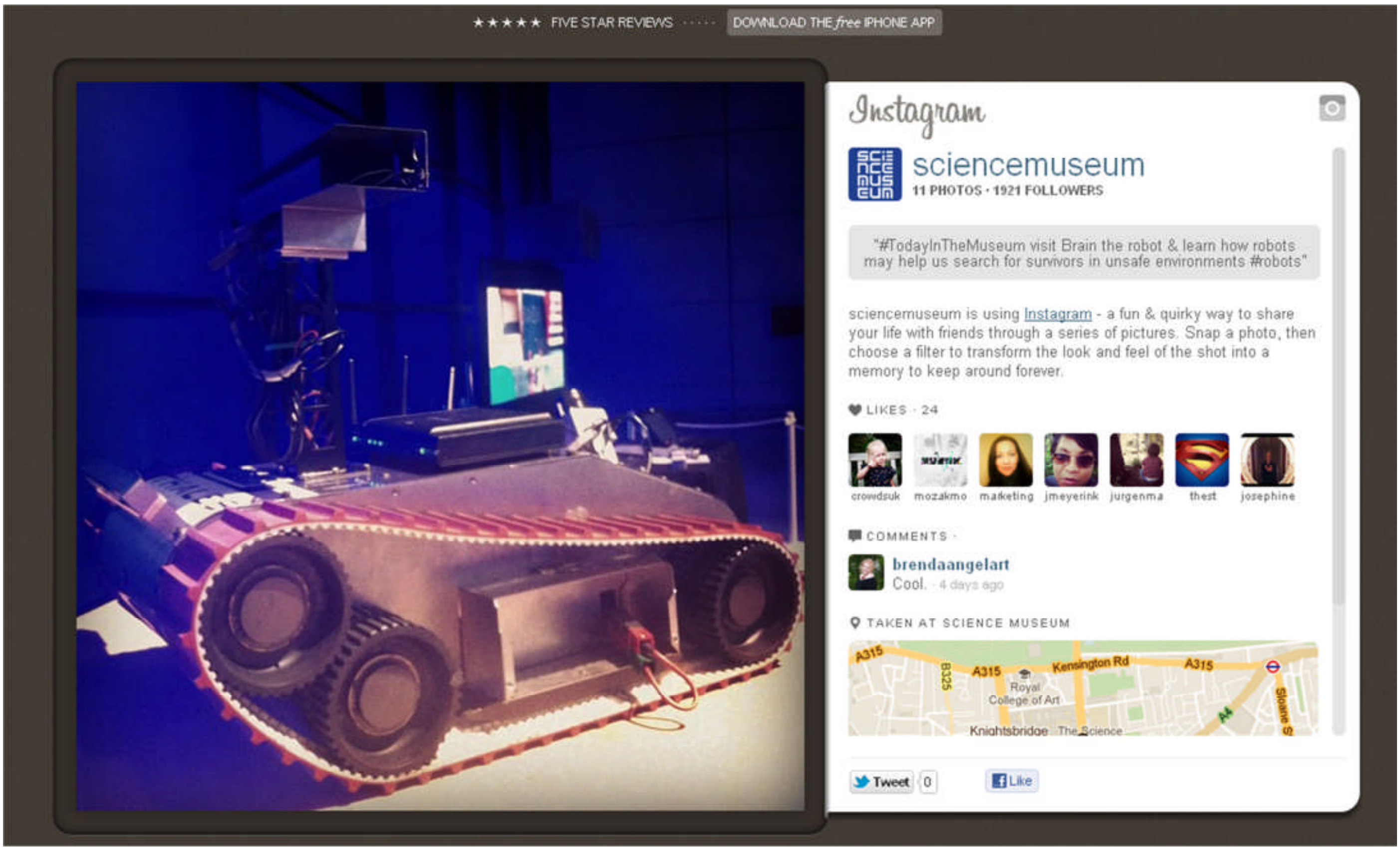

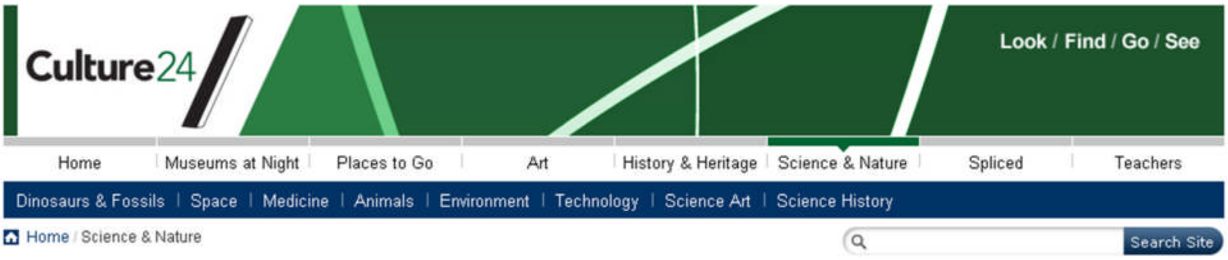

Fénix 2, the 460kg capsule built by the Chilean Navy to rescue 33 miners trapped underground at the San José mine in October 2010, is to go on display at the Science Museum in London.

Painted in the red, white and blue of the Chilean flag, the 3.9 metre steel saviour of the men, who were trapped at the bottom of a 700-metre deep shaft for 69 days, was built by engineers from the Chilean forces.

It was fitted with enough oxygen-enriched air for its 20-minute journey to the surface, as well as communication equipment and retractable wheels.

“It’s an icon of the unprecedented rescue mission of the 33 miners,” announced Katrina Nilsson, the museum’s Contemporary Science Manager, who said the venue was “honoured” to host the capsule.

“I’m sure we can all remember the moment when the first miner was pulled to the surface after being trapped for almost ten weeks.

“By showing the capsule at the museum, we hope to draw attention to the technical and engineering challenges that the rescue team tackled during this extraordinary operation."

The capsule will be on show until May 13, accompanied by a "rescue robot" called Pinky in a special Search and Rescue event during half-term (February 14-16).

Pinky can climb terrains, search for victims and produce impromptu maps, aided by two pairs of flippers, a gripper, a head on a robotic arm and various sensors.

The experts who built it will be on hand to answer questions about the remote-controlled robot while it is in action.

Warwick students come second in international robot competition

Friday 20 April, 2012

» rescue robot proved a hit at Robocup Rescue Championship

Chris Hackett

A team of Warwick students have come second in an international robotics competition.

The eight undergraduates from Warwick Manufacturing Group (WMG) and Engineering also won two awards for their rescue robot at the European RoboCup Rescue Championship.
The team's robot aims to access areas of danger in disasters to find trapped victims and inform rescuers of their location.

It can be remotely operated, has the ability to climb slopes, stairs and uneven terrain and has sensors to detect things like body heat and carbon dioxide. There are also front and rear cameras to give the operator full visibility.

The awards for Best in Class for Mobility and Best in Class for Manipulation were presented at the four-day competition in Germany.

“I think it is a great achievement,” said project manager Kyle Blanch, “We have improved the performance of the robot in the competition.

“I feel particularly proud to be involved in such a recognised project, not least because we were the entrant from the UK and the other teams were made up of PhD students and researchers.”
The robot was put to the test in the competition. It had to find QRcodes and hazard signs as well as plastic dolls which represented victims.
It took five years and five teams to develop the machine. Last year, the team won the mobility award but failed to complete the competition due to technical failures.

The team are supervised by Dr Emma Rushforth and Dr Peter Jones.

Rushforth said, “The students have worked hard on the project and spent a week of their Easter vacation in Germany for the competition. The most important thing is that they have learnt a lot and gained a good deal of experience.”

The project accounts for a quarter of the final year grade for each student.

Blanch described the work as both “enjoyable and stressful”. He added, “I believe we had a strong team ethic, particularly when it counted. It was a really good experience.”

Due to student examinations, the team are unable to attend the finals in June, held in Mexico.

Rushforth said a more investment is needed in rescue robotics: “The underlying reason for having these types of competitions is to push forward the technology so that ultimately it can be used in real disasters. Currently the technology is not reliable enough or adequate.

“The earthquakes in New Zealand the Fukushima nuclear incident in the wake of Japan’s earthquake highlight the need for such robot.”

Continuing participation in future years will depend on funding from the University and sponsors.

Other projects Warwick Mobile Robotics is working on include an autonomous lawn mower for golf courses, urban surveillance and development in cameras collision avoidance for cars.

Rushforth added, “Prior to rescue robots we did robot football but switched to rescue due to a lack of UK teams to play with!”