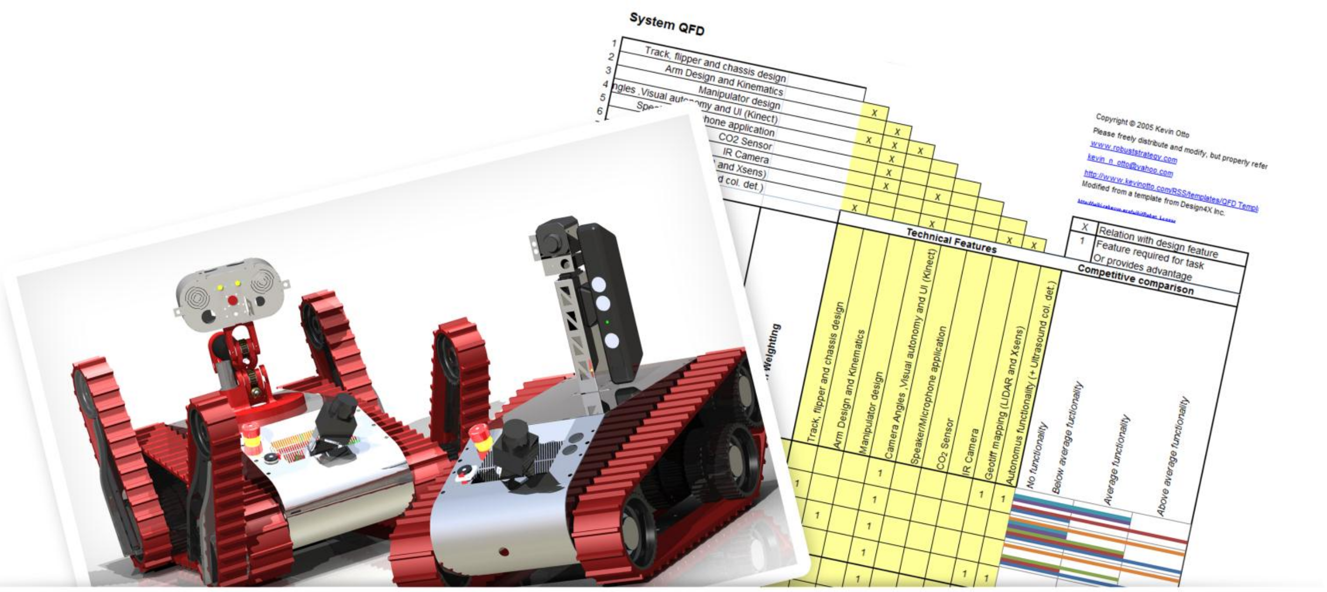
Warwick Mobile Robotics



General Report

WMR Search & Rescue 2010/11

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1 Introduction

1.1 Background and Motivation

1.1.1 Overview of the Project and Robots

In recent years, public interest and research into robotics has increased dramatically. Previously robots were used only in the manufacturing process of consumer products such as cars but we are now welcoming robotics into our homes and the service industry. From robotic vacuum cleaners to the high-tech machines being rolled out by various military contractors (discussed further in section 1.2), it is undeniable that the field will continue to see rapid growth within the coming decade.

Warwick Mobile Robotics is a group of inter-disciplinary students from the University of Warwick. The current crop of students is a mix of multi-skilled engineering students complimented by a team from the Department of Computer Science. It is the intention of WMR that two platforms be developed as a joint effort between the departments, drawing upon the respective skills of team members to produce a world-class robotics platform.

The current project sees students designing and manufacturing a “Rescue Robot”; a platform designed to enter disaster zones that may present significant risks to human entry. The robot is to take part in the “RoboCup Rescue” competition that encourages research groups from around the world to come together and compete in developing the most suitable task for this application, judged against standards set down by the American National Institute for Standards and Technology (NIST).

Natural disasters in current times have highlighted further the need for this class of robots and have shown the use of such platforms beyond the scope of the RoboCup competition. The disaster seen in Japan on the 11th of March, 2011, shocked the world and saw rescue robots being used in a “live” situation, locating victims within the aftermath.

1.1.2 The 2010/11 Team

This year's team consists of 7 members; 3 mechanical engineers, 2 electronics engineers, 1 manufacturing engineer and 1 systems engineer. Each team member had a different skillset that they brought to the group and to function effectively, it is necessary to exploit fully the capabilities of each person.

Figure 1: 2010/2011 WMR Team

At a high level, the mechanical, manufacturing and systems engineers were assigned mostly mechanical engineering design and manufacture tasks. The electronics engineers were assigned both the electronic and software development tasks for the system. The mechanical team was subdivided into teams concentrating on the teleoperated and autonomous platforms but there was some crossover between the two as the project progressed and needs dictated more focussed effort on certain tasks. The electronic engineers were divided into two teams as well, concentrating on the server (robot) half of the programming and the client (control) side. The actual hardware electronics on the robot were shared between the two engineers.

The tasks of financial management and publicity roles were assigned to a member who had spent a year in industry working with finances and another team member who had a keen interest in financial management and publicity. Website maintenance was delegated to a team member with experience in web-development. Our appointed safety officer had a keen interest in safe systems of work and the project leader was chosen for his experience with the previous years' efforts and for his keen interest within the field.

1.2 Robotics Systems Currently Used in Rescue Situations

The Search and Rescue robots that have been developed over the past four years by Warwick Mobile Robotics can be classed as Unmanned Ground Vehicles or UGVs. There are currently several types of UGVs in operation throughout the world. These UGVs are used for a variety of jobs, ranging from the disposal of Improvised Explosive Devices (IEDs) through to remote exploration missions in hazardous or unstable environments, much like the search and rescue robots.

Before further developing the urban search and rescue (USAR) products, it would be wise to look at current UGVs and take their designs into account, possibly applying some of the design ideas to this project. As discussed in the business report, there is also a possibility of the product being commercialised, so there needs to be a direct abilities comparison between the WMR range of robots and commercial robots.

For the USAR products to be commercialised, they must have specifications comparable to that of the UGVs currently on the market, or be of a lower standard but be more cost efficient. Potentially there may be a gap in the market that could be filled by a UGV with a specific search & rescue role.

1.2.1 Current UGVs

There are many different UGVs being used for different applications. There are several applications of teleoperated UGVs, from military reconnaissance to search and rescue. According to the NATO report on 'Bridging the gap in military robotics' there are four different classes of UGVs based on their size alone (NATO Research and Technology Organistation 2008):

- Featherweight – weighing less than 5kg. These are easily transportable and easily deployable
- Man Portable – weighing 5kg -50kg. These are, as the name suggests, transportable by soldiers but have a higher mission length than the Featherweight UGVs.
- Medium Weight – weighing 50kg – 500kg. These UGVs deal mostly in bomb disposal, with dexterous arms or manipulators.
- Heavy Weight – weighing 500kg+. These can be in the form of tanks which can be used to clear mine fields of mines.

This means that the USAR products will be classed as Medium Weight or Man Portable UGVs. However, due to current design, the teleoperated USAR cannot be adapted to be easily carried.

Some of the key specifications of the WMR UGVs are shown in Figure 2. These have been taken so they are directly comparable to the key specifications of some of the most advanced current UGVs.

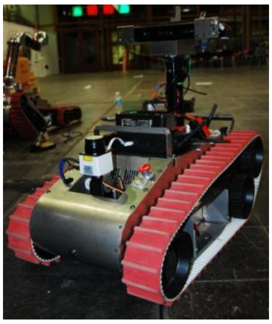
Make and Model and Weight Class	Specifications	Image
WMR: USAR-T (teleoperated) **(Medium Weight)**	Weight: 60kg Speed: 8kmhr^{-} Battery: Lithium Polymer battery 1 hr Communications: WiFi Camera: forward, backward facing Additional: arm and manipulator	
WMR: USAR-A (autonomous) **(Man Portable)**	Weight:25kg Speed:3kmhr^{-} Battery: Lithium Polymer battery Communications: WiFi Camera: Additional: autonomous	

Figure 2: WMR UGVs

Make and Model and Weight Class	Specifications (Department of Homeland Security 2009)	Image
Foster-Miller: Talon **(Medium Weight)**	Weight: 52-71kg Speed: 8.3kmhr^{-} Battery: Lithium Ion battery 4.5h Communications: Radio (2400MHz) Additional: water resistant and high survivability.	
iRobot: Negotiator 200 **(Man Portable)**	Weight: 15.4kg Speed: 5.0kmhr^{-} Battery: - 2-12 hours Communications: Radio (2400MHz) Camera: FLIR cameras Additional: affordable	
Remotec: Wheelbarrow **(Medium Weight)**	Weight: 330Kg Speed: 0-5km/h Battery: - Communications: Radio (1000m) Cable (150m) Additional: 'C of G' manipulator	
DRDO (Defense Research and Development Organistation): Daksh **(Medium Weight)**	Weight: Speed: kmhr^{-} Battery: lasts >3hrs Communications: Cable (100m) Radio (500m) Additional: Wheeled	

Figure 3: Current Commercial Designs

The first UGV shown in Figure 3 is Foster-Miller's Talon robot. This robot has a high reliability, which is an ability that is important when considering urban search and rescue robots. This is a very important ability when considering the conditions that could be present in the Search and Rescue scenarios.

Its direct competition is iRobot's Negotiator, seen in Table 2. iRobot focuses more on the technological side of military robotics, preferring to make more ingenious ideas than to make a robust robot. The Negotiator is the most basic design of UGV from iRobot's line of UGVs with reports of a basic model, Negotiator costing $15,000 1(Miller 2009). This is much cheaper than the USAR-T (urban search and rescue – teleoperated) and USAR-A (autonomous).

Remotec's Wheelbarrow is a mainly a robot for disarming Improvised explosive Devices (IEDs) and this design has a highly dexterous extendable arm. One innovative design feature of the wheelbarrow is that it can change its centre of gravity, which is very useful in situations such as climbing stairs (Strachan 2010).

Several of the teleoperated UGVs shown have manipulators (or robotic arms) for dealing with improvised explosive devices or for use in other situations, which add weight and use power. These can be likened to the arm that appears on the USAR-T, where the robotic arm is used to closer inspect enclosed areas that the whole of the robot cannot enter. However, the USAR-T manipulator is much less dexterous than the other UGVs.

Some of the UGVs currently available have modular systems meaning that the operators can easily change the specific function of the UGVs. These modular abilities allow the UGVs to be used in a variety of situations.

1.2.2 Use of Teleoperation in mobile robotics

There are two differing types of control in mobile robotics, teleoperation and autonomy. Teleoperation is the use of remote control in robotics. This is used in the majority of mobile robotics with some of the first teleoperated robots being used in the Second World War (Singer 2009). Teleoperation is used as it gives several advantages at this time over autonomy that are discussed later in this section 3.2. Teleoperation in this case, uses different forms of communication to transmit the data for control to the UGV and the sensory feedback from the UGV itself.

The advantages of using teleoperation are numerous. With the operator in full control of the UGV, there is a greater amount of reliability from the control system. This avoids the errors and uncertainty in identifying victims/terrain as the operator can use the sensory feedback from the UGV and use their experience to correctly distinguish between the results. This also means the operator can make a quick decision on whether a victim is in the search area. In a search and rescue scenario, this could make the difference between saving someone's life and not. The operator can also judge what is needed to tackle the rough terrain that the majority of Search and Rescue vehicles require.

Despite these advantages, teleoperated robots suffer the obvious disadvantage of the needs to be an operator constantly in communication with the robot. This can prove difficult in some search and rescue scenarios, with line of sight communication becoming very difficult to maintain. Since the computer intelligence needed for autonomy is several years away, control, for now, will have to be through teleoperation. The quality of results, however, rely on the distance of the operator in comparison to the robot and the form of the data the robot sends back to be monitored. At the current level of development within WMR, however, the distance of communication is largely be an unnecessary consideration but will be vital when looking into the commercialisation of the robot.

1.2.3 Need for autonomy in mobile robotics

Autonomy is the alternative for the control method of a UGV to teleoperation. In order to make a fully autonomous search & rescue robot (operating with pre-programmed behaviours and without supervision), a robot requires a complex system of sensory data analysis, route planning and victim identification methods. Autonomy would remove human errors such as miscalculating distances or suffering from lags in communication during search and rescue missions. An autonomous UGV would also be able to build an accurate map of the surrounding environment, much more reliably than an operator.

Some of the most important advancements in autonomous control are in the field of SLAM (Simultaneous Localisation and Mapping). This is a technique used in mobile robotics where the robot builds a map of an unknown environment (without prior knowledge of the environment) whilst keeping track of their current location (Leonard 1991). This could be used on the USAR-T once fully tested on an autonomous robot. This system would allow the robot to map the world around it whilst planning a path to take. This could mean that an ordinarily teleoperated robot could return to the last coordinate it had communication with operator if it loses signal as it can record where it has come from. The robot could also proceed further in the hope of regaining communication with the operator.

For a fully autonomous rescue robot, it would have to be able to map the world as well as search for victims. In future years of this project, autonomous capabilities would hopefully be transferred to the teleoperated robot so that it could find victims without the need for an operator and also make use of the greater mobility of it.

Autonomy has the potential to change the face of mobile robotics but it is reported that this goal is likely to be attained in 30-40 years' time (Harris 2009). It is a vast and complex subject implementing high degrees of mobile autonomy especially over rough terrain and long distances although this level of autonomy has recently been achieved in the DARPA challenge.

It is hard to replicate this level of autonomy in a small low cost UGV, such as the WMR robots. The DARPA challenge involved teams from around the world retrofitting off-road vehicles to navigate autonomously around a 212 km (132 mile) track (Thrun 2006). One of the sports utility vehicles competing, shown in Figure 4 had many thousands of dollars of sensors and 6 computers housed inside.

Figure 4: Stanley (Thrun 2006)

This is impractical for a small UGV, weighing only 50+ kg. For this form of autonomy to be implemented, it would have to fit inside the WMR robots and not have as many sensors.

The varying levels of autonomy have been defined in the Autonomy Levels For Unmanned Systems (ALFUS) (Huang 2004), these are not universally accepted. There are several different ways of defining autonomy, with one paper for example taking into account the missions and the tasks that the Unmanned System (US) will perform. Figure 5 gives an example task and shows how each level of autonomy would deal with the task.

System Scope	Mission Scope	Mission Complexity
System of Systems	Make sure that the NIST campus is secure	Multiple vehicle cooperation, high level of task knowledge, high uncertainty, large spatial and temporal scope
Single Vehicle	Go behind building 202 and keep a lookout for intruders coming through fence	Single vehicle, multiple subsystems, medium level of task knowledge, high uncertainty, medium spatial and temporal scope
Subsystem	Goto_waypoints (UTM1, UTM2, ... UTMn) Scan_direction(UTMa, UTMb, dwell)	Single subsystem, low level of task knowledge, medium-low uncertainty, medium-small spatial and temporal scope
Actuator	Remote control	Single subsystem, no task knowledge, very low uncertainty, small spatial and temporal scope

Figure 5: Examples of levels of autonomy characteristics for USs (Huang 2004)

The levels of autonomy are given as, Actuator, Subsystem, Single Vehicle (or System), System of Systems (SoS) with the actuator representing teleoperation. Subsystem autonomy levels are defined in terms of the subsystems functions performed by the robot, such as mobility. A SoS is the highest level of autonomy that can be achieved with one system governing a group of systems. WMR are not concerned with the 'System of Systems' level of autonomy as lower levels of autonomy have not been achieved yet

1.2.4 Applications of autonomous robots

Autonomous robots have numerous applications; with the majority of autonomous robots in use around the globe are aerial unmanned systems. This is because it is easier to implement autonomy in the air than on the ground as there are many additional uncertainties and obstacles to tackle with UGVs.

A system of systems level of autonomy could be applied in future years for autonomous robot in search and rescue situations as different autonomous vehicles will be able to communicate with each other, mapping the area and building up a larger 3D image of where victims could be. Current levels of autonomy shown in the RoboCup German Open are the detailed 2D mapping of an area, with some Search and Rescue robots struggling to correctly identify a great many victims. Some of the competitors within the RoboCup German Open were experimenting with building a 3D image of the arena.

A low level of autonomy, otherwise known as 'safe teleoperation' has been known in mobile robotics where the robotic system prevents the robot, under operator control, from colliding with obstacles that the operator does not see (Valero 2011). This level of autonomy has a very obvious application in mobile robotics and search and rescue missions. However, it would sometimes be necessary to climb over difficult terrain so the 'safe teleoperation' would need to be switched off.

There are many, more commercial, applications for autonomy in robotics. This is possibly led by the automobile industry, with the need for driverless car. These cars will use the information gathered by the word around it to mimic the decisions made by the driver(Benenson 2008). These cars will be able to sense other traffic and avoid it. This emerging area of self-driving cars does not currently have an application in Search and Rescue UGVs but demonstrates how this technology could be used.

1.3 The RoboCup Recue Competition

Founded in 1997, RoboCup aims to promote research and education in the field of artificial Intelligence. The competition originally began with solely football leagues but has since branched out to include Rescue, Home and Junior divisions. They state their objective as being(Robocup German open 2011 2011):

"By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, comply with the official rule of the FIFA, against the winner of the most recent World Cup."

The Rescue league is obviously a different challenge from the Football division but still maintains the same broad goals of encouraging advancements in artificial intelligence. The Rescue league features a simulated earthquake environment constructed from 1.2 meter square "tiles." Each may have a different obstacle on it selected from a range of possibilities. Walls are created from vertical sheets of chipboard. Teams score points for identifying randomly placed victims throughout the arena. Victims emit different telltale signs of their whereabouts which must be detected by the robots.

Figure 6: a) Victim identifiers b) The Blue Payload retreival area

In the 2011 German open competition in Magdeburg that WMR entered to test its capabilities in a competitive environment. For this year's rules points were scored per victim by (Robocup German open 2011 2011):

- Identifying the victim, and the nearby hazmat labels and eye charts visually.
- Identifying thermal emission, carbon dioxide emissions (breath), and establishing vocal communication both to and from the victim.
- Real-time arena mapping to a Geotiff map and marking the position of the victim on this map.
- Payload delivery, by collecting, transporting and then delivering the payload to the victim.

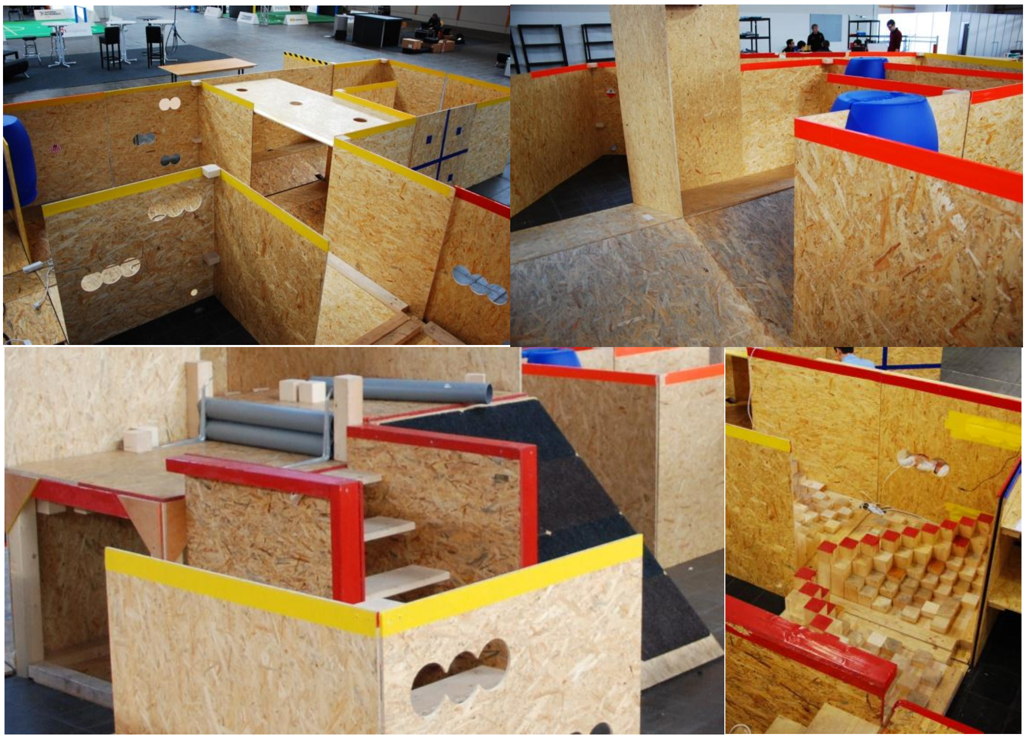


Figure 7: a) The Yellow arena b) The Orange Arena c) The red arena ramp and stairs d) The red arena stepfield

The victims are placed in varying locations around the environment's four areas, in which robots and operators have 30 minutes to place the robot, set up the operating station and search for victims: (Robocup German open 2011 2011)

- The yellow arena tests autonomous navigation and victim identification only due to its simplistic terrain; mostly consisting of flat areas and 15° slopes.
- The orange arena is where both autonomous and teleoperated robots can score points for victim identification. This area consists of 30° ramps to simulate uneven terrain. The layout is similar to the yellow arena, only with steeper slopes.
- The red arena is where both autonomous and teleoperated robots can score points for victim identification. The former, however, will find it very difficult to do so due to the placement of stepfields, 45° carpeted slopes, stairs, shallow pits, loose (rolling) ledges and underground sections.
- The yellow and black arena is a radio-drop out zone, usually consisting of a small area where the purely autonomous function of a robot is tested by removing the operator's communication with the robot.

A points-breakdown of the rules in addition to competition guidelines can be found in Appendix 1 (Robocup German open 2011 2011). This is followed by a sample score sheet in Appendix 2 (Robocup German open 2011 2011). These will be used later in this section for the purposes of subjective statistical analysis through Quality Function Deployment, to identify what future areas for expansion are required and also the specialisations required for next year's teams.

1.3.1 Past Team's papers

1.3.1.1 Competing in the RoboCup Rescue Robot League (Tandy, Winkvist and Young 2010)

An overview of the 2010 European RoboCup Rescue Robot League (RRL) is the main focus of this report. A brief summation of the competition rules and setup are provided as a background to the body of the report but are useful as they are from a first-hand perspective of the competition. It provides insight that would otherwise not be available in the main body of rules such as the introduction of newspaper strewn across the floor of the arena to introduce a slippage factor. This caused problems for the 2009-2010 WMR team who found the limited grip of the autonomous robot struggled upon this loose covering and identified this as a problem in its locomotion system.

The report then goes on to discuss the design and approaches used amongst the different teams at the competition. Interestingly, the machines with the lowest mobility are seen to use off-the-shelf platforms which typically do not feature the more advanced capabilities which are designed into the custom platforms. Also worth noting is the dual-flipper construction of many of the high-mobility robots. Robotic arms are also considered with competitors using a mix of designs including some off-the-shelf purchases. Sensor technology is also discussed and again in detail within the individual reports appendix for each competing team. LIDAR is commonplace amongst the teams with the Hokuyo models taking the lead in popularity for the compact size and low weight. It is pointed out that video cameras are the primary tool used for victim identification, stating that the arena is too noisy to use sound and the carbon dioxide levels relatively low making it difficult to distinguish between ambient and increased levels.

The review of the world competition winner, iRAP_PRO, identifies a striking difference from the majority of other competitors; their LIDAR is mounted statically atop a pole. It seems likely that they therefore use the LIDAR to map the arena from a general perspective as there are no obstacles this high. This makes sense for autonomous robots navigating the relatively flat yellow area which should not pose much a challenge to a robot with a large wheel or track circumference but does not offer much perception in the more challenging yellow/black area. The iRAP_PRO also featured a highly dexterous arm with 6 degrees of freedom as well as a two-pronged gripper device. One of the joints is a prismatic sliding joint, providing the robot with extra reach for some of the tougher challenges in the blue manipulator and black collapsed vehicle areas of the competition. This could indicate a possible direction for arm design in the WMR robots should the current reach of the arm be deemed too short. A gripper is also something not featured on the WMR robot at any point during its history but provides the iRAP_PRO team a chance to score extra points in the blue area of the competition.

1.3.1.2 RoboCup Rescue 2010 – Robot Rescue League Team iRAP_PRO (Thailand) (Uschin, et al. 2010)

This is the paper produced by the RoboCup RLL 2010 winners and describes the basic construction and systems design of their robot. They break down their robot into distinct sections based upon each group members' personal input and describe in minimal detail the operation of each part. There are some striking differences between their robot and the WMR robot from previous years. Unlike WMR, the iRAP_PRO team use a PIC microcontroller to control the robot over an RS-232 link that is broadcast using a wireless router. This has some obvious implications for the control of the robot as it will not be able to perform complex calculations on the robot itself with great speed because of the limited computational power of the PIC chip. They use a video server to transmit to and from the speaker, microphone and camera combination mounted on the robot. Another PIC microcontroller is used to negotiate with the different sensors and transmit the data back to the operator's computer. On the computer, data may be processed and displayed to the operator through their relatively simple interface.

The team clearly focus on quick deployment time as this architecture will facilitate along with their operations centre integrated into the aluminium flight case. A quick set-up time in the arena is crucial to maximising your available time in the simulated disaster zone.

iRAP_PRO also successfully manage to generate a map using their LIDAR data allowing for autonomous navigation by their autonomous robot as well as the GeoTIFF submission part of the competition point scoring system. It is not clear from the report whether they successfully manage to place tagged locations for victims on the map but the map they generate is certainly effective.

The locomotion system fitted to their 2010 entry reflects a similar style to the WMR team with its dual flippers and wide tracks. This is in stark contrast to their previous entry that featured no flippers resulting in highly reduced mobility. This team has proven the effectives of the dual-flipper tracked robot design employed by the WMR team. The differences between the two are subtle and it would appear that the human component and the control software are really holding the WMR robot back as opposed to the physical construction.

1.3.1.3 RoboCup Rescue 2009 – Robot League Team CASualty (Australia) (Sheh, et al. 2009)

Team CASualty placed second in the 2009 RoboCup competition with their platform. Unlike team iRAP_PRO, CASualty use off-the-shelf platforms such as the Negotiator and PackBot. There seems to be a trend with high-scoring teams using the tracked design with the addition of flippers for overcoming more challenging obstacles.

CASualty have also done a great deal of work with artificial intelligence. They have highly advanced mapping capabilities not seen on the other robots such as a terrain model extractor that can model the stepfields. They exhibit some machine learning too, allowing a human operator to drive over the stepfields a few times while the robot watches and then developing a set of rules that the robot can follow to autonomously navigate the fields. They also attempt to model the physics of traversing the fields to simulate the progression of the robot before committing to a movement but claim this technique is slow and computationally intensive. The SwissRanger camera they use for 3D depth perception provides a good system for mapping the terrain ahead of the robot and overcomes much of the problems with 2D depth perception such as LIDAR devices. This comes at an enormous cost of $9,500. An interesting alternative is the Microsoft Kinect that features 3D depth perception at a fraction of the cost of around £120. Comparing the two in terms of accuracy and speed performance could be of great use to the autonomous robot team when mapping the competition space in three dimensions.

Also worth noting is the distributed computation for their simultaneous localisation and mapping (SLAM) algorithm to reduce the load on the robot and operators computer. Their algorithm allows their teleoperated robot to navigate autonomously for brief periods when the communication link drops out between operator and robot.

1.3.1.4 RoboCup Rescue 2009 – Robot League Team Shinobi (Japan) (Mizumoto, et al. 2009)

Placing third at the world finals, Shinobi are a good example of a successful team. Their robots are based on a reconfigurable assembly of sub components allowing the robot to be disassembled and reassembled with new parts to best match the environment in which the robot will be placed.

The team have developed impressive mapping capabilities and a victim identification report sheet creator that can be printed out at the end of a run with information pertaining to each victim and its state such as heat being emitted or noise levels. The robot has full 3D mapping capabilities my rotating a LIDAR to capture data in multiple dimensions.

Shinobi have a number of interesting techniques they have applied to make the operator interface more user friendly. The first of which is the overlaying of thermal imagery onto the live camera feed. This allows the operator to only look at one screen rather than having to concentrate on a number of different views. This is possible thanks to the hot mirror (a mirror which is transparent to visible light but reflects far-infra-red) at a 45 degree angle between the CCD standard camera and thermal imaging camera. This mirror reflects the infra-red light down to the thermal imaging camera and allows the visible light to pass to the CCD so both camera are imaging the same view.

They have also developed a system that allows operator to control a 3D representation of the robot within the real-world environment using past camera data. The full technique is described in another paper and offers a very user-friendly method of control and is fairly robust, coping with video drop-out particularly well (Kagotani, et al. 2004). This is best demonstrated through Figure 8 where the wireframe robot model can be seen in (b) superimposed on the first image from (a). The rest of the images in (a) show that the robot is seeing in the corresponding positions in (b).

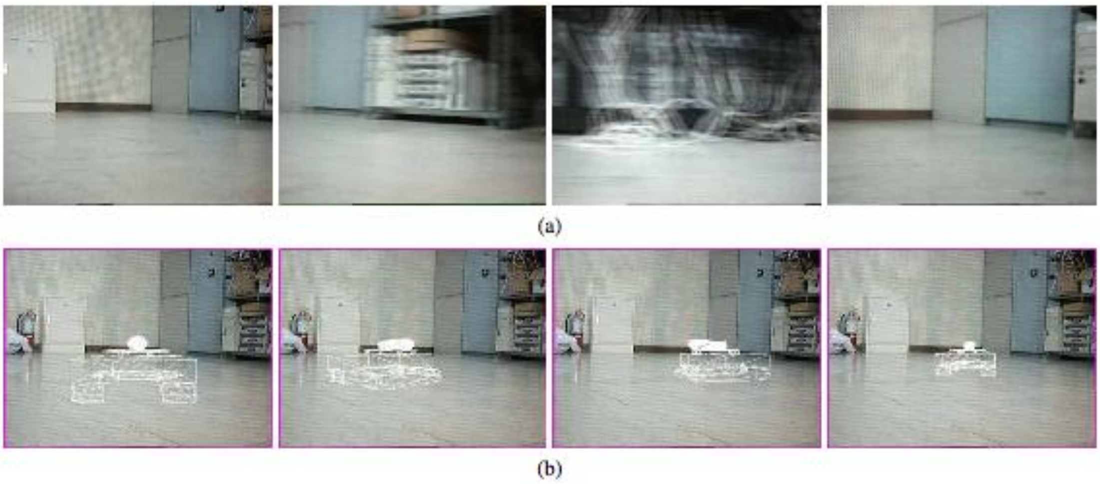


Figure 8 The 3D robot model placed on imagine data (Mizumoto, et al. 2009)

The team also conducted real-world tests, allowing local firemen to come and test out their robot and by taking the robot to the fire departments own simulated disaster sites and test out their performance there. This is in line with this year's WMR team objective to investigate the commercial and real world viability of Rescue Robots.

1.4 Review of Available Literary Resources

RoboCup German open 2011. RoboCup Major results. RoboCup German open 2011, March 31st - April 3rd. (Robocup German open 2011 2011)

The offical Robocup German open competition website provided continually updated results and individual mission scores of each of the RoboCup teams. The website also provided the 2011 RoboCup Rescue rules and the sample score-sheet was provided at the competition with the permission of the judges.

TU Darmstadt. Hector GV. Hector Darmstadt, Heterogenous co-operating teams of robots. (TU Darmstadt n.d.)

The home website of team Hector Darmstadt provided in-depth technical details regarding the function of their co-operating heterogeneous USAR robots.

Project GETbot - der autonome Rettungsroboter. GET lab. (Project GETbot - der autonome Rettungsroboter n.d.)

The homepage of the GET lab team's RoboCup Rescue robot provided an overview of the technical functions of their USAR robot. Unfortunately the page could not be translated well enough to navigate to their publications and so a photo of the team's poster was referenced to, that they displayed at the RoboCup competition.

resko@UniKoblenz and team homer@UniKoblenz. RoboCupRescue 2011 - Robot League Team description paper. Robbie 16 (resko@UniKoblenz and team homer@UniKoblenz 2011)

The homepage of the Robbie 16 USAR provide links to technical documents, and the team description paper was referred to when researching the robot's capabilities. This is the same format of document that the WMR also submitted to the RoboCup association in order to enter the RoboCup Resuce competitions.

SUCCESS, Rajamangala University of Technology Rattanakosin. RoboCup 2010 Rescue Robot League (SUCCESS_Thailand) (Team description paper). (SUCCESS, Rajamangala University of Technology Rattanakosin 2010)

Similar to the above literature, this was another team description paper for the SUCCESS USAR submitted for the 2010 world RoboCup Rescue competition. The technical capabilities of the robot were specified within.

Robust Systems and Strategy LLC. Software for robust systems and strategy.(Robust Systems and Strategy LLC 2007)

This website provided a flexible and simple excel template for QFD charts and other project management software tools. This was favoured over alternatives because it was free of charge and east to adapt and simplify for the purposes of implementing QFD on the WMR team USAR's by treating the competition points system as a customer's requirements.

The University of Warwick. Quality Function Deployment. The School of Engineering.(The University of Warwick 2001)

The school of engineering, and the Warwick business school, provided the required literature background on Quality Function Deployment and its implementation on a product or service.

2011 TRENDnet. TRENDnet (product site).(2011 TRENDnet. 2011)

The TRENDnet product home page was consulted to assess capabilities of the ITSY USAR's internet cameras. It was found that they were, wireless, capable of two-way audio communication and had limited Infra-Red functionality.

2 Aims and Objectives

The task for the Warwick Mobile Robotics team is to continue in the design and development of the WMR Search and Rescue robots with the ultimate aim of creating an effective and commercially viable platform for locating and aiding victims in dangerous environments.

Within this remit WMR has the following aims:

- To continue to improve the current teleoperated platform, addressing the weaknesses identified by the previous team and by a full SWOT analysis.
- To develop and implement a manipulator for the teleoperated robot to enable it to lift light payloads.
- To assess the commercial viability of the WMR Search & Rescue robots.
- Improve the reliability and transportability of both systems.

In order to achieve these aims, we seek to complete the following objectives:

- Procure sufficient sponsorship to buy the materials and components needed for any modifications
- Identify and address any weaknesses identified over the past year with the two robots including looseness in robot joints, the existing Human-Machine Interface, transportability and communication problems.
- Design an improved arm with added manipulator which is able to lift a bottle of water or other similar payload.
- Compete in the RoboCup Rescue competition and win Best in Mobile Manipulation, Best in Mobility and the competition overall

3 Methodology

WMR has adopted a design philosophy in order to ensure the group works effectively. In previous years WMR has adopted a philosophy similar to Remotec, a subsidiary of Northrup Gruman who specialise in producing teleoperated robots. This philosophy was again adopted in the 2010-2011 WMR group. The philosophy is referred to as the systems V-diagram. The

V-diagram philosophy is systems focused and was used as a guide to all project design work.

3.1 Software Design Methods

The Agile software development philosophy is utilised in this project. This approach is appropriate due to the limited project time and ever changing specifications as a result of the ever changing nature of the robot design and finances available to the project. Within this philosophy certain tools are used to support the development process. It also reflects the dynamic nature of the software tasks and team members. Agile methods are discussed in greater detail within the technical report.

Subversion, the version control software, is used to track changes to the robot's code base and maintain a central library of current and historical versions of files. This allows multiple users to work on different machines to view, run and edit the same project. The Subversion server is hosted by Warwick Computer Science Society.

Continuing from the 2010 robot, Java is used for all robot and base station (client) software. Java programs are not precompiled for specific operating systems so the programs can run both on Windows machines for development and for the client, and on a Linux machine when deployed on the robot. This also allows team members to develop software on whatever platform they chose and gives future teams the freedom of changing the operating system on either the client or the robot with minimal touble.

3.2 Hardware Design Methods

Any three dimensional parts files shall be created within SolidWorks 2010, Service Pack 3.1. These parts shall be saved in the relevant file directory conforming to the system below. The directory structure for designs, in the network drive Mechanical Design folder, is as follows:

Design Year → Parts Group → Parts Subgroup → Part inc. Rev →Superseded →parts inc. Rev

The parts created by the team will be suitable for manufacture using in house facilities which include 5 axis milling machine tools and CNC lathes. Any part which cannot be manufactured in house will be purchased externally or re-designed to fit within the capabilities of the WMG. In order to assess the ease of manufacture technicians will be consulted both before detailed design starts and after the design has been completed. Technicians will also be consulted should there be any significant changes during the design process. Most parts to be manufactured shall be saved in '.SLDPRT' format, parts to be laser cut will also be saved as ".DXF" as this is the file type compatible with the laser cutting tools. A standard drawing will be completed for parts which are to be manufactured these will include:

- Overall part dimensions

- Depths and dimensions of all holes, counterbores and cuts Finish of all holes, thread size if tapped, bore if clearance.
- Metric (M) bolts shall be used throughout the chassis for mechanical fastening unless otherwise stated.
- The drawings shall be completed on the WMR sheet design built as a SolidWorks template.
- A works request in (appendix needs to be added) shall be completed for each and every part stating the material of manufacture, quantity and any special manufacturing details relevant to the manufacture of that part.

3.3 Circuit Board Design Process

The design process for a circuit begins with the construction of a specification for its function. The specification should include all the requirements for the circuits, with emphasis on the necessary inputs and the expected outputs.

Once the specification is formalised, a high abstraction diagram is developed that outlines key stages of the circuit. Throughout the design process the levels of abstraction should be expected to decrease in line with the increase of complexity. A contemporary flow diagram or similar UML activity diagrams could expected at this stage. Furthermore, important components, such as microcontrollers or application specific hardware, should be selected to aid in the illustration of the abstracted diagram.

Following the abstract diagram, a circuit diagram should then be developed where the circuit should be expected to provide the full functionality required by the specification, and in the stages outlined by the abstract diagram. All necessary component values should be accounted for and the majority of possible alternatives considered.

Prototyping follows, with the circuit built using available development materials and utilities. It is expected for the majority of the circuit to be built using a Breadboard base while programming/development boards will be used for the programming of any microcontrollers.

Extensive testing will be carried out during the prototyping stage. Initially, sections of the circuit will be isolated for testing before, following successful validations, progressing to testing of the entire prototype. Should the prototype be proved to not be an accurate representation of the specification then the design will be revised and the prototype rebuilt to reflect these modifications.

Once the prototype has been shown to be successful, the circuit design will likely be mapped for the fabrication of a PCB. New components, those typical of use on a PCB, will be ordered in anticipation of their inclusion. Alternatively, should such a concrete design not be desired, the circuit can be built using Stripboard or similar material.

3.4 Organistion

An organisational structure was created to clarify the roles and additional responsibilities of individual members, shown in Figure 9. Each member of the WMR team was assigned work according to their individual speciality, competencies and preferences. Team members were responsible for all work assigned to them for each role they fulfil.

The group is divided into further two teams; the mechanical team who were responsible for the design and manufacture of the robots, and systems team who responsible for the programming and electronic systems. The Computer Science Team was also added to this organisational structure to clarify their position within the WMR team structure.

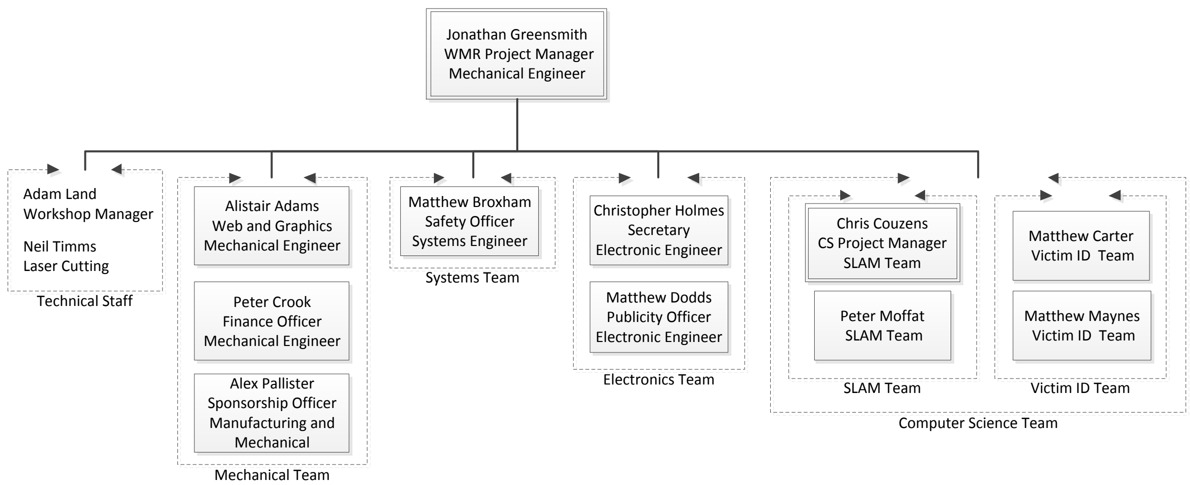


Figure 9: Organisational Structure of team and roles

A more detailed explanation of the organisational structure can be seen in the Business, Publicity, Finance and Management Report.

3.5 Work Plan

A work plan was created in the form of a Gantt chart for this project. It shows the deadlines and milestones of the project, taking into account purchases ordered as well as the manufacturing of part. It is important to assess and manage the progress of the project from week to week ensuring the completion of key targets. A screenshot of the Gantt chart can be seen in Figure 10, with a more detailed version of this work plan in the Appendix of the Business, Publicity, Finance and Management Report.

The milestones that the Computer Science team set were also included in the Gantt chart so the WMR team could monitor their progress.

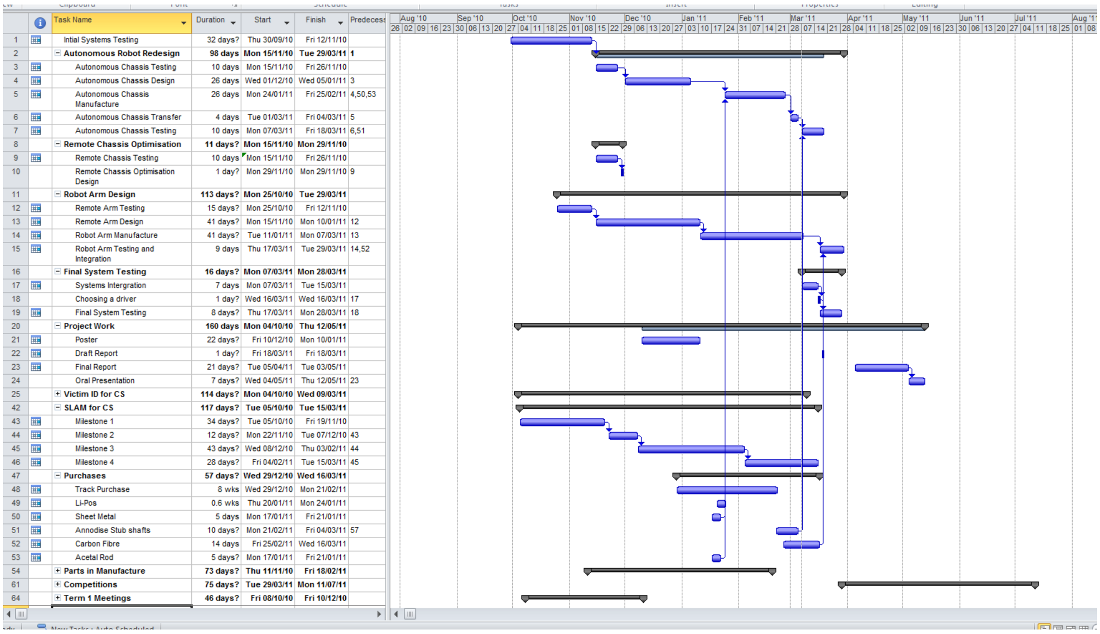


Figure 10: Screenshot of MS Project plan

3.6 Health and Safety

Upon handover of the project, it was revealed that the previous year's health and safety documentation only proceeded as far as a single risk assessment chart for general workshop activities and a single safe scheme of work. Neither of which were added to even after the relatively hazardous implementation of lithium polymer batteries were introduced later that year, nor was a risk assessment written for travel to Germany and Fieldwork abroad; the risks observed in the workshop being significantly amplified with the increased number of people present at the competition. There were not even any detailed instructions regarding the procedure of charging the lithium polymer batteries for the new WMR team.

In addition to updating the risk assessment for mandatory requirements set by the University of Warwick; it was decided that subsequent risk assessments should be created for each and every new undocumented risk that arose throughout the course of the project. This would require that the Fieldwork to be conducted at the German RoboCup open competition in Magdeburg received its own internal risk assessment.

The publication of these documents and safety measures will ensure that required health and safety practices are transferred to the following years, and built upon for any new risks that arise.

3.6.1 Literature Review

Health, Safety and Wellbeing at Warwick University (Beament 2010)

This Website describes and explain in detail the University of Warwick's legislation regarding health and safety procedures, and include the methodology behind publishing risk assessments. This particular source of information was essential in the production of both internal and external (required by the University and the WMR) health and safety documents.

RCToys.com Sells RC Airplanes RC Blimps RC helicopters & Parts: Draganfly Innovations Inc. (Draganfly Innovations Inc. 2009)(Draganfly Innovations Inc. 2009)

This website is a popular resource for remote controlled vehicle hobbyists for both buying parts and as a general source of information typically written in layman terms. This was the main website consulted for the purpose of identifying the key risks and safety procedures to be followed for the use, storage and disposal of Lithium polymer batteries. The articles referenced cover a wide range of implications and scenarios for the LiPo batteries in general (such as storage temperature and partial swelling) and so proved to be a reasonably valid source of information.

Germany Travel Advice: British Foreign and Commonwealth Office (FCO) (British Foreign and Commonwealth Office 2011)

This webpage was used as a reference to the Fieldwork risk assessment; for the travel to Germany for the RoboCup competition in Magdeburg. It covers a wide range of general safety precautions regarding travel to Germany such as road travel, entry level requirements, emergency service numbers, emergency contacts for temporary travel documents, basic health/car insurance requirements, and the legislation regarding currency control in addition to basic statistics regarding general risks. This information is provided by the British Foreign and Commonwealth office and so its validity can be held in high regard.

This website also referenced the German National Tourist's Board (German National Tourist Board. n.d.) for details regarding basic information on driving abroad: Important information regarding the differences in the highway code and road laws when travelling in Germany. As a final note this national Tourist Board also referenced the German Federal Environment Ministry's laws (The German Federal Environment Ministry n.d.) (Federal

Environment Agency n.d.) regarding travel through low emission zones. A map (Federal Environment Agency n.d.) of such zones revealed that the WMR team would not be likely to encounter any of these low emission zones on their drive through Germany.

Caroline Cousins; Health and Safety Adviser, Safety Office

Ms. Cousins acted as the team's main health and safety consultant and provided both information and feedback on our published risk assessments. She assisted in outlining areas of importance in specific risk assessments and also identified commonly overlooked areas. The information she provided proved invaluable in the planning stages of formulating risk assessments prior to their application to the specific activities of the WMR team.

3.6.2 Methodology regarding Risk Assessments and Risk documentation

In creating a risk assessment documentation a specific procedure should be followed (all table references are in Appendix 4 (Beament 2010):

1. A task or activity is identified, and its specific hazards are listed and their severity determined in accordance with the severity rating table(Beament 2010).
2. The likelihood of a hazard's scenario occurring is then determined based and on the pre-existing measures taken if there are any. The table for the likelihood of a risk is consulted for the appropriate likelihood rating.
3. The persons affected by said hazards are then determined, and are taken into consideration in future control measures.
4. The severity and likelihood rating of the hazards and hence activity are cross-referenced in the table for their overall risk order to determine the priority of additional control measures. The prioritisation of risk factor table advises how much further action needs to be taken to sufficiently reduce the risk.
5. Appropriate risk-reducing methods, designs and information are determined, documented and applied to the activity. After which the risk assessment is reviewed with the newly implemented controls in mind.

Aside from manufactured means of risk reduction (e.g. attaching handles to the USAR-A2 chassis to allow single persons to lift it) documentation in the form of Safe Schemes Of Work, worst-case scenario documentation, operating instructions, safety checklists and itineraries.

3.6.3 Implementation

Risk assessments at the start of the project re-assessed the risks of common activities with the inclusion of the undocumented Lithium polymer batteries. The need to maintain the current safety features inbuilt in the robots were identified and clarified, in addition to the future requirement for the handles that were attached to the USAR-A2. A new safe scheme of work was written to accommodate the hazards identified with regards to the Lithium polymer batteries, in addition to detailed charging instructions to accompany the charging equipment. Appendix 5 and Appendix 6are the risk assessments for the workshop and Lithium polymer batteries respectively. Appendix 7 and Appendix 8 are the safe scheme of work and LiPo battery charging instructions respectively.

Two serious incidents occurred regarding the operation of the robot when the battery containers were left open during operation. A sharp turn would cause the sharp metal edges of the container to cut into the positive rail of the Lithium Polymer batteries, and would cause the exposed wires would electrically weld themselves to the chassis of the robot with a highly visible and dangerously sparking arc. It was only fortunate that the packaging of the Lipo battery itself was not perforated or burnt, exposing the lithium inside to the moisture of the air, resulting and swelling and combustion of the hydrogen produced. This could have been a very dangerous scenario, but fortunately the fuse connected to the chassis of the USAR-T3.5 blew out and severed the electrical circuit through the chassis. This first incident heralded the implementation of an accident report sheet for the purposes of documenting these overlooked hazards and immediately assessing risk reduction methods. This documentation ensured that similar incidents would not occur and that future year's teams would not make the same mistake.

New risks arose when it was required to travel to the German Open RoboCup Rescue competition in Magdeburg: With the requirements to transport the robots, the necessary tools, the 9 team members attending in addition to the amplification of workshop risks in the venue; increased footfall and bystanders around the working area specifically.

Risk assessments were conducted for general risks regarding laws and travel in Germany (Fieldwork, Appendix 9), work on the robots at the venue (Appendix 10), and finally a risk assessment for transport of the robot and the team; both those travelling by car and associates travelling by air (Appendix 11). Emergency scenario documentation was acquired and summarised in a document alongside insurance procedures in the event of an accident (Appendix 12). Finally due to the increased requirement to lift heavy objects repetitively; a checklist provided by the Warwick University health and safety office was completed to ensure that a proper lifting procedure was properly established (see Appendix 13: Lifting Procedure).

An itinerary was constructed detailing the journey, route maps, times and locations complete with all of the team member's contact details, next of kin, additional contact details for home agents (the project directors), and finally emergency service contact details for emergency travel documents. These itineraries were distributed to all associated persons and two hard copies were kept in each car during travel. Satnavs with European maps were purchased and routes synchronised where possible, and walkie-talkies were used to maintain constant contact between the vehicles (a van for transporting the robots, and a car transporting the majority of the team) en route.

3.6.4 Conclusion and Recommendations

Mandatory health and safety documentation requirements required by the university were met and maintained throughout the progression of the project. With the implementation of up-to-date risk assessments and appropriate documentation, future teams will for the most part be able to copy and expand upon the information provided as new risks and hazards arise and learn from the documentation and incidents recorded.

It is recommended that the next year's team continues to update and expand upon these documents whenever new risks arise, so that future groups will not be unnecessarily exposed to undocumented hazards.

4 Designs and other outcomes

4.1.1 USAR-T Robot outcomes

The addition of a new arm to the USAR-T platform is the most striking addition to its design. Although the design and manufacturing process were riddled with delays it should not be without note that the new arm is a significant improvement over the previous design. The new arm was not fully tested in a live situation, during the competition in Magdeburg, but since the competition has been integrated closely with the software control systems in place. Its strength and rigidity were significantly improved, giving the capacity to lift more weight and massively reducing the positional uncertainty within each joint.

In order to achieve the manipulation objective, a manipulator has been attached beneath the head of the robot. The manipulator provides gripping functionality and is capable of carrying a variety of masses, where a water bottle is the chief requirement. The manipulator is powered using a servo motor, which is controlled using existing infrastructure within the robot.

The new arm has been complemented by a fully functioning inverse kinematics system, allowing control of the head assembly to be more intuitive. Previous years attempts at an inverse kinematics solution at not worked particularly well, exhibiting unpredictable and potentially dangerous behaviour during operation. In addition, real-time positional tracking of the arm is now possible, which, in conjunction with the inverse kinematics and software-based queuing system, allows for translation-based movements and linear interpolation. This year, a more thorough adoption of continuous integration testing through the development of unit tests has enabled the development team to provide a more reliable control system for the operator of the robot continuously during the development lifecycle.

Plates holding the motors controlling the flippers were redesigned and strengthened, reducing the amount of play in the flippers considerably, resulting in a more predictable behaviour from the flipper control systems.

The client software has been re-written to help, rather than hinder, the operator of the robot. Notification systems and more intuitive control mechanisms have been put in place to provide the operator with not only a natural method through which to control the robot but also a more assisted driving experience. The workload placed on the operator during missions has been reduced by allowing the client software to take responsibility for analysing the data transferred from the robot and only notifying the operator when necessary.

An electronic hardware solution has been constructed as well, complimented by the battery notification on the client software, to ensure a fail-safe method of determining the battery status within the robot by emitting a beep when a critical voltage has been reached. Its incorporation with the rest of the system will ensure the risk of excessively discharging batteries in the future is mitigated significantly.

A significant restructuring of the code base on both the server and client software has resulted in a more maintainable code base. Future years should find the code more easily understood and extended upon.

4.1.2 USAR-A Robot outcomes

The entire chassis of the autonomous robot has been overhauled and the internal electronics and electro-mechanical systems refactored to fit them within a modified USAR-T chassis. With the ultimate goal of cross-compatibility between the autonomous and teleoperated robots, this design choice has brought the two platforms even closer toward this point. The benefits of adapting the USAR-T chassis and fitting the USAR-A with the same tracks were made apparent during teleoperation of the autonomous robot during the final rounds of the RoboCup. Thanks to these alterations, WMR managed to win the Best in Class Mobility award using the autonomous platform, a feat that could not have been achieved with the previous platform.

The sensory array has also been updated to a more sturdy arrangement atop the robot. The new structure provides a secure mounting point for the vast array of electronic devices including the new Xbox Kinect.

A stack, similar to that featured in the USAR-T has also been created this year to compliment the reworking of the chassis. This new design allows for the easy removal of all the electronic internals of the robot with ease. The same Harwin-brand connector system has replaced the unreliable spade connectors used in the previous model

4.1.3 Asset Improvements

Other than the overall design improvements made to the USAR robots, the 2010/11 team improved several assets of WMR. This was both so the current team could function better, but also future years could benefit from the work.

It was decided that the WMR lab had become over-crowded, with a large amount of unnecessary equipment and parts. Figure 11: Before, shows the large amount of clutter and the small amount of free space to work on, and operate the robots. The new office maximises the amount of desk space that can be used and creates a large area in the centre of the office where the robots can be manipulated. This space is also useful to hold group meetings in, and is also useful for when sponsors come to visit the team. The two new work benches have created a safe area to solder and work on the robots.

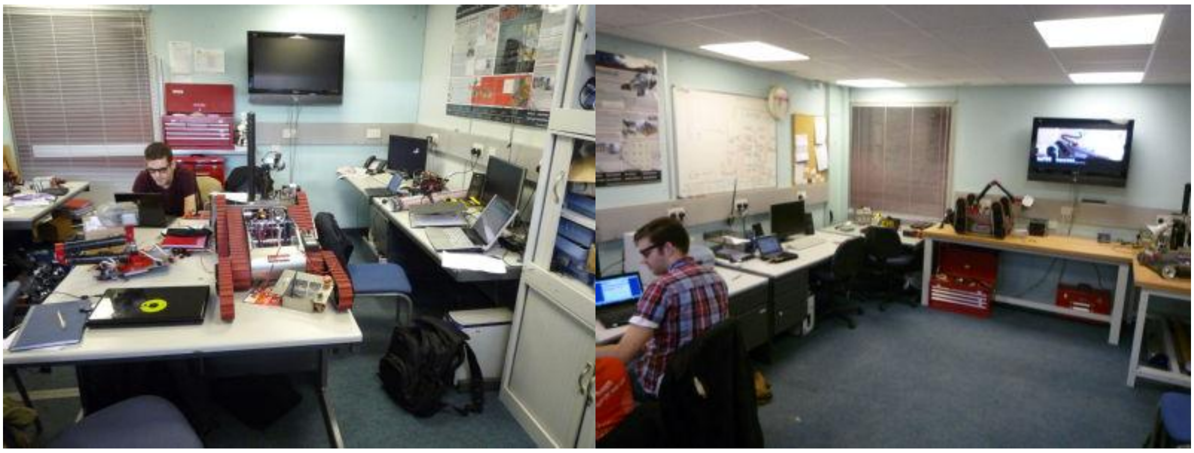


Figure 11: Before and after photographs of the WMR lab

As well as these changes, this year's team significantly improved the CAD suite of the WMR lab, with two new work-stations, meaning the mechanical teams could use the CAD software to work on the complex designs needed for the project without being hindered by poor hardware.

As well as these improvements, tools were purchased that needed replacing, a new charging station for the lithium polymer (LiPo) batteries was also created, giving a safe area to easily recharge the batteries.

4.1.4 Sponsorship, Publicity and Awareness

With a working robot and no legacy balance passed on from previous years, the sponsorship focus was on cash-raising as this provided the team with added flexibility for various developments. Out of previous years' sponsors the School of Engineering, WMG, IMRC, and Harwin provided continued financial support to the value of £10,350. It was vital the team secured additional funding for all their developments throughout the year. This was achieved through a large drive of publicity and sending speculative letters through WMR's growing network of contacts. From new sponsors, the team was able to raise £8,947 from Mouser, Thales, the Office of the Vice Chancellor (Warwick University), and Xsens. This is a grand total of £19,297, out of which £17,350 (before tax) was cash sponsorship.

This total could not have been possible without the large amount of publicity this year's team has received. Throughout the year, WMR has appeared on television, online, radio, newspapers, magazines, and has demonstrated their product at the Gadget Show Live exhibition. Some of the larger publicity events include (for a full list please see the Publicity section of the Business, Publicity, Finance, and Management Report):

- Appearing on the Gadget Show which has an estimated weekly viewership of 2.5 million
- Appearing on BBC Click with an estimated worldwide weekly viewership of 75 million
- Being interviewed on BBC World Service with an estimated worldwide audience of 180 million

4.1.5 The WMR team's performance at the competition

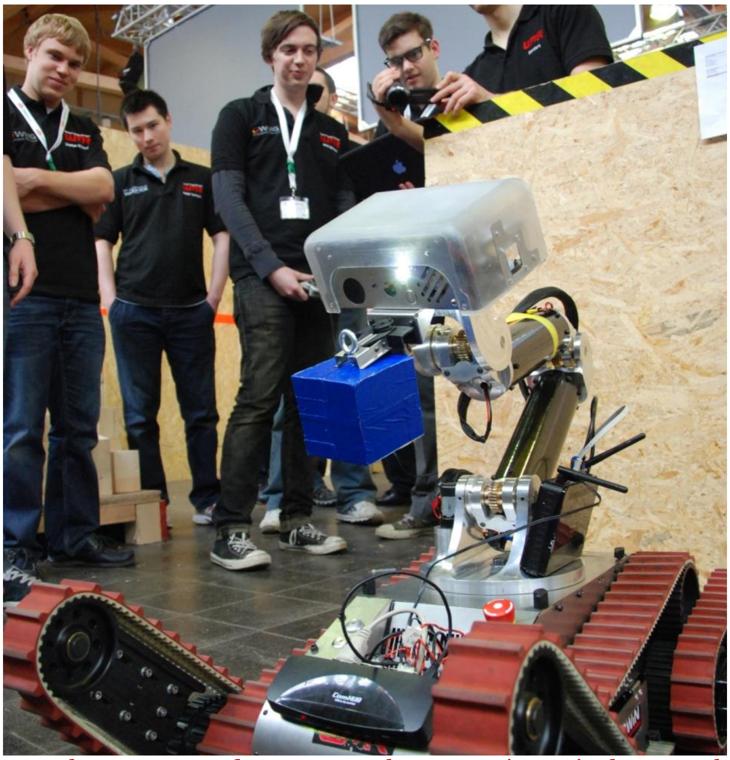


Figure 12: The WMR team demonstrates the USAR-T's manipulator capabilities

Despite a constant stream of technical issues caused by the late production and development of the new USAR-T arm (discussed in greater detail in the Technical Report), after a quick adaptation of the USAR-A to allow for tele-operability, it was capable of earning the best in mobility awards due to its caterpillar track and chassis design. In addition the WMR team qualified for the Robocup world competition In Istanbul, Turkey in July. The technical issues are discussed in detail in the evaluation section of the individual technical report sections, however, the basic list of the most time-consuming problems were:

- The first run of the USAR-T resulted in the damage of the router mounted in the head. It was caused by the robot reversing over one of the orange arena's slopes and its head colliding with the opposite wall as it rocked back.
- High mechanical stresses present in the arm's motors meant that the motor speed controllers were unable to produce enough current without catastrophically overheating and having to be replaced by a more powerful controller.
- The high loads in the shoulder joint caused internal damage in the motor itself, and so rendered that joint inoperable (only the base rotary, elbow and wrist joints in the arm could be operated).

Minutes after the competition ended, the USAR-T's arm was completed to a standard to where it was capable of navigating the red arena terrain and also capable of retrieving a payload to deliver to one of the judges. If this operation was achieved earlier the WMR team may have fared better in the competition itself.

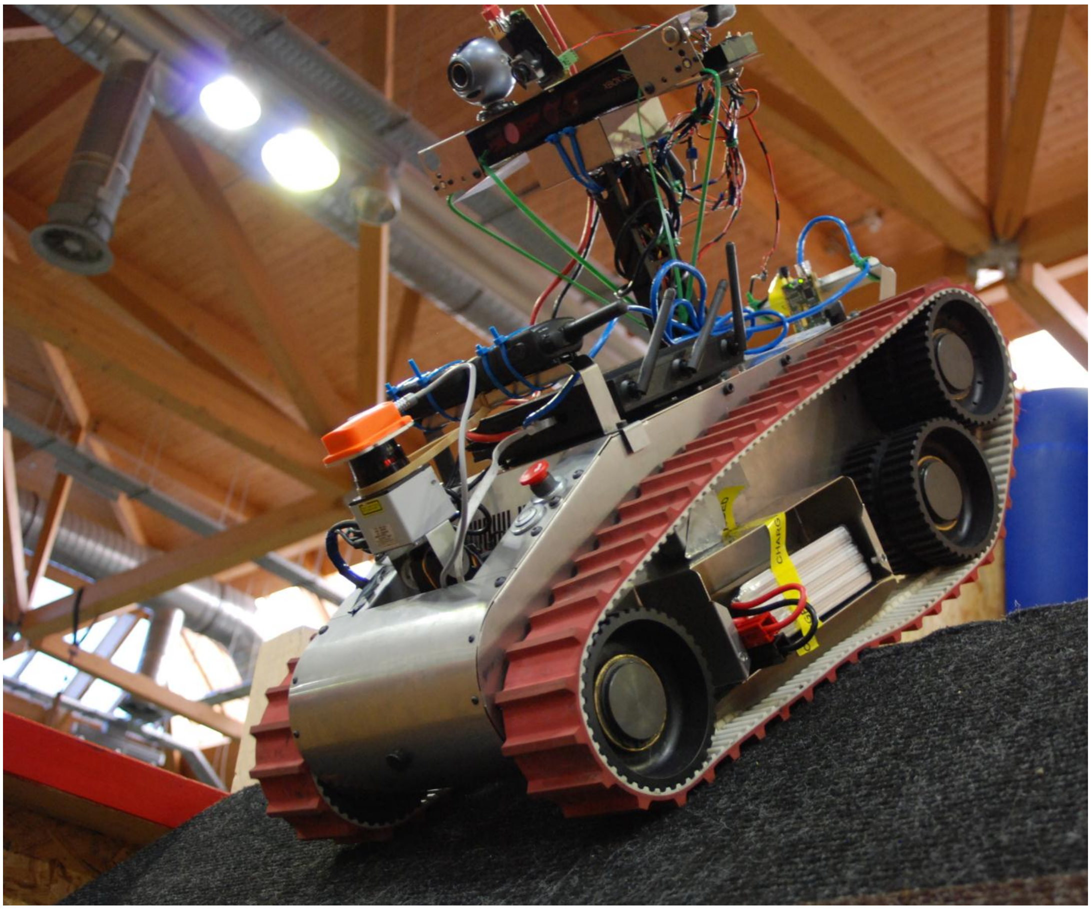


Figure 13: The adapted USAR-A could navigate some of the Red arena's terrain thanks to the design of its tracks

The tele-operated USAR-A was capable of navigating the orange arena's 30^{o} slopes and the red arena's 45^{o} slopes. Points were scored by integrating web-cameras from the USAR-T platform onto the USAR-A and by securing walkie-talkies to the front handle. Due to the lack of autonomous mapping capability; mapping was attempted by utilising the code from the WMR hexapod project, it utilised the LIDAR and the Xsens as the Kinect code was not yet developed enough for use. However, the arena was not mapped in real time, to the Geotiff format and finally due to connection problems mid-run; a map was unable to be retrieved for additional points. Because the phidget device interface board was still not operational on the USAR-A CO_2 sensor functionality was also not available. Without an arm or manipulator, visual identifiers such as viewing the hazard symbols and complete eyechart were also problematic (the front webcam was positioned atop the robot for high areas, and the rear webcam positioned low for low areas), and payload delivery was out of the question. Another frequently experienced problem was that the webcams would cut out after a large bump and need to be reset over the course of two minutes, costing valuable time in a middle of a round.

For these reasons the statistical performance for the 2011 Robocup German Open competition will not be used due to its poor representation of the true capabilities of our upgraded platform. The results from this year's competition can be found in Appendix 3.

4.1.6 Competitor Analysis

The main focus of the competing teams at the competition in Germany was on autonomous operation, and so many of the platforms the WMR competed against had far superior mapping capabilities and yet did not share the design for mobility the USAR-T3.5 or the USAR-A2 nor were the designs for manipulation or the repositioning of sensors as advanced as the potential operation of the USAR-T3.5's. For the purposes of assessing our competitors technical capabilities thorough subjective QFD analysis an additional competitor will be assessed that have similar capabilities to the USAR-T3.5; the SUCCESS, Rajamangala University of Technology Rattanakosin: World RoboCup Rescue champion 2010.

The following information has been provided from the team's publications and where possible provided by the team members themselves via e-mail.

4.1.6.1 Team Hector Darmstadt, TU Darmstadt, Germany(TU Darmstadt n.d.)

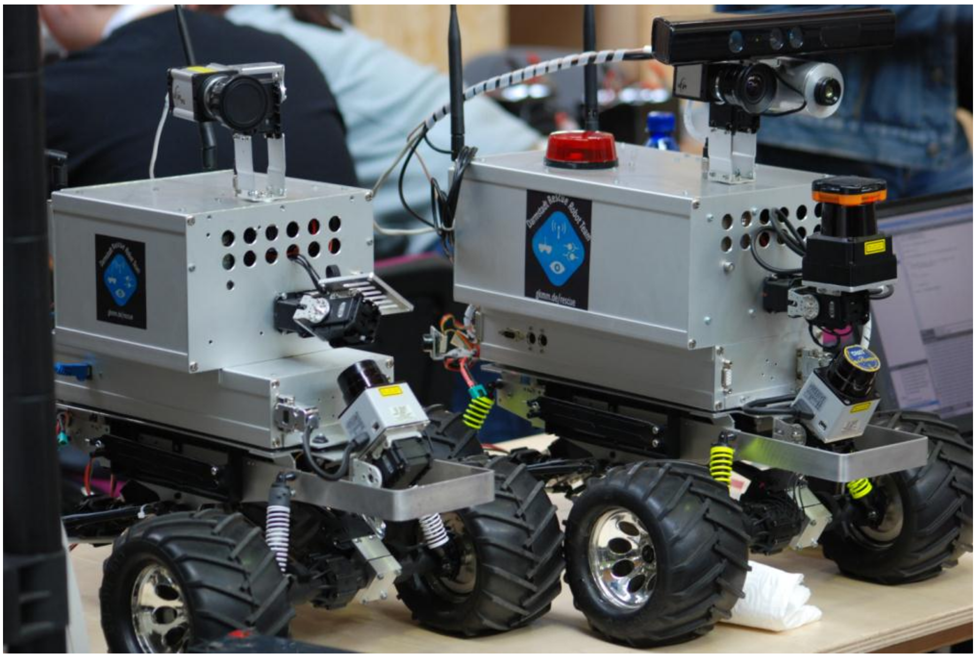


Figure 14: The Hector G3 USARs

- Team hector uses a modified Kyosho Twin Force RC model, the advantage of which is four wheel drive and steering to allow for up to 35^{o} longitudinal travel. The platform at the completion was also observed to be very fast but could not navigate the step fields in the red arena.

- Wheel encoders, a Lidar, inertial measurement unit and navigation filter provide the USAR with mapping and positional capabilities. Rear ultrasound sensors were also used for collision detection and the Kinect used to plot drivable routes through the arena autonomously and identify victim holes.
- Thermal imaging cameras and a high resolution camera were used to visually identify victims and vision based recognition software was used to identify victims faces and hazmat symbols. The use of a Nividia graphics card is used to process the images in real-time.
- This team based best in class for autonomy against its three competitors and include the co-operation between two robots in the arenas.
- The robot could not audibly communicate with victims.

4.1.6.2 ISTY, University of Versailles, France

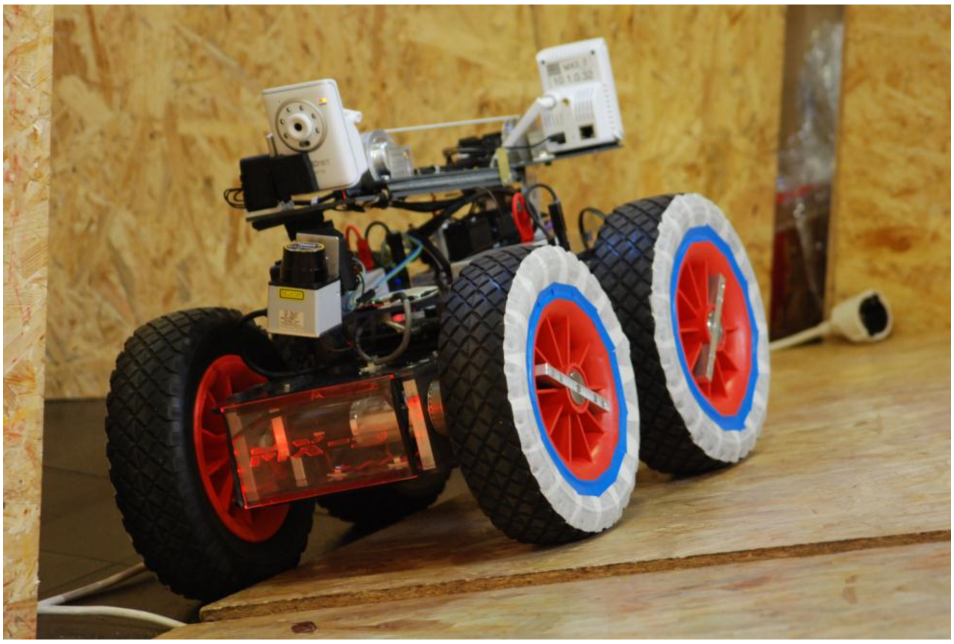


Figure 15: The ISTY USAR

- The robust and simplistic chassis and comparatively large wheels of the USAR allowed the team to navigate the step fields in the red arena but nothing more.
- There was an actuator atop the USAR that allowed the robot to elevate its front webcam but only keep it facing forward. Their robot was modified by placing a non-retractable stick to the actuator to collect payloads and was only used for the best in class in manipulation award.
- The wireless cameras were capable of full audio communication with victims. (2011 TRENDnet. 2011)

- The Lidar was kept level through an inertial sensor and was used to map the arena in real-time.
- The robot could not operate autonomously, or detect CO_2 levels.

4.1.6.3 GETbot, Universitat Paderborn, Germany (Project GETbot - der autonome Rettungsroboter n.d.)

Figure 16: The GETbot USAR

- The chassis is an amalgamation of supporting struts attached to a pre-bought Pioneer P3-AT with a four wheel drive system and wheel encoders. It was only capable of navigating the yellow and some of the orange arenas.
- Mapping and object avoidance is achieved by a Lidar sensor, inertial measuring unit and the wheel encoders in the drive system. The Kinect is used for path finding by identifying difficult (resko@UniKoblenz and team homer@UniKoblenz 2011)terrain. The team also used the data to prototype a three dimensional model of the arena to simulate successive autonomous tests without having to use the USAR itself.
- An IR camera and webcam is used for automated victim identification.
- The robot could not communicate audibly with victims or sense CO_2 levels.

4.1.6.4 resko@UniKoblenz, University of Koblenz-Landau, Germany(resko@UniKoblenz and team homer@UniKoblenz 2011)

Figure 17: The Robbie16 USAR

- The chassis is an amalgamation of supporting struts attached to a pre-bought Pioneer P3-AT with a four wheel drive system and wheel encoders. It was only capable of navigating the yellow and some of the orange arena sections.
- Two coupled LIDARs and interial sensors are used to map the arena.
- Three cameras and thermal sensors at varying and adjustable heights are used to detect victims.
- The USAR is not capable of audio contact with victims or sense CO_2 levels.

4.1.6.5 SUCCESS, Rajamangala University of Technology Rattanakosin: World RoboCup Rescue champion 2010 (SUCCESS, Rajamangala University of Technology Rattanakosin 2010)

Figure 18: The SUCCESS USAR (SUCCESS, Rajamangala University of Technology Rattanakosin 2010)

- SUCCESS's platform is custom made, features wide caterpillar tacks and both front and rear flipper tracks making it able to navigate any arena environment. It has a circularly gripping manipulator, and its large arm can collapse in on itself for compact navigation over difficult terrain, correcting its center of mass, and its 'head' is suitably compact for investigating small spaces.
- Three internet cameras are utilised; two attached to a rotating tower on the rear of the chassis for navigation one attached to the arm for navigation and observation of the arm, and finally an analogue camera is mounted in the head for victim identification. A thermal sensor and microphone is also mounted in the head of the USAR.
- Automatic mapping is achieved though motor encoders, a digital compass and two ultrasound position sensors, resulting in a very inaccurate map.

- The robot is incapable of autonomous function; however the team's strength lies in the intense training of their operators, the mobility of the robot and versatility of the arm. It should also be noted that these technical specifications are one year out of date.

5 Critical Review

5.1 Evaluation: Quality Function Deployment

5.1.1 Definition and explanation:

Quality Function Deployment is a system that translates the needs of the customer into technical requirements for each stage of development or production of a product or service.

By treating the competition's point scoring requirements as the customer and the technical features of the USAR's (the USAR-T3.5 and USAR-A2) as the technical requirements, the first stage of basic QFD can identify future areas for expansion in the WMR team's platforms.

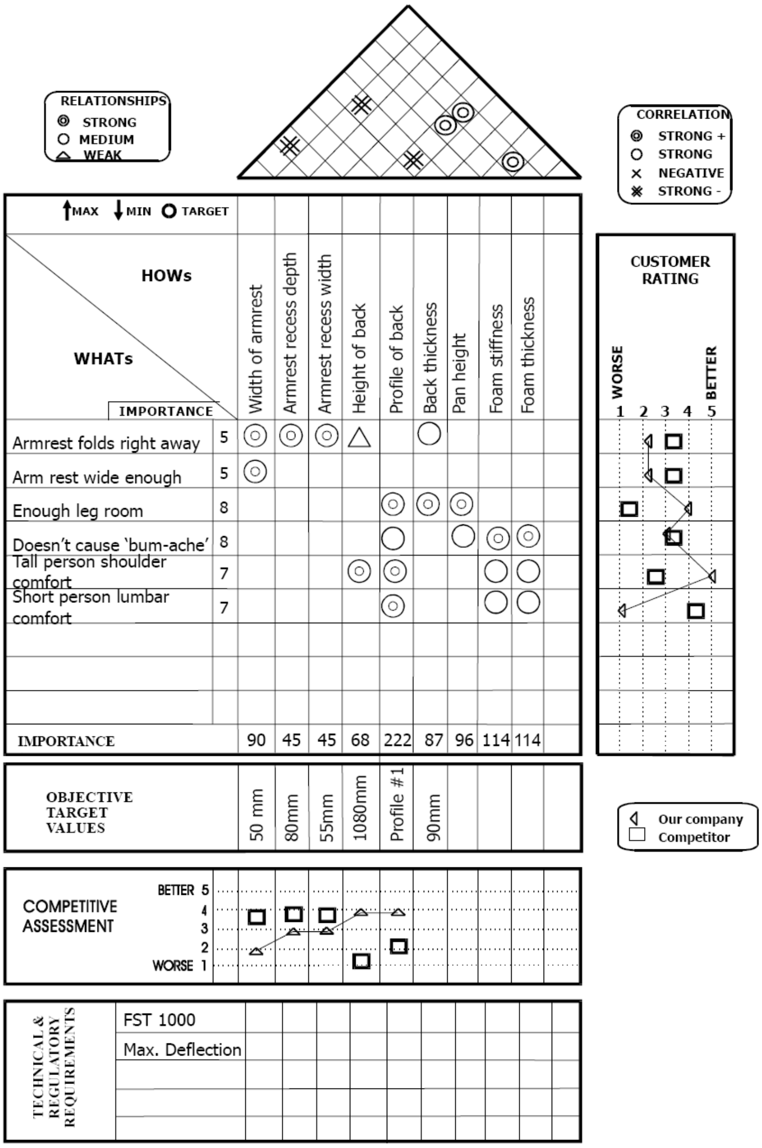


Figure 19: A QFD matrix(The University of Warwick 2001)

The process for basic QFD is as follows: (The University of Warwick 2001)

1. The required functions are listed and an importance rating associated to each of them individually. (In this case total available points)
2. The individual design features of the product are listed, including potential future features.
3. Correlations between design features are mapped and their impact on the required functions determined. Both are marked as symbols on the QFD chart.
4. The performance of the product and competitors with regards to required functions are determined and compared in a chart to the right of the chart. (Because a points breakdown of the opposing teams was not allowed to be listed during the competition, this will merely have to be determined subjectively by assessing the performance of the USAR technical features)
5. Finally the importance of each design feature is calculated based on the importance of the required functions they associate with.

Additional stages missing for the purposes of this simplified form of QFD for the USARs are the statistical values of design features (objective target values) and the competitor deviation from the values at the bottom of the chart. Also missing are the industry-set regulations on said statistical values. The formula for determining the importance of a design feature at the bottom of the column:

$$\sum(Importance\ of\ required\ function * level\ of\ relationship)$$ (The University of Warwick 2001)

The end result is an order of importance of design features, both pre-existing and not yet existing, and a comparison to the advantages the product has over its competitors. An important design feature not yet implemented would be the cause of the quality gap with a competitor for a (or several) required functions. QFD displays this in a diagrammatic form.

5.1.2 The WMR USAR platforms' QFD

For the purposes of treating the competition as a customer rating of importance, the total potential score of each of the four arenas and the individual victim point scores multiplied by the total number of 14 victims in a single round. Such a target is almost impossible to reach, but appropriately weights the importance of each requirement. The relationship is kept binary, so a design feture either contributes towards earning the points of a required task or not. Finally, a crude bar chart displays the breakdown of competitor team's performance compared to the WMR team.

The final top five design features in order of importance as determined by Figure 20: the WMR platform QFD matrix: (Robust Systems and Strategy LLC 2007)

1. Camera angles
2. Arm design
3. Geotiff mapping
4. Track and flipper design
5. Autonomous functionality

These statistical conclusions should be considered lightly regarding their subjective roots, however competitor analysis identifies some otherwise unseen advantages or opportunities. It seems none of the listed teams other than WMR invested in a CO_2 sensor nor have any team invested in the autonomous function without radio contact. The world champions, the SUCCESS team, focused on perfecting mobility and training its operators as opposed to incorporating every sensor, mapping technique into the robot. This could prove to be a lesson for the next year's WMR team. In addition, the implementation of working software to the LIDAR and Xsens infrastructure, on the USAR-T3.5 to generate Geotiff maps during teleoperated function could boost the point score of the team significantly. This is partially proved by the level of importance the QFD chart displays Geotiff mapping.

System QFD

http://wiki.robocup.org/wiki/Robot_League

X	Relation with design feature
1	Feature required for task Or provides advantage

	Technical feature	1	2	3	4	5	6	7	8
1	Track, flipper and chassis design								
2	Arm Design and Kinematics	x							
3	Manipulator design		x						
4	ngles ,Visual autonomy and UI (Kinect)	x	x	x					
5	Speaker/Microphone application		x						
6	CO2 Sensor		x						
7	IR Camera		x		x				
8	Geotiff mapping (LIDAR and Xsens)								
9	us functionality (+ Ultrasound col. det.)	x			x			x	x

	Competition task	Competition Weighting	Track, flipper and chassis design	Arm Design and Kinematics	Manipulator design	Camera Angles ,Visual autonomy and UI (Kinect)	Speaker/Microphone application	CO_2 Sensor	IR Camera	Geotiff mapping (LIDAR and Xsens)	Autonomus functionality (+ Ultrasound col. det.)
1	Navigating: Yellow Arena (4 victims)	280				1				1	1
2	Orange Arena (4 victims)	280	1			1					
3	Red Arena (4 victims)	280	1	1		1					
4	Black/Yellow Arena (2 victims)	140				1				1	1
5	Visual identification	140		1		1			1		
6	Motion sensors	70		1		1					
7	Thermal sensors	70		1					1		
8	CO2 Sensors	70		1				1			
9	Audio: Victim -> Operator	70		1			1				
10	Audio: Operator -> Victim	70		1			1				
11	Mapping: Geotiff map	140								1	
12	Mapping: Location Accuracy	140								1	
13	Payload Delivery	280		1	1	1					
		Raw score	560	1050	280	1470	140	70	210	700	420
		Scaled	0.381	0.714	0.19	1	0.095	0.048	0.143	0.476	0.286
		Relative Weight	11%	21%	6%	30%	3%	1%	4%	14%	9%
		Rank	4	2	6	1	8	9	7	3	5

Competitive comparison

Figure 20: the WMR platform QFD matrix (Robust Systems and Strategy LLC 2007)

5.2 Recommendations

The next stage of quality performance involves the importance rating of the design features being broken down into a subsystem level; expanding upon the technical requirements of the platforms. For example, Geotiff mapping without autonomous function is a clear area for expansion that the WMR team has not entirely invested time in, and yet the resources are available. Even if autonomous function cannot be achieved by computer science the team could invest time next year in the software implementation of LIDAR mapping in the teleported platform.

Project: WMR RoboRescue
Date: date
Input areas are in yellow

Subsystem QFD

	Technical Requirements	Tech Rqmt Relative Weights	Subsystem Requirements																			
1	Track, flipper and chassis design	11%																				
2	Arm Design and Kinematics	21%																				
3	Manipulator design	6%																				
4	Camera Angles ,Visual autonomy and UI (Kinect)	30%																				
5	Speaker/Microphone application	3%																				
6	CO2 Sensor	1%																				
7	IR Camera	4%																				
8	Geotiff mapping (LIDAR and Xsens)	14%																				
9	Autonomus functionality (+ Ultrasound col. det.)	9%																				
		Raw score																				
		Relative Importance	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Rank																				

Figure 21: The subsystem QFD chart determined from the QFD matrix (Robust Systems and Strategy LLC 2007)

6 Further Work

6.1 Future technical improvements for the USAR-T

With reference to the mechanical section of the technical report future mechanical improvements of the USAR-T should include a new bespoke manipulator, changes to the arm and head, and finally improvements to the flipper drive.

A bespoke manipulator design could be developed, improving upon the current bought-in solution. Doing so would allow for better design for differing payload and grip stroke requirements. An additional suggestion would be incorporating pressure feedback to the UI.

Changes to the arm and head should include: the reduction of the reduction of weight in the arm base reinforcement, the use of anti-backlash gears for the worm gears in the arm joints, to reduce free vertical movement and finally the router should be repositioned in a far more protected location than its current location in the head.

The poor transmission observed in the flipper motor drive could be solved with a better transmission system, via direct gearing as opposed to chains.

With reference to electronics systems section of the technical report future electronic improvements to the USAR-T should include upgrading of the arm electronics, improving computer hardware, improvements to the battery monitor and motor controller board upgrades. With the requirement of more powerful motors in the arm further testing will be necessary to determine the specifications of the new motors.

Upgrades in computer hardware to a higher-performing, but similar configuration would improve the versatility of the robot by increasing its capability to execute operations at a greater speed. Alternatively physically smaller and lesser power/mobile chipset would occupy a smaller space and extend the battery life of the robot.

The recommended additions to the battery monitor, to improve its functionality, are to design for the inclusion of current and charge management, monitoring the voltage of individual cells and the integration with the existing power board.

With reference to software sub-section of the technical report future software improvements to the USAR-T should include improved dynamic arm control, manipulator control, integration with ROS (Robot Operating System), and further miscellaneous changes and additions to the Robot Client Software.

Improvement of the joint class would provide the arm forward and inverse kinematics with a far more dynamic design. It would be feasible to develop a system where the addition of joints to the arm would dynamically alter the forward and inverse kinematics of the system.

Improved manipulator control and would allow the operator to determine the distance between the gripper's fingers and so operate the device more effectively than just opening and closing a fixed distance.

The implementation of ROS would not require any additional hardware. With extensive libraries for a wide variety of sensors, the ease of writing new entries and a large community base of contributors; expansion on the platform could be conducted with relative simplicity.

With the rebuilding of the robot client into an extendible fashion the following additions could be implemented into the software: The reintegration of the IR camera feed into the user interface is a priority and requires the use of an averaging algorithm to identify and then communicate signs of life to the operator. Assisted control could be implemented through the autonomous identification of signs of life and communicating this back to the operator. The implementation of mapping in any form would assist navigation around the arena. Two-way audio communication is another victim identification method yet to be fully incorporated. Finally the control of the arm through the control pad using inverse kinematics would benefit the operator through smoother manipulation and victim identification.

6.2 Future technical improvements for the USAR-A

With reference to mechanical systems section of the USAR-A portion of the technical report; the upgrading of the USAR-A chassis is mostly complete mechanically with the exception of the required lids for the battery holders. The supporting structure for the head requires a redesign for the purposes of weight reduction, stability and two degrees of freedom with space for all the required sensors atop it.

With reference to section 3.4.2 the required modifications to the future electronics of the robot are similarly brief. The "Mag" motors present in the robot should be replaced with the Maxon brand to replace the damaged motor and promote standardisation between the platforms. A replacement phidget board will have to be bought, and the addition of a front 12V front fan. A secure method of fixing the 12V power converter to the chassis should be devised in addition to determining a method of integrating new components to its already spatially overburdened terminals. The wires leading to the emergency stop button should also be lengthened for accessibility.

7 Knowledge Transfer

WMR Search and Rescue is a continuing student project which is undertaken by a new team of engineers every academic year. The Search and Rescue project is currently in its fourth year and knowledge transfer is becoming an increasing problem due to the increasing complexity of the product.

7.1 Justification

Due to the complexity and size of the project this year many task which should have been simple have proven to be very difficult these include (to name a few):

- E-Mail addresses and passwords
- Contact details of past and present sponsors and stakeholders, along with any agreements held
- Location and naming system of design files
- Details on basic processes such as purchase orders
- Full and detailed information on the competition and points scoring system
- Competitor information

The WMR team typically has a hard task at the beginning of the project year as they are unfamiliar with the project and the tasks which they must undertake. This year there have been many obstacles to overcome which could have been avoided.

The 2010/11 team has relied very heavily on students who were involved in the project in previous years who have remained at the university, whilst this is useful it is unreasonable to rely on these students who have other commitments and may not necessarily be at the university for the future years of the project.

It was also made clear to us during numerous meetings with our industrial partners that knowledge transfer is of utmost importance and an issue they regularly face. It is important for WMR to provide a method of knowledge transfer in order to aid next year's team and help secure the future of the WMR project.

7.2 Approach

There are three approaches which have been adopted in order to transfer knowledge to next year's group

- A clear filing system on both the WMR computers and in the WMR filing cabinets
- A concise hand-over document which is easily read and referenced
- Setting up third-year projects which will introduce students to the project earlier

A filing system has been implemented within the office to organise most of the paper administrative documents used throughout the year. This is to be used as a reference for future purchases and details on past suppliers for the group.

The hand-over report is to be an informal document detailing all the expertise that the group has learnt through trial and error or have retained through repeated use. This is typically a form of tacit knowledge lost with the transfer of teams and requires a form of externalisation in order to document it all. Traditionally, companies can be expected to lose this knowledge when key technical people leave and it is a growing concern within large corporations. No previous years have successfully transferred expertise in a structured fashion. This hand-over report is generated and submitted to all future students separate from this report in order to maintain security of passwords and other sensitive data.

It has been suggested to involve third-year students in the WMR project in order to smooth the transition of teams. Not only would this serve to build interest in the project earlier on in the Engineering degree, but also lessen the future team's reliability on the aforementioned hand-over report. As the project is highly complex and time-consuming it was suggested that certain aspects could be separated off and worked on individually by a third-year student, such as redesign of the chassis and electronics stack.

8 Conclusions

As Warwick Mobile Robotics is continually pushing itself towards becoming a commercially viable product, it has had to create more challenging engineering aims year-on-year. This year's efforts have produced a very good engineering system and have successfully addressed weaknesses of the previous years' platforms. Significant manufacturing delays resulted in the team not being able to produce a fully tested platform at the competition in Magdeburg, therefore not being able to retain the title of European Champions, nor achieve Best-In-Class Mobile Manipulation. However, practice runs after the end of the competition demonstrated far superior manipulator capabilities than other competitors and the USAR-A still managed to achieve Best-In-Class Mobility, retaining that title for the team. This mobility title could not have been achieved without successfully implementing the USAR-T's proven chassis design onto the USAR-A in an effort to bring both platforms towards a point of easy interchangeability and standardisation. During the practice runs, the team was able to impress judges with manipulation and mobility enough to earn an invitation to attend the RoboCup Rescue World Championships in Turkey.

An impressive working system has brought about interest in the product as a commercial product, including enquiries from various individuals with a speculative interest in purchasing the USAR robots for use in real-world applications. Much of the business aspect of WMR was considered this year and a meeting with Warwick Ventures outlined the best course of action for taking further steps in the direction of commercialisation. Ultimately though, possible issues with intellectual property rights (solely attributed to the requirements made out by the RoboCup that all papers must be publicly available) have meant the long term feasibility of the USAR robots as a sellable product is limited.

9 Works Cited

2011 TRENDnet. TRENDnet. 2011. http://www.trendnet.com/langen/default.asp (accessed April 2011).

Active Robots. *Robot Kits, Gripper Kits*. 1 Feb 2011. http://www.active-robots.com/products/robots/lynx-a-gripper.shtml (accessed Feb 1, 2011).

BeagleBoard.org. *beagleboard.org*. April 2011. http://beagleboard.org/.

Beament, Claire. Warwick University. 10th November 2010. http://www2.warwick.ac.uk/services/healthsafetywellbeing/ (accessed October 18th, 2010).

Benenson, R., Parent, M. *Design of an urban driverless ground vehicle*. Scientific Paper, Nice: IEEE International Conference on Intelligent Robots Systems, 2008.

British Foreign and Commonwealth Office. *Germany Travel Advice*. British Foreign and Commonwealth Office (FCO). 2011. http://www.fco.gov.uk/en/travel-and-living-abroad/travel-advice-by-country/europe/germany (accessed Feburary 28th, 2011).

Chen, Y J, E C Haas, K Pillalmarri, and N C Jacobson. "Human-Robot Interface: Issues in Operator Performance, Interface Design and Technologies." 2006. http://handle.dtic.mil/100.2/ADA451379 (accessed 11 20, 2010).

Department of Homeland Security. *Robot Guide 2009*. 9 April 2009. http://www.isd.mel.nist.gov/US&R_Robot_Standards/Robotguide2009.pdf (accessed January 14, 2010).

Draganfly Innovations Inc. *How To Safely Use, Charge, and Discharge Lithium Polymer (Lipo) Batteries*. Draganfly Innovations Inc. 19th May 2009. http://www.rctoys.com/pr/2009/05/19/how-to-safely-use-charge-and-discharge-lithium-polymer-lipo-batteries/ (accessed October 18th, 2010).

—. *Important Safe Use Document for Lithium Polymer Batteries Including Thunder Power RC LiPolys*. Draganfly Innovations Inc. 19th May 2009. http://www.rctoys.com/pr/2006/10/20/safe-use-document-thunder-power-lithium-polymer-batteries/ (accessed October 18th, 2010).

Federal Environment Agency. *Umweltzonen und Luftreinhaltepläne in Deutschland (Environmental zones and air quality management in Germany)*. Federal Environment Agency. http://gis.uba.de/Website/umweltzonen/index.htm (accessed February 28th, 2011).

Geartronics. *Pneumatic Paddle Shift System.* 3 March 2011. http://www.geartronics.co.uk/paddleshift.htm (accessed April 6, 2011).

German National Tourist Board. *Driving in Germany - German Highway code - Low emission zones - Speed limits - Winter tyres and much more.* German National Tourist Board. http://www.germany-tourism.co.uk/EGB/practical_information/driving_in_germany_9829.htm (accessed February 28th, 2011).

Harris, Mark. *The Times Online.* 31 May 2009. http://technology.timesonline.co.uk/tol/news/tech_and_web/article6389337.ece# (accessed October 7, 2009).

Harwin Plc. *Harwin PLC - Electrical Connectors and SMT PCB hardware.* 2011. http://www.harwin.com/ (accessed October 2010).

Huang, H.M., Messina, E., Albus, J. *Toward a Generic Model for Autonomy Levels for Unmanned Systems (ALFUS).* Gaithersburg: National Institute of Standards and Technology, Intelligent Systems Division, 2004.

Jacoff, Adam. *RoboCupRescue Robot League Progress Update and Future Directions.* NIST, 2009.

Kagotani, Georges, Maki Sugimoto, Masahiko Inami, and Fumitoshi Matsuno. "A Novel Teleoperation Method for a Mobile Robot Using Real Image Data Records." *Proceedings of the 2004 IEEE International Conference on Robotics and Biomimetics.* Shenyang: IEEE, 2004. 233-238.

Leonard, J., Durrant-Whyte, H. "Simultaneous Map Building and Localization for an Autonomous Mobile Robot." *International Workshop on Intelligent Robots and Systems* III (August 1991): 1442 - 1447.

Markoff, John. *The New York Times, Google Cars Drive Themselves, in Traffic.* 9 October 2010. http://www.nytimes.com/2010/10/10/science/10google.html (accessed March 28, 2011).

Massy-Westropp, N., W. Rankin, M. Ahern, J. Krishnan, and T.C. Hearn. "Measuring grip strength in normal adults: Reference ranges and a comparison of electronic and hydraulic instruments." *The Journal of Hand Surgery* 29, no. 3 (2004): 514-519.

Miller, Paul. *Engadget - Web magazine.* 6 August 2009. http://www.engadget.com/2008/08/06/irobot-negotiator-is-a-tactical-bot-for-those-mean-suburban-stre/ (accessed October 7, 2009).

Mizumoto, Hisashi, et al. "RoboCup Rescue 2009 - Robot League Team Shinobi (Japan)." 2009.

NATO Research and Technology Organistation. *Bridging the Gap In Military Robotics*. Technical Report, Bonn, Germany: NATO, 2008.

NHS. *European Health Insurance Card*. NHS. https://www.ehic.org.uk/Internet/home.do (accessed Feburary 7th, 2011).

Project GETbot - der autonome Rettungsroboter. http://getwww.uni-paderborn.de/research/getbot (accessed April 2011).

resko@UniKoblenz and team homer@UniKoblenz. "RoboCupRescue 2011 - Robot League Team description paper." *Robbie 16 (website)*. March 2011. http://userpages.uni-koblenz.de/~robbie/16/wp-content/uploads/2011/01/RCR2011_resko_TDP_v110210.pdf (accessed April 2011).

Robocup German open 2011. *Robocup Major results*. March 2011. http://www.robocupgermanopen.de/en/major/schedule?page=1 (accessed March 2011).

Roboteq. *Brushed DC Motor Controllers*. April 2011. http://www.roboteq.com/brushed-dc-motor-controllers/brushed-dc-motor-controllers-selector.

Robust Systems and Strategy LLC. "Software for robust systems and strategy." *Robust Systems and Strategy - Your source for strategic and reliable technology development expertise*. 2007. http://www.robuststrategy.com/Software/ (accessed March 2011).

ROS (Stanford, Willow Garage). *ROS.org*. April 2011. http://www.ros.org.

RS Online. *Finger Type Mechanical Gripper*. http://uk.rs-online.com/web/search/searchBrowseAction.html?method=getProduct&R=0478040#header (accessed Feb 1, 2011).

—. *Finger-Type Mechanical Gripper*. http://uk.rs-online.com/web/search/searchBrowseAction.html?method=getProduct&R=3663626#header (accessed Feb 1, 2011).

Sheh, Raymond, Adam Milstein, Claude Sammut, Bernhard Hengst, Gamini Dissanayake, and Jaime Valls Miro. "RoboCup Rescue 2009 - Robot League Team CASualty." 2009.

Singer, P.W. *Wired for War*. 1st. The Penguin Press, 2009.

Strachan, J., Bhatti, I.,, interview by Jonathan Greensmith. *Northrop Grumman, Remotec UK Ltd* (9 March 2010).

SUCCESS, Rajamangala University of Technology Rattanakosin. "RoboCup 2010 Rescue Robot League (SUCCESS_Thailand) (Team description paper)." *Slideshare - Upload and share presentations and documents*. March 2010. http://www.slideshare.net/amirhst/rcr2010-thailand-successtdp (accessed April 2011).

Tandy, M, S Winkvist, and K Young. "Competing in the RoboCup Rescue Robot League." *RISE 2010*, 2010.

The German Federal Environment Ministry. *Low emission zone / emissions-control windscreen sticker* . The German Federal Environment Ministry. http://www.bmu.de/english/air_pollution_control/general_information/doc/40740.php (accessed February 28th, 2011).

The University of Warwick. "Quality Function Deployment." *The School of Engineering*. 2001. http://www2.warwick.ac.uk/fac/sci/eng/eso/modules/year3/es382/resources/qfd/qfd_2001.pdf (accessed March 2011).

Thrun, Sebastian. *Stanley: The Robot that Won The DARPA Grand Challenge*. Technical Report, Wiley InterScience, 2006.

TU Darmstadt. *Hector GV*. http://www.gkmm.tu-darmstadt.de/rescue/?q=node/3 (accessed April 2011).

Uschin, Kathawut, et al. "RoboCup Rescue 2010 - Robot League Team iRAP_PRO (Thailand)." (King Mongkut's University of Technology North Bangkok (KMUTNB)) 2010.

Valero, A., Gabriele Randelli, Chiara Saracini, Fabiano Botta, Massimo Mecella. *The Advantage of Mobility: Mobile Tele-operation for Mobile Robotics*. Scientifc Paper, Rome: Universita di Roma, 2011.

Warwick Mobile Robotics. *2009/2010 Technical Report*. University of Warwick, 2010.

10 Appendices

Appendix 1: Scoring Information

Source: (Robocup German open 2011 2011)

RoboCupRescue Robot League

RULES-AT-A-GLANCE (2011.1)

RECENT ADDITIONS

- A radio drop-out zone with crossing pitch/roll ramp flooring to encourage mobile robots to demonstrate autonomous navigation capabilities in complex terrains.
- Payload delivery to encourage mobile manipulators using inverse kinematics to perform automatic payload grasping, tool changing, object retrieval, and precision placement tasks on complex terrains. Three items can be carried as payloads from the start, additional items can be grasped in the arena.
- Two-way communications tests to establish victim identification by a remote operator (and judge) using randomly spoken numbers played as audio files within victim boxes.

MISSION OVERVIEW

- Teams should queue at the paddock entry with their robot(s) and operator interface(s) prior to their scheduled start time.
- 15-30 minute missions include robot placement at the start point and operator station setup. Each team is responsible for making sure victims in the arenas are functional (heat, batteries, tags) prior to mission start.
- The operator station will be limited to a 120 cm wide x 60 cm deep desk with walls. Teams are allowed only one operator in the operator station at any time during missions. Teams may switch operators whenever necessary.
- All robot start points will be in or around the Yellow arena and facing the same direction (marked as "north" on your map). The initial direction may be facing a wall. Teams with multiple robots will be co-located at the start point (as near as possible) and facing the same direction.
- Victim placements will be known to the operators and audience prior to missions, and changed each round to ensure complete arena coverage over multiple missions.
- All teams should map the Yellow arena, but robots must perform autonomous navigation and victim identification to score Yellow arena victims. Operators may remotely teleoperate the robot at any time to navigate into the Orange and Red arenas but must return to the start point to resume autonomous searches to find Yellow arena victims.
- Teleoperative robots can only score Orange or Red arena victims, which are likely placed on both sides of the Yellow arena to encourage complete mapping of all arenas.
- An operator (or team leader) may request a "ROBOT RESET" to fix a robot during a mission, but suffers loss of accumulated victim points, maps, and elapsed time. The robot must re-start the mission from the initial mission start point and work for the remaining time available. The robot can be teleoperated to the start point to fix with no loss of points.
- GeoTiff maps are required and will be compared to ground truth for accuracy. Map quality will be based on Technical Committee review.
- Bumping penalties will be assessed if the administrator must replace or fix arena elements prior to next mission.
- The league will assign 802.11A channels for practice and missions. All league SSID's must be "RRL-TEAMNAME". No other radios using either 2.4 GHz or 5 GHz radio frequencies are allowed.

MISSION SCORING

Robots must be within 1 meter directly in front of found victims to score points. Several key capabilities are specifically rewarded in the scoring metric. Since victims are distributed across all arenas, more capable robots have access to more victims. In general, up to 70 points are available per victim found:

VICTIMS PER ARENA

- 4 Yellow (auto nav. & ID only)
- 4 Orange (auto or teleop)
- 4 Red (auto or teleop)
- 2 Radio Drop-Out Zone (auto nav.)

POINTS PER VICTIM

VISUAL IDENTIFICATIONS (10 pts)

- (5 pts) Hazmat labels
- (5 pts) Eye charts

OTHER DETECTIONS (20 pts)

- (5 pts) Motion sensors
- (5 pts) Thermal sensors
- (5 pts) CO_2 sensors
- (5 pts) Audio: victim ---> operator
- (5 pts) Audio: operator ---> victim

ARENA MAPPING (20 pts)

- (10 pts) Quality of geotiff map
- (10 pts) Accuracy of victims

PAYLOAD DELIVERY (20 pts)

- (20 pts) Placing of payloads blocks or bottles into found victim boxes.

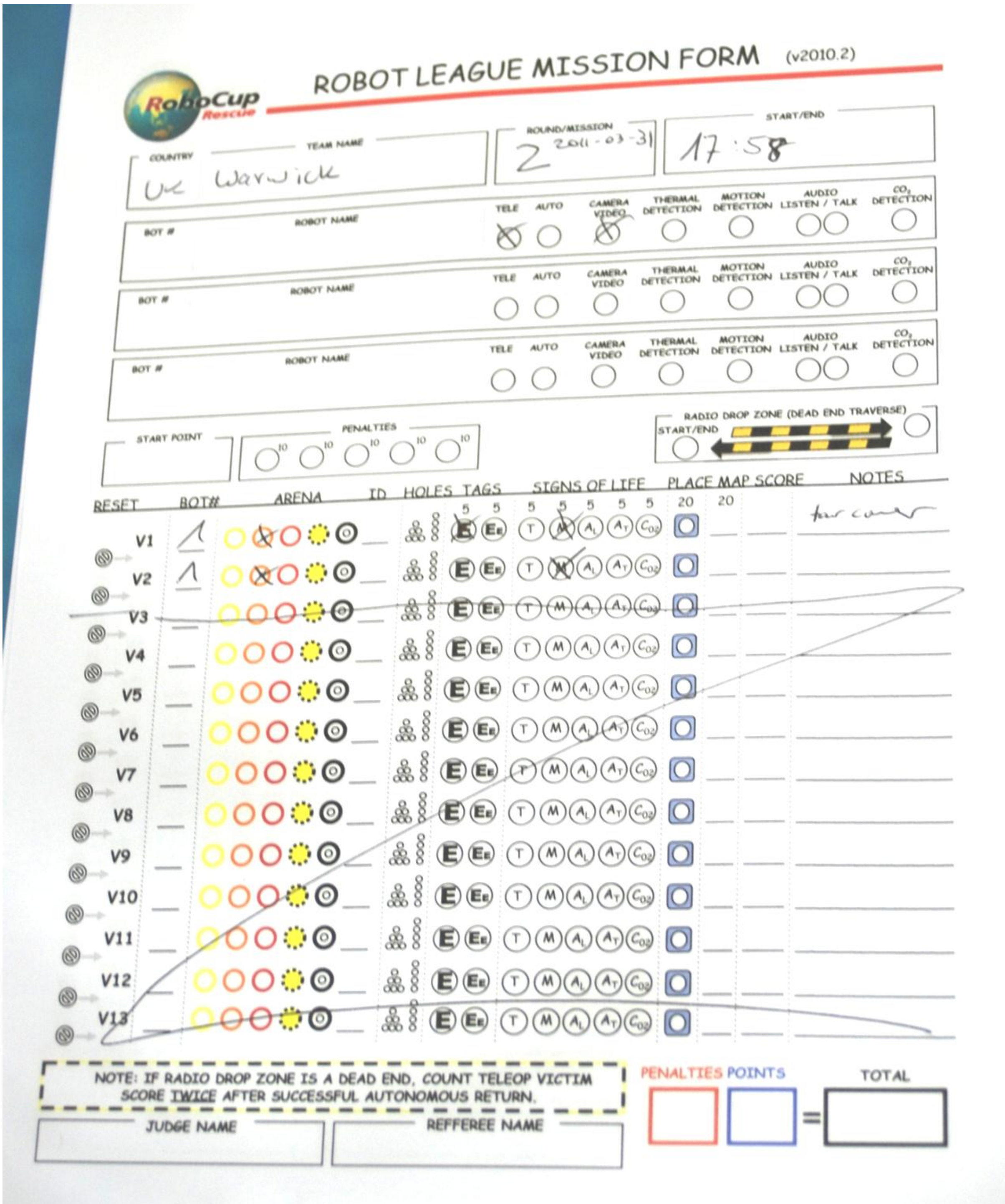
PENALTIES (-10 pts per event)

- Assessed when arena elements need to be replaced

[26]

Appendix 2: Sample Score Sheet

Source: (Robocup German open 2011 2011)


ROBOT LEAGUE MISSION FORM (v2010.2)

RoboCup Rescue

COUNTRY: UK | TEAM NAME: Warwick | ROUND/MISSION: 2 2011-03-31 | START/END: 17:58

BOT # | ROBOT NAME | TELE | AUTO | CAMERA VIDEO | THERMAL DETECTION | MOTION DETECTION | AUDIO LISTEN / TALK | CO_2 DETECTION

BOT # | ROBOT NAME | TELE | AUTO | CAMERA VIDEO | THERMAL DETECTION | MOTION DETECTION | AUDIO LISTEN / TALK | CO_2 DETECTION

BOT # | ROBOT NAME | TELE | AUTO | CAMERA VIDEO | THERMAL DETECTION | MOTION DETECTION | AUDIO LISTEN / TALK | CO_2 DETECTION

START POINT | PENALTIES 10 10 10 10 10 | RADIO DROP ZONE (DEAD END TRAVERSE) START/END

RESET | BOT# | ARENA | ID | HOLES | TAGS | SIGNS OF LIFE | PLACE | MAP | SCORE | NOTES

5 5 5 5 5 5 5 20 20

V1 – V13

NOTE: IF RADIO DROP ZONE IS A DEAD END, COUNT TELEOP VICTIM SCORE TWICE AFTER SUCCESSFUL AUTONOMOUS RETURN.

JUDGE NAME | REFFEREE NAME | PENALTIES | POINTS | = | TOTAL

Appendix 3: 2010/11 Competition Results

Start time	End time	Robot league	Competitor	Mission number	Points scored
31.03	13:00	Rescue Robot League	ISTY, University of Versailles, France	Mission 1	40
31.03	13:25	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 1	0
31.03	13:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 1	20
31.03	14:15	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 1	20
31.03	14:40	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 1	0
31.03	16:00	Rescue Robot League	ISTY, University of Versailles, France	Mission 2	20
31.03	16:25	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 2	5
31.03	16:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 2	15
31.03	17:15	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 2	45 (1 autonomes Opfer)
31.03	17:40	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 2	15
01.04	10:00	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 3	0
01.04	10:25	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 3	0
01.04	10:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 3	0
01.04	11:15	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 3	0
01.04	11:40	Rescue Robot League	ISTY, University of Versailles, France	Mission 3	25
01.04	13:00	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 4	60 (1 autonomes Opfer)
01.04	13:25	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 4	- skip -

01.04	13:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 4	0
01.04	14:15	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 4	40 (1 autonomes Opfer)
01.04	14:40	Rescue Robot League	ISTY, University of Versailles, France	Mission 4	45
02.04	10:30	Rescue Robot League	ISTY, University of Versailles, France	Mission 5	65
02.04	10:55	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 5	60 (1 autonomes Opfer)
02.04	11:20	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 5	55 (1 autonomes Opfer)
02.04	11:45	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 5	20
02.04	12:10	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 5	110
02.04	13:00	Rescue Robot League	ISTY, University of Versailles, France	Mission 6	55
02.04	13:25	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 6	45 (1 autonomes Opfer)
02.04	13:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 6	60 (1 autonomes Opfer)
02.04	14:15	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 6	20
02.04	14:40	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 6	35
03.04	13:00	Rescue Robot League	ISTY, University of Versailles, France	Mission 7	55
03.04	13:25	Rescue Robot League	GETbot, Universität Paderborn, Germany	Mission 7	130
03.04	13:50	Rescue Robot League	resko@UniKoblenz, University of Koblenz-Landau, Germany	Mission 7	65
03.04	14:15	Rescue Robot League	Team Hector Darmstadt, TU Darmstadt, Germany	Mission 7	110
03.04	14:40	Rescue Robot League	Warwick Mobile Robotics, University of Warwick, United Kingdom	Mission 7	40

Competitor	Final Position	Points
Team Hector Darmstadt, TU Darmstadt, Germany	1st	380
ISTY, University of Versailles, France	2nd	305
GETbot, Universitat Paderborn, Germany	3rd	280
resko@UniKoblenz, University of Koblenz-Landau, Germany	4th	215
Warwick Mobile Robotics, University of Warwick, United Kingdom	5th	114 (95 over 5 missions)

Appendix 4: Matrix for risk evaluation

Source: (Beament 2010)

THE UNIVERSITY OF WARWICK

Matrix for risk evaluation

Risk					
	Severity of injury				
Likelihood	Superficial	Minor	Serious	Major	Extreme
Unlikely	Very low	Very low	Low	Low	Moderate
Possible	Very low	Low	Low	Moderate	High
Likely	Low	Low	Moderate	High	Very high
Very likely	Low	Moderate	High	Very high	Very high
Extremely likely	Moderate	High	Very high	Very high	Very high

Rating for severity of injury	
Superficial	**Injury;** none, delay only **Property damage;** minimal
Minor	**Injury;** bruising, minor cuts, light abrasions. **Health effects;** mild irritation of skin or eyes, headaches, ill-health leading to temporary discomfort. **Property damage;** minor **Lost time;** < 3 days
Serious	**Injury;** loss of consciousness, lacerations, concussion, serious sprains, minor fractures, deafness, asthma, burns or injury resulting in absence from work. **Health effects;** acute health effects, e.g. harmful if inhaled/contact with skin/ or swallowed, dermatitis, ill-health leading to minor but permanent disability. **Property damage;** serious but confined to a work-room or area. Oxidising, flammable and highly flammable substances. **Lost time;** > 4 days – 3 months
Major	**Injury & illness;** affecting one person, permanent disability or other reportable injury/disease for example amputations/major fractures. Severely life shortening diseases, acute fatal diseases. **Health effects;** affecting one person, toxic by inhalation/contact with skin or swallowed. Damage to eyes, respiratory system, skin sensitization, effects on fertility, prolonged exposure risks, limited evidence of carcinogenic effects. **Property damage;** major. Extremely flammable and explosive substances. **Lost time;** > 3 months
Extreme	**Injury;** fatal incidents affecting more than one person **Health effects;** affecting more than one person or chronic medical disability due to, for example exposure to a probable carcinogen, may cause sensitization by inhalation. **Property damage;** the loss of one or more buildings.

Rating for likelihood	
Unlikely	Appropriate control measures in place with effective management of risk
Possible	Appropriate control measures in place with partial management of risk
Likely	Inadequate / inappropriate control measures in place with partial management of risk
Very likely	Inadequate / inappropriate control measures with no management of risk
Extremely likely	Absence of control measures with no management of risk

Prioritisation of risk factors	
Very low	Acceptable risk; no action required
Low	Tolerable risk; reduced as low as reasonably practical, further action may not be required
Moderate	Plan required to reduce the risk as far as is reasonably practical
High	Urgent action required to allow activity to continue. Plan required for sustainable risk control.
Very high	Risk intolerable; activity must cease until the risk has been reduced

Appendix 5: Workshop Risk Assessment

Risk assessment - Travel

THE UNIVERSITY OF WARWICK

Warwick Mobile Robotics

Title of risk assessment	RoboRescue Project Workshop Risk Assessment	Department	Warwick Mobile Robotics	Date	02/03/2011

Description of activities: **Using computer workstations, Soldering, Operating the Robots, Modifying the Robot, Manual Lifting**

*Further assessment may be need to be undertaken as required by the relevant legislation

Hazards Include brief explanation as to how they may cause harm.	Existing control measures Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE. etc	Persons affected	Additional control measures required Required to prevent/reduce likelihood of hazard occurring.	By whom/when Person responsible and completion date.
Repetitive strain due to prolonged use of computers.	Any user showing symptoms of repetitive strain injury is to stop using the computer immediately. Computers are to be used for no more than one hour per sitting.	Students	No further action to note.	
Evaluation of risk **Severity: Minor**	**Likelihood: Unlikely**		**Risk factor: Very Low**	
Burns due to soldering.	Care to be taken when handling soldering iron. Experienced users to only use soldering iron only.	Students	No further action to note.	
Evaluation of risk **Severity: Minor**	**Likelihood: Possible**		**Risk factor: Low**	
Inhalation of fumes when soldering	User to avoid leaning over iron when in use, Fume extractor to be used.	Students	No further action to note.	
Evaluation of risk **Severity: Minor**	**Likelihood: Possible**		**Risk factor: Low**	
Injury due to human/robot collision or entrapment of extremities whilst operating.	A minimum of two users must be present when the robot is automated. The robot is fitted with an emergency stop. Onboard safety system will turn off the robot so if the software fails the power to the motors is cut.	All	No further action to note.	
Evaluation of risk **Severity: Serious**	**Likelihood: Possible**		**Risk factor: Low**	

Hazards Include brief explanation as to how they may cause harm.	Existing control measures Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE. etc	Persons affected	Additional control measures required Required to prevent/reduce likelihood of hazard occurring.	By whom/when Person responsible and completion date.
Electrocution by on-board circuitry.	Maximum on-bard voltage is limited to 24 volts, battery connectors are shrouded and a kill switch has been added for the purposes of connecting components to avoid arcing.	Students	Future modifications must replicate the existing control measures.	The WMR team
Evaluation of risk **Severity: Minor**	**Likelihood: Unlikely**		**Risk factor:**	
Injury due to lifting and carrying the robot.	The robot weight has been kept low. A separate risk assessment has been carried out regarding repetitive lifting of the robots.	Students	The lifter must be aware of the safest way to lift the robot; this is to be included in the safe scheme of work. The robot will be designed to be lifted with greater ease by attaching handles.	The WMR team The WMR team
Evaluation of risk **Severity: Minor**	**Likelihood: Possible**		**Risk factor: Very Low**	
Fire caused by the overheating of components of the robot.	A CO_2 fire extinguisher is available in the laboratory and sufficient cooling systems have been added to the robot.	All	The heating of new components is to be carefully considered in the design phase and extra cooling systems should be added if necessary.	The WMR team
Evaluation of risk **Severity: Major**	**Likelihood: Unlikely**		**Risk factor: Low**	

Summary of assessment: The area / activity has been assessed against existing control measures in place. The assessment has identified (number) issues and made (number) recommendations for additional control measures.

Signature of assessor: ______________________ **Name:** ______________________ **Date:** ____________

Manager's Approval:

I have reviewed this risk assessment in consultation with the Assessor and accept the issues identified along with additional control measures that will be implemented in order to reduce any residual risk to a level that is low as is reasonably practicable.

Signature of manager: ______________________ **Name:** ______________________ **Date:** ____________

Appendix 6: Battery Risk Assessment

Risk assessment - General

Warwick Mobile Robotics | THE UNIVERSITY OF WARWICK

Title of risk assessment	Lithium Polymer Battery Risk assessment	Department	Warwick Mobile Robotics	Date	11/11/2010

Description of activities:

Handling and storage, charging the battery, using (or discharging) the battery and handling and disposal of damaged and swelled batteries

Persons at risk	Staff	Students	Visitors

*Further assessment may be need to be undertaken as required by the relevant legislation

Hazards Include brief explanation as to how they may cause harm.	Existing control measures Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE etc	Additional control measures required Required to prevent/reduce likelihood of hazard occurring.	By whom/when Person responsible and completion date.
A lithium polymer battery "flares up" and catches fire: Lithium polymer batteries begin to swell under adverse temperatures (above 70ºC)/ charging (a rate above the mAh capacity rating)/ excessive discharging conditions. If the plastic packaging ruptures the lithium in the battery will react with the moisture in the air. In addition to igniting the burning lithium will also release hydrogen. The flames are substantial enough to cause major injuries to those handling the battery and are an extreme risk if said fire spreads.	The WMR team already owns specialised chargers for the lithium polymer batteries. These devices monitor the level of charge in the battery to ensure that fully charged batteries are not overcharged and so cause a flare-up. Batteries are placed in a liposack during charging, this bag has been proven to drastically reduce the severity of a possible "flare-up". The batteries are stored and charged in plain sight, at room temperature and away from miscellaneous conductive material that may accidentally bridge the connector. Damaged and swelling batteries are never to be charged. Basic fire safety and precautions are installed in the workshop An instruction manual for battery charging has been written	Safe disposal of swelled and damaged batteries needs to be discussed in detail. This will involve transporting battery to a fire-safe area and observing for 15 minutes. A new system needs to be integrated into the robot to observe when the battery level is approaching 3.3 open voltage per cell to avoid detrimental discharging (and loss of charge memory). Batteries with an open voltage of below 3.3V per cell must never be recharged.	*The WMR team 24/11/2010* *The WMR team* *The WMR team*
Evaluation of risk **Severity: Major**	**Likelihood: Possible**	**Risk factor: Moderate**	

Hazards Include brief explanation as to how they may cause harm.	Existing control measures Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE. Etc	Additional control measures required Required to prevent/reduce likelihood of hazard occurring.	By whom/when Person responsible and completion date.
Skin/eye exposure to lithium. Lithium exposure to skin is harmful and direct exposure to the eyes is dangerous.	Only severely damaged batteries will result in direct exposure to the lithium inside the plastic film.	A safe scheme of work is to include instructions regarding the unlikely event of direct exposure. (washing hands/eyes and seeking medical advice) The procedure for the safe disposal of batteries must include the use of gloves and eye protection.	The WMR team *24/11/2010* The WMR team *24/11/2010*
Evaluation of risk **Severity: Serious**	**Likelihood: Unlikely**	**Risk factor: Low**	
Electric shock.	Appropriate shrouded connectors have been attached to the battery terminals and the circuitry of the robot is never modified whilst powered.	None to mention.	
Evaluation of risk **Severity: Minor**	**Likelihood: Unlikely**	**Risk factor: Low**	

Summary of assessment: The area / activity has been assessed against existing control measures in place. The assessment has identified (number) issues and made (number) recommendations for additional control measures.

Signature of assessor: ______________________ **Name:** ______________________ **Date:** ____________

Manager's Approval:

I have reviewed this risk assessment in consultation with the Assessor and accept the issues identified along with additional control measures that will be implemented in order to reduce any residual risk to a level that is low as is reasonably practicable.

Signature of manager: ______________________ **Name:** ______________________ **Date:** ____________

Appendix 7: Safe Scheme of Work

Safe Scheme of Work (18/11/2010)

Using the computers

Ensure that a fifteen minute break is taken per hour of working at a computer. If any signs of repetitive strain injury arise (aches and pains in wrists or arms) cease work immediately.

Handling the robot (and practice arena)

When lifting the robot please wear safety shoes and practice safe lifting technique. Lift with your back and not with your legs. Never handle the robot whilst it is in use.

Soldering

Only use the soldering iron if you are trained and confident in doing so, never lean directly over the workpiece whilst soldering and always ensure that fume extractor is switched on. Never leave a heated soldering iron unattended.

Charging the batteries

- Please refer to the 'Lipo charging instructions' sheet when charging the batteries.
- Always place charging batteries in the provided Liposack.
- Do not recharge damaged or swelled batteries.
- Do not charge fully-charged batteries, these will be labelled by the yellow 'charged' tape provided.
- Do not recharge batteries whose charge has dropped below 3v per cell.
- Use the correct preset mode on the top equaliser for the respective battery.
- Report swelled and/or damaged batteries immediately and place in the provided Liposack, then follow the safe disposal procedure (yet to be discussed).

Exposure to battery chemicals

For skin contact, immediately clean with soap and water. For eye contact rinse under a cold tap and seek medical attention

Appendix 8: LiPo Charging Instructions

Lipo Charging Instructions

Safety notes

- Always place charging batteries in the provided Liposack.
- Do not recharge damaged or swelled batteries.
- Do not charge fully-charged batteries, these will be labelled by the yellow 'charged' tape provided.
- Do not recharge batteries whose charge has dropped below 3v per cell.
- Use the correct preset mode on the top equaliser for the respective battery.
- Report swelled and/or damaged batteries immediately and place in the provided Liposack, then follow the safe disposal procedure (yet to be discussed).

The Charging procedure

Start with the battery disconnected.

1. Switch on the power supply and tap the knob on the top voltage equaliser.
2. Attach the output 1 terminals of the top equaliser to the Lipo monitor.
3. Attach the shrouded connectors (the square ones) from the Lipo monitor to the battery.
4. Choose the appropriate adaptor circuit board for the battery and attach to the Lipo monitior.
5. Attach the battery's port into the plug that fits (if it doesn't fit; it is the wrong adaptor!)
6. Select and click on the mode name using the knob, on the top equaliser, to cycle through the possible charging modes and select the one that corresponds to the battery.
7. Press and hold the knob to go to the charging screen.
8. Press the mode button on the Lipo Battery monitor.
9. Select charge on the top equaliser and press and hold down the knob. Your battery is now charging, the top equaliser will notify you when it is fully charged with a tone.
10. Place the battery in a Liposack and ensure that it is not left charging unsupervised.
11. When you have finished charging the battery it is safe to turn all of the equipment off at the power supply.
12. Label fully charged batteries over the top of their connectors with the yellow 'charged' tape.

Appendix 9: Fieldwork Risk Assessment

Risk assessment - Fieldwork Abroad

Title of risk assessment	RoboRescue Project - Fieldwork Abroad Risk Assessment	Department	Warwick Mobile Robotics	Date	20/03/2011

Description of activities: **Free Time, Overseas Travel*, Residence in a Hotel, Use of Public Transport, Transport (Vehicle Hire)*, Operating/Modifying/Transporting the Robots*, Manual Handling***

*Summarised or Expanded in separate risk assessments (attached)

Activity and Hazard Include brief explanation as to how they may cause harm.	Existing control measures Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE. etc	Persons affected	Additional control measures required Required to prevent/reduce likelihood of hazard occurring.	By whom/when Person responsible and completion date.
Free time, Overseas Travel and stay: Becoming a victim of crime Loss of a Passport Becoming lost and losing contact with group Emergency situations Unsuitable behaviour (Continued...)	It has been confirmed that all attendees (the WMR team, Computer science team and third party attendees) have important travel documents to hand: Driving licences, British passports and EUHI cards. Fieldwork Leader has been designated. The two members of the team that are capable of speaking basic German should be referred to should their skill be required. Peter Moffat is certificated in first aid, and so will be our designated first aider for all activities. Other members of	The WMR team The Computer Science team Third party Attendees	• Home agent(s) to be designated: Fieldwork Leader and Home agent(s) to retain a master list of important personal details should an emergency situation or loss of a passport occurs. Procedure in place in case of the loss of passport credentials: Details regarding the contact of the British Consulate General and British embassy call centre to be recorded. • Contact details of ALL attendees must be recorded and added to the phonebooks of ALL attendees. Phones must remain charged and switched on unless instructed otherwise. • Attendees must understand local laws and abide by them in addition to behaving appropriately: As representatives of Warwick University, the WMR team (UK representatives), the WMG and finally respective sponsors. • Proper fire and emergency procedures are to be identified on arrival at the venue. • During Free time attendees must remain vigilant regarding the presence of potential criminals or criminal activity. The emergency numbers in Germany are 110 (Police) and 112 (Fire Brigade & Ambulance).	

1

(Continued...)	the group have received basic first aid training in the past, but not within three years. Two Phd students (Former and existing WMR members) will be travelling by plane and so will be exempt from the risk of vehicle transport. The appropriate WMG **authorisation to travel** form has been filled in, submitted and confirmed.		• The two PHD students that are travelling by plane should pack their luggage in accordance with their airline provider they are flying with, and should endeavour to meet with the WMR team on arrival. • The relevant food/medicine allergy and medicinal needs information of individual members should be included on the itinerary. • All existing health and safety documentation regarding the robots, workshop, fieldwork and travel should be brought by the WMR team and appropriately referred to. • This is in addition to the **WMG overseas travel risk assessment** and **manual handling assessment** documents.	
Evaluation of risk — **Severity: Minor/Serious**	**Likelihood: Unlikely**		**Risk factor: Low**	
Residence in a hotel: Becoming a victim of crime Loss of belongings Emergency situations Unsuitable behaviour	Hotel recommended by the venue has been booked by the Fieldwork Leader.	The WMR team The Computer Science team Third party Attendees	• Proper fire and emergency procedures are to be identified on arrival. • Unattended rooms must remain locked and keys must be provided to all respective occupants. • Lost belongings must be reported to the hotel reception as soon as possible. • Attendees must understand local laws and abide by them in addition to behaving appropriately: As representatives of Warwick University, the WMR team (UK representatives), the WMG and finally respective sponsors.	
Evaluation of risk — **Severity: Minor/ Serious**	**Likelihood: Unlikely**		**Risk factor: Very low / Low**	
Use of Public transport: • Becoming a victim of crime • Loss of belongings • Emergency situations • Unsuitable behaviour	None to date.	• The WMR team • The Computer Science team • Third party Attendees	Public travel arrangements to be planned and verified in advance. Recommended modes of transport by the venue to be used exclusively. Otherwise hired transport is preferable.	
Evaluation of risk — **Severity: Minor/ Serious**	**Likelihood: Unlikely**		**Risk factor: Very low / Low**	

2

Appendix 10: Robot Operation RA

Risk assessment - Using the Robot during Fieldwork

Warwick Mobile Robotics

THE UNIVERSITY OF WARWICK

Title of risk assessment	RoboRescue Project - Fieldwork Abroad Risk Assessment	Department	Warwick Mobile Robotics	Date	20/03/2011

Description of activities:	**Operating/Modifying/Transporting the Robot during Fieldwork, Charging/Storing the LiPo batteries, *Manual handling**

*Summarised in separate risk assessment (attached)

Activity and Hazard	Existing control measures	Persons affected	Additional control measures required	By whom/when
Include brief explanation as to how they may cause harm.	Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE, etc		Required to prevent/reduce likelihood of hazard occurring.	Person responsible and completion date.
Operating, Modifying and testing the Robot at the Robocup Venue: Harming operators and bystanders by crushing, impact damage, electrocution and burns. Loss/lease of equipment to other teams.	Workshop risk assessment in place with basic precautions. Operators understand and abide by risk reduction precautions stated on the workshop operation risk assessment.	Bystanders The WMR team Operators (trained WMR team personnel) The Computer Science team Third party attendees	Procedures should be in place to ensure the safety of bystander during the operation of the robot. This is especially important with regards to the increased numbers of people in the working environment. A log of equipment should be made with regards to equipment brought with the WMR team. This is to ensure that all equipment remains in an organised state for the return journey. ONLY members of the WMR team should be allowed to modify the Robots exclusively. All existing health and safety documentation regarding the robots, workshop, fieldwork and travel should be brought by the WMR team and appropriately referred to.	
Evaluation of risk — **Severity: Serious**	**Likelihood: Possible**		**Risk factor: Low**	

1

Transporting the LiPo Batteries: Overheating/preforation during travel due to sunlight or poor air conditioning. (Resulting in swelling and a possible fire)	A risk assessment has been conducted and enforced especially for the LiPo batteries and should be continued to be referred to, in addition to the printed charging instructions. Liposacks are used to store the LiPo batteries and will significantly reduce the risk of a serious fire.	Bystanders The WMR team Operators (trained WMR team personnel) The Computer Science team Third party attendees	Proper fire and emergency procedures are to be identified on arrival. Including a method for the safe disposal of expanded LiPo batteries. Batteries must not be stored in direct sunlight with regards to the summer weather, and consideration should be taken regarding the temperature of the storage conditions of the battery in transit. Batteries must be safely stored so that the risk of perforation is minimised. LiPo batteries should also continue to be stored in plain sight. Batteries must not be handled by anyone other than the WMR/Computer science team.	
Evaluation of risk — **Severity: Major**	**Likelihood: Unlikely**		**Risk factor: Low**	
Lifting the Robot: Repetitive lifting into and out of a van. Transporting the robot by hand over long distance.	Correct lifting instructions have been taught to and practiced by the group. The practice of lifting the robot between two people has been appropriately practiced. Safety shoes are supplied and worn by those lifting the robots. A trolley has been acquired and will be used for long distance transportation of the robot.	The WMR team Third party attendees	Unfortunately lifting handles will not be able to be manufactured for the tele-operated robot, however, by following the guidelines and practices already in place such risks should be sufficiently reduced already. The **manual handling assessment** form should be referenced with regards to a safe lifting procedure.	
Evaluation of risk — **Severity: Serious**	**Likelihood: Possible**		**Risk factor: Low**	

2

Appendix 11: Transport RA

Risk assessment - Transport (Vehicle Hire)

Warwick Mobile Robotics | THE UNIVERSITY OF WARWICK

Title of risk assessment	RoboRescue Project - Fieldwork Abroad Risk Assessment	Department	Warwick Mobile Robotics	Date	20/03/2011

Description of activities: **Transport (Vehicle Hire)**

*Summarised in separate risk assessment (attached)

Hazard or Activity	Existing control measures	Persons affected	Additional control measures required	By whom/when
Include brief explanation as to how they may cause harm.	Consider; safety devices, cut-out switches, safety signs, SOPs, training, PPE. etc		Required to prevent/reduce likelihood of hazard occurring.	Person responsible and completion date.
Unsafe driving: Inexperienced drivers Tired drivers	Two experienced drivers will be present in each car in addition to one 'reserve' driver. The six hour ferry trip will be used to let the designated drivers sleep should they require to. Experienced drivers will alternate to cope with the journey across Germany, and necessary breaks shall be taken at service stations. A satnav and two European maps have been purchased in preparation for the journey, and the itinerary specifically states the single route both vehicles intend to take through Germany.	The WMR team The Computer Science team Other drivers and pedestrians	Additional information regarding European-specific road signs and road laws are to be provided to the drivers. And a defensive driving mindset will have to be adopted, especially during night-time travel. Heavy goods (such as the robot) should be appropriately packaged in their flight cases where possible, and secured when transported in the vehicle. Occupants should also wear seatbelts at all times.	
Evaluation of risk — Severity: Extreme/Major	Likelihood: Unlikely		Risk factor: Moderate	
Unpreparedness regarding insurance, hired car information or driving documents.	Driver's licence information to be brought and on-hand during travel through both the UK and Germany. The European breakdown cover includes overseas assistance.	The WMR team The Computer Science team Other drivers and pedestrians	Vehicle safety checks and damages to be recorded before and after the hire and return of the hired vehicles. In an event of an accident the insurance company should be called immediately (after contacting the emergency services if necessary), photographs and documentation of the accident should then follow any required emergency procedures. The **vehicle hire agreement** will be added to the safety documentation with regards to the provided insurance instructions should an accident occur.	
Evaluation of risk — Severity: Serious	Likelihood: Possible		Risk factor: Low	
Unpreparedness for emergency situations.	Previous years have already invested in all necessary emergency equipment.	The WMR team The Computer Science team Other drivers and pedestrians	It should be ensured that an emergency situation procedure should be printed out and included in the health and safety documentation.	
Evaluation of risk — Severity: Extreme/Major	Likelihood: Unlikely		Risk factor: Moderate	

Summary of assessment: The area / activity has been assessed against existing control measures in place. The assessment has identified (number) issues and made (number) recommendations for additional control measures.

Signature of assessor: ______________________ **Name:** ______________________ **Date:** ____________

Manager's Approval:

I have reviewed this risk assessment in consultation with the Assessor and accept the issues identified along with additional control measures that will be implemented in order to reduce any residual risk to a level that is low as is reasonably practicable.

Signature of manager: ______________________ **Name:** ______________________ **Date:** ____________

Appendix 12: Fieldwork Safety Document

Appendix 13: Lifting Procedure