2014 ROBOCUP PROGRESS REPORT 3

EVALUATION REPORT

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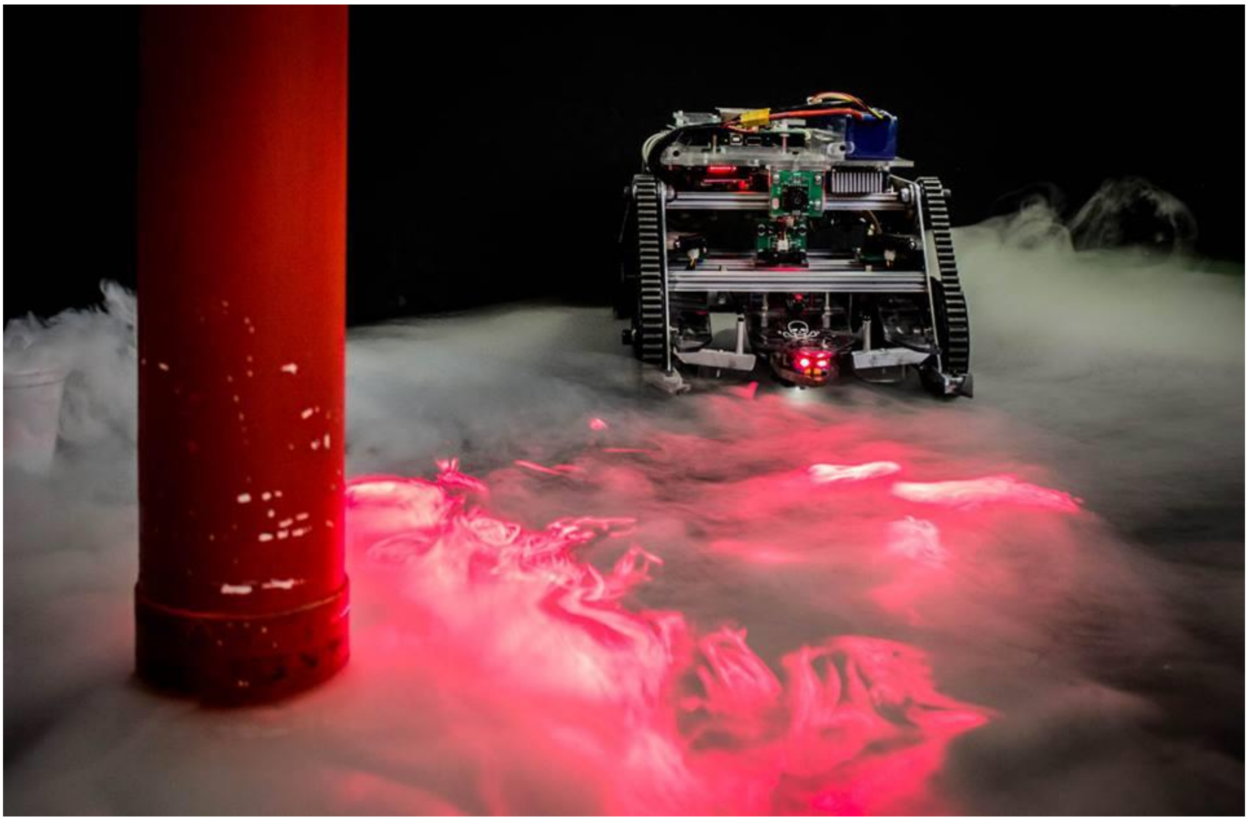

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EXECUTIVE SUMMARY

This evaluation report is focused on the evaluation of a robot which competed in the 2014 University of Canterbury Robocup. The 2014 Robocup involved two robots competing to collect the greatest mass of packages over a 5 minute time period. The robot discussed in this report performed exceptionally well winning the 2014 Robocup competition.

A description of the final constructed robot is first outlined in this report to provide a context for the following evaluation. The robot's distinguishing features included a set of 3D printed wheels, an active laser package identification system and a collection mechanism which allowed the robot to collect packages without stopping.

The performance of the robot with respect to a set of general requirements is then evaluated. Such an evaluation considered the navigation systems, package and obstacle identification systems, package collection mechanism, manoeuvrability, battery performance and cost of the robot. All of the general requirements except for the ability to collect packages in the corners of the arena were meet by the robot. The robot was also assessed with respect to its competitive performance. One of the key identified competitive advantages of the robot was its superior speed of up to three times that of the other robots in the competition.

An evaluation of the other robots in the competition found that the designed and built robot had the most reliable collection mechanism and most effective driving mechanism which could consistently drive over obstacles. With the use of IR sensors however group 8 was found to have the most reliable package detection system.

Lastly this report considers several potential advancements which would have further the competitive performance of the robot. A significant competitive disadvantage of the robot was its inability to reliably detect packages. An alternative solution to improve this reliability of this system is suggested involving the use of green lasers, colour filters and multiple positioning cameras.

Overall this evaluation concluded that the robot was successful with respect to both the general requirements and competitive nature of the competition.

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1.0 INTRODUCTION

The 2014 University of Canterbury Robocup takes the setting of a post zombie apocalypse where teams must design and build an autonomous robot to compete at collecting food packages about a ‘city’ or arena. Food packages (packages) take the exterior form of metal cylindrical weights and may be of 3 different masses of 0.5kg, 0.75kg and 1kg. The team with the winning robot is determined through a process of knockout rounds with each round involving two groups competing to collect packages scattered within the arena. The winner of each round is determined by the robot with greatest accumulative weight of packages including those either on-board the robot or within the robots color-coded headquarters (HQ). Based on this scenario the objective of this project was to design and build an autonomous robot to collect the greatest accumulative weight of ‘food packages’.

This report proceeds both a conceptual and detailed design report and completes a full account of the design process carried out for a competing robot in the 2014 Robocup. The first conceptual design report (CDR) considered the general requirements for a robot competing in this competition and evaluated three alternative designs. The second detailed design report (DDR) provided a comprehensive description of the recommended robot from this CDR.

With a few modifications to the design specified in the DDR the constructed robot performed exceptionally well in the competition, winning the 2014 Robocup. This final evaluation report first outlines the final design of the robot which competed. An assessment with respect to both the general requirements specified in the CDR and competitive performance of the robot is then presented. Four other competing robots in the competition are further evaluated highlighting the aspects which made these robots both successful and unsuccessful. Finally the report concludes with further developments which would have improved the competitive performance of the robot.

2.0 DESIGN DESCRIPTION

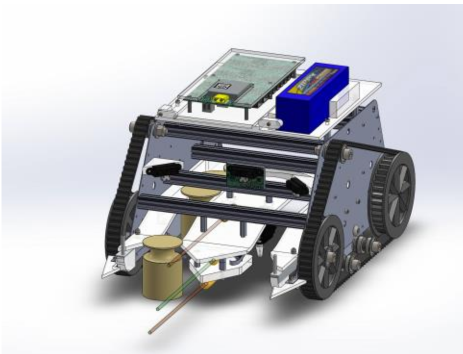

FIGURE 1: FINAL DESIGN OF ROBOT

The design of the final robot, as pictured in Figure 1, can be considered as a combination of five sub-systems. These sub-systems include the package collection mechanism, obstacle detection system, navigation system, package identification system and driving mechanism. The N2 diagram in Figure 2 illustrates the overall interactions between these sub-systems.

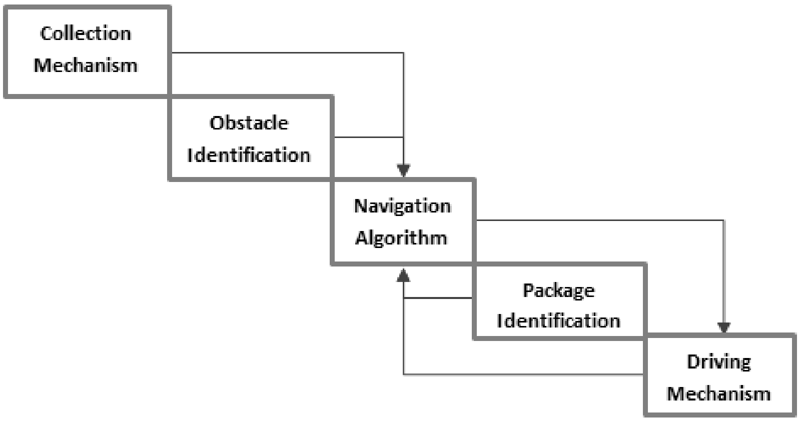

FIGURE 2: N2 DIAGRAM OF INTERACTIONS BETWEEN SUB-SYSTEMS

A brief overview of each of these sub-systems is presented in order to provide a context for the following evaluation. For a comprehensive description of the robot refer to the DDR.

NAVIGATION ALGORITHM

The navigation sub-system determined the overall behaviour of the robot by determining the optimal path with which the robot should follow. This sub-system was required to interface with all of the robot's major sub-systems, as shown in Figure 2. The functionality of this navigation algorithm is outlined in the finite state machine in Figure 3 as a series of states and sub states.

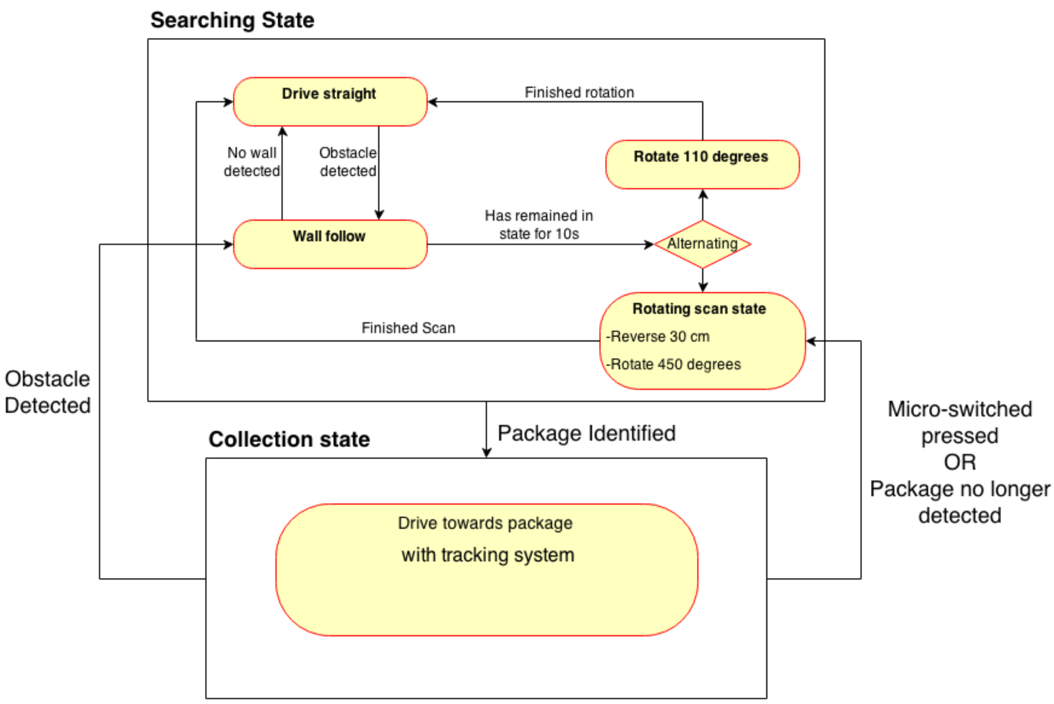

FIGURE 3: STATE DIAGRAM OF NAVIGATION ALGORITHM

The navigation algorithm described in the DDR was modified for the final competition as shown in Figure 3. The additional states and sub-states to from the algorithm presented in the DDR increased the overall robustness of the robot's navigation. An example of such increased robustness was the additional reversing functionality to ensure overturned packages were not permanently confined beneath the robot.

COLLECTION MECHANISM

The collection mechanism as illustrated in Figure 4 was designed to be independent from the other sub-systems. Such an independent design increased the overall robustness of the system to collect packages.

Packages are detected by the collection mechanism with the use of micro-switches from the two collector inlets labelled in Figure 4. Each of the collectors consists of a set of primary and secondary paddles. Where the primary paddles feed the packages up onto the Perspex track and the secondary paddles then feed the packages around the 'U' shaped track. One of the key benefits of this design was that packages could be collected without the robot required to slow down.

An additional piece of Perspex was attached below the micro-switches as shown in Figure 4 to further support the packages as they were feed into the inlets. A colour sensor positioned at the base of this additional piece of Perspex is used to identify the opposition's base. If the oppositions base is detected the paddles obstruct the inlets from collecting packages.

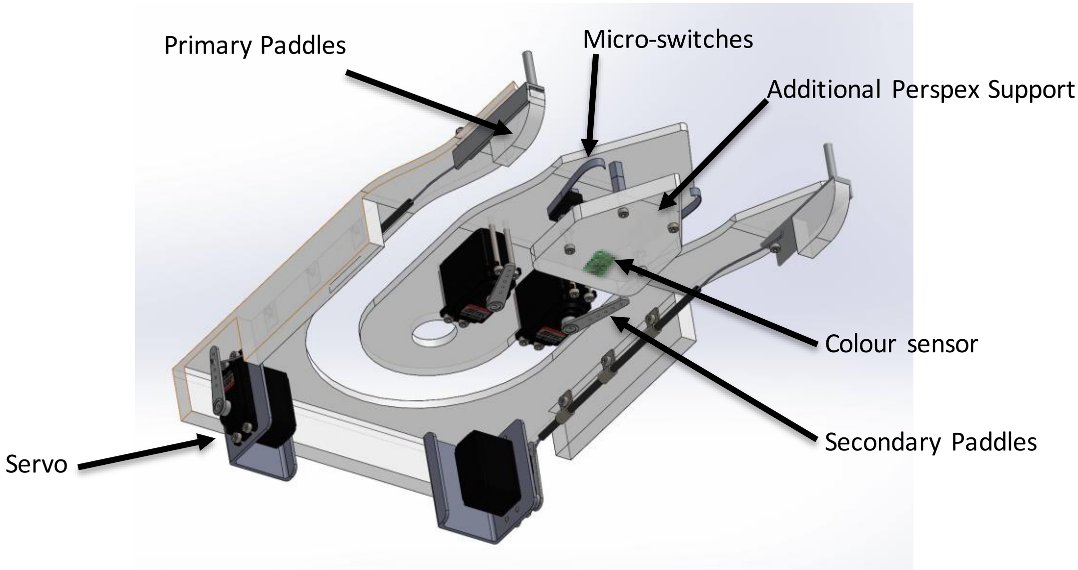

FIGURE 4: PADDLE COLLECTION MECHANISM

PACKAGE IDENTIFICATION

The package identification sub-system consists of an IR positioning camera (modified to detect light in the visible spectrum), two 5mW red line lasers and two IR sensors.

In order to identify a package two IR sensors were positioned vertically above each other with one at a height above the package and another at a height which can detect a package. The system was able to distinguish between packages and other objects when the two IR sensors gave different distance readings.

The positioning camera is used to search for the red laser beams reflected by the packages. The bronze packages were expected to be distinguished from other objects by the positioning camera detecting a higher intensity of the reflected light from the packages relative to the surrounding environment. These packages could be tracked by the positioning camera.

In the original detailed design report the IR sensors were not incorporated into the identification system. IR sensors were later added as it was believed to be more robust to have two independent package identification systems. A green laser was also specified in the DDR to assist in the identification of long range packages. Unfortunately this green laser malfunctioned the night before the competition and therefore could not be incorporated as a feature of the final robot.

OBSTACLE IDENTIFICATION

Four IR sensors were used as a simple mechanism to detect walls and obstacles surrounding the robot. Each of these IR sensors were positioned above the height of the packages to ensure packages were not identified as walls or obstacles. The detection paths of these sensors around the robot are shown in Figure 5.

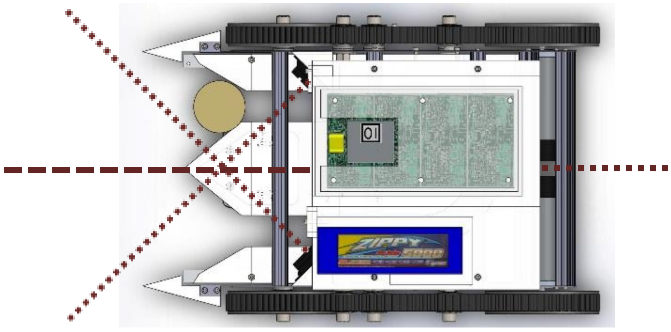

FIGURE 5: DETECTION PATHS OF IR SENSORS

The IR sensors mounted on the inside walls of the chassis were angled to detect obstacles as close to the sides of the robot as possible. A frontward facing IR sensor was used to detect objects directly in front of the robot. An IR sensor was also mounted to the rear centre rail of the robot to detect obstacles behind the robot. This sensor was an addition to the design described in the DDR. Initially this functionality to detect obstacles at the rear of the robot was not required with the navigation algorithm described in the DDR not having the ability to reverse.

DRIVING MECHANISM

The driving mechanism was designed primarily with a mechanical based focus. The key features of this design include the 3D printed wheels, rear wheel drive DC motor system and support bearings.

Custom wheels were 3D printed with slots around the outer rim of the wheels to accommodate the supplied tracks. A significant increase in speed was expected by increasing the diameter of the wheels from the standard supplied 60mm to 100mm. Furthermore it was expected that the larger wheels would provide a mechanical advantage to navigate effectively over obstacles.

Support bearings were positioned beneath the chassis as shown in Figure 6 to releive the stresses on the rear wheels by supporting the weight of the robot.

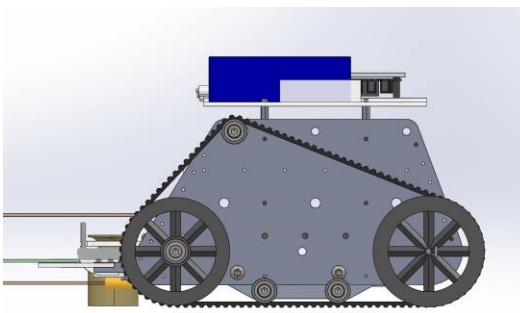

FIGURE 6: MECHANICAL LAYOUT OF DRIVING MECHANISM

3.0 EVALUATION OF PERFORMANCE

A full set of general requirements was generated in the conceptual design report for this project. These requirements are assessed throughout the following section considering separately the robots ability to identify packages, manoeuvre, collect packages and navigate about the arena. The robots competitive performance is also considered with respect to these aspects.

IDENTIFICATION OF PACKAGES

PACKAGE IDENTIFICATION
R1.1 The robot shall be able to identify the food packages to be collected.

GENERAL REQUIREMENT FOR PACKAGE IDENTIFICATION

The robot successfully identified packages in the arena complying with R1.1. Tests were performed on the robot before the competition to determine the range with which packages could be detected. The positioning camera was found to have a viewing angle of 33° and could detect potential packages up to a distance of 700mm away. This camera detection range allowed the robot to only identify potential packages which were directly in front of the robot as shown in Figure 7. However in order to differentiate between a package and another obstacle the IR sensors were required to be a distance of 700 mm from the object.

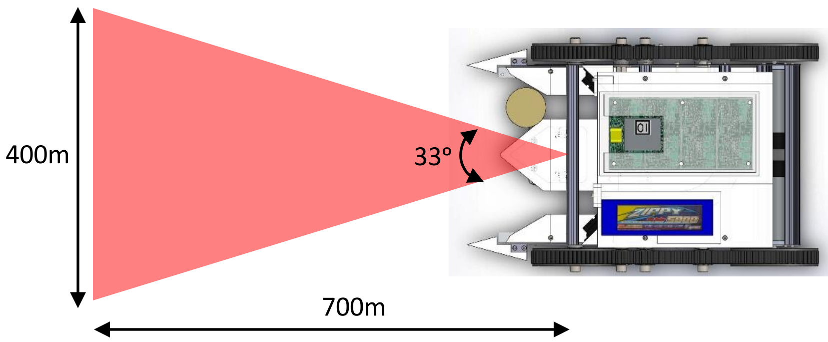

FIGURE 7: DETECTION RANGES OF PACKAGE IDENTIFICATION

With respect to the competitive nature of the project several issues relating to the reliability of the package detection systems were identified. One of these issues was that the IR sensors because they were slightly misaligned often confused the obstacles as packages. This resulted in the robot driving towards these obstacles instead of continuing to search for other packages. Such an issue had a significant impact on the ability of the robot to detect packages with the obstacles often being detected in a rotating scan before a package would have been detected in the same scan.

Lights on other robots in the competition were found to reduce the reliability of the positioning cameras. These lights were often confused with packages by the positioning camera causing the robot to navigate towards other robots.

Once a package was detected the navigation algorithm would consistently track the location of the packages relative to the positioning camera. This proved an effective means of maintaining a course for the detected package to ensure they were collected.

MANEUVERABILITY

> MANEUVERABILITY
>
> R2.2.2 The robot shall be able to maneuver over rectangular profile speed bumps no greater than 25mm high.

GENERAL REQUIREMENTS FOR MANEUVERABILITY

The robot successfully manoeuvred over all of the obstacles throughout the competition. Testing before the competition proved that the robot was able to manoeuvre over rectangular objects up to 40mm in height surpassing R2.2.2. The robot was therefore easily able to navigate over speed bumps which were no greater than 20mm in height in the competition. The successfulness of the robot to manoeuvre over these obstacles was attributed to the large 3D printed wheels.

Tests before the competition showed that the 3D printed wheels gave the unloaded robot a top speed of $0.71ms^{-1}$. This corresponded to a 200% increase in speed compared to using the standard supplied driving mechanism. This increased speed allowed the robot to cover a greater area each round increasing the probability the robot would collect packages.

EFFECTIVENESS OF NAVIGATION

> NAVIGATION
>
> R2.1 The robot shall be able to navigate towards the locations of identified packages.
>
> R2.2 The robot shall be able to navigate about obstacles including:
>
> R2.2.1 Walls with a minimum gap separation of 0.5m.
>
> R2.2.4 Another robot in the arena

GENERAL REQUIREMENTS FOR NAVIGATION

The robot was able to successfully navigate between obstacles placed a minimum distance of 300mm apart surpassing R2.2.1. Requirement 2.2.4 was also satisfied with the robot able to successfully navigate about the other robots in the competition.

The IR sensors were set to a low sensitivity to allow the robot to navigate between objects placed close together. This low sensitivity meant the navigation algorithm would only attempt to avoid an object if they were detected to be less than 20mm from the sides of the robot. A compromise of this low sensitivity was that the robot would on occasions drive into obstacles or other robots. Such a compromise was considered necessary in order to collect the packages which were close to obstacles. These low sensitivities increased the risk that the robot would become damaged this was not however an issue in the competition.

Another measure of the effectiveness of the navigation algorithm was the robots ability to quickly cover a large portion of the arena. Where the larger the space covered by the robot the more likely the robot was to detect a package. It was found that whilst the wall follow state was effective at navigating about the outside of the arena, it was not effective at navigating towards the inner regions of the arena. The functionality to turn towards the centre of the arena every 10 seconds was found to significantly increase the area the robot covered.

Once a package was detected it was found that the robot would continue to drive towards that package in 90% of cases using the proportional differential controller. This tracking of the packages ensured that the robot was able to successfully navigate towards these detected packages satisfying R2.1.

EFFECTIVENESSS OF COLLECTION MECHANISM

PACKAGE COLLECTION

R1.2 The robot shall be able to identify the HQ's as either its own or the other teams.

The robot's required interactions with food packages can be itemized to the following:

- R3.1 The robot shall be able to move with food packages.
- R3.2 The robot shall be able to collect food packages over 1kg.
- R3.3 The robot shall be able store at least 7 food packages either on its own body or in the HQ.
- R3.4 The robot shall not pick up other food packages identified to be in a HQ.
- R3.5 The robot should be able to pick up packages that are positioned against a wall or a corner.

GENERAL PACKAGE COLLECTION REQUIREMENTS

Overall the collection mechanism was found to be an efficient and suitable means of collecting packages. However the system yielded two major disadvantages including the inability to collect packages in the tight corners of the arena and the inability to collect packages which were on their sides.

The ability of the robot to collect packages at full speed without decelerating was identified as a key advantage over the other competing robots. Testing showed that after the micro switch was triggered it would take 1.3 seconds for the collection mechanism to secure a package on the rail storage system.

The rail storage system could store up to 9 packages and manoeuvre about the arena with these packages meeting requirements 3.1 and 3.3. The rail storage system was found to reliably store the packages with no packages leaving the system once they were collected throughout the competition.

Generally the collection mechanism was found to reliably feed the packages into the collector inlets without knocking them over. Testing before the competition was performed to determine the frequency with which the robot, when travelling at full speed, knocked over packages. Packages were distributed at various angles relative to the robot to simulate a wide range of potential scenarios in these tests. From these tests it was found that in no case the robot knocked over packages as they were being collected.

The robot successfully met R3.3 in tests before the competition where the paddles were found to successfully obstruct packages from entering the inlets. A disadvantage of this additional functionality was that the paddles would on occasions obstruct the inlets of the collectors as the robot drove over any obstacles. This was attributed the colour sensor falsely detecting a headquarters due to the change in height of the sensor. Such a flaw in the design was not found to be an issue in the competition however where no packages were obstructed from the inlets.

As the collection mechanism required the robot to drive into packages the system was unable to pick up packages in the tight corners of the arena and therefore failed to meet R3.5. This was identified as a major disadvantage inherent with the package collections design.

Another major competitive disadvantage of this collection mechanism was it was unable to pick up packages positioned on their side. A total number of 5 packages could not be collected because they were knocked over throughout the four rounds the robot competed.

BATTERY PERFORMANCE

BATTERY PERFORMANCE

R4.1 The robot shall be able to operate on the same battery for a minimum of 5 minutes.

GENERAL BATTERY LIFE REQUIREMENT

It was calculated in the detailed design report that the robot would last on the same battery an estimated time of 16 minutes 55 seconds. This calculation was however found to be an underestimate in the competition where it was found the total battery life decreased on average by 6% each round. This corresponded to an average actual battery life of 1 hour 20 minutes. The calculated battery life was significantly smaller than the actual battery life as this accounted for a worst case scenario with all the components assumed to be running at full power. Overall the robot could successfully operate on the same battery for the minimum required time of 5 minutes throughout the competition meeting requirement 4.1.

Tests before the competition were conducted to measure the performance of the robot as the battery was drained. Figure 8 shows the relationship between the battery life and the speed of the robot. When operating on a low battery it was also found that the robot was unable to navigate over the larger obstacles. It was therefore critical in the competition that the batteries which were used were fully charged.

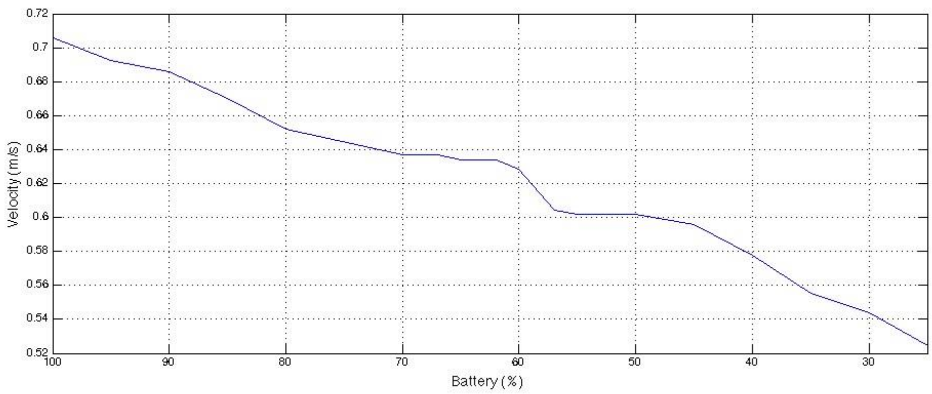

FIGURE 8: SPEED OF THE ROBOT WITH PERCENTAGE OF BATTERY CHARGE

COST

> COST
> R5.1 The total cost of additional components must be no greater than $50. The following additional allowances which shall not be exceeded are available in excess of this.
>
> R5.1.1 An allowance of $5 to accommodate for circuit board componentry.
>
> R5.1.2 An allowance of $10 (200g of material) for 3D printed componentry.

GENERAL COST REQUIREMENTS

In order to comply with R5.1 a cost evaluation of the robot was carried out. The total cost of the robot including the costs of supplied equipment was estimated to be $650.18 as calculated in the bill of materials (Appendix A). It should be noted however that some supplied components were not included in this costing analysis as the prices of these components were not available. When considering the cost requirements of the robot only the additional costs were considered relevant to meet these requirements. To reduce costs many of the components were imported, at US exchange rate of $1.17.

TABLE 1: SUMMARY OF ADDITIONAL COMPONENTRY COSTS

TYPE OF BUDGET	COST
CIRCUIT COMPONENTRY	$2.35
3D PRINTING	$20.15
ADDITIONAL COMPONENTRY	$41.97
TOTAL	$56.52

Whilst the 3D printing budget was exceeded, these exceeded costs were covered by the additional componentry budget. As summarized in Table 1 and outlined in Appendix B the robot therefore adheres to the cost requirements for the competition including requirement 5.1.1 and requirement 5.1.2.

4.0 EVALUATION OF COMPETITION

An evaluation was carried out to assess four other robots with the highest places in the competition. This evaluation was carried out to identify the aspects which contributed to a successful robot. The distinctive features of each of these robots are discussed in these evaluations.

GROUP 5

COLLECTION MECHANISM

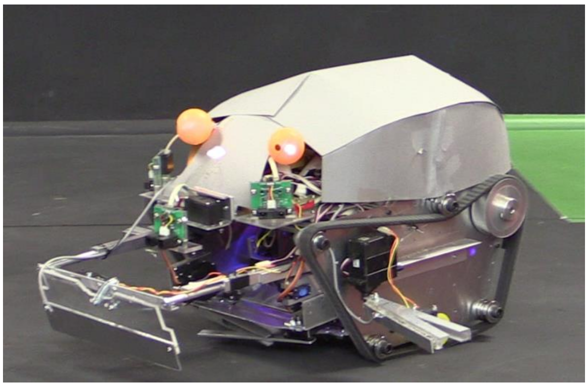

FIGURE 9: FINAL CONSTRUCTED GROUP 5 ROBOT

The collection mechanism for this robot consisted of a set of arms which swept the packages onto a ramp which was lowered when a package was collected. Such a system allowed the robot to collect packages without stopping. Another advantage of this design was that overturned packages could be collected by the robot. This collection mechanism was not reliable however with only 60% of the detected packages in the competition collected.

PACKAGE IDENTIFICATION

This robot identified other packages by measuring a change in capacitance when the metal packages made contact with the metal tab across the front of the robot. The primary disadvantage associated with this identification system was the limited detection range of the system with the robot required to drive into the packages in order for them to be detected. This package identification system was also unreliable with the metal tab often misidentifying other robots in the arena for packages.

MANOEUVRABILITY

A standard supplied track design was used to drive the robot about the arena. The addition of a custom roller also provided support through the centre of the track system to manoeuvre over speed bumps in the arena. Such a driving mechanism was found to have a top speed of $\approx 0.3ms^{-1}$. Although relatively slow the mechanism proved reliable with the robot not becoming immobile on the speed bumps at any stage throughout the competition.

OTHER ASPECTS OF DESIGN

With eight out of ten robots in the competition unable to collect packages on their sides an offensive strategy incorporated into this robot was to purposefully knock over packages in the arena. Extended arms on the side of the robot knocked over any packages in the robots path. These arms were designed to retract upon detection of a non-metal obstacle to increase the manoeuvrability of the robot. The probability that a package was overturned in the arena was further increased with the robot knocking over packages before they were collected. This behaviour ensured that if this robot failed to collect a package another robot could not collect it.

COLLECTION MECHANISM

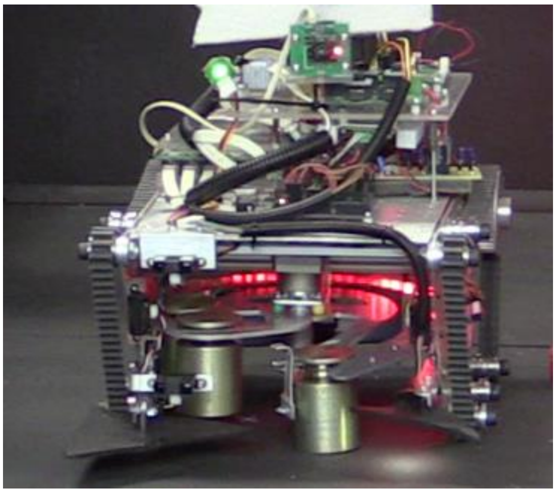

FIGURE 10: FINAL CONSTRUCTED GROUP 7 ROBOT

Packages were feed with a mechanical arm around a helical rail system in order to be collected. The collection mechanism proved reliable in the competition collecting 90% of packages which were detected by the identification system. One of the disadvantages of this system was that the robot was required to stop for a minimum of 16 seconds before a package was secured on the robot storage system. This was found to significantly reduce the time the robot could search for packages in the competition. Another disadvantage of this collection mechanism was that packages on their sides could not be retrieved.

PACKAGE IDENTIFICATION

Two sensors were vertically positioned with one at a height above the packages and another at a height which can detect packages. The system could distinguish between packages and other objects when the two IR sensors gave different distance readings. This system had a maximum detection range of 1.2m.

MANOEUVRABILITY

This robot used the standard supplied track design with two bearings placed to support the mid-section of the lower tracks. These support bearings were positioned to enable the robot to navigate over the speed bumps in the centre of the arena. These support bearings proved successful where at no stage in the competition did the robot become immobile on the speed bumps. This driving mechanism provided a top speed of $0.45ms^{-1}$ compared to the other robots in the competition.

In the second round of the competition the robot flipped itself onto its two rear driving wheels when it collided with one of the pillars. In this position the robot was unable to drive around the arena and collect packages. Such an issue highlighted the importance of distributing the mass of components evenly about the robot.

OTHER ASPECTS OF DESIGN

A flashing LED matrix was positioned at the rear of this robot in order to interfere with the image processing systems on other robots. This proved ineffective against the designed robot discussed in this report where the image processing systems were successfully able to distinguish between packages and these flashing LEDs.

COLLECTION MECHANISM

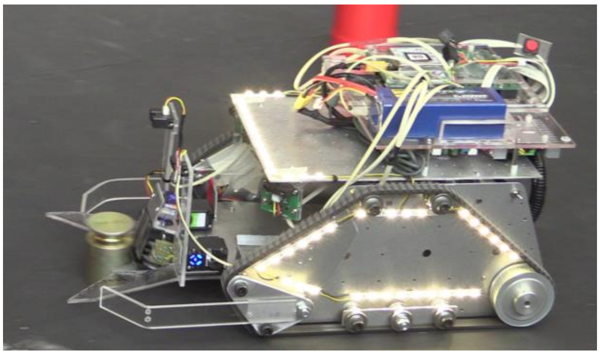

FIGURE 11: FINAL CONSTRUCTED GROUP 8

A magnet which could effectively be turned on and off using a servo was a key component to this collection mechanism. The packages if upright were guided to be collected by the magnet which was then rotated to store the packages in an open area within the robot. Once a package was within collection range the robot was required to stop for approximately 2 seconds to secure the package in the storage area. This collection mechanism was found to be relatively reliable compared to the other collection mechanisms used in the competition successfully collecting 90% of the detected weights. The disadvantage of this collection system was that packages were required to be upright to be collected. This lack of functionality proved to be an issue with 5 packages unable to be collected by this robot throughout the competition.

PACKAGE IDENTIFICATION

An IR sensor array system was used to detect packages. This identification system was found to be very reliable with the robot consistently only detecting packages within range of the sensor each time the robot performed a full rotation.

MANOEUVRABILITY

The track system on the robot was modified to increase the manoeuvrability of the robot over obstacles. Three support bearings were positioned along the bottom tracks to ensure the robot did not become immobile when manoeuvring over speed bumps. Additional bearings were also positioned at the front of the robot to increase the ability of the robot to drive onto the speed bumps in the arena. These modifications successfully increased the reliability of the robot to drive over speed bumps where throughout the competition these obstacles did not cause the robot to become immobile. This driving mechanism provided the robot with a top speed of $0.27ms^{-1}$.

OTHER ASPECTS OF DESIGN

The addition of LEDs around this robot was made to inhibit the image processing systems of other robots within the arena. These higher intensity LEDs proved to successfully compromise the navigation systems of the designed robot discussed in this report which often confused these bright LEDs for packages. Once within an appropriate range however the designed robot was able to distinguish between this robot and packages with the use of its IR sensor system.

GROUP 9

COLLECTION MECHANISM

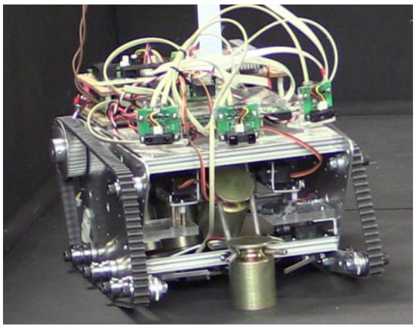

FIGURE 12: FINAL CONSTRUCTED GROUP 9 ROBOT

This robot collected packages using two aluminium rods positioned to align with the grooves of the packages. Once aligned the packages were lifted, in a similar way to a forklift, and guided onto a rail storage system. The robot was required to stop for 2 seconds in order to align and collect a package.

One issue in the competition with this particular design was that the rails would be occasionally obstructed from being fully lowered by a stored package. Such a scenario would delay the collection of another package where the rails were required to be repetitively raised until the obstructing package was freed.

PACKAGE IDENTIFICATION

A multi IR sensor system similar to those used on the other robots discussed was used to identify packages within the arena. This system proved to be an effective means of identifying packages. However the IR sensor system was occasionally found to have difficulties aligning the packages directly with the fork collection mechanism which increased the time it would take to collect some packages. If a package was misaligned limit switches behind the forks would detect the package and the robot would reverse before attempting to recollect the package.

MANOEUVRABILITY

The standard supplied track design was used to drive the robot with a top speed of 0.30ms^{-1}. A single support bearing was positioned at the centre of each of the bottom tracks to ensure the robot could successfully drive over speed bumps without becoming immobile. Although the robot was found to consistently manoeuvre over the speed bumps the poor obstacle detection systems on the robot resulted in the robot becoming immobilized each round by other obstacles within the arena. These obstacle detection systems consisted of three IR sensors positioned at various angles at the top of the robot as shown in Figure 12.

PERFORMANCE SUMMARY OF COMPETITION

A summary of the quantitative performance of each of the robots is outlined in Table 2.

TABLE 2: SUMMARY OF QUANTATIVE PERFORMANCE OF EACH THE ROBOTS

	Group 5	**Group 9**	**Group 7**	**Group 8**	**Group 1**
Maximum speed	≈0.3 ms^{-1}	0.30 ms^{-1}	0.45 ms^{-1}	0.27 ms^{-1}	0.62ms^{-1}
Stop time to collect	0 s	2 s	16 s	3.5 s	0 s
Packages collected once detected (%)	60%	55%	100%	90%	100%
Average weight per round	0.83 kg	1.13 kg	0.80 kg	2.63 kg	3.69 kg
Overall place in competition	5th (equal)	4th	3rd	2nd	1st

Compared to the other robots in the competition the robot focused on in this report (group 1) was found to have the most effective driving mechanism based on its speed performance. The collection mechanism was also found to give group 1 a further competitive advantage over the other groups. The reliability and ability to pick up packages without slowing down made this collection mechanism superior to the other mechanism. Group 8 with the use of IR sensors was found to have the most reliable package identification system where this robot did not confuse other obstacles for packages in the competition.

5.0 FURTHER CONSIDERATIONS FOR DEVELOPMENT

In order to further the competitive performance of the robot as discussed in the evaluation further developments of the package identification system are recommended. The unreliability of the robot to differentiate between packages and other obstacles was identified as the key competitive disadvantage of the robot. This unreliability was related to the misalignment of the IR sensors causing the false detection of packages.

Because of the technical difficulty to accurately align the IR sensors it suggested that this system should no longer be used. Instead it suggested that the packages are to be only detected by the positioning camera and line laser setup.

To rely solely on the positioning camera to accurately detect packages three significant improvements were identified. These improvements were the use of green line lasers instead of red, two positioning cameras and a Band pass colour filter.

- It suggested that green line lasers be used instead of red in order to reduce the reflected light from the red obstacles. This would reduce the probability a red obstacle is falsely detected as a package increasing the overall reliability of the system.
- The use of a specific colour band pass filter on the positioning camera would only allow light with same wavelength as the line lasers through. This would reduce interference caused by lights and IR LEDs on other robots furthering the reliability of this system.
- Two positioning cameras would further increase the detection area in front of the robot furthering the performance of the system.

6.0 CONCLUSION

The robots performance with respect to both the general requirements specification and competitive nature of the project was evaluated in this report. The robot was found to meet and in some cases surpass the general requirements specified in the conceptual design report except for the requirement to collect packages in the corners of the arena. The necessity of such a requirement however was not prevalent in the competition where the robot won each of its rounds.

The robot performed exceptionally in the competition winning the 2014 Robocup. The competitive success of the robot was attributed to both the superior driving and collection mechanisms. The increased manoeuvrability and speed from the large 3D printed wheels was considered to give the robot a significant advantage over the competition. The ability of the robot to reliably collect packages without slowing down also gave this robot a further advantage over the competition.

Several improvements to further the performance of the design were however identified after considering the performance of the top 5 robots in the competition. This included further advancements to the package identification system where this system was found to be unreliable and only detect packages within a relatively close range.

Considering the overall evaluation it can be concluded that the robot was fit for purpose as defined by the original general requirements and the competition environment.

APPENDICES

APPENDIX A- BILL OF MATERIALS

Sensors and Motors

Part	Component	Price per unit	Units	Brand	Model	Cost
01-01	Motor DC	$53.00	2	DFRobot	FIT0277	$106.00
01-02	Servo Standard	$12.00	4	Hobbyking	HXT12K	$48.00
01-03	IR short range sensor	$17.00	3	Sparkfun	2D120X	$51.00
01-04	IR long range sensor	$18.00	2	Sparkfun	2Y0A02	$36.00
01-05	IR Camera	$25.00	1	DFRobot	SEN0158	$25.00
01-06	Colour Sensor	$10.00	1	AdaFruit	SEN0019	$10.00
01-07	Micro switch	$1.50	2	SonarPlus	SM1039	$3.00
01-08	4000mah 11.1v Lipo	$32.00	1	Hobbyking	NA	$32.00
01-09	RGB LED	$2.00	1	DFRobot	DFR0239	$2.00
Total						**$313.00**

Mechanical Materials

Part	Component	Price per unit	Units	Brand	Model	Cost
02-01	AL U Bar	$0.80	1	Ullrich	n/a	$0.80
02-02	Perspex 300*300*5	$6.00	1	Dotmar	n/a	$6.00
02-03	Perspex 300*150*10	$8.00	2	Dotmar	n/a	$16.00
02-04	Servo mount	$6.00	2	Pro Metal	n/a	$12.00
02-05	Main Body single side	$16.00	2	Pro Metal	n/a	$32.00
02-06	Roller bearings	$1.00	16	UC	n/a	$16.00
02-07	16mm Timing Belts	$7.38	2	UC	n/a	$14.76
02-08	225mm 15*15 AL Extruded bar	3.38	4	Pro Metal	n/a	$13.52
02-09	Perspex battery/Arduino bay	Not Priced	1	Dotmar	n/a	-
02-10	AL Plate 300x300	Not Priced	1	Pro Metal	n/a	-
02-11	6mm Socket head Bolts	0.02	8	UC	n/a	$0.16
02-12	Springs (Various)	Not Priced	8	UC	n/a	-
02-13	Heat-sink	Not Priced	2	UC	n/a	-
02-14	Cable ties	-	10	UC	n/a	-
02-15	Construction Bolts/Nuts 3mm	0.02	50	UC	n/a	$1.00
02-16	Misc construction materials	Not Priced	1	UC	n/a	-
Total						**$112.24**

Controller Boards and Other Electronics

Part	Component	Price per unit	Units	Brand	Model	Cost
03-01	Servo Board	Not Priced	1	UC	n/a	-
03-02	Battery Board	Not Priced	1	UC	n/a	-
03-03	Power regulator	4.7	2	ProDCtoDC	n/a	9.4
03-04	IO Board	Not Priced	1	UC	n/a	-
03-05	Arduino Micro board	40	1	RobotShop	n/a	40
03-06	DC motor Driver	$92.43	1	RobotShop	n/a	92.43
03-07	DC Motor cables	Not Priced	2	UC	n/a	-
03-08	Colour Sensor cables	Not Priced	1	UC	n/a	-
03-09	RJ45 Patch cables	Not Priced	n/a	UC	n/a	-
03-10	1X 4000mAH 3S Lipo	27.15	1	Zipper	Na	27.15
Total						**$168.98**

Additional Items

Part	Component	Price per unit	Units	Brand	Model	Cost
04-01	Red line laser	$4.75	2	DX.com	n/a	$9.50
04-02	3D printed wheels	$5.04	4	UC	n/a	$20.16
04-03	IR Camera	$23.32	1	DFRobot	SEN0158	$23.32
04-04	Cable sleve	$0.05	1	HobbyKing	n/a	$0.05
Total						**$53.03**

Electronic circuits

Part	Component	Price per unit	Units	Brand	Model	Cost
05-01	KA7909	$1.12	1	Element 14	KA7909	$1.12
05-02	1uf Capacitor	$0.10	2	Element 14	n/a	$0.20
05-03	10k Potentometer	$0.20	1	Element 14	n/a	$0.20
05-04	PCA9540BD	$1.19	1	Element 14	n/a	$1.19
05-05	Resistor 10k	$0.02	6	Element 14	n/a	$0.12
05-06	PCB board	Not Priced	2	UC	n/a	-
05-07	LED	$0.02	5	Element 14	n/a	$0.10
Total						**$2.93**

Total Cost	**$650.18**

APPENDIX B –BREAKDOWN OF ADDITIONAL COSTS

Additional Componentry Costs

Item	Cost/unit	Unit	Number of Units	Total Price
Red laser	$ 4.75	Component	2	$ 9.50
IR Camera	$ 22.32	Component	1	$ 22.32

Circuit Componentry Costs

Item	Cost/unit	Unit	Number of Units	Total Price
Multiplexing Circuit	$ 1.35	Component	1	$1.35
4 surface mount resistors	$ 0.04	Component	4	
PCA9510B	$ 1.19	Component	1	
Voltage regulator	$ 3.20	Component	0	$3.20
10K Potentiometer	$ 1.00	Component	1	$1
Capacitor	$ 0.10	Component	2	$0.2
Voltage regulator	$ 2.00	Component	1	$2

3D Printing Costs

Item	Cost/unit	Unit	Number of Units	Total Price
3D printed wheels	$ 0.05	grams	403	$20.15

Summary of additional costs

Circuit componentry costs	$ 2.35
3D printing costs	$ 20.15
Additional componentry (Including supplementary 3D	$ 41.97
Total additional costs	$ 56.52