ENMT 301

Design Evaluation Report

Progress Report 3

Group 5

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26/10/2014

1 Executive summary

A scenario describes a post-apocalyptic society which requires an autonomous robot as a means of collecting food packages from the environment. This report briefly describes, and then evaluates the final design of a robot intended to fulfil this purpose.

The robot was designed with the intention of using a ‘Knockover’ method, where if a weight was missed by the collection mechanism, it would be knocked over by arms located on the side of the robot. The collection was thus designed such that it could collect knocked over weights. The design also included a metal detection plate which was used in place of a dual infrared system to detect when a weight was in a collectable position, as well as a large idler bearing to facilitate ease in traversing obstacles.

In the final competition the robot was able to navigate the arena with a top speed of 0.35m/s and collect a detected weight in under five seconds. The performance in competition was mixed with undetected bugs causing the robot to underperform, this resulted in the robot placing 5th equal in a field of 10 averaging 0.83Kg over the three competition rounds. This performance of the robot in the final competition was then evaluated against a number of specifications that were outlined at the beginning of the robot development. These specifications help to identify strengths and weaknesses in the robot design, and also to see how the focus of the design shifted throughout the process.

Following this, four competitor designs were examined in an attempt to further understand effective designs and strategies. Using this information, the aspects that contributed to the success of the stronger designs were outlined as: reliable collection mechanism, wide effective collection area and robust mechanical build. This helped to further show the strengths and weaknesses of the final robot design, and outlined what could have been changed to be more effective in the competition, these were found as:

- **Implement smart servos**: the increased range of motion would have helped to increase the effectiveness of the collection mechanism
- **Increase reliability of metal detector**: the metal detector used was prone to noise which meant that it did not perform as desired, other possible configurations are outlined.

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2 Introduction

In a post-apocalyptic society it was desired that a food retrieving drone should be designed and built to retrieve food packages from a ruined city. These food packages were represented by ferric weights ranging from 0.5 to 1.0 kg, while the ruined city was simulated by an arena with small blocks of wood used to represent debris. This report outlines an overall design description of a robot designed to perform this task before an evaluation is undertaken of the overall design and competition performance.

The evaluation process focusses on three areas:

- Performance of the robot in competition
- Performance of four other robots in competition
- A post-mortem summary of the robot's design focusing on adaptations/improvements to the design which would improve the competitiveness of the robot.

The evaluation process will pay weighting to the system requirements set out in the conceptual design report (CDR) and further development in the detailed design report (DDR). This will help give a framework in which the robot can be evaluated to and thus determines the systems fitness for purpose.

It is intended that concluding on the overall design process and further development of the subsystems will help to summarise the project and concisely relay alterations that would have been made if the system was to be redesigned.

3 Design Description

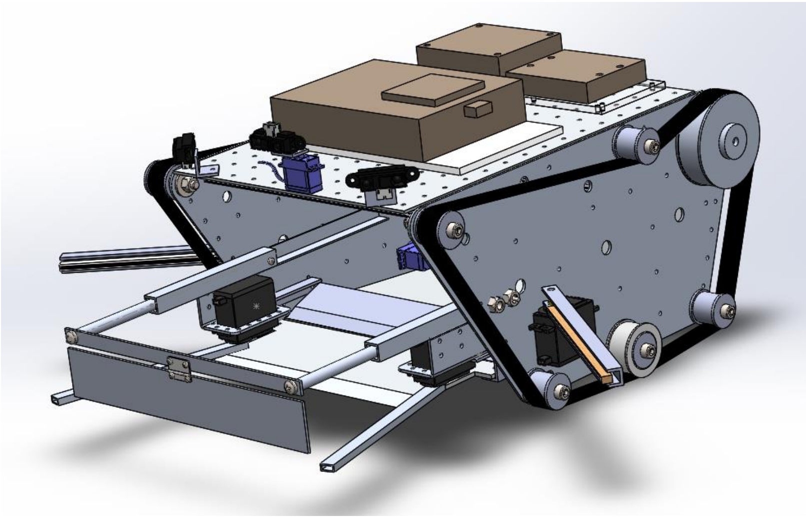


Figure 1: Final design for the robot

For the most part a strong mechanical design was aimed for, such that the requirements for the software were reduced and thus higher level abstractions such as strategy could be focussed on.

The robot used a combination of IR sensors to navigate around the arena and relied on a metal detection plate, paired with a limit switch, to trigger weight collection. The collection process began with a ramp being lowered so that the two sweeper arms could be rotated inwards, such that the weight could be pushed into the main body of the robot. The storage consisted of an area which was sloped downwards to ensure that the weights rolled to the back. A small lip was located at the front of the storage area to prevent the weights from rolling out of the robot once collected. This small lip had a limit switch inbuilt to confirm a successful collection, thus allowing the robot to transition back to searching mode.

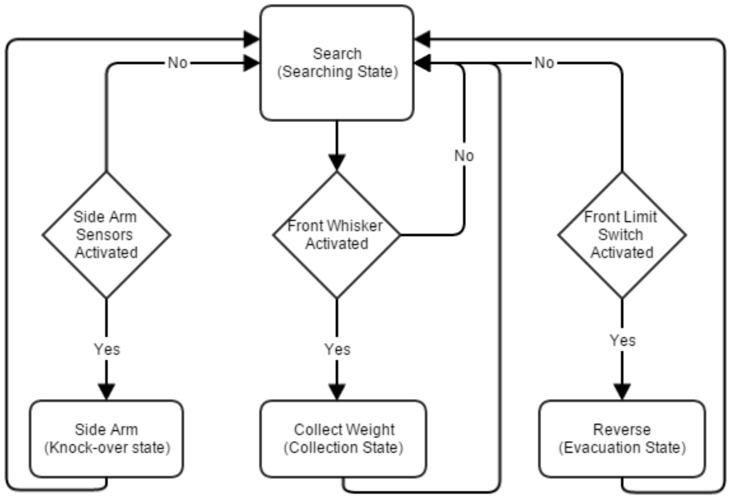


Figure 2: Software operation overview

Figure 2, a state diagram of the robot used in competition, shows how different states within the code were activated and the transition conditions associated with them. Though the robots complexity was far greater than shown in Figure 2, the overall system followed this simplistic model which is detailed further in Appendices 6.1-6.4. The code consisted of a high level main function which called individual standalone modules containing functionality code. This design lowered the codes coupling as well as lending to strong code cohesion. Robust code was necessary in a competitive environment as bugs causing unwanted system behaviour would likely lead to reduced competitiveness.

A more comprehensive description of the design can be found in the DDR.

3.1 Developments

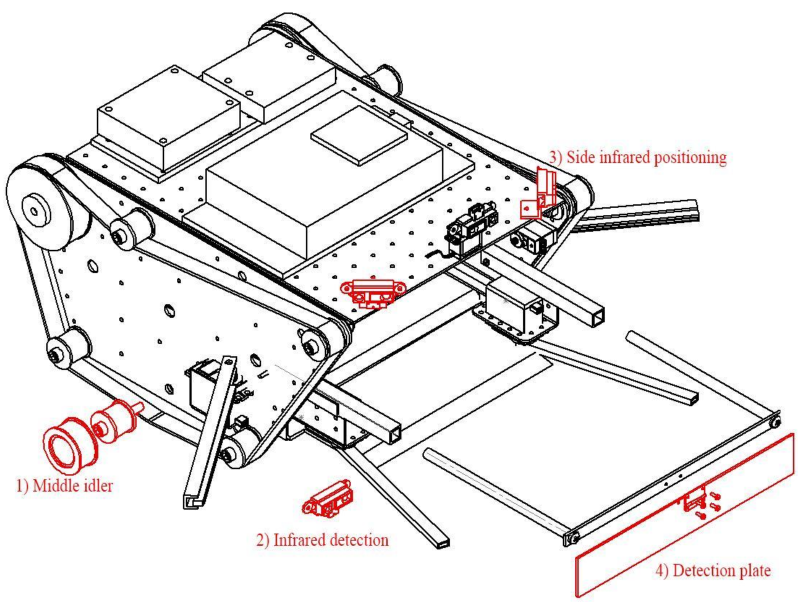


Figure 3: Diagram indicating changes between the DDR and the final design

A number of changes were made between the completion of the DDR and the final competition. These are outlined as follows:

3.1.1 Middle Idler

The supplied chassis system had a flaw in that the front bearing did not extend far enough forward, meaning that the chassis frame protruded in front of the tracks - this restricted movement over lips and bumps within the arena. To overcome this, an idler was added between the front and back bearings, with a 3D printed cover which increased the diameter to 35mm. This had the effect of moving the pivot point of the robot forwards, allowing the robot to tilt backwards when coming into contact with an obstacle. This addition greatly increased the robot's mobility around the arena and therefore its effectiveness in collecting weights.

3.1.2 Infrared Detection

The dual infrared detection system was abandoned in the final design, with the bottom long range sensor being removed. This decision was motivated by hardware constraints caused by the collector arms needing to be tucked under the collection ramp during normal navigation, causing the bottom sensor to be blocked.

3.1.3 Side Infrared Position

Arena navigation was performed using infrared (IR) sensors which in the DDR were specified as being mounted on the front and sides. As space became a concern, the side IR sensors were moved to the top to allow space for the side arms.

3.1.4 Detection Plate

The front whisker system - which was used to distinguish weights from enemy robots and arena obstacles, was implemented using a rotating solid plate. The detailed design report outlined the front whisker system would be single metal tabs, however this method did not provide a sufficient connection with the weights for detection. A solid metal plate which pivoted on a hinge was instead used – this addition also allowed a limit switch to be implement. The limit switch was activated when the plate rotated backward, indicating a weight had been collection. As the whisker system was prone to incorrect triggering, this gave a second check before the weight collection subsystem was initiated.

3.1.5 Colour Sensor

Note that this isn't annotated in Figure 3

The colour sensor and short range IR sensor mounted on the underside of the robot were discarded near the final robot deadline. Determining surface colour and thus arena position was deemed redundant as no groups had implemented a drop off mechanism in their robots. Removing these two sensors allowed for greater clearance on the underside of the robot along with increasing system reliability and decreasing response time.

3.1.6 Strategy

It was initially intended and outlined in the DDR to navigate to the opponent's base and start knocking over weights, thus directly competing and therefore inhibiting that robot. However it was found that this strategy was disadvantageous as the opponent may have collected a number of weights before the robot arrived at their base. Thus the robot began the competition in a searching mode, and simply used the knock over arms to hit any weights that were missed by the collection mechanism.

4 Evaluation

4.1 Performance Overview

The robot competed in three rounds in total:

- **First Round; Opponent - Group 1; Weight Collected - 0.75 kg**

The first round was matched against the most difficult opponent - who went on to win the competition, and was a lot closer than the final weights indicated. The first arena was by far the easiest and most suited to the robot, thus had its greatest opportunity to perform well. However, early in the round the enemy robot crashed into the robot and ripped out a crucial connection; without the ability to re-fix this connector it was impossible for the robot to pick up any of the weights it came across.

This round also marked the round where the Knockover method proved most effective, in that the opponent was deprived of collectable items early in the round which would have given a good chance at victory had any weights been detectable.

- **Second Round; Opponent - Group 6; Weight Collected - 1.25 kg**

The second round was staged after an eight round hiatus, with a modification being made such that the broken connector no longer caused issues for the collection of weights. This round was more successful than the last collecting two weights against the opponents 0. The ease of this round was mainly due to the fact that the opponent got stuck on a ridge which preventing it from moving for the majority of the round.

The eight round gap meant that the robot did not compete in the “medium” difficulty arena and was immediately placed in the “hard” difficulty arena. This was an issue as the hard arena featured a number of weights placed close enough to walls such that they were rendered uncollectable - which can be marked by the robots small number of weights collected in this round.

- **Third Round; Opponent - Group 9; Weight Collected - 0.5 kg**

With the knowledge of the difficulty of the round, very small modifications were made to the code to: one, bring the robot slightly closer to walls, and two, begin the competition in wall follow mode. Both of these modifications were restrained as it was seen as undesirable to make a major change to the code without the opportunity to test.

The change to begin in wall follow was highly successful and a weight was collected almost immediately. Unfortunately, within the first minute, one of the robot arms got stuck on a pole and a bug meant that it did not retract correctly - thus resulting in the robot becoming stuck for over four minutes of the final competition.

4.2 Specification Analysis

A number of specifications were outlined in the conceptual design report that were to be used as metrics in determining the success or failure of the final design. The following section will highlight a number of important specifications and summarise how the robot performed both in the competition and in testing beforehand. A full overview of the achievement of each of the outlined specifications can be found in Appendix 6.5.

4.2.1 The Robot shall be able to find actively search for, and find a weight

There are two parts of this specification which were originally assumed to be entirely complementary, but with further development turn out to be somewhat independent.

4.2.1.1 Analysis

'Search for'

As described in the DDR it was intended that a dual infra-red system would perform the task of actively searching for the weights - this was an extremely common method of locating weights, with only one group (Group 1) employing a different method. However, due to restrictions in the collection mechanism, this system could not be implemented on the final robot. This meant that the first part of the specification - that a weight should be actively searched for - was not achieved by the robot.

'Find'

The weight detecting sensor situated out the front of the robot formed the 'finding' part of the specification. This detector was made up of two parts; a metal detection plate and a limit switch. The two were intended to work together such that the limit switch would prevent noise from incorrectly triggering the metal detector, and that the metal detection would prevent obstacles from incorrectly triggering the limit switch. While the metal detector circuit did not perform consistently enough to be reliable (Section 4.4.2), the front sensor, as a whole, performed its job with a lot of success.

It is difficult to accurately define the success of the weight finding system in the final competition, thus the pre-competition testing provides feedback as to how well this requirement was achieved. In pre-competition testing, the robot was put in an arena with a number of weights and allowed five minutes to collect as many as it could. In each of the testing scenarios the robot was able to collect one or more weights and retain them until the end of the round. The most successful collection run was able to collect 4.75 kg of weights autonomously after collecting 6 of the 11 weights randomly placed in the arena. Thus, it can be said that this part of the specification was achieved.

4.2.1.2 Evaluation

This weight detection design proved to be a major point of difference between the robot and the competition and, if the system was made to be more reliable, would have been a great example of how a simpler design can often prove to be more effective. The lack of searching ability wasn't seen as a serious disadvantage to the robot, as the combination of a wide collection area, and high collection speed meant that weights were visited at a similar rate to other teams' robots.

4.2.2 The Robot should be able to "drop off" the weights at the home base

4.2.2.1 Analysis

This specification can be seen as achieved, despite the fact that the final implementation of the robot could not perform any of the requirements. As described in the DDR, the robot was fitted with a colour sensor and distance sensor pair that would detect the colour of the floor of the arena, and prevent false readings, respectively. In each of the functionality assessments, the robot was able to turn away from an opponent's base in order to not collect a weight - thus indicating that it was *able* to perform the requirements. As detailed in Section 3.1 the colour sensing functionality was removed from the robot used during competition.

4.2.2.2 Evaluation

This final omission is one of the stronger design decisions made for the final robot. It was realised that the large chassis size and strength of the DC motors meant that there was little tactical advantage of returning to the home base - which was a fact that every team in the competition identified. This resulted in no team adding the functionality of returning to the home base or “dropping off” the weights, thereby making each a number of the outlined requirements redundant. As a result, support for the colour sensor was provisionally removed for the final design which proved to make the robot react faster, and more reliably.

4.2.3 The Robot should be able to pick an object from within 5mm of the wall

4.2.3.1 Analysis

The software was not implemented in such a way that it allowed the robot to identify and thus collect weights placed too close to a wall. This proved to be a critical flaw in the final competition as rounds two and three were dominated by weights that were located close to walls (within 10 mm). The robot was not able to collect any of these weights, therefore indicating that it failed this specification.

4.2.3.2 Evaluation

While the hardware implementation allowed for weights to be picked up close to walls, this functionality was not implemented in software - the reason for this being that this specification was deemed unnecessary for the final design. The trade-off that occurred was that the closer the robot got to a feature, the more likely it was that it might go below the minimum sensor range and then simply crash into a wall. The decision was thus made that the robot would not get too close to walls under the assumption that only a few weights would be located within 5mm of a wall. This was a calculated risk proved was a critical mistake which ultimately impacted negatively on the robots performance in the final competition.

The crux of this issue was that presumptions were made about the layout of the arena; these proved not to be true. It was assumed that the practice arena would be fair representation of the arena for the final competition. The increased complexity of the final arena can be noted in Figure 4. The changes that were required for the robot to perform better were relatively simple (Section 4.2.3.3), but without the ability to test the robot with the altered code, these last-minute changes were risky. For the most part, due to the risk involved, these risks were not taken and as a result the robot under performed in the more difficult arena.

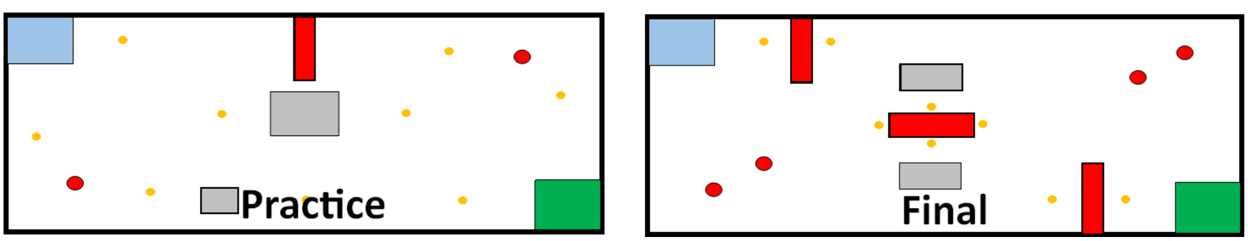


Figure 4: Increased arena complexity between the practice and final arena. NB: Grey squares indicate debris

4.2.3.3 Proposed Solutions

Two simple solutions could have been employed to solve this issue; the first of these would be to decrease the distance at which the robot would recognise a wall. There were a number of features on the robot which would work to prevent the robot from crashing and getting stuck on the wall, but to make this change without testing could have ended catastrophically.

The other possible solution would have been to more vigorously employ the wall-follow mode. This mode was developed early on in the robot and used PID control to navigate the robot around the walls of the arena. If this wall follow mode had been tested more for this application, it could have been employed to quickly target all of the weights located close to any of the walls. When coupled with a timer to break the robot out of loops, this could have been a powerful tool to quickly collect many of the weights that was unable to locate in the final competition.

4.2.4 The Robot shall be able to traverse obstacles of at most 25 mm in height

4.2.4.1 Analysis

The track design proved to be a common point of difference between all of the robots as the 25 mm bumps in the centre of the arena were found to be a difficult barrier to overcome. As outlined in section 3.1 alterations to the track system involving additional bearings and increased idler size was implemented to overcome traction issues, thus increasing system mobility. In the final competition there were no points of time where the robot got stuck traversing any of the 25 mm bumps – thus indicated the successful completion of this specification.

4.2.4.2 Evaluation

Originally, the front bearing diameter was increased in size with the enlarging cover, which made it more effective at climbing obstacles. This naturally had the effect of tilting the entire chassis backwards by an angle of 2 degrees (α in Figure 5 This change, while slight, was enough that the collector arms were no longer able to push the larger weights up the ramp.

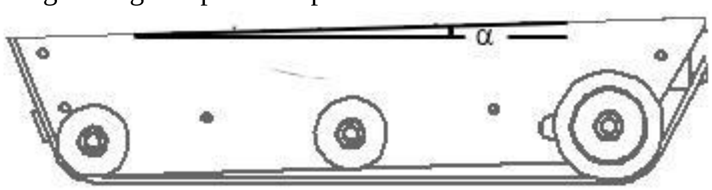


Figure 5: Attempted configuration for track system

The final solution to this problem proved to be both simple and elegant. Easily allow the robot to traverse the necessary obstacles, but also tilting the chassis forward (β in Figure 6) which allowed weights to be *more* easily collected by the robot – increasing the success rate of the collector arms dramatically. It can be reflected, though, that a more synergistic design could have been achieved, had this parameter been considered earlier in the design process.

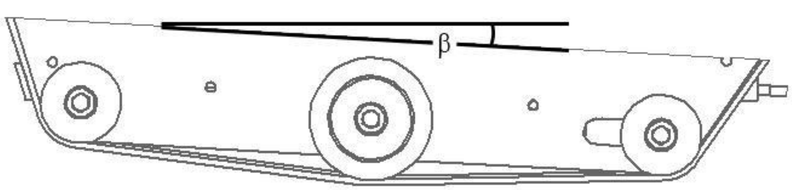


Figure 6: Final Configuration for track system

While a solution to the problem was found, this highlighted a key flaw in the collection mechanism (discussed further in Section 4.3.5).

4.2.5 The Robot should detect when it is stuck, and therefore change its behaviour

4.2.5.1 Analysis

This is the second crucial specification that the robot did not achieve. Instead of focussing on this functionality, the robot was instead designed so that it was very unlikely that it would get stuck. For this reason, there wasn't a lot of emphasis placed upon detecting when the robot had become stuck. This proved to be a serious error in the third round when an unexpected bug meant one of the arms did not rotate inwards, resulting in the robot simply circling a pole for the majority of the round.

4.2.5.2 Evaluation

The reason that ignoring this specification became an issue was the consistent performance during testing, and the increased complexity of the final arena. While this specification was chosen to be ignored, which resulted in underperformance on competition day, it is still believed that it is better to have attempted to solve the bugs that the robot presented than to add provisions for the event that they went wrong. Failsafe's are an important tool, but should not be used in place of having a reliable design - which was decision made by a number of teams.

4.2.5.3 Possible Solution

The solution to this issue would have been simple; a watchdog timer that made sure that the robot did not stay in the same state for too long. When triggered, this timer would change the robot to its "evacuate" state and hopefully dislodge it from the obstacle.

4.2.6 The Robot should be able to undermine the opponent's collection of weights

4.2.6.1 Analysis

The intended method of achieving this specification was the "Knockover method" described in both the conceptual and detailed design reports. Most competitor's designs relied on the grooves cut in the top of the weight, meaning that they were unable to pick up weights on their sides. The solution would be to then knock over any weights that the robot was not able to collect, and simply collect them later. This knocking over functionality was performed by the side "wings" that would sit out horizontally from the robot.

While the arms weren't entirely reliable, the robot was reasonably successful in knocking over weights - mainly due to the ease with which a weight could be knocked over. In the first round of the competition the robot was able to knock over five weights, which resulted in a characteristic low collection for the opponent who eventually got stuck on one of the knocked over weights. Thus, this specification was completed to some degree but could use some development to ensure that it was entirely reliable.

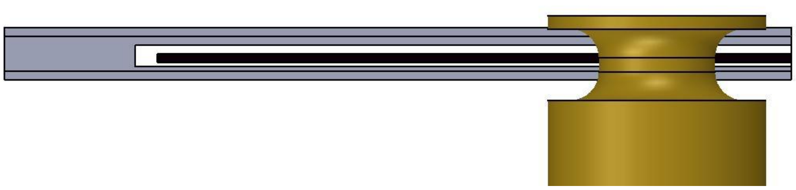


Figure 7: Knockover 'wings' intended to give competitive advantage

4.2.6.2 Evaluation

The intention of this specification was to try and competitively disadvantage other teams, which could have been extremely effective if the robot as a whole had been robust and reliable. All but one other team were completely incapable of collecting knocked over weights, and the robots' collection mechanism designed to be able collect these. Thus, the arms were intended to increase the effective collection area without creating issues with the collection mechanism. However, because of failures in other areas of the design the additions of the side arms did not provide the competitive edge that was desired, and time could have been better put to use in developing other functionality.

The main cause of unreliability was the metal detecting circuitry that was used to distinguish between an obstacle and a weight. There was a large amount of noise inherent to the detecting plate which meant that it would commonly misread the difference between weights and obstacles and would incorrectly rotate inwards when it should have knocked over a weight.

4.2.7 The Robot should be designed to avoid interference with an opponent

4.2.7.1 Analysis

A viewer noted in the practice rounds that the robot was one of the most "well-behaved" robots in the competition. This is partly due to the ability to turn away from any unexpected obstacle. Most of the competitor robots in the competition relied on the wall-avoidance sensors to also facilitate competitor avoidance - this led to a large number of crashes in the competition. The final design of the robot included a touch sensor (described in Section 3) which would activate if the robot inadvertently crashed into something, which was commonly the opponent's robot. Thus, this specification can be said to have been achieved.

4.2.7.2 Evaluation

This was evidently a specification that few teams chose to focus on, meaning that the inclusion of this functionality for the robot proved to be somewhat unique in the competition. It can be reflected that this specification was not crucial to the final robot design as most interference with other robots was relatively minor. For the robot, the functionality was in fact a by-product of wishing to avoid any issues with the poles located around the arena, thus the amount of time spent on developing robot-avoidance by the teams in the competition is reflective of its importance to the final design.

4.3 Competitor Analysis

A useful tool to identify strengths and weaknesses in the design is to compare the performance of the robot with the competitors' robots. Identifying what was done well, or poorly for all of the competitors is incredibly important if one is to learn from the experience.

A total of four competitor robots will be analysed and their relative strengths and weaknesses brought to attention with respect to the performance of other robots. These competitors include Groups 1, 6, 8 and 9. Note that Groups 1, 6 and 9 were groups that the robot competed against in the final competition, and that Group 8 was a team whose robot was competed against in a number of practice rounds.

4.3.1 Group 1 Position: 1st Average Weight Collected: 3.7kg

4.3.1.1 Overview

Group 1 had by far the most robust build in the competition, which meant that it performed consistently and well. Laser diffraction was used to navigate the arena as well as locate weights – using the logic that the weights were remarkably more reflective than anything else in the arena. The collection mechanism formed a Perspex holder with a track cut out of it; the robot would drive into a weight and a servo arm would push it such that the grooves of the weight would travel along the tracks. Other notable features of their design include the large 3D printed wheels which allowed it to quickly manoeuvre around the arena, and small gates which prevented weights from being collected in the opponent's base.

4.3.1.2 Strengths

The whole robot was extremely well put together, with a professional air about it. This robustness meant that the robot was not prone to mechanical errors, while also putting less pressure on software design to make up for mechanical faults. Corollary to this, the design was finished very early in the development and did not change remarkably between the first functionality assessment and the final competition. This meant that all further development time could be used to increase the reliability and competitiveness of the final design.

One of the greatest strengths of the robot was the combination of a wide collection area, weight searching system and weight detection system. The wide collection area was created by Perspex channels such that any weight located within the width of the chassis would be funnelled towards one of the two weight storage tracks (Figure 8) - this design negated the need for high accuracy when driving into weights. The weight searching system was the most sophisticated in the competition - utilising a diffraction of lasers to search for reflective materials - this was especially effective at operating at high speeds. The weight detection system worked together with the wide collection area, using a mechanical switch to indicate when the weight was in an appropriate position to be collected. All of this combined to create a robot which was excellent at finding weights but had little need for fine accuracy when collecting them - meaning that it was especially fast.

4.3.1.3 Weaknesses

The biggest weakness of Group 1's design was that it relied on the grooves cut around the top of the weight to pick up a weight, which meant that it could not pick up any weight which had been knocked over. In addition to this, the height of the components meant that it was extremely easy for weights to become trapped under the chassis and prohibit movement. This weakness can be observed in the first round where five weights were knocked over before Group 1 was able to collect them; two of which got trapped underneath the chassis and preventing the robot from moving. If more teams had been able to exploit this weakness, Group 1 may not have performed so well in the competition.

4.3.2 Group 6 Position: 6th equal Average Weight Collected: 0.5kg

4.3.2.1 Overview

Notable features of Group 6's design was the claw-like mechanism located in front use for collecting weights, and the infrared sensors mounted on servos to be used for navigation. As was common in the competition, Group 6 relied on the grooves cut in the tops of the weights to collect them, employing a claw mounted on a servo which would rotate the weights such that they could slide onto rails in the located in the chassis. The infrared sensors mounted on servos proved to be a unique design, and aimed to decrease the size of their robots blind spots, such that it would not get stuck driving into an object.

4.3.2.2 Strengths

The design was such that the weights could not move around while the robot was moving - this was advantageous in that it prevented weights from falling out once collected. While this didn't prove to be an issue in the final competition, a number of teams had issues with this in the lead up.

4.3.2.3 Weaknesses

Poor code design became a notable weakness for Group 6; it was reflected that the code was written in a complicated manner such that it became too unwieldy to debug, and was difficult for other members of the team to assist in writing the code. Coupled with this was that sophisticated code was required to provide high accuracy necessary for the claw to be able to collect a weight. In the competition a number of weights were identified by the robot, which it then failed to collect as there would be some error which would cause it to miss.

What proved to be an equal weakness for the team was the track design. The design was changed relatively late in the development process, which evidently resulted in a lack of testing being performed as in two of the three rounds that were competed in, the robot got stuck on terrain in some fashion. In the third round this proved to be catastrophic, as the robot was unable to dislodge itself from the terrain and remained stuck for the entirety of the round. This again highlights the merits in spending time ensuring that each aspect of the design is covered early in the development process, so that last minute alterations are not required.

4.3.3 Group 9 Position: 4th Average Weight Collected: 1.1kg

4.3.3.1 Overview

Group 9 had a very similar design to Group 6 with a fork system in the middle of the robot used to rotate weights onto a rail system within the chassis. They similarly used a dual infrared system to locate weights from a distance.

4.3.3.2 Strengths

The collection mechanism was consistent in collecting weights and good track design meant that the robot did not get stuck on any of the terrain. One large advantage the group had was that the sensing system meant that the robot was able locate and collect weights placed close to walls, which proved to be advantageous in the later rounds of the competition.

4.3.3.3 Weaknesses

Using the dual infrared system, it was incredibly important that the top and bottom sensor were exactly in line, or false triggering would be common. Group 9 demonstrated this issue as a number of times the robot incorrectly identified one of the poles as a weight and then spent a time driving into it. Due to time constraints, the team did not fix this issue, instead they implemented a watchdog timer which would simply change the state of the robot after a certain amount of time elapsed. This proved relatively effective, managing to win two rounds before being knocked out - but the performance of the robot could have been greatly improved if the bugs were found and fixed instead.

4.3.4 Group 8 Position: 2nd Average Weight Collected: 2.6kg

4.3.4.1 Overview

Group 8 had a relatively unique design, employing a permanent magnet to be able to collect weights. This magnet could be turned on and off with a servo meaning that a weight could be picked up and then dropped in the body of the robot. The design employed large fins out the front to channel weights towards this magnet, and similarly used a dual-infrared system to locate weights from a distance.

4.3.4.2 Strengths

One of the most notable strengths of Group 8's robot were the fins used to funnel weights towards the magnet. The group did not originally intend to use this system, but had trouble getting enough accuracy to line up the weights for the magnet to collect. These fins served the purpose of increasing the effective collection area, as well as mechanically lining up the weights. Once this was done the robot was made much more competitive as can be noted by the performance in the competition.

One strength that Group 9 focussed on was to minimise the number of mechanical parts, as the more moving parts the more possibility there was for something to go wrong. This had the effect of increasing dependence on strong code design, but since the mechanical design was much simpler the group had more time to work on the reliability of their code. This highlights how the choice of design space, as mechanical or electrical, can affect the development process.

4.3.4.3 Weaknesses

The robot used the dual infrared system to locate weights from a distance - this was an effective system, but proved to be unreliable at higher speeds. This meant that the robot had to navigate the arena relatively slowly. This tactic did not present any issues against robots who had trouble simply collecting weights, however, in the final, it was a matter of who could collect them more swiftly - this proved to be Group 1 which employed the more sophisticated laser system.

4.3.5 Learnings

From analysing the competitors, it can be seen that the most effective designs were those that had reliable collection mechanisms, wide effective collection areas (see Figure 8) and simple mechanical designs. This last point is where the final design of the robot failed to achieve - with a large number of independent moving parts meant that there were a lot of things that could go wrong on the final day. This increased mechanical complexity also had the effect of dragging out the mechanical design process, where the two winning teams had much of their design finished by the first functionality assessment. Coupled with this was an attitude that a number of components would be improved 'later' in the development process, which was then replaced with an attitude that it was too late to improve the components – meaning a number of components were not as well designed as they could have been.

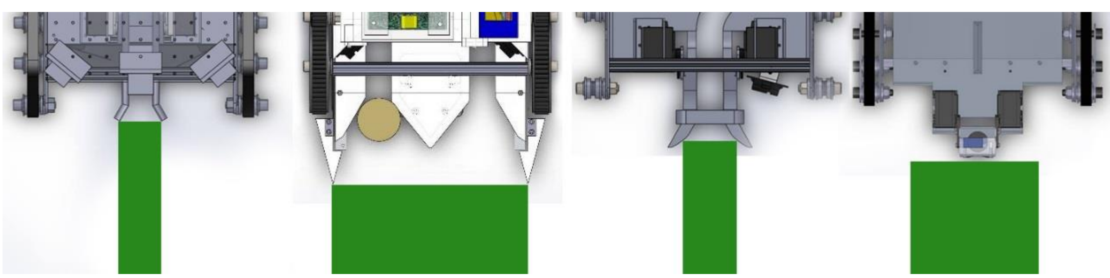


Figure 8: Demonstrated effective collection areas for Groups 9, 1, 6 and 8, respectively

A wide collection area was actually intended to be developed for the robot, but as is discussed in Section 4.4.1, this was not achieved in the final design. Though, it can be observed that a number of teams would have performed a lot better if their design had included a mechanical feature which would increase their effective collection area – this can be noted in Figure 8.

4.4 Post-mortem Summary

4.4.1 Smart servos

As is apparent from the Specification Analysis, a common issue was that the collector arms chosen were incredibly restricting. It was intended that these arms would initially sit out at an angle (Figure 9), and then rotate inwards when a weight was detected so as to collect the weight.

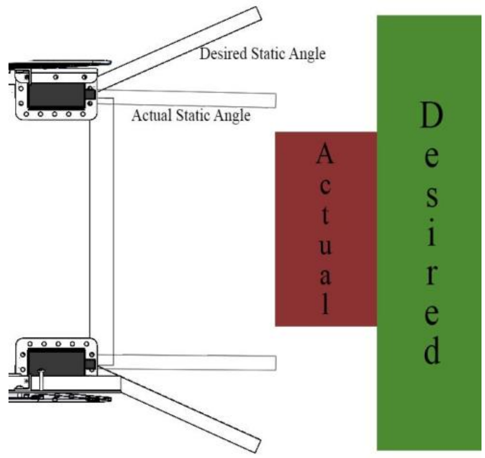


Figure 9: Demonstrated the desired against the actual collection area for the robot

This was unable to be achieved - mainly due to restrictions in the servo;

- The servos could not rotate for the expected 180 degree range. This meant that the arms could not both rotate fully inwards to collect the weight, and sit out at the desired angle when navigating the arena.
- The plastic servo horns allowed too much flexure. If the arm hit too high on the weight, it would flex and simply travel over the weight. This resulted in the arms needing to be angled heavily downwards so that the arm remained low enough on the weight so that it was not able to flex over.
- The arms were only just strong enough to push the weights up the ramp. This presented itself as an issue when the track configuration was attempted to be changed, as discussed in Section 4.2.4.

All of these factors combined to markedly decrease the effectiveness of the collection mechanism. One of the biggest issues was that the furthest the arms could sit out was straight ahead (actual static angle marked in Figure 9), coupled with the fact that the arms were angled heavily downwards; this meant that they were prone get caught on the edges of obstacles. To solve this, these arms had to be tucked under the ramp while navigating; when a weight was detected they would be quickly rotated outwards so that the robot could then collect it. This created a very complicated process of rotating the arms in and outwards, which was prone to hitting weights out of the way, while also meaning that the bottom infrared sensor could not be used, as the arms block the view.

All of these issues could have been remedied through use of the smart servos. These smart servos had 340° of continuation rotation - meaning the arms could have had an extremely wide range of movement and allowing the collection area to be implemented as it was intended. Coupled with this, the connection points for the smart servos allowed very little flexure meaning that less angle would be required to prevent the arms from flexing over the weights. The smart servos also have an encoder which provides feedback as to its current position – this could have provided extremely useful information which could indicate if the smart servo was stuck in some way.

The smart servos were originally discarded as an option, because of difficulties other groups were having with implementing them onto the robot. The boons of using the smart servos were not fully discovered until much later in the development process – when it was too late to implement them in both hardware and software.

4.4.2 Metal Detection

Common to a number of the failed features outlined in Section 4.2, was the unreliability of the metal detecting sensors. There were no other teams which attempted to employ metal detection in any way, and having reliable functionality would have given a competitive edge to the robot.

For all intents and purposes the metal detection circuit did work, and when tested was effective at identifying weights. It was sensitive enough to detect the difference between different sizes of weights, as well as being able to detect an enemy robot. The issue was that this testing was performed using a single wire, which did not give a wide range of detection - thus this wire was connected to a metal detection plate. When connected to this plate, there was a significant amount of noise introduced into the system, which unfortunately was greater than the drop in frequency from when a weight touched the plate. This error was attempted to be mitigated through use of a coaxial cable and filtering, but was unfortunately unable to be brought to a reliable level.

There are two simple methods that could have been used to replace this sensor:

- A metal detecting switch: this would simply be two sheets of metal forming an open switch. When a metal weight touches both plate, the circuit would be completed - indicating that a weight was present.

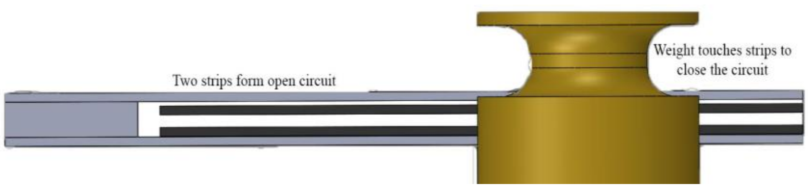


Figure 10: Possible configuration for weight detecting sensor (A)

- The weights were unique in the arena in more ways than simply being made of metal, namely that of height. It would have been possible to use this fact, along with a number of limit switches to distinguish the shorter weights from the taller obstacles.

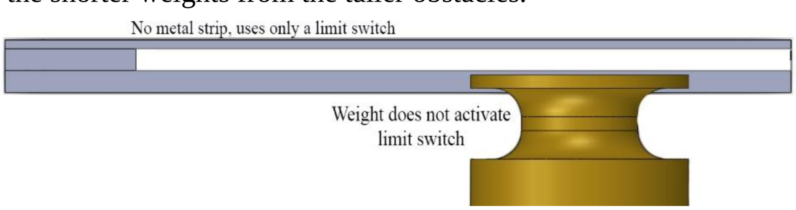


Figure 11: Possible configuration for weight detecting sensor (B)

If either of these methods were employed, both the Knockover method, and the corresponding collection mechanism could have been more effective at giving a competitive edge to the robot.

5 Conclusion

The Robocup is a competition which intends to give insight into a normal design process and to integrate what has been learnt in a number of classes. This report sought to evaluate the performance of a robot designed and developed to participate in the Robocup competition.

The final design employed a ramp and sweeper arm system to enable collection of weights that were both standing and knocked over. In an attempt to give a competitive edge, 'wings' were added to each side of the robot with the intention that they would knock over any weights that had been missed by the collection method. Other notable features included a metal detecting panel which was used to trigger the collector arms and a limit switch on a bar which provided feedback as to if the robot had inadvertently crashed into a wall. A number of state machines, combined with basic driver code, were used in implementing the software for the robot. This allowed code to be develop which focussed on high-level strategies.

Through the process of evaluation - both of the robot and the competitors, the strengths and weaknesses of this final design were discovered.

- While most teams relied heavily on IR in a dual configuration which, as noted in Section 4.3 was at times problematic, the metal system employed in the final design of the robot provided a unique alternative which proved to be less complex, however, reliablity was jeopardised.
- A wide collection area proved to be greatly beneficial in the final competition – as noted with first and second place employing this design. While this design was desired for the robot, it was not achieved due to hardware constraints.
- Track design was crucial for success, with a number of teams becoming stuck in the competition on obstacles intended to represent debris. The robot was successful in this area, with the simplest solution to the issue of these obstacles.

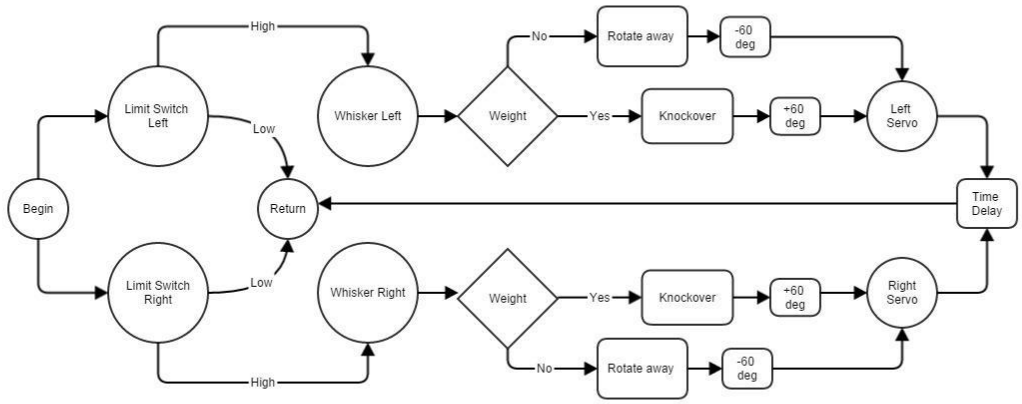
This evaluation not only provides an opportunity to note how the robot performed, but to also identify weaknesses, and thus what might be changed if the challenge was to be undertaken again. The two changes identified as being particularly beneficial are outlined as:

- **Replacing the collection mechanism servos with smart servos**: This would increase the rotational range and would therefore have increased the effectiveness of the wide collection area.
- **Increasing reliability of metal detectors**: A number of components relied on the success of the metal detection, which unfortunately was never reliable enough to be implemented.

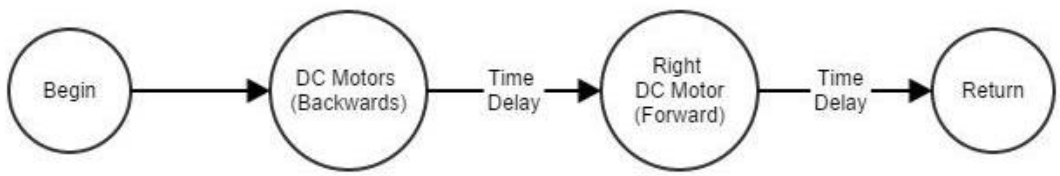
The evaluation process reinforced the strength of the overall governing design, but highlights how a number of mechanical issues lead to the underperformance of the robot on the competition day. Though improvements could be made to the robot to increase performance the system produced met the majority of design requirements (appendix 6.5), thus it can be concluded that the autonomous cyborg was 'fit for purpose'.

6 Appendix

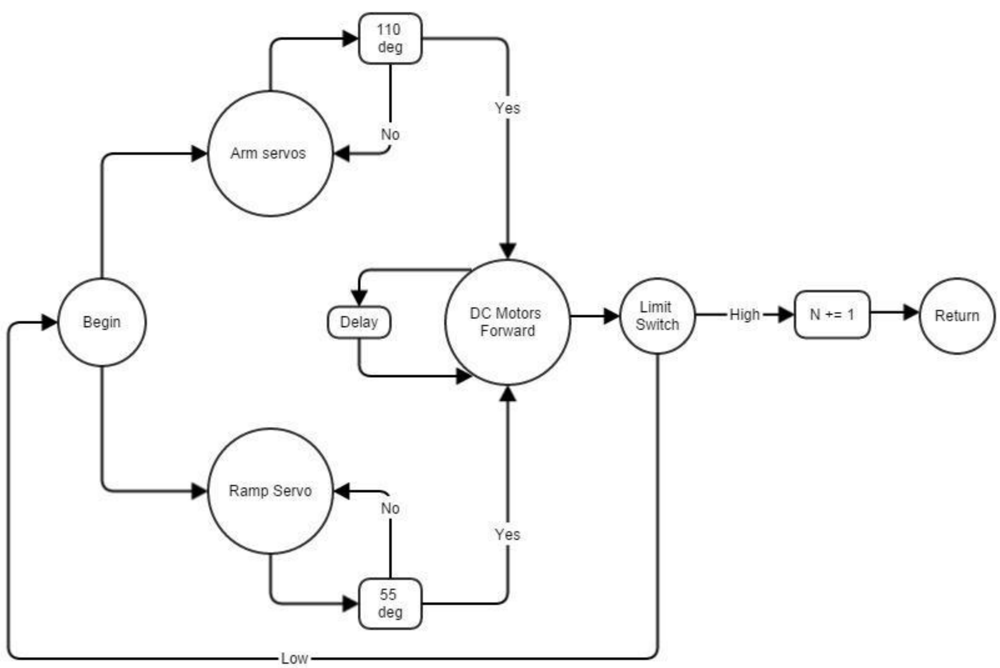
6.1 Knock-over State



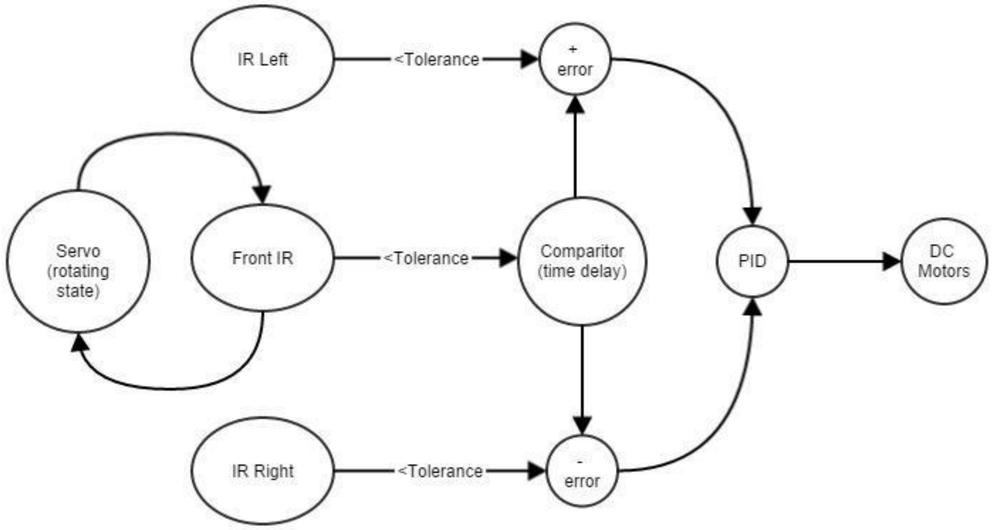
6.2 Evacuation State



6.3 Collection State



6.4 Navigation State



6.5 Evaluation of Robot against Requirement Specification Metric

NB: An asterisk (*) notes a specification that is discussed in the report body.

Criteria	Evaluation
1.1 **General**	
1.1.1 The Robot will be controlled by an Arduino Mega ADK board.	Achieved
1.1.2 The Robot will be fully autonomous	Achieved
1.1.3 The Robot should be able to restart itself if a severe error occurs.	Achieved
1.1.4 Any costs for extra equipment beyond that provided will be less than $50	Achieved
1.1.5 The Robot shall have a clearly defined front end.	Achieved
1.1.6 The Robot shall operate reliably for the full 5 minutes of the competition.	Achieved
1.2 **Collection**	
1.2.1 The Robot shall be able to find actively search for, and find a weight*.	Not Achieved, Achieved
1.2.2 The Robot shall be able to pick up a weight of maximum 1 kg in mass.	Achieved
1.2.3 The Robot shall be able to determine the current number of weights it is carrying.	Achieved
1.2.4 The Robot shall be able to carry at least 3 weights within its body.	Achieved
1.2.5 The Robot should be able to “drop off” the weights at the home base*.	Failed
1.2.6 The Robot should be able to pick an object from within 5mm of the wall	Achieved
1.2.7 The Robot should be able to pick up a weight in under 15 seconds.	Achieved
1.3 **Navigation**	
1.3.1 The Robot shall be able to locate its home base	Achieved (see spec 1.2.5)
1.3.2 The Robot shall be able to traverse obstacles of at most 25 mm in height*.	Achieved
1.3.3 The Robot shall be able to navigate the entire arena within the time limit.	Achieved
1.3.4 The Robot shall be able to fit through a gap of 0.5 m.	Achieved
1.3.5 The Robot shall not exit the arena at any point.	Achieved
1.3.6 The Robot should be able to detect when it is stuck, and as a result change its behaviour*.	Not Achieved
1.3.7 The Robot should be able to mount obstacles with a full load.	Achieved
1.3.8 The Robot should be able to distinguish an obstacle from a wall.	Unnecessary
1.3.9 The Robot should be able to manoeuvre around a corner.	Achieved
1.3.10 The Robot should be able to return to its home base within 30 seconds.	Achieved(see spec 1.2.5)
1.4 **Competitive**	
1.4.1 The Robot shall be able to distinguish an opponent’s home base from its own.	Achieved (see spec 1.2.5)
1.4.2 The Robot shall not be able to pilfer an opponent’s weights from their base.	Achieved (see spec 1.2.5)
1.4.3 The Robot should be in some way able to undermine the opponent’s collection of weights*.	Achieved
1.4.4 The Robot should be in some way able to interfere with the opponent’s navigation of the course.	Achieved (see spec 1.4.3)
1.4.5 The Robot should be able to identify and avoid an opponent.	Achieved (see spec 1.4.6)
1.4.6 The Robot should be designed to avoid interference with an opponent*.	Achieved