ENMT 301

Robocup:
Progress Report 2

Group 5

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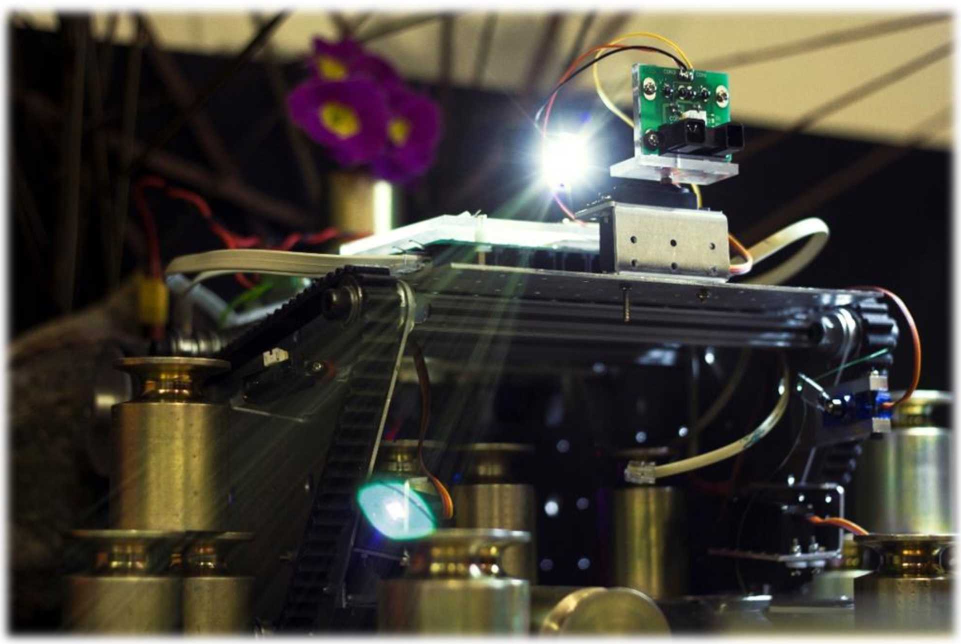

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1 Executive Summary

The University of Canterbury RoboCup Competition provides a scenario where food packages need to be collected by an autonomous robot in a post-apocalyptic arena. This report provides a description and evaluation of the design process undertaken to produce said robot.

The robot is made up of a number of subsystems outlined as follows:

Subsystem	Hardware	Design Considerations
Locomotion	Brushed DC motors, track system	Chassis orientation
Navigation	Infra-red sensors	Sensor angle, Blind spots
Weight Detection	Infra-red sensor, whisker detection circuit	Sensor height
Collection	Collection arms, ramp	Ramp angle, servo strength, arm orientation, Collection area
Knock Over	Servos, whisker detection circuit, limit switches	Arm length, Arm Height
Storage	Aluminium plate, limit switches	Weight Detection, Plate angle
Electronics	Provided	Placement

The aspect of the design which brings all these separate subsystems together is the overarching strategy. Assuming the opponent is disadvantaged by weights that are horizontal, the strategy is as follows.

1. Using the **locomotion** and **navigation** subsystems, follow a wall to the opponent's base.
2. Change **navigation** state to searching such that the robot employs the **weight detection** subsystem
3. If the **detection** subsystem locates a weight, activate the **collection** subsystem. Similarly, if that weight is not collectable at that time, **knock it over** to be collected later.
4. When **collected**, **store** the weights on board the robot.

The main advantage to this strategy is the high speed of collection, sureness of collection and – most importantly – the ability to undermine an opponent's collection method.

While the robot has not been fully developed, it is important to analyse if it can achieve the requirements – outlined in the Conceptual Design Report. The robot has been evaluated against these criteria (Appendix B). As the design process has proceeded, some of these criteria have become redundant through adapting design and strategy changes.

The majority of mechanical parts of this robot have been produced and fitted to the robot. The next stage is to develop the control system which will control the overall functionality of the robot.

2 Introduction

In a post-apocalyptic society it is desired that a food retrieving drone should be designed and built to retrieve food packages from a ruined city. These food packages are represented by ferric weights ranging in weight from 0.5 to 1.0 kg, with the ruined city being an arena using small bumps to represent debris. This report outlines, in depth, the design of the drone built to retrieve these theoretical food packages.

There are six main areas of focus in the design of the robot, these being:

- Locomotion
- Navigation
- Weight Detection
- Collection
- Knock over
- Chassis design

Equally important to the functioning of the robot is how these subsystems interact, thus the interfacing design is described to give a fuller picture of how the robot will operate in the environment.

The collection strategy chosen in the Conceptual Design Report (CDR) was the “Knockover method”; where the weights would be first knocked over before being rolled into the main body of the robot. Within this the Single Bar was chosen as the most effective way of implementing this method; this decision has been changed after it proved difficult to implement the design within the constraints - thus the design has changed to favour the Wings and Sweepers method. The main cause for this change was the difficulty in converting from rotary to linear motion - which proved to be more troublesome than anticipated, coupled with the high cost of off-the-shelf solutions.

3 Design Description

3.1 Overview

For the most part a strong mechanical design was aimed for, such that the requirements for the software side were reduced and thus programming could remain highly abstracted from lower level interfaces.

A combination of locomotion and navigation subsystems will initially be employed to follow the closest wall, in an effort to quickly navigate to the opponent’s base. Once situated, the robot will begin searching for weights through employing a detection subsystem. The collection subsystem will be employed once a metal-detecting sensor is activated; confirming that a weight is within the range of the collector arms. Once a weight is detected, a ramp will be lowered so that the two sweeper arms can be rotated inwards – causing the weight to be rolled into the main body of the robot. The storage consists of a storage area which is sloped downwards to ensure that the weights roll to the back. A small lip is located at the front of the storage area to prevent the weights from rolling out of the robot once collected.

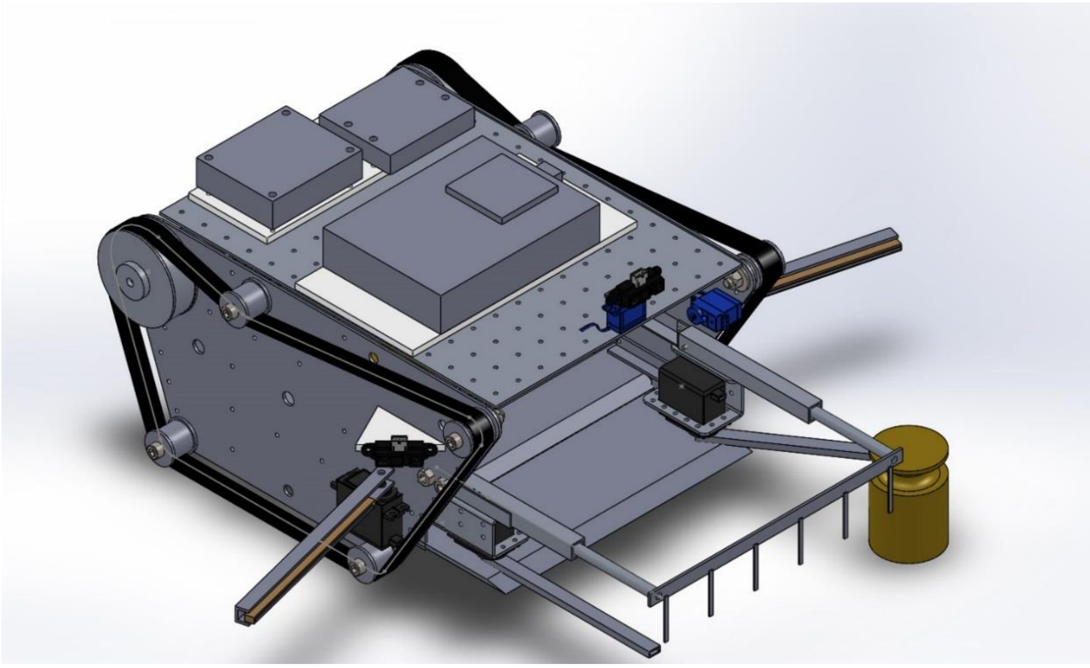

Figure 1: SolidWorks model of the full robot

On the software side, the control system is split into modules, linked together by function. There are four different functions the robot must perform; Navigation, Locomotion, Weight Detection and Collection. The way each module interfaces with hardware is shown in Figure 2. Section 3.2 contains a further analysis of these functions, including the software and hardware requirements involved.

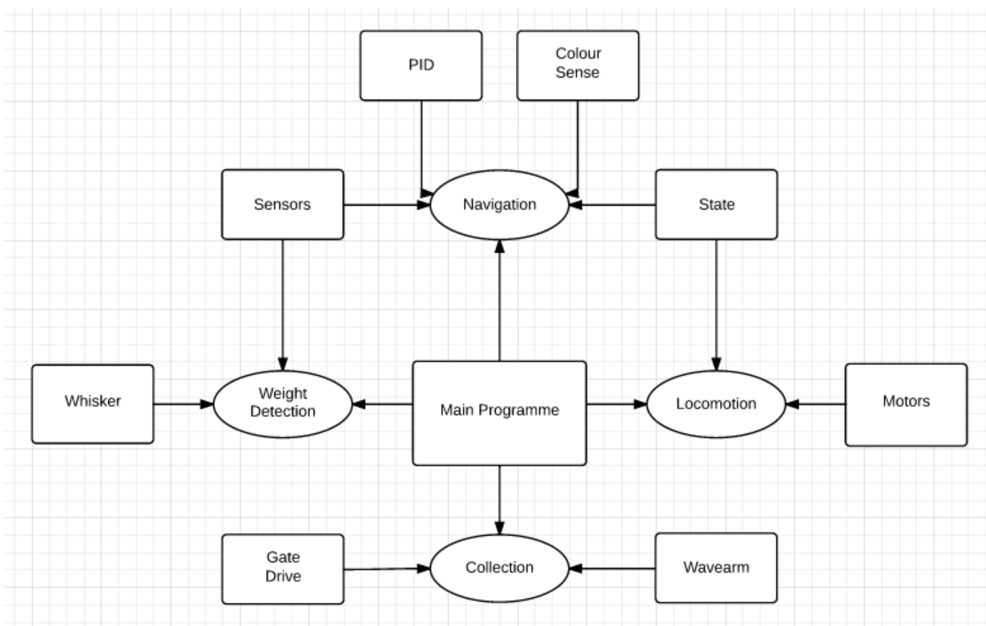

Figure 2: Overview of program modules

3.2 Programme Subsystems

3.2.1 Locomotion

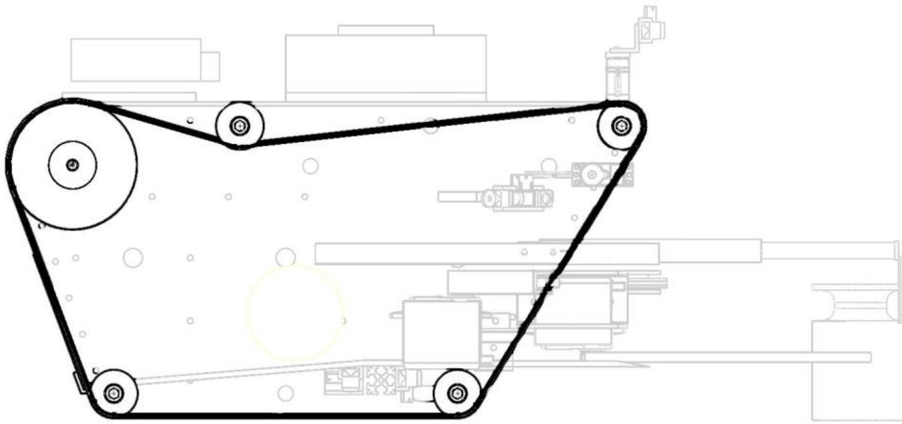

Figure 3: Locomotion Subsystem

3.2.1.1 Overview

The main locomotion for the robot is provided by tank-style rubber tracks; these tracks have small ridges located along their length to give the ability to grip onto an edge. The tracks are driven independently, meaning that the robot has the ability to turn on a point - allowing greater ability in turning to avoid obstacles. The tracks are driven by two DC motors located in the top corner of the chassis, as can be noted on Figure 3. These motors are fitted with a gearing system to ensure maximum torque, as well as optical encoders which enables the robot to measure the distance travelled. There is small slot built into the chassis which allows the tracks to be tightened or loosened, this action can change the tension on the motors, creating a trade-off between torque and speed. Moving this bearing forwards also decreases the likelihood that the robot will become stuck on a lip.

3.2.1.2 Design Decisions

The largest obstacle to the movement of the robot is a number of small rises that are placed throughout the arena. The CDR specifies that the robot must be able to traverse obstacles of 25 mm in height. Because of the trapezium shape of the chassis, the orientation of the side panels defines the robots ability to climb objects.

The decision was made to orientate the given chassis with the smaller edge at the bottom and the larger end at the top. This orientation gives an acute angle at the bottom such that the ridges on the tracks could be employed to climb obstacles with more ease.

Similarly, the track angles are not the same at the front and the back end of the robot, with the back angle being around 73° and the front being 57°. The steeper the angle, the easier it is to

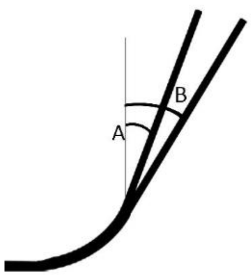

Figure 4: Angles of the front and back of the chassis

mount obstacles, but a steeper angle at the front also makes the robot more susceptible to tipping. Calculations were made with assumptions about the robot's centre of mass, supported by empirical testing, and it was found that the lower angle of 57° proved to be the superior design decision.

The success of the robot design heavily relies on speed; the robot's speed will be reduced by extra weight. With the robot travelling at its minimum speed, it was able to carry 7.5 kg before it was unable to move. Increasing the speed to 50% of the max speed allowed it to carry 11 kg with minimal effect on the speed. This testing suggests that the extra load will have minimal effect on the robots performance.

To estimate the distance the robot would be able to cover in five minutes, the robot was put into wall follow mode was made to navigate the arena. The average time taken to travel this distance was 22.6 seconds (Appendix K). This means that the robot could quite comfortably travel a distance of 73 metres in five minutes – satisfying requirement 6.5.3 outlined in the CDR.

3.2.1.3 Further Developments

One possible issue is the robot becoming stuck when driving over the lip to the home base. This is due to the flexure in the tracks which can bend up such that the edge of the chassis rests on the lip. To avoid this a spring loaded mechanism could be added to the midpoint of the bottom tracks, this would ensure that the tracks stayed in contact with the arena at all times and would help to prevent the robot from becoming stuck.

During testing it was found that a weight could occasionally become trapped beneath the tracks which would naturally cause the robot to attempt to climb over it - often causing the robot to tip over. When the design is fully implemented this would be unlikely to happen, but to avoid a possible catastrophe a protective plate could be made to block any weights from entering that area.

3.2.2 Navigation

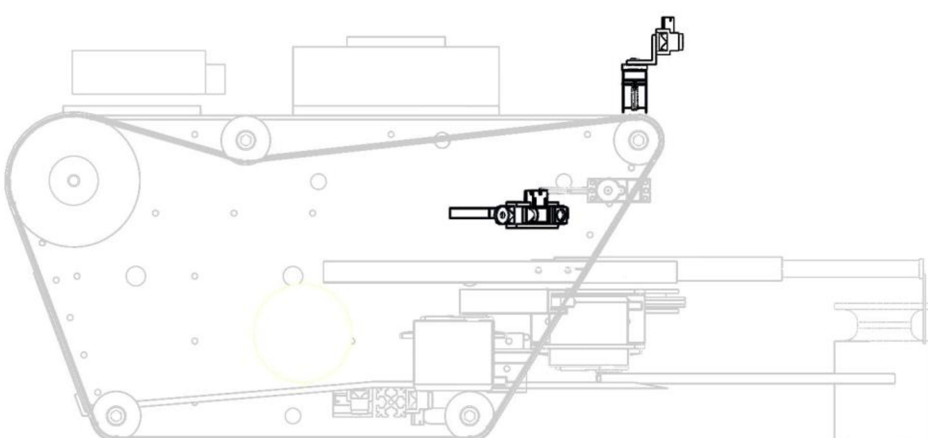

Figure 5: Navigation Subsystem

3.2.2.1 Overview

The navigation has two main states: wall follow and searching. They both use similar methods in order to navigate around the arena; three infrared sensors are employed to follow or avoid walls in the arena.

Two identical mid-range sensors are placed on the side of the robot at an angle of 45° to the wall, with a third long-range sensor mounted on the top of the chassis pointing directly forwards. Figure 6 shows the approximate viewing angle of the robot and highlights any blind spots. While each of the sensors has a very narrow field of view, the movement of the robot while each obstacle remains static is what creates these fields of view. The sensors are also limited in that they have a minimum range, it should be avoided that the robot should move beyond these ranges.

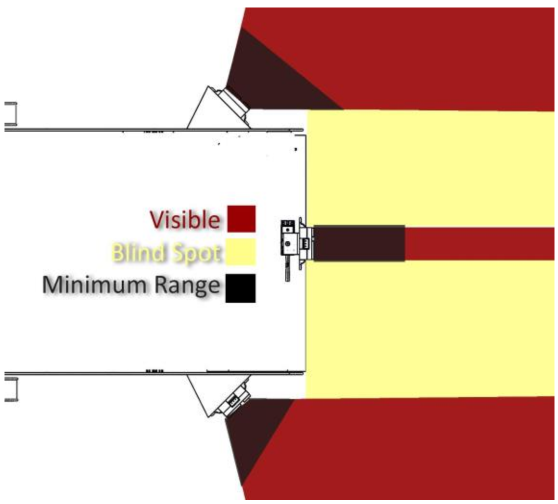

Figure 6: Identifying blind spots of the robot

A requirement of the contest is that weights may not be collected from the opponent's home base. The home bases are located on a coloured patch within the arena, with a different colour for each base. These bases will be detected using a colour sensor mounted on the bottom of the robot. This sensor has been shown to change values drastically when the distance from the floor is altered. To reduce the chance of false colour readings, an IR sensor has also been mounted on the base of the robot, this will give feedback so that the colour sensor values will only be used when the sensor is the correct distance from the floor.

3.2.2.2 Implementations

Wall Follow

In the wall follow navigation state, the two mid-range sensors mounted on the sides are used to firstly, determine which wall it is currently closest to, and secondly, determine how far away from the wall it currently is. A software-based P-controller is then used to keep the robot at a certain distance away from the wall.

When the front sensor reports that the robot has reached a corner, the code will change into a turning state. The front sensor is pivoted using the mini-servo, the robot is then turned until such a point that the front sensor no longer reads below a certain threshold - this indicates that the robot has turned the correct angle. At this point the state returns to the wall-following mode and the front sensor is moved back to the correct position.

Searching

The searching mode is similar in operation to wall follow mode. The searching mode employs the same method for turning as the wall follow mode but does not employ the P-controller which keeps it following the wall. The turning functionality is expanded such that if any of the three sensors are close to a wall they will turn away from it. This has the effect of “bouncing” the robot around the arena which allows it to randomly search for weights until such a point that a weight is detected by any of the methods to be mentioned in Section 3.2.3.

3.2.2.3 Design Decisions

It should be noted that the robot has little ability to identify exactly where in the arena it is, and that there is no absolute positioning included in the robots navigation strategy. Instead, the robot is navigated using logical assumptions, for example, if the robot was required to navigate to its home base it would simply find the nearest wall and follow it until such a time as it reached home. This approach was taken in an attempt to simplify the navigation complexity. If precise navigation was required this decision would come at the cost of speed.

The side sensor angles was an important design decision that was mainly based on empirical testing. There was a balance between the size of the robots blind spots and the effectiveness of the P controller. It was found that $42°$ was the ideal angle for these medium range sensors to be mounted (Appendix F). This allows the robot to follow a wall with the collector arms outstretched at $45°$.

3.2.2.4 Further Developments

To increase the effectivity of the searching mode, the robot should frequently stop and spin by some angle. In addition to this, when it is driving straight it should oscillate to some degree. These actions are intended to increase the dual-infrared sensor detection mentioned in Section 3.2.3, as they will increase the total viewing area for the robot.

Similarly, there is the possibility that the top long-range sensor should oscillate left to right while the robot is driving forward as this should help to reduce the size of the blind spots. This requires further testing though, as this could cause the sensor to falsely identify a wall, and could also interfere with the accuracy of the dual-infrared sensor detection.

Since, as found in Sections 3.2.4 and 3.2.6, it is not essential that the robot should have to return to the home base for success, absolute navigation is unlikely to be necessary. If the robot should need to return to home base, the addition of an absolute infrared sensor would be desirable. This would also require additions in the code to help unify the system to give the most optimal performance.

3.2.3 Weight Detection

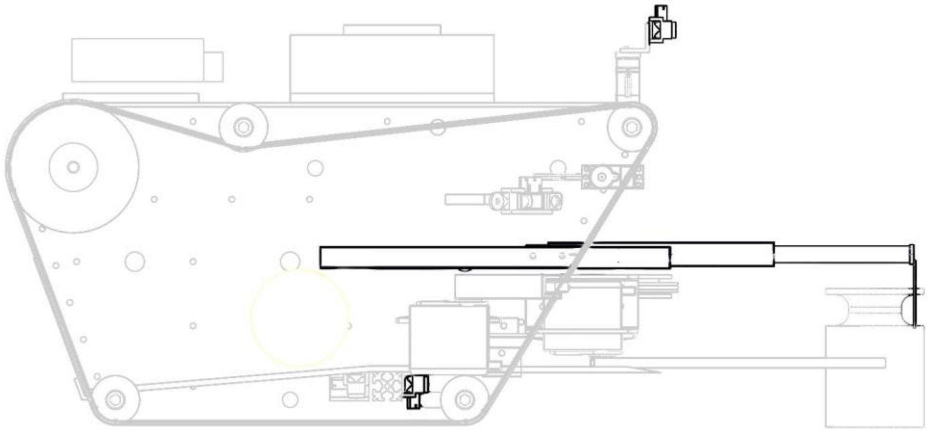

Figure 7: Weight Detection Subsystem

3.2.3.1 Overview

There are two methods of detection that work together to ensure that weights can be found swiftly and that the collection of weights is only triggered when a target is assured to be a weight.

- The first method is a long-range method using two long-range distance sensors together.
- The second employs a simple metal sensor which uses a change in capacitance to detect a metal object.

Long Range

In conjunction with the long range sensor mounted on the top of the robot, there is an identical sensor mounted beneath the ramp. Note that the bottom sensor is mounted in such a way that it is only effective when the ramp is raised.

The method works on the premise that the weights are all identical in height, and that no other objects in the arena are at a similar height to the weights. Since the top sensor is much higher than a weight sits, and the bottom is at around the height of weight when it is knocked over, the method simply uses the idea that if the bottom sensor sees an object that the top sensor cannot see, then that object must be a weight. This is it highlighted in Figure 8.

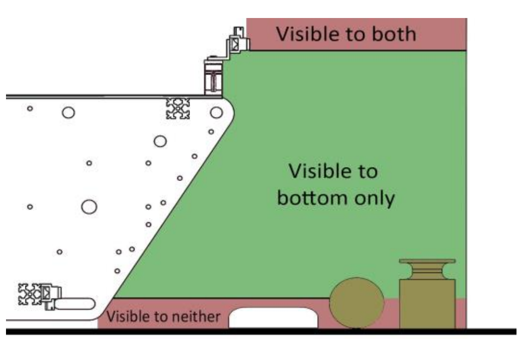

Figure 8: Outlining operating principle of dual-infrared detection method

Once this long range sensor detects a weight, the robot will manoeuvre itself in the direction that the sensor is pointing.

Metal Detector

In order to easily identify weights, the decision was made to design a metal detector.
This sensor charges and discharges an antenna and outputs a frequency depending on the time this takes. If the antenna touches a metal object, the capacitance will increase - this will cause the frequency to drop. Consequently, it would be possible to determine what object the antenna is touching since an enemy robot, large weight and small weight all have different capacitances.

In testing the metal detector was able to identify different weights (Appendix L). The weights vary from each other by a frequency change of around 50 Hz. The chassis of opponent robots produces a frequency drop of 9 kHz. The frequency fluctuation observed in testing was around 20 Hz either side of the average reading. Although these frequency ranges do not cause any overlap between different weights, noise from other components has caused large reading fluctuations in previous tests.

The main detector is mounted on a frame which is not able to rotate. The antenna itself consists of a curtain of semi-flexible rods hanging down from the frame. This curtain is set to be just ahead the sweeper arms so that if a weight is found by the detector, the arms will activate to collect the weight. Since the frame extends further than the collector arms, the frame was made to be telescopic, this is to give access to weights located against a wall.

3.2.3.2 Design Decisions

The decision to mount the second sensor beneath the ramp was mainly made because of physical space limitations, but proves to be a robust design decision when considered in the overall operation of the robot. Firstly, the ramp must be lifted when the robot is in searching mode - this is to avoid it getting caught on the lip of an obstacle and thus preventing the robot from moving. The only time that the ramp will get lowered is when a weight has been detected - thus the long distance sensor is not required for use. Secondly, the height of the cross beam is the ideal height for weight detection in the arena, thus removing the necessity for a mounting bracket to be constructed. This sensor could also be utilised to determine if the ramp is incorrectly lowered.

There is a small level of risk of having the sensor at this low level, though, as testing found that if an obstacle was mounted from the wrong angle, the sensor could be struck by the edge. The risk of this is mitigated through a protective plate that should prevent any damage occurring to the sensor.

The main drawback of the metal detector is that it must make good contact with the object for a set period of time. The Arduino is currently programmed with a low pass filter to minimise noise from neighbouring electronics. This filter will increase the time taken time to settle at a new value and therefore the minimum contact time. The filter will be optimised to have a small contact time and good noise filtering with the goal being to have maximum frequency variation below 10 Hz. The effect of the quality of contact is large - made more difficult due to some of the weights appearing to have a non-conductive coating, which has caused false negatives in testing. Thus it is important that the contact area is not only large - to give the best chance of a good contact, but also stiff - in order to ensure that the antenna is firmly pressed against the weight.

3.2.3.3 Further Development

The addition of a limit switch on the telescopic whisker mount would indicate when the robot has come in contact with a wall. This limit switch not only helps to reduce the blind spots of the robot, but also negates the issues associated with the navigational sensors having a minimum detection range, as shown in Figure 9.

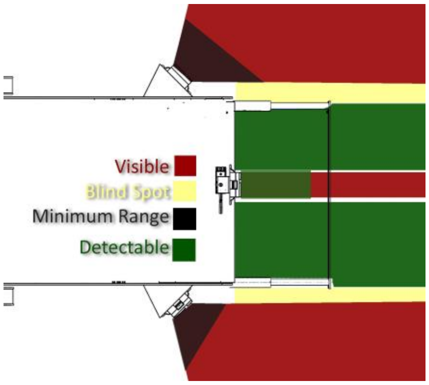

Figure 9: Blind spots of the robot with added whisker bar

3.2.4 Collection

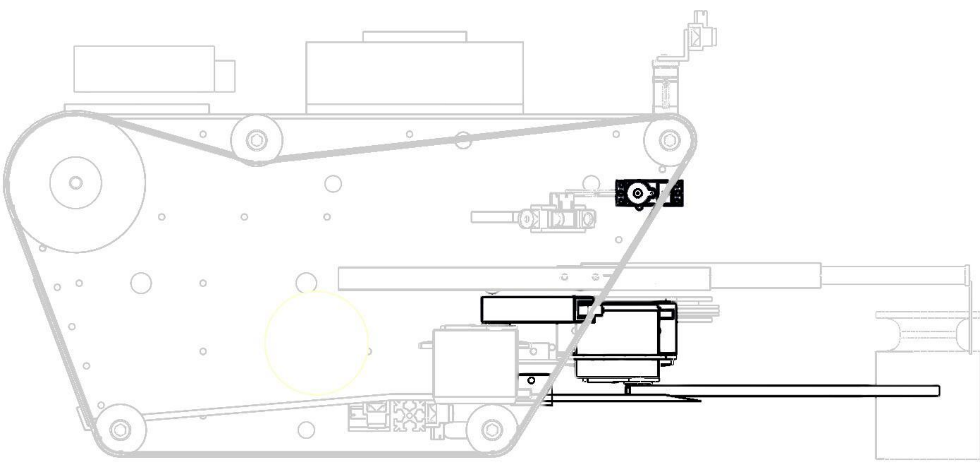

Figure 10: Collection Subsystem

3.2.4.1 Overview

A ramp and two servos are utilised together to slide or roll the weights up into the main body of the robot. The sweeper arms are located 10 mm behind a metal detector. When this sensor is triggered, a weight has been located. This will cause the ramp to be lowered to the ground and the sweeper arms to be rotated in unison towards the body, having the effect of pushing the weight up the ramp into the collection area within the robot. A limit switch is located inside the collection area, so that a successfully collected weight will trigger it. This will cause the sweeper arms to return to their neutral position and will trigger the ramp to be lifted.

The main advantage of this method of collection is the ability to collect weights that are both standing up and knocked over. As was discussed in the Conceptual Design Report, and will also be discussed further in Section 3.2.5, the strategy attempts to knock over weights as well as collect them - for the purpose of hindering the opponent's ability to collect weights. Thus it is crucial the weights should also be able to be rolled into the container.

Sweeper Arms

The collection is facilitated by the help of both the sweeper arms. These are located at either side of the entrance to the storage area. Each arm has a length of 140 mm and a rotation angle of 180 degrees. The arms move from pointing at a 45 degree angle from the robot inwards. So each arm sweeps over 135 degrees outside the chassis. The arms are angled downwards at 7.8 degrees for the left arm and 4.1 degrees for the right arm. The difference in the angles allows for the right arm to pass over the left arm, so that both arms will work together to collect a weight. Both arms are mounted at a height of 20 mm from the floor.

Ramp

The ramp allows weights to enter the storage area. It rests on two hinges which allow it to freely rotate around a 22.8 degree range. To lift the ramp, a servo is attached to a cable which is fixed to a point on the ramp. When the servo rotates it will lift the ramp so that it is parallel with the ground such that clearance is given for the long range IR sensor mounted below. The ramp is lowered by rotating the servo to its lowest position to loosen the cable and letting the weight of the ramp bring itself down. In testing, the ramp was able to be accurately raised in 0.14 seconds, and lowering typically took 0.36 seconds (for further information see Appendix J).

3.2.4.2 Design Decisions

It was found during tests, that the joints from the servos allowed too much flexure. This frequently allowed for a sweeper arm to pass over a weight instead of push it up the ramp. If an arm were to be forced over top of the weight, it could cause damage to the collector and possibly jam the entire collection mechanism. This required the addition of angles discussed in the Overview section. The downwards tilt ensures that the arm will strike well below the centroid of a knocked over weight, which is 25 mm above the ground. This prevents the arm from passing over the weight, as the curvature of the cylinder forces it downwards. The downwards angles also mean that the servos more closely match with the ramp height, such that they will push from a consistent height through the collection process.

Also discussed in the Overview section is that the collector arms are 140 mm long and rotate through an angle of 135 degrees outside the robot. As a result, the total area ahead of the robot which is within range of at least one collector arm is 392.6 cm^2. This assumes that the arms can collect a weight at any point along the arm. As suggested in Appendix G, the recommended maximum distance the robot can be from the weight at collection is 10.3 cm.

The decision to use two servos was to prevent weights from being pushed against the far wall of the chassis, causing jamming. It would also prevent the weight from being able to rotate out of the path of the sweeper, so that collection within a certain area is guaranteed. Similarly, the use of two arms meant that the weight was pushed to a consistent position for every collection attempt - this means that the distance between the weight and the servo is also consistent, and thus gives a consistent force required to push up the ramp.

Through calculation, the HX12K servos were confirmed as appropriate for the collection task, as their stall torque (0.108Nm) exceeded the worst case scenario collection of 0.073N.m (Appendix D). The length of the sweeper arms was only constrained by the width of the chassis and not torque requirements due to the collection action. The longer the sweeper arms, the larger the effective collection area is, however, they must be able to rotate fully into the body and thus are constrained to be less than the width of the chassis.

The success rate of the collection mechanism was tested by loading weights in to the collection area in various orientations and positions. A full summary of the results are located in Appendix I. There was a 30-35% failure rate for collection of all weight sizes when they were lying down. With weights standing up, the failure rates were 35%, 30% and 80% for the 0.25 kg, 0.5 kg and 1 kg weight respectively.

Due to space considerations within the storage area, it was decided that the mini-servo would be used to control the ramp. The specification states that this servo is able to provide 0.157 Nm of torque [2]. As calculated in Appendix D, at the point where the servo is attached to the ramp, it would be able to lift 0.034 kg centred at the centre of the ramp. For this reason, the ramp can't be used as an aid to lift a weight into the chassis. The micro servo must rotate $25.5°$ to rotate the ramp unto the horizontal position.

3.2.4.3 Future Developments

When collecting weights standing up, failure was due to weights getting caught on the lip of the ramp. The failure rate due to this increased as weight increased. For the lightest weight, failure was also due to the weight passing over top of the sweepers. With weights lying down, failure was due to the weight rolling over the sweepers. A future development is in planning, with the aim of reducing the occurrence of this problem. For this test the robot was stationary. The prediction is that when the robot is moving, this would provide enough momentum to tip over the weight with the lip, and allow it to be collected. This has not yet been tested due to the current difficulty in implementing this in software within the time constraints.

There has currently been very little design work into the shape of the collector arms. Currently, the arms are simply straight pieces of aluminium. There has been a small amount of investigation into other designs, mainly the addition of a hook on the arm. An addition such as this could either help to either increase the effective collection area while remaining below the constrained length (as discussed in Section 3.2.4.2), or could increase the successful collection rate. This would be an iterative process and would require a number of different ideas to trial for their effectiveness.

A further possible software function would be to change the maximum collection distance, depending on the weight. This could be achieved through the metal detector (as described in Section 3.2.3). Doing this would increase the total collection area, and also limit damage to the servos.

3.2.5 Knock over Arms

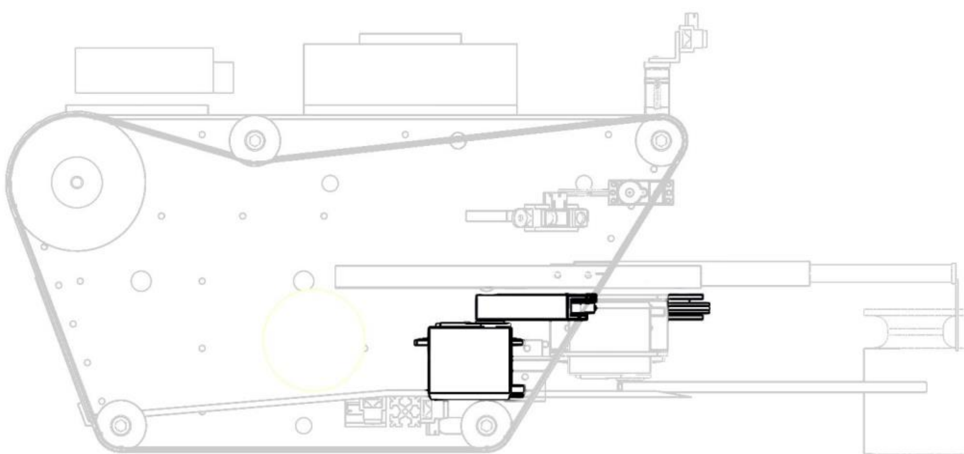

Figure 11: Knock over arms subsystem

3.2.5.1 Overview

The greatest advantage of the sweeper arm collection method is that it allows for weights to be collected in a horizontal and a vertical orientation. For this to become an advantage, though, it must be paired with a mechanism that knocks weights over. It is essential that the weight knock over doesn't compete with the weight collection, and that it does not slow the robot down in any way.

The solution to this problem takes that form of two large bars, similar to the sweeper arms, that are mounted on large servos located on the sides of the chassis. They will naturally be rotated such that they stick out from the body of the robot; from this position they can quickly rotate forwards to knock a weight over, or backwards to be flush with the side of the chassis. To give the greatest chance that weight will be knocked over, the arms will sit at a height of 65 mm, so they can strike the weight at the top.

3.2.5.2 Design Decisions

The length of the knock over arms is limited by the length of the chassis, calculations show that the robot should be able to knock a weight over at a distance of 188 mm (Appendix C). However, the arms must be able to rotate to be flush against the body of the robot. If the arms are too long they could interfere with, or possibly damage, the tracks. Thus, the arms will have a length of 180 mm.

It is important that the arms know when they have come in contact with a weight so that they can react by quickly rotating forwards - for this reason the arms will have a built in limit switch which will be pressed if the arms hit a solid object. However, there are a number of other obstacles in the arena which the arms should not attempt to knock over. To this end, the limit switch will have a metal detection whisker on its edge, such that a weight can be distinguished from an obstacle or wall. This means that the arms should not negatively impact on the robot's manoeuvrability. The addition detection area also has the effect of removing the blind spots from the minimum ranges of the side sensors - as noted in Figure 12.

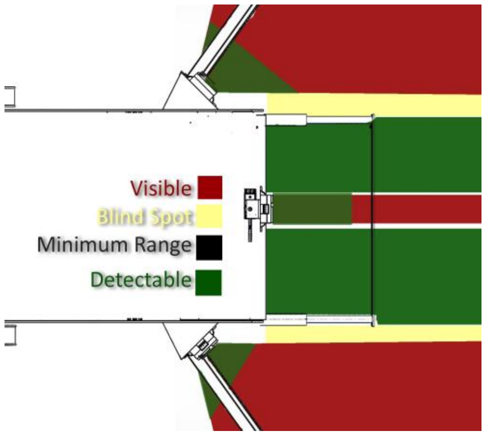

Figure 12: Identifying blind spots with whisker bar and wings

3.2.6 Storage System

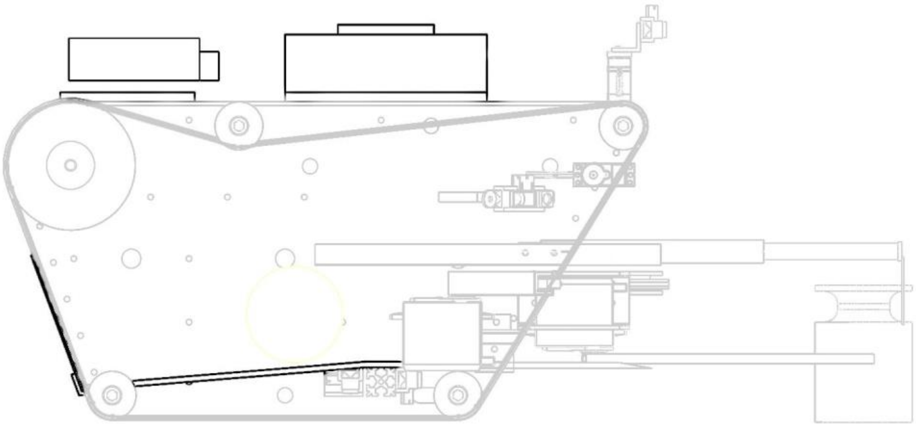

Figure 13: Storage and Electronic subsystem

3.2.6.1 Overview

The entire bottom plate forms the storage area for the weights. Storage takes advantage of gravity and the mass of the weights; at the top of the ramp is a small lip, and then a decline to the backmost part of the chassis. The weight is pushed past this lip such that it drops down into the storage area and rolls into the lowest position. This lip is a spring-loaded ramp that will allow the weight to pass over in one direction but will prevent any weights rolling out once collected. A limit switch is employed here to facilitate a basic count, and to give feedback to the motors as to whether a weight has correctly been collected.

The storage area is capable of storing seven weights. The minimum weights required to ensure success over an opponent is eight - this figure assumes that all the weights collected are 0.5 kg and the only weights left are the heaviest l kg. Thus, while the seven limit is not the full eleven weights in the arena, if this capacity is reached then it is probable that the robot has won the competition.

3.2.6.2 Design Decisions

The storage area was kept as low to the ground as possible. This limits the energy needed to collect the weight by reducing the height of the ramp. The minimum height of the storage area was mainly determined by the height required by the dual infrared sensor detection as the bottom sensor needs to be high enough to not pick up the obstacles in the arena. The angle towards the back was then calculated by using this height and the minimum clearance to navigate the arena.

Using driving dimensions of the robot, namely the side panels and supports, the downwards slope of the robot internal floor was calculated to be 7 degrees (Appendix E). This allows storage from the back to front.

3.2.6.3 Further Developments

While it is unlikely that the robot will require unloading the weights, it is a functionality that could improve performance and lower power requirements. This functionality would be added by no longer fixing the back plate and instead hinging that from the bottom plate. This door would then be actuated upwards and downwards by a servo in a similar fashion to the ramp at the front.

3.2.7 Electronics

As can be seen in the previous sections, the size of the chassis is often a limiting factor, thus the layout of the components is key to a successful design. In an effort to reduce the footprint of circuit boards the main body of the electronics for the robot are attached to a drilled aluminium panel which sits at the top of the robot. The Arduino, power supply and motor driver board are all fixed on the top side of the panel with the motor transformer and sensor interface board mounted on the underside.

Through choosing a stronger mechanical design, there are less electronic requirements - this means a number of the supplied boards were omitted as their corresponding components were not included in the robot design. This helped to reduce the controller footprint and create more space to fix sensors and actuators to.

3.2.7.1 Design Decisions

The placement of the electronics was constrained by three factors: footprint size, required connections, and plug accessibility. Wires between boards were made to be as short as possible - especially those carrying higher currents, thus the power supply, and motor drive were all kept clustered together. The Arduino board was set apart from the others to allow the plugs to be accessed with ease. Similarly, the sensor interface board was mounted on the underside of the plate to bring it closer to the motors and colour sensor - both of which are located in the main body of the robot.

3.2.7.2 Further Developments

There is a requirement to design at least three PCB boards for the robot. One of these boards is the whisker detection circuit, the other two proposed boards are described as follows:

State Board

To help development and testing of the autonomous robot a state board will be implemented which signals through LED lights what current state the robot is in. This will help performance improvements to be made which in turn will increase the effectiveness of the robot. A PCB board will be created which has 16 LED lights representing an equal number of possible states of the robot.

Switch Board

To further aid testing of the robot and its autonomous functionality a switch board could be developed. This would help switch between states and when paired with the state board would similarly increase testing effectiveness. A further possible use for this board would be to choose different attributes for the robot depending on the competitor, and dynamically assign the best strategy to compete with them.

3.3 Interfacing

3.3.1 Overview

For the robot to be able function, the subsystems described in Section 3.2 must be interfaced together in order to produce a final, synergistic design. For many of the systems, the ways in which they connect with other subsystems has already been implicitly described in their respective sections. The following N^2 chart explicitly defines these relationships in order to fully understand how the systems can be linked together.

Note that a red X represents a shared resource.

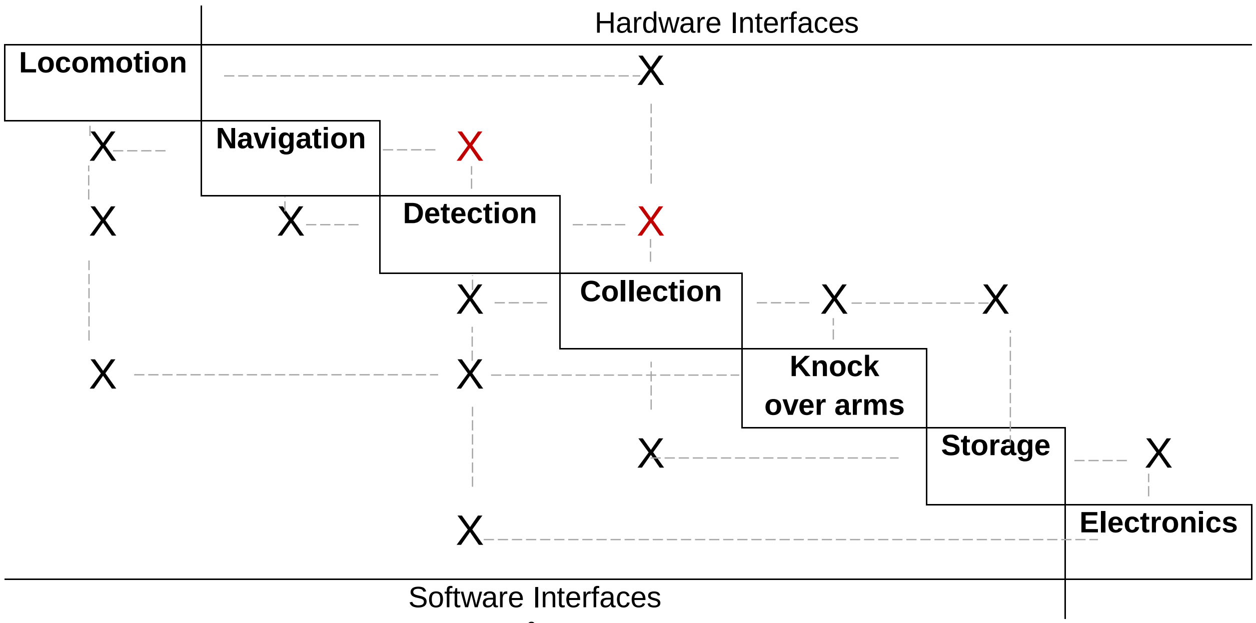

Figure 14: N^2 chart for the robot subsystems

3.3.2 Software Design

While the software functionality of the robot has yet to be developed, the code which has been programmed so far has focussed on building low level functions to create a high level of abstraction for future development. This then means that the final software can simply use a number of finite state machines, calling abstracted functions. The finite state machines intended to define the software, as well as the subsystems that they relate to are demonstrated in the flow chart found in Figure 15.

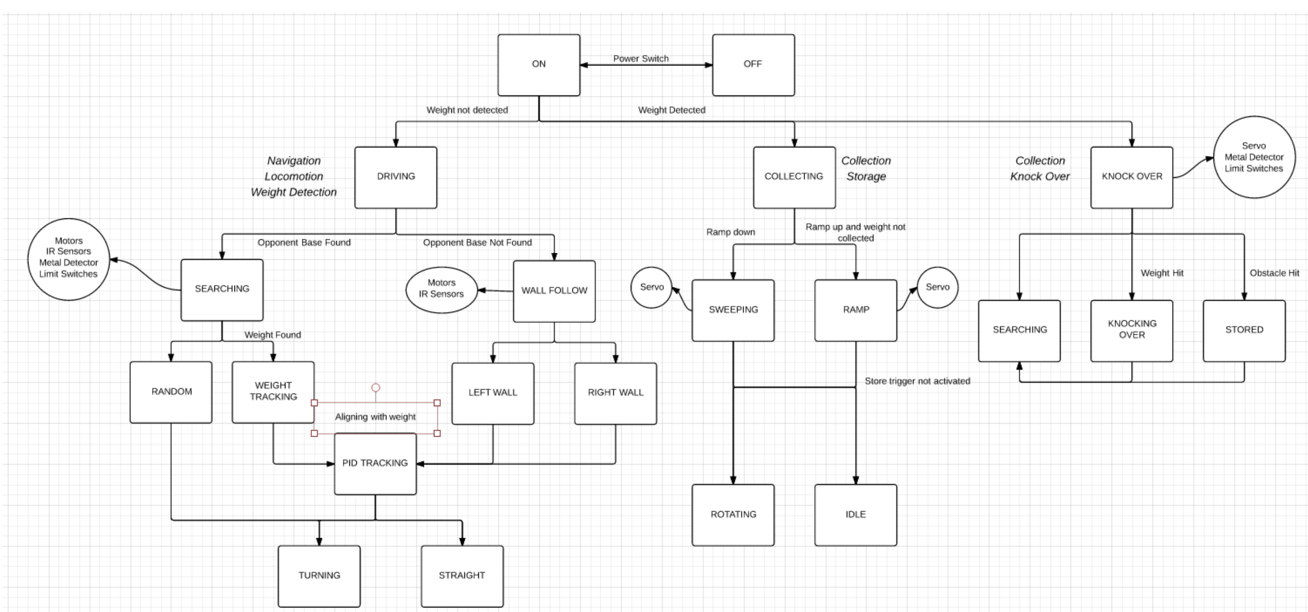

Figure 15: Predicted State Diagram for the Final Robot Design

3.3.3 Strategy

The key design aspect which interfaces each of the different subsystems is the competitive strategy. The strategy to be employed determines what functionality the robot must be able to provide, and thus determines the design of the finite state machines mentioned previously.

The diagram which follows (Figure 16), describes the strategy employed against an opponent which cannot pick a weight up when it is horizontal.

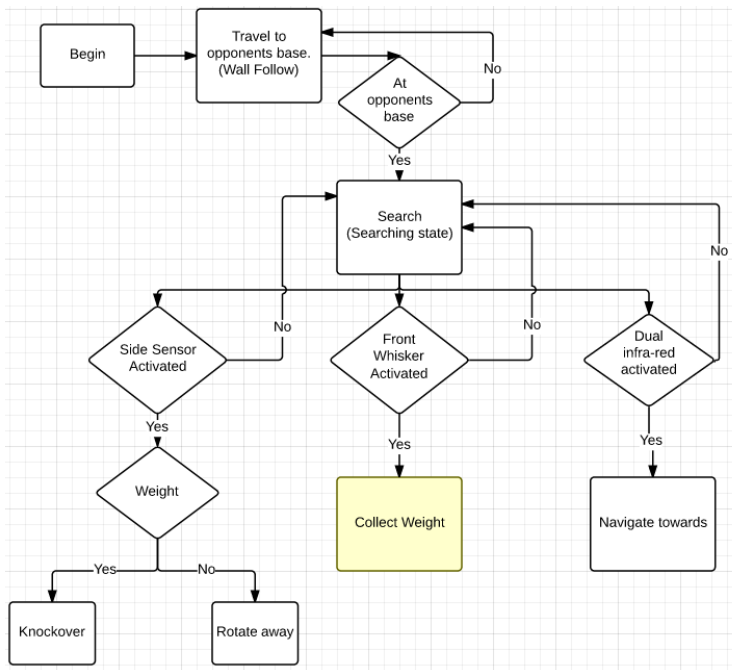

Figure 16: Primary Strategy Flow Chart

The key idea behind this strategy is to starve the opponent of collectable items by navigating quickly to their starting area and either collecting or knocking over their weights first. As described in Section 3.2.5, it is important that the knock over mechanism doesn't interfere with the collection mechanism, as such, you can see that the two operate in tandem meaning that if a weight is missed by the collection mechanism, it will be knocked over by the side arms.

The current robot design, however, allows for a number of similar strategies - implemented in different fashions. Some strategies will be more effective against different opponents, thus, in order to provide the best competitive advantage, a number of these strategies will be developed. On the competition day a judgement call will then be made about which strategy to employ against which opponent, and the appropriate strategy will be chosen by means of a number of the switches on the proposed PCB board.

4 Evaluation

4.1 Overview

In the conceptual design report a number of requirements based on the assignment specification were set and have acted as a functionality guideline throughout the development phase.

The table found in Appendix B evaluates the robot in its current form against these criteria. It should be noted that the evaluation of robot has been performed in tandem with the development, thus a fair amount of the evaluation has already been implicitly described in earlier sections of the report. Thus, this section is focussed on highlighting important features of the comparison between the current states of the robot against the functional requirements.

6.4.5 The Robot should be able to “drop off” the weights at the home base.
The robot is currently unable to drop off weights once they have been brought on board. Though this was a set design criteria it has been ignored as the current robot can carry 7 weights, therefore making the drop off functionality redundant. The act of dropping of the weights has be decided a waste of time and this time is better spend undermining the enemy robot. Stemming from the decision not to drop weights of means that criteria 1.3.1 and 1.3.10 have also not been achieved.

6.3.8 The Robot should be able to distinguish an obstacle from a wall.
Distinguishing walls and objects has provided more difficulty than initially anticipated. Though objects within the arena have been painted red, the identification of this requires implementing image processing. Under the current design the ArduCam is not used in order to reduce design complexity and save processing power. It has been found that no significant navigational disadvantage is involved with this choice not to distinguish these two options.

6.4.1 The Robot shall be able to distinguish an opponent’s home base from its own
Removing a weight from an enemy’s base results in a penalty of that weight being removed from the pilfering teams total while the weight in question is still part of the enemy’s total. The colour sensor and short distance IR sensor have been successfully implemented together to notify the robot when it is in the oppositions base. This however is mounted under the robot and therefore the robot could still remove a weight placed on the edge of the base without knowing. This is a weakness that will need to be addressed under further development.

Not yet implemented
The majority of the not implemented criteria marked “Not yet implemented” will be eventually achieved through software development – this process has been delayed by the physical building of the robot.

Competiveness of the robot has not been achieved to the level in which would have been hoped at this point, however, a working robot is needed before competitive features can be added. Currently, the majority of mechanical parts of this robot have been produced and fitted to the robot. The next stage is to develop the control system which will control the overall functionality of the robot.

5 Contribution Statement

Michael McAdam

- SolidWorks Development
- Diagrams
- Design Description
- Report Formatting

Sarah Howe

- Whisker Description
- Testing
- State Diagram
- Calculations
- Quality Control

Taylor Howatson

- Bill of Materials
- Calculations
- Evaluation
- Executive Summary

6 References

[1] Hextronik, "Hextronik HXT900 - 9g Micro Servo," [Online]. Available: http://www.servodatabase.com/servo/hextronik/hxt900.

[2] Herkulex, "User Manual," [Online]. Available: http://www.robotshop.com/media/files/PDF/manual-drs-0101.pdf.

[3] Acroname Easier Robotics, [Online]. Available: http://www.acroname.com/articles/sharp.html.

7 Appendices

7.1 A: PCB Details

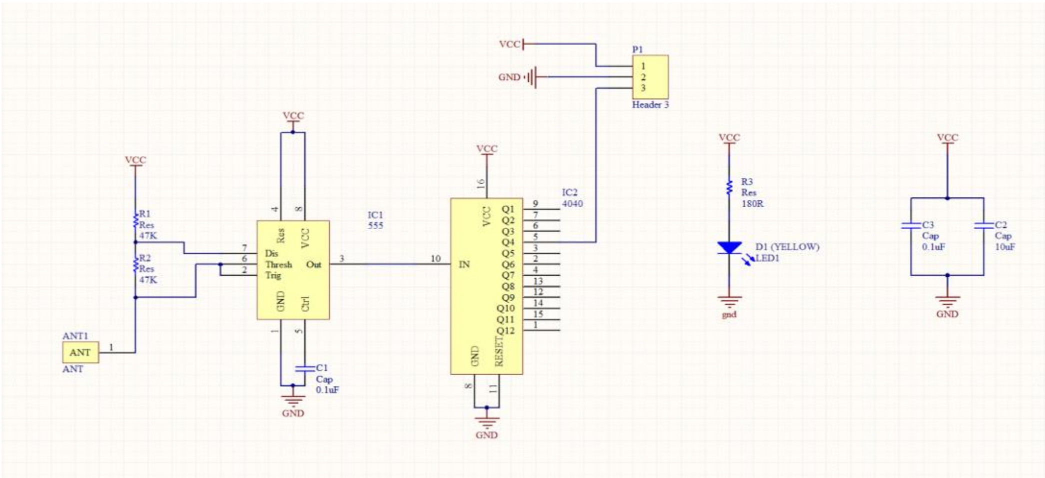

Figure 17: Whisker Schematic Diagram

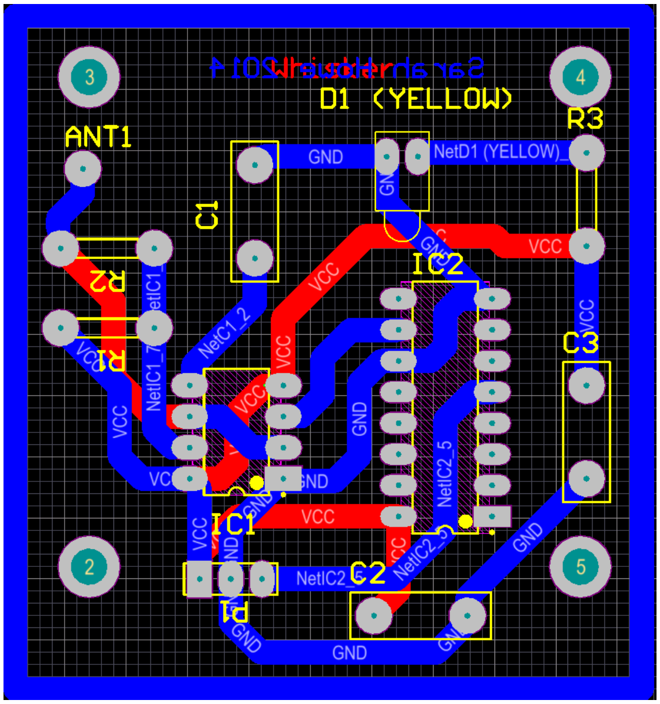

Figure 18: Whisker PCB

7.2 B: Conceptual Design Report

Table 1: Evaluation of Robot against Requirement Specification Metric

Criteria	Evaluation
7.3 General	
7.3.1 The Robot will be controlled by an Arduino Mega ADK board.	Achieved
7.3.2 The Robot will be fully autonomous	Achieved
7.3.3 The Robot should be able to restart itself if a severe error occurs.	Not yet implemented
7.3.4 Any costs for extra equipment beyond that provided will be less than $50	Unavailable
7.3.5 The Robot shall have a clearly defined front end.	Achieved
7.3.6 The Robot shall operate reliably for the full 5 minutes of the competition.	Unavailable
7.4 Collection	
7.4.1 The Robot shall be able to find actively search for, and find a weight.	Not yet implemented
7.4.2 The Robot shall be able to pick up a weight of maximum 1 kg in mass.	Achieved
7.4.3 The Robot shall be able to determine the current number of weights it is carrying.	Not yet implemented
7.4.4 The Robot shall be able to carry at least 3 weights within its body.	Achieved
7.4.5 The Robot should be able to “drop off” the weights at the home base.	Failed
7.4.6 The Robot should be able to pick an object from within 5mm of the wall	Achieved
7.4.7 The Robot should be able to pick up a weight in under 15 seconds.	Achieved
7.5 Navigation	
7.5.1 The Robot shall be able to locate its home base	Partial Achieved
7.5.2 The Robot shall be able to traverse obstacles of at most 25 mm in height.	Achieved
7.5.3 The Robot shall be able to navigate the entire arena within the time limit.	Achieved
7.5.4 The Robot shall be able to fit through a gap of 0.5 m.	Achieved
7.5.5 The Robot shall not exit the arena at any point.	Achieved
7.5.6 The Robot should be able to detect when it is stuck, and as a result change its behaviour.	Not yet implemented
7.5.7 The Robot should be able to mount obstacles with a full load.	Achieved
7.5.8 The Robot should be able to distinguish an obstacle from a wall.	Failed
7.5.9 The Robot should be able to manoeuvre around a corner.	Achieved
7.5.10 The Robot should be able to return to its home base within 30 seconds.	Failed
7.6 Competitive	
7.6.1 The Robot shall be able to distinguish an opponent’s home base from its own.	Achieved
7.6.2 The Robot shall not be able to pilfer an opponent’s weights from their base.	Partial Achieved
7.6.3 The Robot should be in some way able to undermine the opponent’s collection of weights.	Not yet implemented
7.6.4 The Robot should be in some way able to interfere with the opponent’s navigation of the course.	Not yet implemented
7.6.5 The Robot should be able to identify and avoid an opponent.	Not yet implemented
7.6.6 The Robot should be designed to avoid interference with an opponent.	Not yet implemented

7.7 C: Equations for Side Arm

DRS-0101 Stall Torque = 12 Kg.cm = 0.117 N.m
Modelling the weight as a solid cylinder and using largest weight (1Kg)

$$M_A = 0\text{:}\ -0.025 * 1 + F_A * 0.060$$
$$F_A = 0.416N$$

Don't want to __ servo at stall torque therefore will use $\frac{2}{3}$ of this torque

$$T = Fd$$
$$d_{max} = \frac{2}{3} * \frac{0.117}{0.416} = 0.188m$$

This shows that the longest length in which the knock over arms will be effective.

7.8 D: Equations for Ramp

When ramp is lowered it has an incline of 25 degrees.
Using a 1Kg weight, the worst possible collection orientation is a weight being pushed up the ramp long ways.

$$F_{downramp} = (1 * 9.81) * \sin(25)$$
$$F_{xplane} = F_{downramp} * \cos(25)$$

When the collection arms come into contact with the weight there are at 40 degrees and contact point is 95mm along arm. Both arms come into contact with the weight at the same time and therefore collectively help push up the ramp.

$$T = \frac{1}{2}(F_{xplane} * \cos(30) * 0.095)$$
$$T = 4.93Kg.cm$$

Using 3/2 factor $Servos\ torque > 7.40Kg.cm$
Friction force has been included in the 3/2 factor as little friction between the two materials.
At 6V HX12Ks stall torque is equal to 11Kg.cm and therefore well suited for this application. The Larger S04 BBM servo has a stall torque of 17Kg.cm and therefore another possible servo for this application.

Calculating the largest load that the ramp could be place under and still be lifted using the HXT900 Micro Servo.
Stall torque = 1.6Kg.cm = 0.0157N.m
Largest force is needed when ramp is fully lowered ($25°$)

$$F_{servo} = \frac{0.0157}{0.025} = 0.63N$$

$$d_{CM}F_{CM} = d_A F_{servo}\cos(25)$$

$$F_{CM} = \frac{0.025 * 0.63 * \cos(25)}{0.04} = 0.356N$$

$$M = \frac{0.356}{9.81} = 0.036Kg\ at\ center\ of\ ranp$$

This shows that the micro servo will stall with any load greater or equal to 36g centred at the centre of mass of the ramp. Due to the system not being as efficient as calculated the true value of this will be slightly smaller

7.9 E: Equations for Floor

Ramp slope is needed to help stop weights exiting through the front. Length of 130mm and drop of 16mm is possible within the current chassis.

$$\emptyset = \tan^{-1}(\frac{16}{130}) \cong 7°$$

Length of cord

Cord is connected on the underside of the ramp and rotates the ramp at a point 25mm from the centre of rotation.

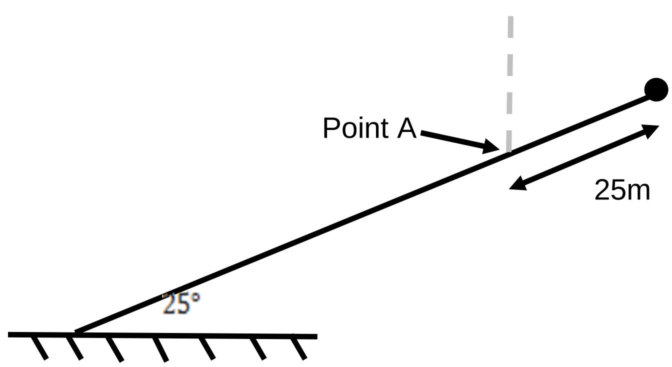

Figure 19: Cord Length

$$\Delta Y\ Point_A = \ 25 * \sin(25) = 10.6mm$$
$$\Delta X\ Point_A = 25 - 25 * \cos(25) = 2.34mm$$
$$\Delta\ Point_A = \sqrt{2.34^2 + 10.57^2} = 10.83mm$$

This means that the cord needs to be drawn in 10.83mm to lift ramp $25°$
Cord is connected 25mm from centre of servo.

$$a^2 = b^2 + c^2 - 2ab * cos(A)$$
$$A = \cos^{-1}\left(\frac{25^2 + 25^2 - 11^2}{1250}\right) = 25.5°$$

Therefore the servo must rotate $25.5°$ to lift ramp to horizontal position.

7.10 F: Equations for Wall Sensor Angle

Robots navigation around the arena is controlled using a set of IR sensor. IR sensors mounted on the side of the robot using part 06-003 which sets them at a designated angle. While following a wall the collector arms are to be no further away than 20mm from the wall. This allows the robot to effectively pick up weights close to the wall.

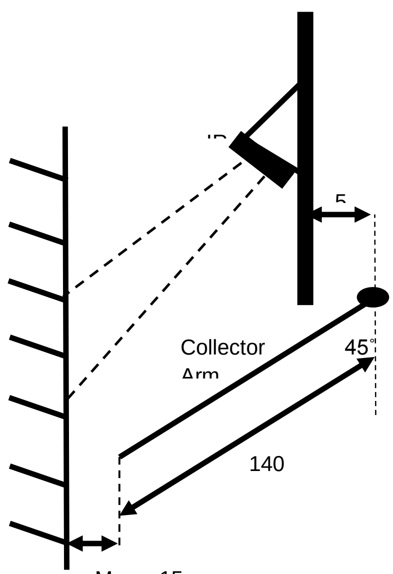

Figure 20: Wall Sensor in Relation to Robot

For the medium range IR senor (GP2D12) the minimum length of operation is 100mm and maximum range is 800mm. using the criteria that the distance between the end of the arm and wall must not exceed 15mm the angle in which would allow the medium range IR sensor to work effectively needs to be found.

Robot to wall distance (max) = $15 - 5 + 140 * \cos(45)$ = 110mm
Robot to wall distance (min) = 95mm
For best operation have medium sensors beam length at 150mm when wall is 100mm from robot.

$$\cos^{-1}\left(\frac{110}{150}\right) = 43°$$

Therefore for best operation the angle the medium IR sensor should be mounted is 43 degrees from the body of the robot.

7.11 G: Equations for Sweeper Arms

The maximum rated speed for the sweeper servo is 0.18 seconds per 60 degrees. Decreasing the servo speed to half of this rating, the predicted time for the servo to sweep 180 degrees is 1.1 seconds. This is assuming the servo does not slow when pushing a weight.

$$0.18/60 = 0.003 \text{ s}$$
$$0.003 * 2 * 180 = 1.1 \text{ s}$$

The stall torque of the motor is 9 kg.cm (0.883 Nm). At the end of the arms, the stepper will be able to provide 0.46 kg of force. This means both steppers should be used together to pull the weight.

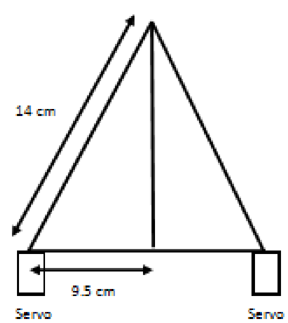

Figure 21: Meeting Point of Sweeper Arms

$$\sqrt{14^2 - 9.5^2} = 10.3 \text{ cm}$$

The point where the servo arms first cross is located 10.3 cm away from the robot. This is the maximum allowable distance the weight may be from the robot when sweeping starts.

7.12 H: Equations Concerning Power

7.12.1 Overview

Running all sensors and servos simultaneously draws 1.7A. The voltage drawn is 10.66V.

$$P = 10.66 * 1.7 = 18.1W$$
$$E = 18.1 * 3600 = 65\ kWh$$

A small battery is rates at 1800mAh and supplies 11.1V.

$$E = 1800 * 11.1 = 20kWh$$
$$\frac{20}{65}(60) = 18.5minutes$$

In actual use, the robot would not use all processes constantly allowing for longer battery use.

7.12.2 IR Sensors

Power consumption requirements: 5.5V/33mA

$$P = 5.5x0.033 = 0.19W$$

7.12.3 Servos

HX12K
Idle: 6V/9.1mA
Under load: 6V/450mA

$$P_i = 0.0091x6 = 0.06W$$
$$P_l = \ 0.450x6 = 2.70W$$

HXT900 Micro Servo

7.12.4 DC Motor

No Load 12V:0.23A
Stall 12V:3.6A

7.13 I: Test Data for Collection Mechanism

For each weight, tests were done with the weight standing up and lying down. The weights were loaded from random locations with the robot stationary.

Table 2: Collection Rate for Sweeper Arms

	1 kg Weight		0.5 kg Weight		0.25 Weight	
	Standing Up	Lying Down	Standing Up	Lying Down	Standing Up	Lying Down
Failure	7	7	6	7	12	6
Success	13	13	14	13	3	14

When standing up, failure was due to weights getting caught on the lip of the ramp
This increased as weight increased. In the lightest weight, the weight also passed over top of the sweepers. When lying down, failure was due to the weight rolling over the sweepers.

7.14 J: Test Data for Ramp

The maximum rated speed for the servo is 0.12 seconds per 60 degrees. The speed used in this test was half of this rated speed.

Table 3: Ramp Lowering and Raising Times

Trial	Time to Lift (s)	Time to Fall (s)
1	0.16	0.29
2	0.11	0.38
3	0.11	0.43
4	0.11	0.38
5	0.16	0.38
6	0.07	0.29
7	0.25	0.43
8	0.16	0.29
9	0.11	0.29
10	0.16	0.43
Average	0.14	0.36

The time to lower the ramp takes longer than raising it, as is expected, since it is lowered by the weight force of the ramp. Limitations in this data are human error in timing.

7.15 K: Test Data for Travel Distance

The robot was set to drive at 70% of its maximum speed from one base to another. The robot was programmed to follow the wall at a distance of 20 cm from the wall. This test mimics the starting action of the robot in the contest.

Table 4: Time to Travel To Other Base

Trial	Time taken (s)
1	*22.41*
2	*22.09*
3	*22.68*
4	*22.99*
5	*22.86*
Average	*22.6*

The distanced travelled was 5.5 m. In a five minute period, the robot will therefore be able to travel at least 73 m. This is enough to cover the entire area of the arena.

7.16 L: Test Data for Whisker

Table 5: Whisker Frequency of Different Objects

Object	**Frequency (kHz) ± 0.02**
None	15.46
1 kg Weight	14.99
0.5 kg Weight	14.94
0.25 kg Weight	14.89
Robot chassis	6.60

The error is the observed variation in measured values.