RoboCup Progress Report 1

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Contents

1. Executive Summary

This report details the design process of Team 8 in the 2014 RoboCup Competition. For the competition, each team must build a robot that can navigate an arena to collect food packages. Hardware and software constraints, in addition to the project brief, were used to create a framework of specifications for the robot. Brainstorming within these specifications produced a variety of different methods for each aspect of the robots performance, which were used to develop a final set of three concepts. The three concepts were: a street sweeper which scoops packages into a holding bay; a robot which runs over the packages and forces them onto a set of parallel rails for storage; and a magnet which latches on to target packages and drops them into a storage bay. These three concepts were evaluated on a number of criteria including cost, reliability and power requirements. The magnet concept was chosen as final design to proceed with as it best fulfilled the evaluation criteria.

2. Introduction

Every year, 2nd Pro Mechatronics students at the University of Canterbury compete in the Canterbury RoboCup Competition. Students are split into teams of three, with each team designing a robot that can autonomously navigate an obstacle course and collect “food packages” represented by metal cylinders. The food packages are visually identical but vary in mass from 0.5 kg to 1 kg. Two robots are placed in the arena at the same time and after 5 minutes, or when all the food packages have been picked up, the robot with the most mass wins. Each team must face off each other in a round-robin style competition, at the end of which the team with the most victories is labelled the winner.

This report covers the specification and initial design process of Group 8 in the 2014 RoboCup. More specifically, the report will cover the project specifications and how the initial concepts have been generated. The report then goes on to discuss each concept in detail and how they were evaluated to choose the final design on which to construct the robot.

3. Project Specifications

3.1 Functional Requirements

These are compulsory requirements that define specific behaviour of the robot:

1. The robot shall be capable of automatically resetting itself in case of a fault.
2. The robot shall be capable of picking up and storing food packages aboard the robot.
3. The robot shall be capable of picking up food packages which are placed against arena walls or obstacles. This includes food packages in the corner.
4. The robot shall function on a single charge for greater than 10 minutes.
5. The robot shall be able to negotiate all obstacles within the arena while driving forwards or backwards.
6. The robot shall maintain knowledge of its position within the arena at all times. This will be done by combining information from all available sensors.
7. The robot shall maintain a count of the cumulative weight of food packages aboard the robot. This could be done by measuring the weight of all newly picked up packages, or the weight of the entire container where packages are deposited.
8. The robot firmware shall implement a *scheduler* so that it is trivial to have the robot perform multiple tasks simultaneously.
9. All sensors shall be implemented in such a way that any module reading its value need not understand the underlying sensor dynamics.
10. The robot shall fulfil all requirements autonomously without any form of human interaction

3.2 Non-Functional Requirements

1. The robot shall be capable of operating for 5 rounds without requiring any servicing other than a battery charge.
2. The distance from the centroid of the robot to any other point on the robot shall be less than 250mm when viewing the robot from above. This is to ensure that the robot can turn on the spot at any point in the arena.
3. The robot shall be the very best like no robot ever was.
4. Upon satisfaction of the mission objectives, the robot shall cease all operations and begin spinning on the spot while playing the sound bite located at the following link: http://bit.ly/1gtu6pz

3.3 Performance Requirements

1. The robot shall be capable of satisfying all mission objectives in less than 5 minutes. Mission objectives include:
   I. The robot should collect more mass than the opposing robot
   II. The robot should collect 7 packages within 5 minutes
   III. The robot should be durable enough to resist interference from the opposing robot
2. In case of a fault, the robot shall recover and resume normal operation within 10 seconds.
3. The robot shall be capable of detecting objects at a distance of 1m within an 120 degree arc from the front of the robot and determining whether they are a food package or an obstacle (wall or otherwise).
4. The robot shall be capable of negotiating all obstacles within the arena with a full 7kg payload.
5. The robot shall be capable of determining its position to within +/- 100mm inside the arena.
6. The robot shall be capable of picking up a food package in the upright orientation on the first attempt in 90% of cases.
7. The robot shall be capable of lifting and storing at least 7 food packages on board OR be capable of storing at least 4 food packages on board and navigating back to HQ to deposit the food packages.

3.4 Constraints

These requirements are dictated by the hardware provided and competition rules:

1. The robot shall be controlled by an Arduino Mega ADK controller.
2. All robots shall meet general safety standards for rotating machinery, electrics and lasers. In particular:
   I. Radiated output from any single laser diode shall not exceed 5mW.
   II. Motors shall not exceed 200 rpm unless adequate guarding is in place.
   III. Voltages may not exceed 100V DC.
3. The robot shall be composed of parts from the following sources:
   I. Those provided to all groups as part of the “robot kit” provided to all groups.
   II. Those purchased with the $50 budget provided to all groups.
4. The robot shall be designed in such a way that the potential for any damage, unintentional or otherwise is minimised.

3.5 Operational Requirements

These requirements are dictated by the physical environment in which the robot must operate

1. The robot shall be able to operate in temperatures between 10 and 40 degrees Celsius.
2. The arena walls or the floor outside the arena may not support any of the robots weight.
3. The robot shall operate the same in both the Mechatronics Design Room C212 and the NZi3 foyer where among other factors, the lighting conditions and the starting orientation (with respect to compass bearing) differ.

4. Design Space

4.1 Hardware

The general limitations of the robot are largely dictated by the specifications laid out in Section 3. However, the physical hardware of the robot also limits its capabilities. In addition to a $50 budget, each team has been supplied with the following components.

- 1x Arduino Mega ADK Microcontroller
- 2x 12V DC Motor w/ Encoder and Gearbox
- 3x IR LEDs
- 4x 7.2V Standard Servo
- 4x 6V Micro Servo
- 2x 12V Smart Servo
- 2x 3V Stepper Motor
- 2x 3V Stepper Motor w/ Gearbox
- 1x 10 DOF Inertial Measurement Unit
- 1x Positioning IR Camera
- 1x Medium Range IR Distance Sensor
- 1x Short Range IR Distance Sensor
- 1x Variable Range IR Distance Sensor
- 1x Long Range IR Distance Sensor
- 1x Sonar Sensor
- 1x Weight sensor

Figure 1 outlines how all the available hardware is linked, and shows the information flow between each component. Note that Figure 1 shows all available hardware, not all of which will necessarily be used.

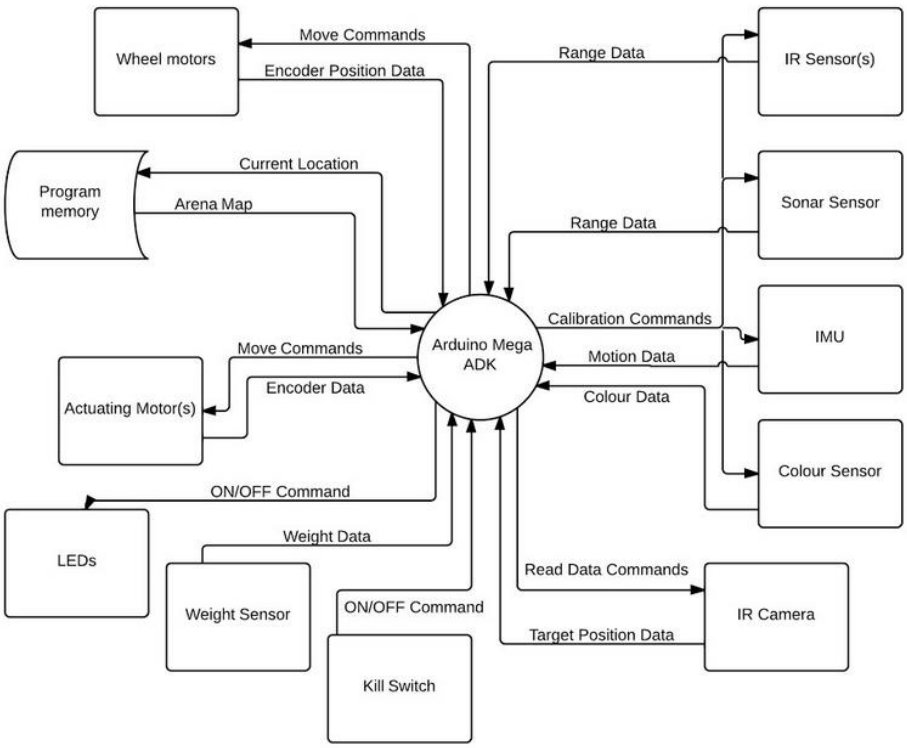

***Figure 1**. Context Diagram for the System*

This diagram was used during brainstorming to help generate the methods shown in Table 2.

4.2 Concept Generation

The competition can be broken down into five rough stages shown by the headings in Table 2. For each stage a variety of different strategies were brainstormed by collecting a random assortment of parts from the scrap bin, and discussing how each could potentially be used to sense/collect/store the food packages. The results were entered into the concept matrix (Table 2). Each column represents a different role/task that the robot must perform, with each entry in a row representing a different method of fulfilling that role.

Navigation	**Sensors**	**Package Collection**	**Package Storage**	**Package Handling**
Wander randomly	Infrared (IR)	Magnet	Open bay	Store every food package, don't return to HQ
Grid based search method	Sonar	Gripping arm	Parallel rails,	Return to HQ to drop off packages
Navigate relative to landmark	Contact switch	Conveyor belt	Rotating storage compartments	Record package mass, replace low mass with high mass, don't return to HQ
Wall-hugging	Compass	Rails		
	Colour sensor	Street sweeper		

***Table 2**. Concept Matrix for different roles.*

Movement of the robot could also be considered, however it was decided at the start of the project that the supplied chassis would be used to avoid having to spend extra time developing a new chassis.

4.3 Concept Development

With the aid of the concept matrix (Table 2), various combinations of strategies were combined to generate the final three concepts discussed in Section 5. Because navigation and sensors were largely independent of the actual methods used to collect and store food packages, a grid-based search method using a combination of the IMU and the infrared and sonar sensors were chosen as the ideal combination for navigation and package detection. This concept is discussed in Section 5.2

The first concept was based on the observation that two parallel rails fit into the grooves cut in the side of the food packages. That the food packages could then slide further up the rails into a holding area was the natural extension of this idea (see Section 5.1 for illustrations). Storing all collected food packages in a straight line on rails did restrict the robot to carrying 4-5 food packages, forcing the robot to return to the HQ to drop off some collected food packages. However by spring-loading the rails to separate from each other, the robot could drop all collected food packages in a straight line, giving the robot a fast and easy way to drop its payload.

The second concept was inspired by previous RoboCup winners, using two rotating wheels with brushes/fins to "sweep" the food packages into a holding bay. This concept works by effectively running over the food package and using the force of the sweepers to pull the package into the robot (see Section 5.2 for illustrations). Because of the imprecise nature of the sweepers, the only real option for storing the packages is to loosely accumulate them in a large open tray directly behind the sweepers. And like the rail concept, this relied on the package starting in an upright orientation.

The previous two concepts assumed that the food packages would all be in an upright orientation. But because this could not be guaranteed (the robot or an opposing robot might knock one over) a collection method was desired that could collect a food package regardless of orientation. A magnet was determined to be the best way to achieve this, and because the food package could theoretically be in any orientation the options for storage were limited to an open bay. The advantage of having a large open bay for storage was that lots of food packages (at least 7) could be stored without the need to return to the HQ; however the impact on steering of this many packages requires further investigation.

5. Proposed Concepts

This section details the specific operation of each concept for collecting and storing food packages. All concepts use the same combination of grid based searching and IR sensors for navigation. Because only the collection and storage methods are different for each concept, a Finite State Machine diagram has been made for the collection method of each concept only.

5.1 Concept 1: Rails

This concept stemmed from the idea that two parallel rails could be used to store food packages. Two rails are held under the body of the robot, with the ends bent outwards and down to help funnel the food packages onto the rails. Once a food package has been identified the robot can pick it up by driving over it, so that the rails engage with the grooves cut into the food package and push the food package up onto the rails. To help the packages get to the top of the rails, a motorised rubber wheel spins against the top of the package and "kicks" it up on to the rails (refer to Figure 2). The rails are unable to collect toppled food packages which could be a limitation if a failed attempt at collection topples the food package.

The height of the rails is high enough so that there is some clearance between the bottom of collected food packages and the ground. Both rails are spring-loaded so that they can be triggered to spring apart, causing the food packages to drop straight down. This design feature allows the robot to quickly drop any collected food packages off in the HQ. The storage space of this design is limited to the length of the chassis, so this robot would only be able to hold 4-5 food packages at most, forcing it to drop of food packages if any more are to be collected. The robot utilises limit switches to determine when the rails are full and that it is time to return to HQ. Table 3 highlights some of the key advantages and disadvantages of this concept, while Figure 3 gives a brief outline of how the rails will operate.

Advantages	Disadvantages
• Doesn't require any moving parts other than the drive motors to collect food package. • Only requires one small servo to actuate food package deposit. • Remains fast and manoeuvrable due to smaller onboard weight. • Easy to detect collection of food package.	• Has limited on board storage space and must return to base once full. • Cannot collect toppled food packages. • Needs to be able to recognise toppled packages from all other food packages in the arena. • Cannot collect packages in the corner.

***Table 3**. Advantages and Disadvantages for Rails Concept.*

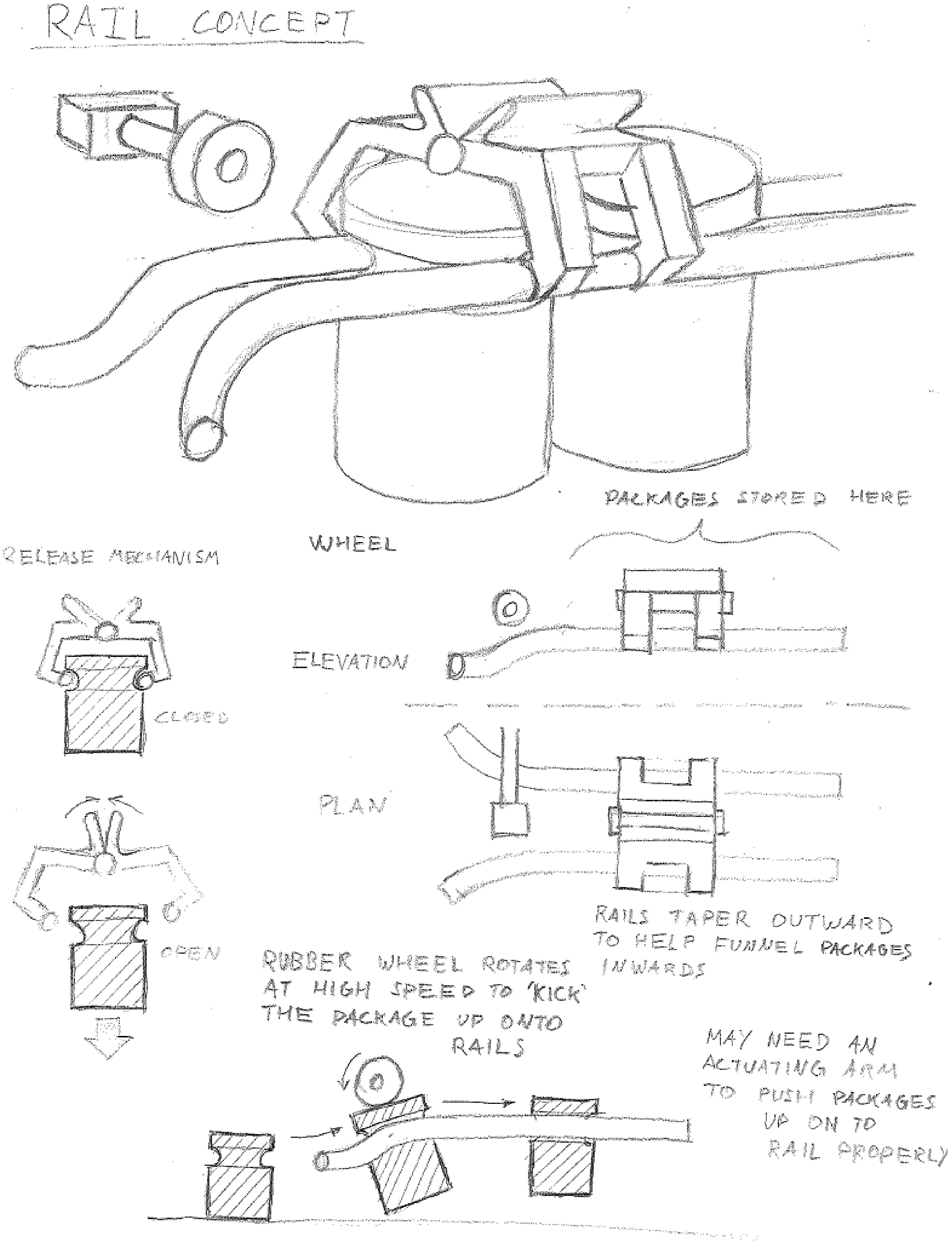

Figure 2: *Initial sketches for Rail concept*

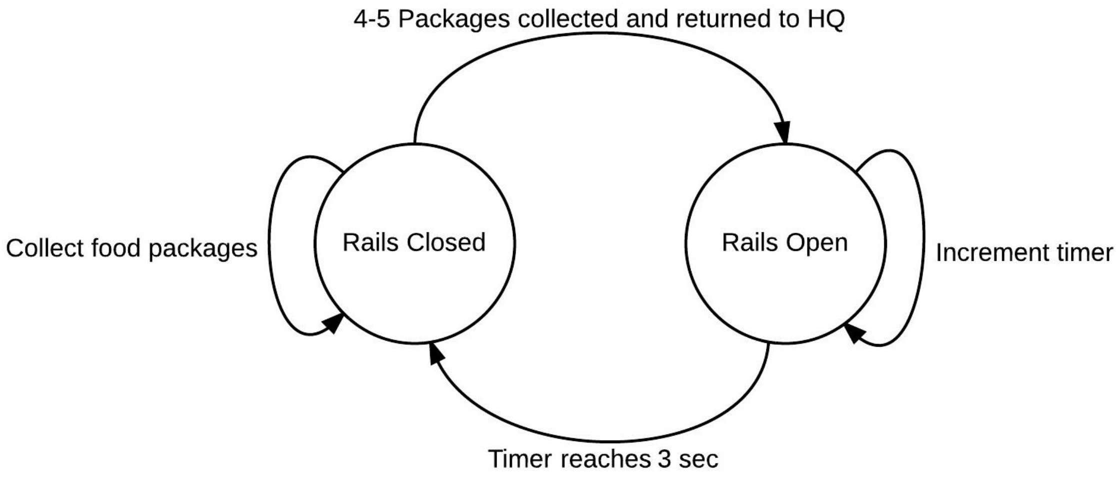

Figure 3: *Finite State Machine diagram for rail operation*

5.2 Concept 2: Street Sweeper

This concept was inspired by previous winners of the RoboCup. It involves using brushes or teeth to pull the food packages into the storage tray within the robot. A benefit of this design is the ability to not need to know the positions of each sweeper motor, meaning any slip is negligible and does not need to be accounted for. A significant disadvantage is that the sweeper teeth will be unable to collect toppled food packages or those located in a corner, limiting the number of collectable food packages to upright food packages that are not in a corner. These unavailable food packages could still distract the robot, so improvements to the food package recognition and navigation would need to be made so that the robot will ignore these packages and not waste any time.

Limitations of this design include a possible bunching effect of the food packages as more are collected during the rounds. This would increase the torque the motors have to produce significantly if the blockage is not accounted for. To correct for this, the storage tray is sloped away from the sweepers to allow the food packages to slide to the back of the tray. This allows the robot to be able to fit all of the food packages on board making it independent of HQ so that no extra time is wasted returning to HQ to deposit collected food packages. The weight sensor could be used to detect an increase in the mass of the holding bay, indicating that the package had been successfully acquired. Table 4 lists the advantages and disadvantages of this concept, while Figure 5 outlines how the sweepers will function.

Advantages	Disadvantages
• Simple motor control. • Can store maximum amount of food packages available because the design does not use any internal space. • Independent of HQ.	• Hard to detect successful collection. • Susceptible to blockages of sweeper teeth. • Cannot collect food packages located in corners. • Cannot collect toppled packages. • Needs to be able to distinguish upright food packages that are not in any corners from any other food packages in the arena.

Table 4. Advantages and Disadvantages for Street Sweeper Concept.

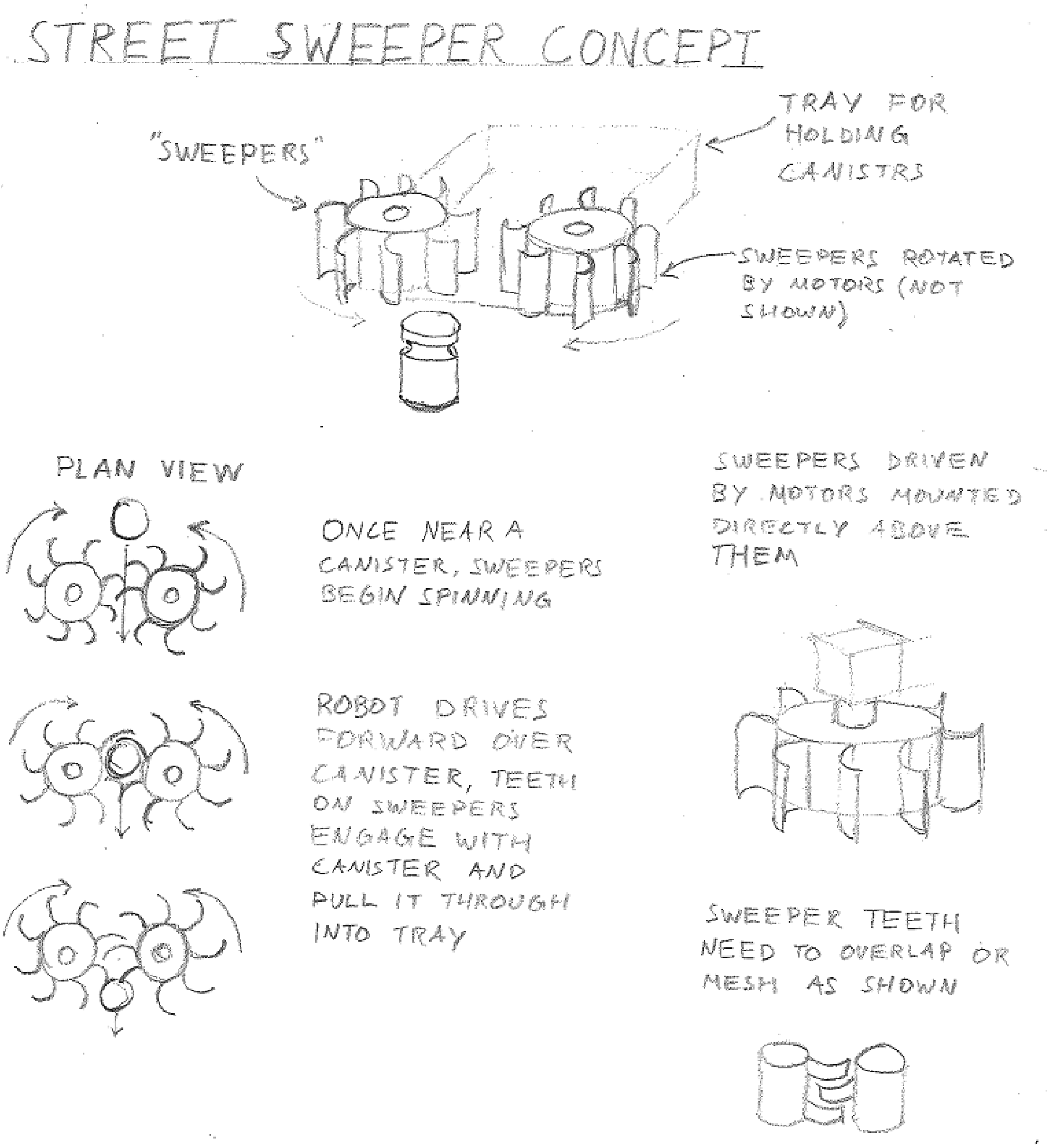

Figure 4: *Initial sketches for Street Sweeper concept*

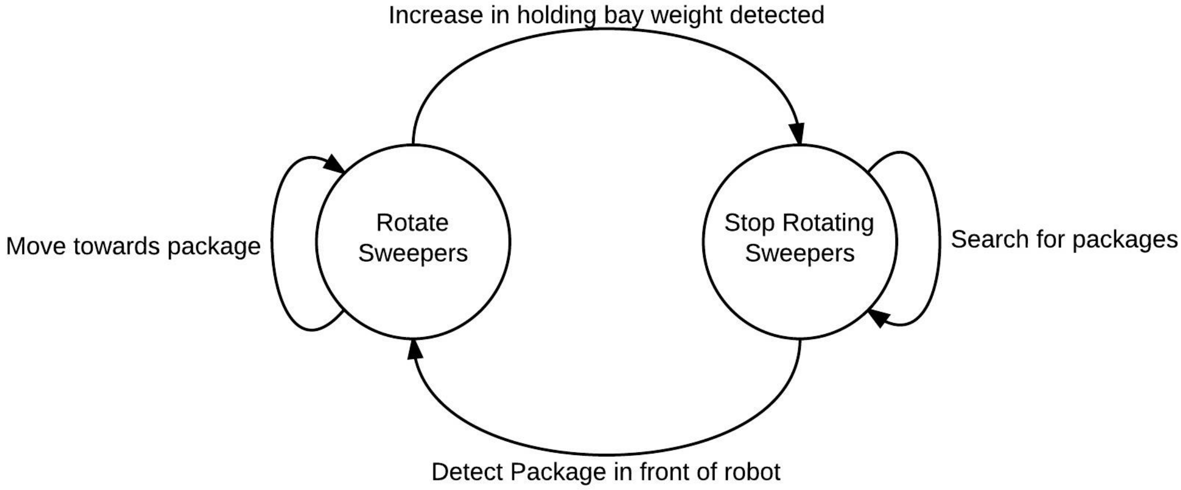

Figure 5: *Finite State machine diagram for Street Sweeper concept*

5.3 Concept 3: Magnet

This concept was a result of the desire to pick up a food package in any orientation. This concept uses a mechanically operated magnet to collect a food package (all of which are made from iron). The benefit of using a mechanically operated magnet is that there is no power is required to sustain the magnetic field, allowing for large savings in battery life. The magnetic field is activated by turning the internal magnet 90 degrees with a small servo motor. The magnet is mounted on an axis, so that once it has acquired a food package, it can simply pivot on its axis and drop the food package in a storage tray inside the robot.

Attaching the magnet mount and motor to the weight sensor will allow the robot to detect whether or not the magnet has successfully fixed up a package. This will provide another method of differentiating between the food packages and the non-ferrous obstacles in the arena. The magnet can be mounted outward out the front chassis, allowing the magnet to collect packages in corners. In addition, the magnet provides some offensive capabilities to the robot, as the robot could latch on to any ferrous components of the opposing robot and drag it in a random direction, disrupting its ability to move and collect packages.

Advantages	Disadvantages
• Robot only needs to make contact with the food package in order to pick the package up. • Can store maximum number of food packages because the design does not use any internal space. • Independent of HQ. • Relatively simple design	• Requires the robot to drive directly into the food package. Alignment may be present challenges. • Rotating the magnet assembly to deposit the food package may require a lot of torque depending on magnet housing geometry and the orientation the magnet is picked up in.

Table 5. *Advantages and Disadvantages for Magnet Concept.*

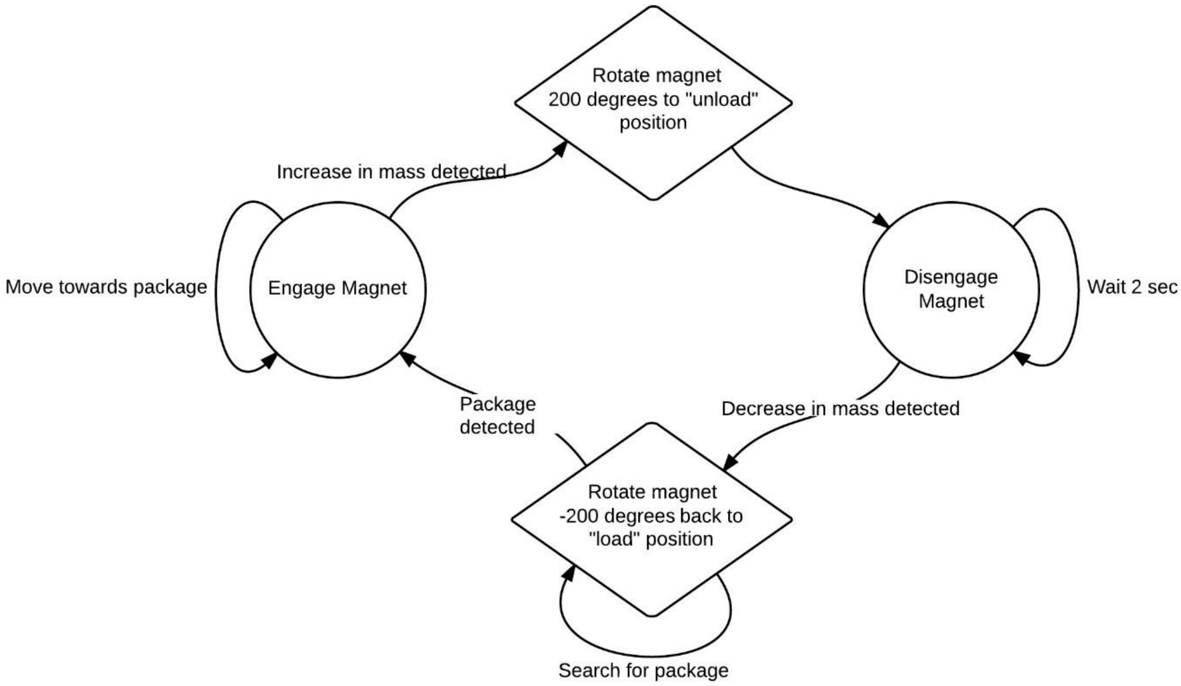

Figure 6: *Finite State Machine diagram for magnet concept*

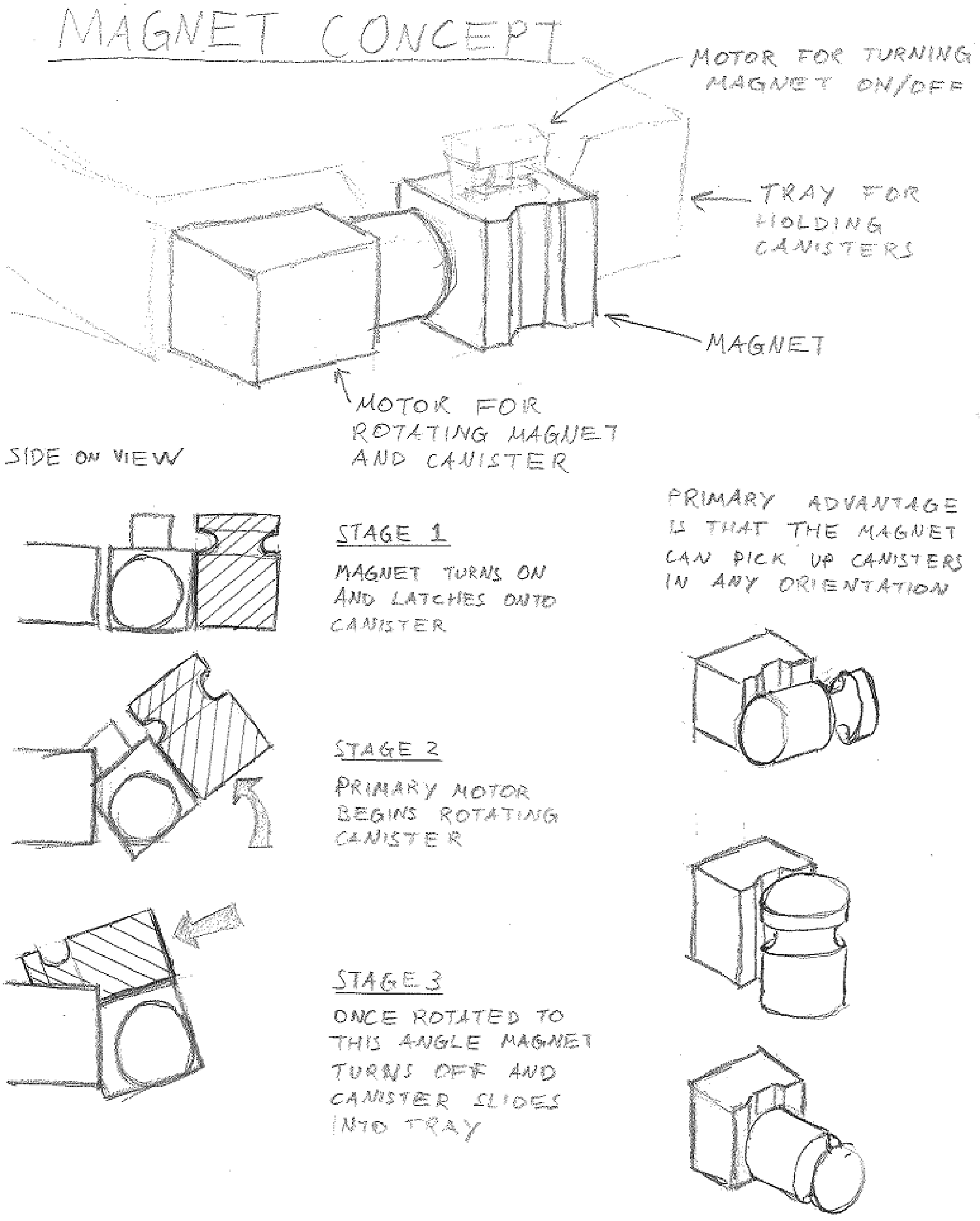

Figure 7: *Initial sketches for Magnet concept*

5.4 Navigation software

5.4.1 Grid Search

The grid search concept takes advantage of the fact that many of the weights are unlikely to be clustered together. For example, if a food package is found in square 1 it is less likely that a food package will be found in an adjacent square. And while the robot will still need to search them, it may do so more quickly and with less rigour as the chance of finding something there is comparatively lower. This will allow the robot to search the arena more quickly by searching places more or less carefully depending on whether it expects to find an object; and preventing it from accidentally searching the same place twice.

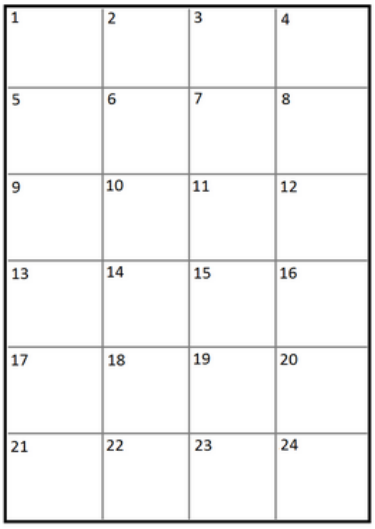

Figure 8. *Grid Pattern*

5.4.2 Mapping and Navigation

The mapping and navigation part of the software is responsible for determining where the robot is in the arena at all times. It will use information from a variety of sensors, including:

- Inertial Measurement Unit performing dead reckoning to give a live estimate of position.
- Compass to determine current heading.
- Infrared Distance Sensors measuring the distance and angle between robot and walls.
- Infrared Camera measuring direction and distance between robot and IR tower.

The information from these sensors can be combined using a suitable sensor fusion algorithm such as an Extended Kalman Filter to generate a reasonably accurate approximation of the current position of the robot within the arena.

At this stage, more detailed software design has not been considered. This is because some of the mechanical design decisions will dictate how the software is designed. With the objective of making the mechanical design as simple and robust as possible, this can reduce much of the requirement for complexity in the robot software and making the robot as a whole much more reliable.

6. Concept Evaluation

6.1 Explanation of how the FOM for Critical Design Features were calculated

All factors of merit (FOM) and weightings are ranked from 1 - 3 to describe how well each concept satisfies the various critical design features relative to each other (3 = best, 2 = average, 1 = worst). Each collection and storage mechanism concept is scrutinised in the following design features: The power requirements of mechanism, the storage capacity, the ability to access food packages in various orientations and locations, the reliability of the collection mechanism, the cost to manufacture and the independence from HQ the mechanism gives.

Each concepts power requirements are weighted by the number and size of motors that drive the collection mechanism. 3 is awarded 1 small motor and 1 large motor, 2 is awarded for 2 large motors and 1 is awarded for more than 2 large motors.

The storage capacity of each concept is weighted by the amount of food packages the robot can hold. 3 is awarded for 8 or more food packages, 2 for 6 - 7 food packages and 1 for 5 food packages or less.

The food package accessibility of each concept is weighted 3 for the ability to collect all food packages in any orientation within the arena, 2 for all upright food packages within the arena can be collected, and 1 for all upright food packages not in the corners of the arena can be collected.

The reliability of each concept is a measure of how consistently the collection mechanism succeeds in picking up a food package. 3 is awarded for a success rate of greater than 90%, 2 for success rate of 70% - 90% and 1 for a success rate of less than 70%. These success rates are based on experiments with early prototype of each concept.

The cost of each concept is weighted 3 if it is entirely constructed from given parts and salvaged parts, 2 if construction requires parts to be purchased that total less than $25, and 1 if construction requires parts to be purchased that total more than $25.

The independence of each concept from HQ is weighted 3 if entirely independent from HQ, and 1 if the robot is required to return to base to deposit food packages.

6.2 Concept Matrix

	FOM	Rails	Street Sweeper	Magnet
Power Requirements	3	3	2	3
Storage Capacity	3	1	2	3
Food Package Accessibility	3	2	1	3
Reliability	2	2	1	3
Cost	1	3	2	2
Independence from HQ	3	1	3	3
Overall Score		**28**	**28**	**44**

Table 7. Concept Matrix comparing the three different concepts.

The evaluation matrix shows the Magnet out-performing both the rails and the sweeper concepts in the majority of the chosen critical design aspects. It can be decided from the overall score that the Magnet concept is the best solution.

6.3 Current progress

With the final concept chosen, progress has begun on construction the first functional prototypes, as displayed in Figure 9. Although rather than mounting the magnet directly on to a motor as shown in the initial concept sketches (see Figure 7), the magnet has been mounted on an axle, which will be driven by a motor via a cam belt. With construction of a mounting point for the magnet and housing, initial testing and programming of the robot can begin.

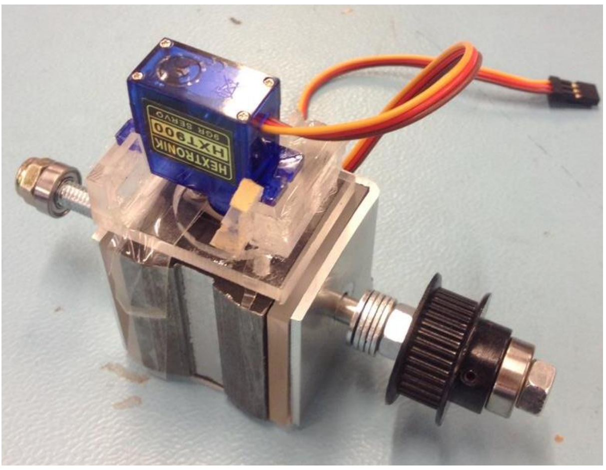

Figure 9: Magnet housing prototype

7. Conclusion

From evaluation of the three concept ideas it is recommended that the magnet collection mechanism be developed further in conjunction with a grid search navigation method. The Magnet design was chosen due to its ability to perform the given task simply and reliably. The design allows the robot to be independent for HQ by its capability to store all of the possible food packages on board with only some losses to the steering performance. The design also allows the robot to collect food packages in any orientation and location including those in corners or against obstacles.

8. Contribution Statement

8.1 Matt Young

- Concept generation
- Sketching concepts
- Report writing
- Re-configuring motor board
- Prototyping of magnet housing

8.2 Hamish Black

- Concept Proposals
- FOM calculations and Evaluation Matrix

8.3 Chris MacEwan

- Requirements Specification
- Magnet acquisition/prototyping
- Xbox Controller support to make the robot fun to drive around and aid mechanical prototyping.
- Navigation/software section