Robocup – Conceptual Design Report

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Introduction

This report includes the requirements specifications, three proposed concepts, concept evaluations and recommendations for a design that group 31 will take forward for Robocup 2024. In this year's Robocup, teams aim to accumulate the highest score in 2 minutes by collecting target weights and the 'snitch' while avoiding dummy weights with an autonomous robot. The competition involves two robots navigating the arena simultaneously, with points awarded for collecting target weights and delivering them back to the home base, and the team with the highest score at the end of the time limit wins.

The arena consists of a 2.4 x 4.9 m arena with 400 mm high walls, coloured black. Within the arena are two coloured home bases as well as several obstacles including pipes, ramps, and speed bumps. The target weights are steel cylinders of diameter 50 mm and height 70 mm with a groove to facilitate gripping. They weigh between 0.5 and 1 kg. The dummy weights are the same size and shape as the target weights but are made mostly of plastic with a metal insert at the top. The snitch consists of a Sphero Bolt robot, which has a spherical plastic shell, is 73 mm diameter and moves randomly.

This competition has four main components: Identifying weights, navigating to weights, collecting weights, and returning to base. The robot which can complete these tasks the most consistently and fastest will be the robot that is moved forward with. To determine this, requirement specifications were first decided on, then several material and hardware tests were undertaken, and a decision matrix will be employed to decide on the final design.

Requirements specifications

1. Functional Requirements:

1.1. The robot must turn on.

1.2. The robot must run on one battery for at least 120 seconds (2 minutes) with the equivalent of three weights onboard.

1.3. The robot should collect metal weights and not dummy weights with a success rate of 80%.

1.4. The robot should ignore weights that are not orientated upright.

1.5. The robot must be modular.

1.6. The robot must be able to identify obstacles including ramps, walls, and pipes.

1.7. The robot should be able to manoeuvre through the arena without becoming physically stuck

- 1.7.1. The robot should be able to move through the gaps between walls (0.4 m).
- 1.7.2. The robot should be able to move over speed bumps (25 mm).
- 1.7.3. The robot should be able to move over the rim within each base (~ 10 mm).
- 1.7.4. The robot should be able to move over ramps with a gradient of 30 % if necessary.
- 1.7.5. The robot should be able to avoid walls and pipes.

1.8. The robot must avoid damaging opponent robots.

1.9. The robot must be able to identify home base, enemy base, and the normal arena.

1.10. The robot must be able to move faster than 0.2 meters per second and slower than 7 meters per second with a load equivalent to three weights.

1.11. The robot must continue to move under its own power if the track is removed.

1.12. The robot must have independent wheel movement and be able to complete a 360-degree turn on the spot at any point.

1.13. The robot must collect three target weights before returning home.

1.14. The robot must not collect more than three weights at a time.

1.15. The robot must be able to carry and deposit an object with a weight of 1.0 kilogram.

1.16. The robot should not collect weights in the opponent's base.

1.17. The robot shall not leave the arena at any point.

1.18. The robot must move under its own power (no external power sources).

1.19 The robot shall be able to navigate to home base from any location in the arena.

2. Sensing Requirements:

2.1. The robot shall differentiate between plastic (dummy) and steel weights using an inductive proximity sensor.

2.2. The robot shall use a sensor at 350 millimetres to identify walls while avoiding weights.

2.4. The robot shall use a colour sensor to identify home base, enemy base, and the arena.

2.5. It must have sensors more than 50 millimetres apart and more than 70 millimetres high to detect ramps or the enemy robot.

2.6. It should have two sensors lower than 70 millimetres high and spaced less than 50 millimetres apart to detect weights.

3. Performance Requirements:

3.1. The robot should withstand collisions from other robots and walls without taking on any debilitating damage.

3.2. The robot should take no longer than 20 minutes to replace any faulty part on the robot, including time to disassemble and reassemble it.

3.3. The robot should not attempt the same movement for more than 15 seconds in a row.

3.4. The robot must be able to move over 25 millimetres obstacles in less than two seconds.

3.5. The robot must identify the sides of ramps to avoid ramming into them.

3.6. The robot should not actively target the snitch as the snitch moves too fast to catch.

4. Constraints:

4.1. The robot body should be made of only steel, Perspex, and wood.

4.4. Extra components must cost less than $50.

4.5. The robot should have no sharp edges and be safe for picking up or handling.

Proposed concepts

Concept 1: The Mazerunner. (Solomon)

This robot is meant to deal with multiple challenges that may confuse it in the arena. For example, walls on two sides, which have caused other Robots to spin around in circles. Another challenge being ramps that are driveable, but other robots interpreted them as walls. In short, this robot is meant to be precise and predictable in all reasonable cases. A sketch of this is shown in Figure 1.

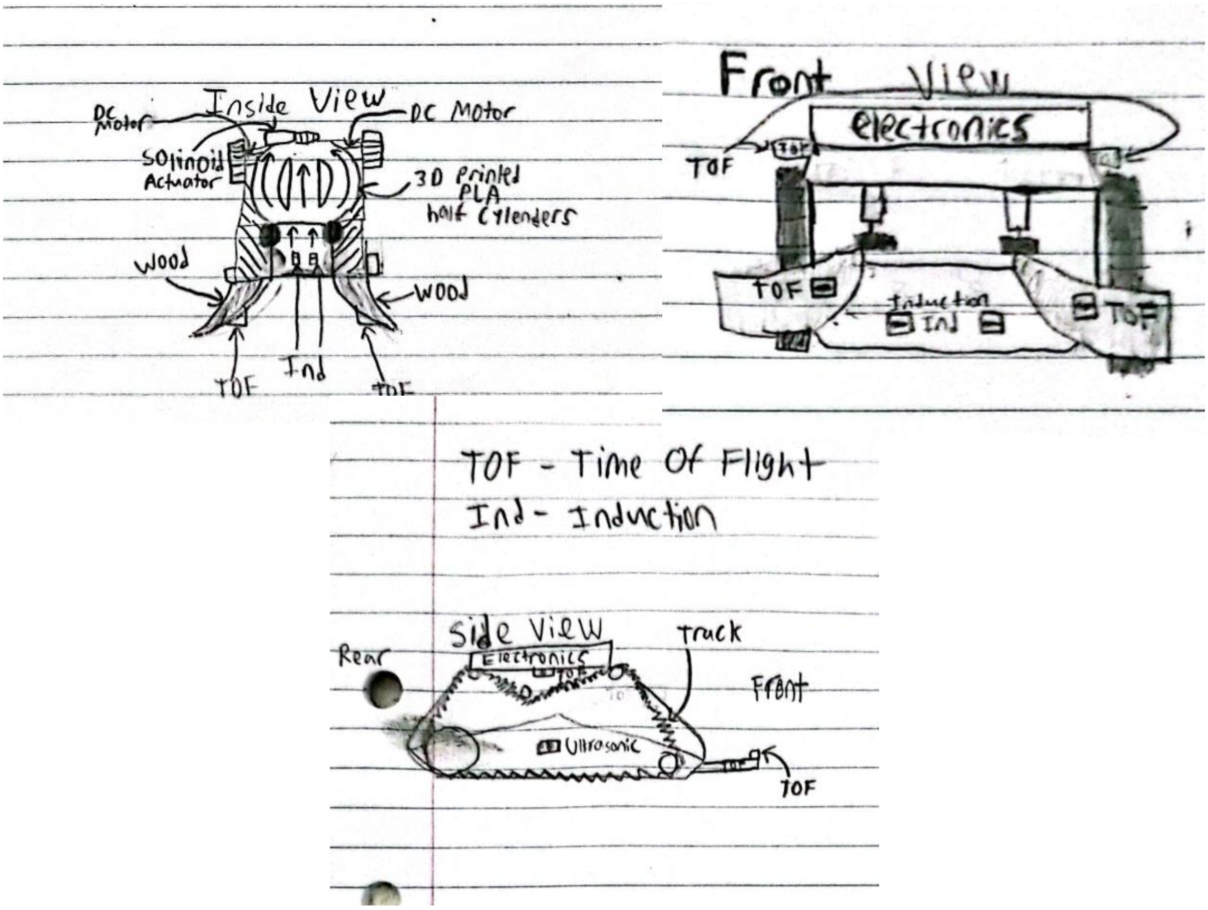

Figure 1: A sketch of the layers of Concept 1.

The following are descriptions of the main components of the design.

Weight release mechanism and storage:

A solenoid will be used to let the weights in and out of the storage chamber (3 cylindrical tubes to store the weights). There will also be a ramp to get the weights to the storage chamber with 2 200rpm DC motors facing downwards with PLA grid track wheels to push the weights in.

Navigation Algorithm:

The IMU and MCU does navigation. In these repeating steps:

1. Looking for walls with Time of Flight Sensors.

If a wall is detected in front of the robot at a short range from both the Time-of-Flight sensors on both sides of the robot (at different heights to detect driveable ramps), and the Time-of-Flight sensors at the rear and sides say there is nothing, then the robot rotates to the relevant angle of the clear sensor and continues. If there are objects in front and behind the robot, then the time-of-flight sensors determine the direction with the most distance to an object, and the robot will go that way. They will also determine if it is not a wall by checking the distances to the detected objects on both sides of the robot.

2. The inductive proximity sensors check for ramps or dummy weights.

The inductive proximity sensors will detect vertical ramp sides or dummy weights when the robot gets close. If a ramp is detected, the robot will move around the ramp by checking with 2 ultrasonic sensors on either side which direction is open and moving in that direction at an even distance until they say the ramp is gone. When that happens, the robot will rotate 90 around the ramp and back the same distance towards its intended path. If there is another object at the top end of the ramp. The robot will move around the first ramp the other way.

3. The robot moves to pick up the weight and stores it if is a valid weight.

More in the collection section below.

4. The robot returns the way it has come and drops weights at the home base if needed.

When the robot returns, either because it is getting close to the time limit or it is possessing 3 weights, then the IMU navigates the robot back to the starting position. The robot will release the weights at the home base.

5. The robot will sway back and forth with a radius of 1m, looking for a weight.

The 12m range for the TOF sensor and the 5m range for the ultrasonic sensor means the robot doesn't have to shift too much to detect weights all around the arena of less than 5m. It will look for the weights with all its sensors (but mainly the front two mini TOF sensors) based on how long the objects on them are detected for. Alternating which motor is off and on for each side to turn.

Figure 2. shows the flow chart of the navigational algorithm.

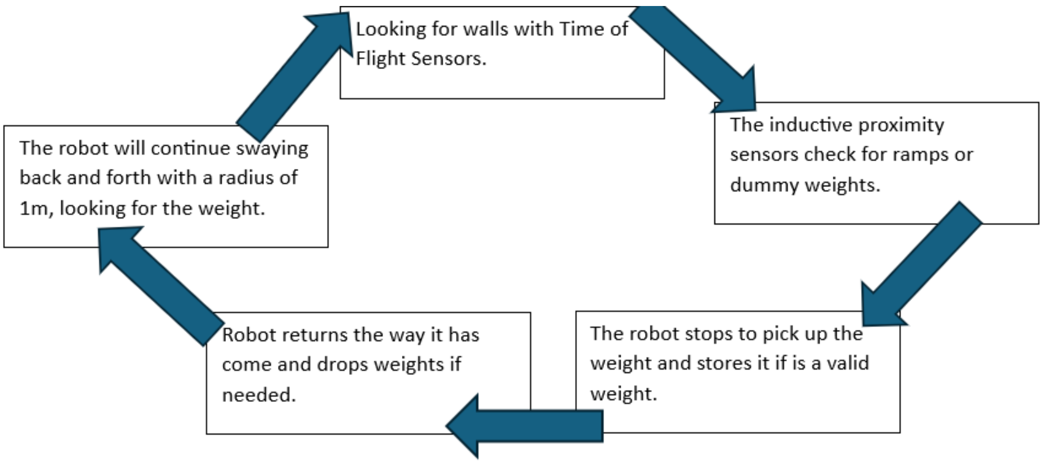

Figure 2: A flow chart of the navigational algorithm

Drivetrain:

The motor will be lower down to power the robot tracks through the main drive wheel. The robot will therefore still move under its own power even without the tracks (should they fall off), but the wheels will also have guards to prevent this. Since the weights and therefore the centre of gravity will be towards the rear, it must be driven from the rear by two motors.

Chassis:

The chassis will be positioned long side down. This is to make the robot more stable as it makes the centre of gravity closer to the ground. But it will keep 30mm of clearance to go over bumps.

Collection:

When the Time of Flight Sensors spot a weight, the robot will head straight in that direction. The robot will have convex strips of wood to guide any incoming weight inwards. If the weight is a dummy weight, the inductive proximity sensor under the collection ramp will detect this and the robot will move back and continue. The real weight will be put into the collection chamber via a ramp guided by two motor driven wheels with grippy tracks of PLA. The weight will also be knocked on its side in this process to keep it facing flat in storage.

Functional architecture:

A functional architecture diagram of the system is seen in Figure 3.

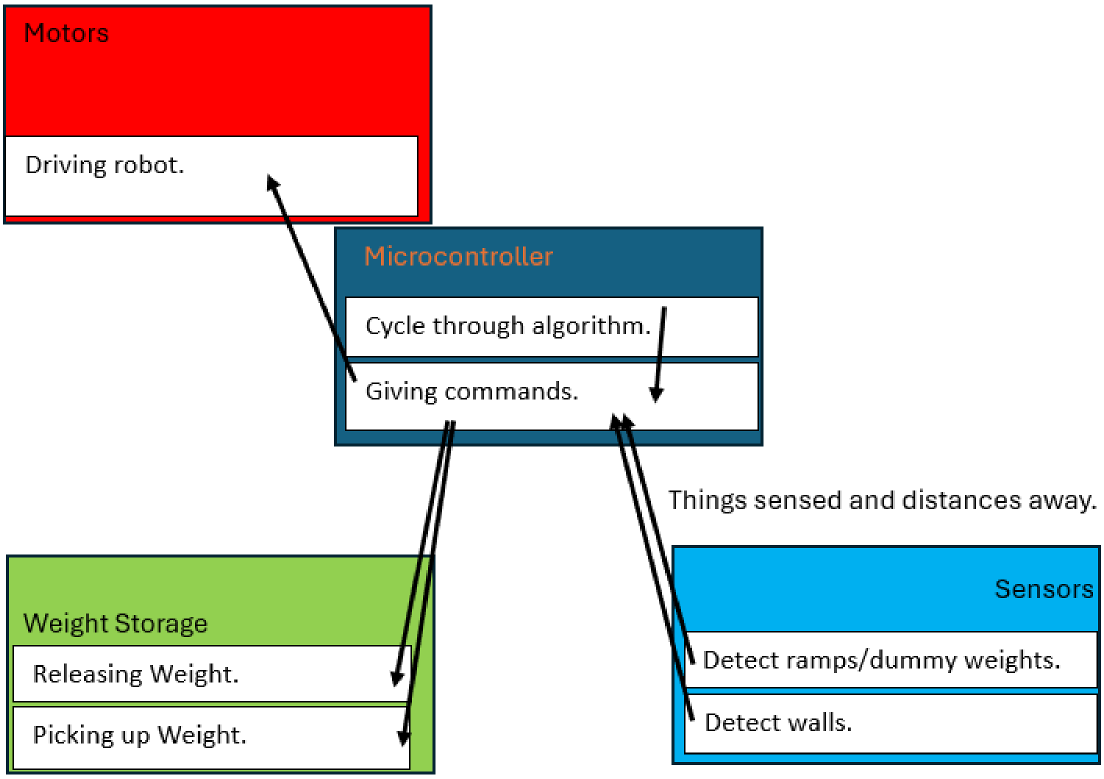

Figure 3: A functional architecture diagram of the system

Concept 2: The Filter (Oliver)

The basic design of concept 2 is as follows. It passes through all weights, and filters them using, ultrasonic sensors and electromagnets. By locating the weights using ultrasonic sensors at a distance, it will filter through many different dummy or target weights. With the implementation of it being able to run straight through dummy weights, no state is required for the robot to move backwards when dummy weights are passed into the robot. Figure 4. displays concept sketches of the 'Filter' design.

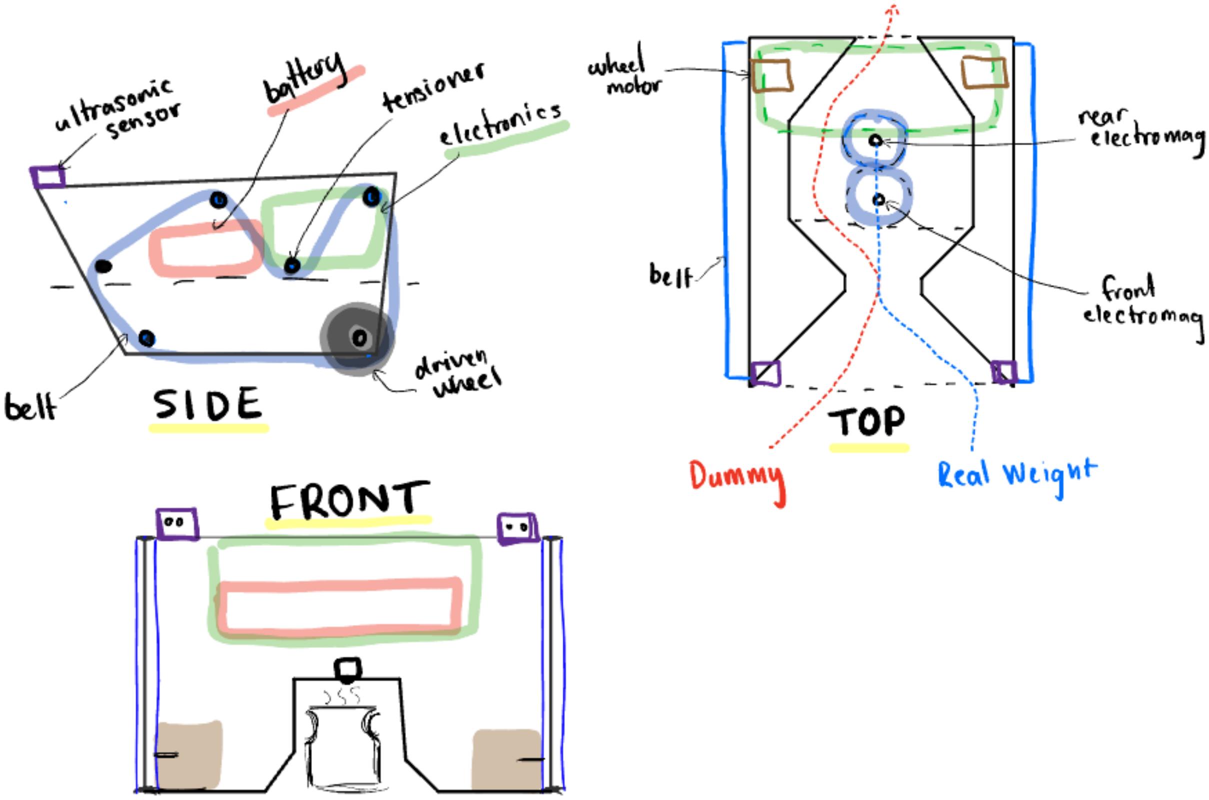

Figure 4. Robocup Concept 2 'Filter' design

Locomotion:

The robot is driven by two rear motors, each operating a belt that transmits power to the drive wheels. These belts are tensioned to ensure consistent traction across varying surfaces in the arena. Positioned on either side of the robot, the motors provide strong, reliable propulsion that allows the robot to navigate efficiently. At the front, an opening permits weights to pass through, while the larger central area is designed to hold collected target weights and filter dummy weights.

Weight Collection and Filtering System:

To collect and filter weights, the robot uses two strategically positioned electromagnets. The rear electromagnet is centrally located in the containment zone and serves as the primary collector by attracting target weights when they pass through the front opening. The front electromagnet, positioned closer to the entrance, activates only after the rear electromagnet has secured a weight. This dual setup ensures that target weights remain held securely while allowing non-magnetic dummy weights to pass through and be ejected without obstruction. Using pulse-width modulation (PWM) or a variable voltage regulator, the magnetic field of each electromagnet is dynamically controlled to pick up and release weights efficiently.

Weight Identification and Navigation:

Multiple ultrasonic sensors are arranged around the robot to detect the presence and location of weights at various distances. Front ultrasonic sensors identify approaching weights. Within the robot, weights are identified by two inductive proximity sensors. This information is then processed by a state machine that controls the robot's behaviour, shown in Figure 5.

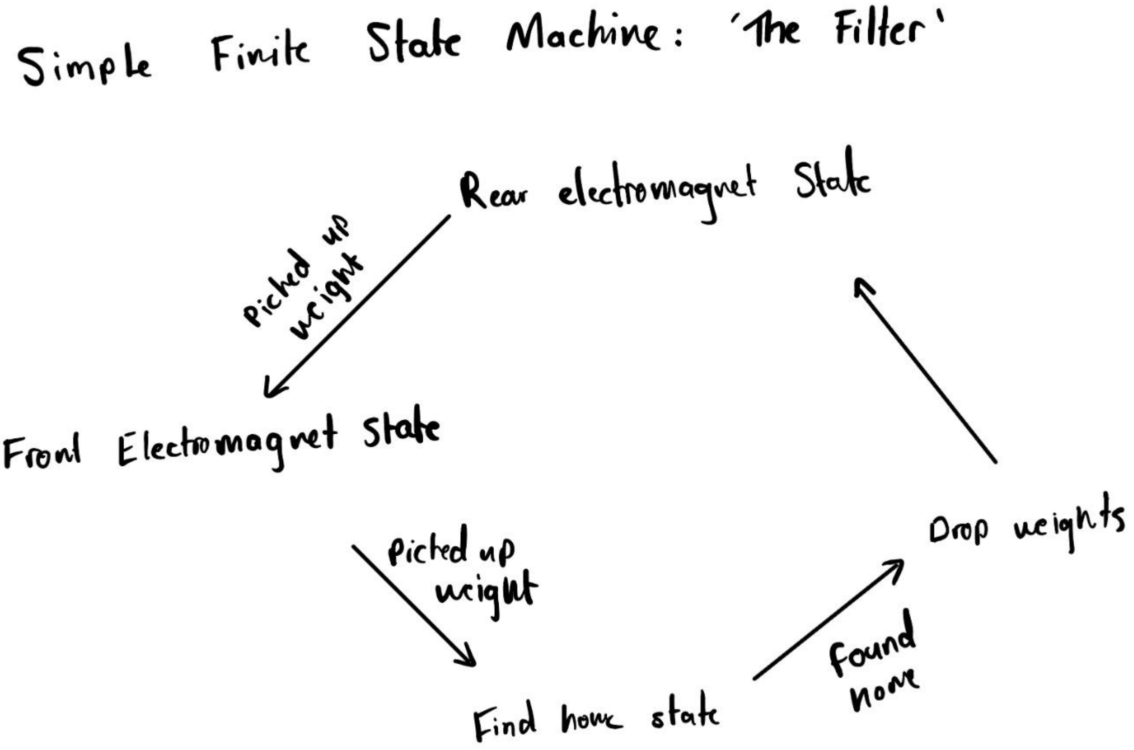

Figure 5: Robocup Concept 3 'The Filter' State Machine

Rear Electromagnet State: In this initial state, the rear electromagnet is activated to attract target weights while the robot searches for more.

Front Electromagnet State: After the rear electromagnet secures a weight, the front electromagnet activates to hold additional target weights.

Find Home State: Once the weight limit is reached or the timer requires, the robot switches to finding the home base using ultrasonic and colour sensors.

Arena Navigation: The robot follows a grid search pattern across the arena to maximize coverage, efficiently moving up and down the field. Ultrasonic sensors at the front and sides help detect and avoid obstacles, ensuring the robot can continue its search without interruption. The colour sensor detects the unique colour of the home base to trigger the return sequence once the robot has collected enough target weights.

Drop-off Mechanism: When the robot reaches the home base, the electromagnets are deactivated to release the collected target weights onto the platform.

By using the dual electromagnet system, rear belt-driven motors, and a methodical state machine-based control system, this robot can effectively and continuously collect target weights while filtering out dummy weights without requiring any changes in direction.

Concept 3: Garbage truck (Aeneas)

The basic design of concept three is like that of an autonomous garbage truck. It will locate and move to the weights, securing a weight in its arm. Once ensuring it is not a dummy weight, it will rotate the arm approximately 200 degrees, moving the weight upside down and 'dumping' it off in the sloped storage area. The weight(s) will be held in with a gate which can move up and down to release the weights when at home base. Figure 6. shows the design of the garbage truck.

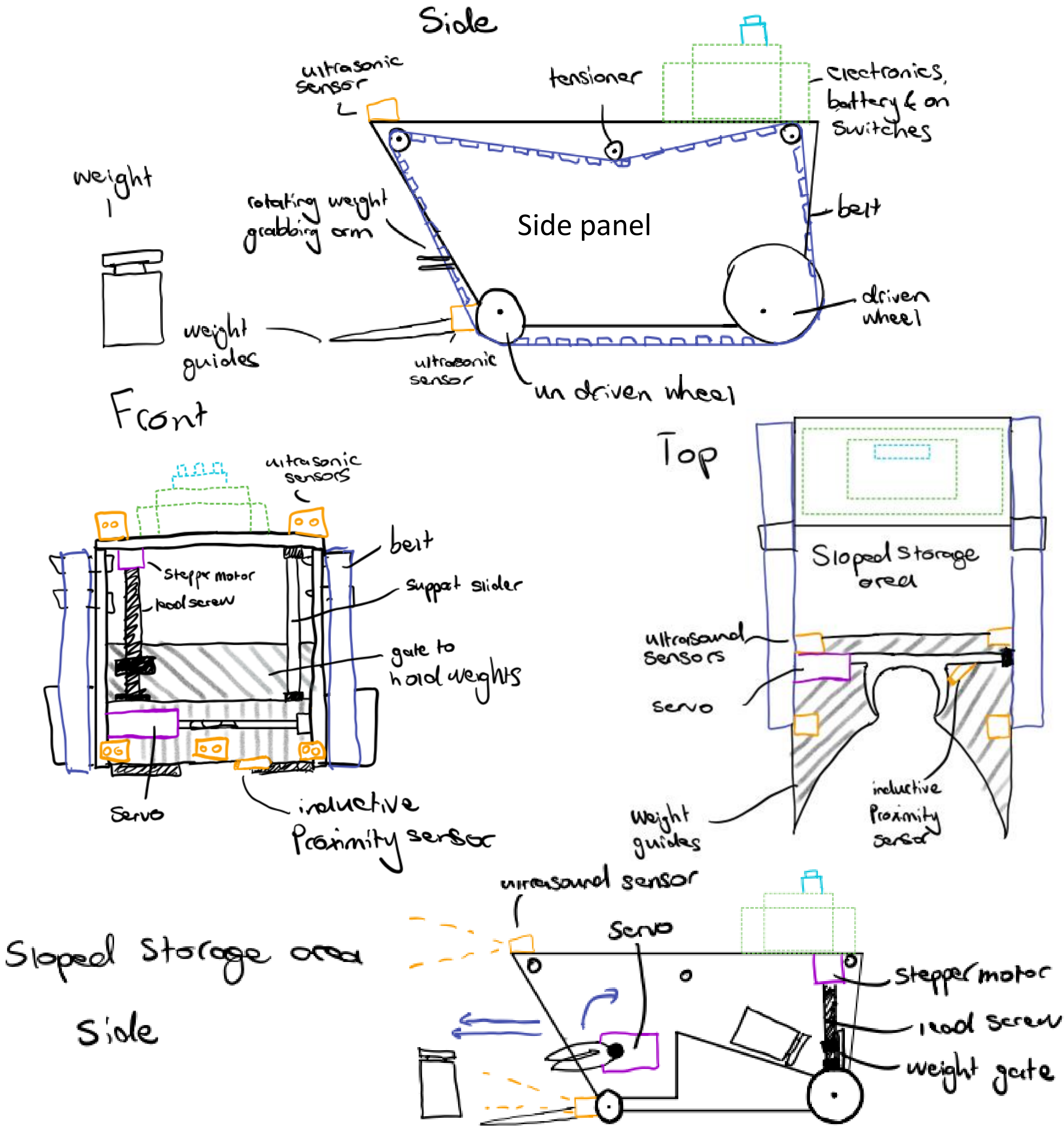

Figure 6. Robocup Concept 3 'Garbage truck' design.

A brief description of each major section of the design - sensing, locomotion, weight depositing and weight drop off – each with specific sensor and actuator choices are provided in figure 7.

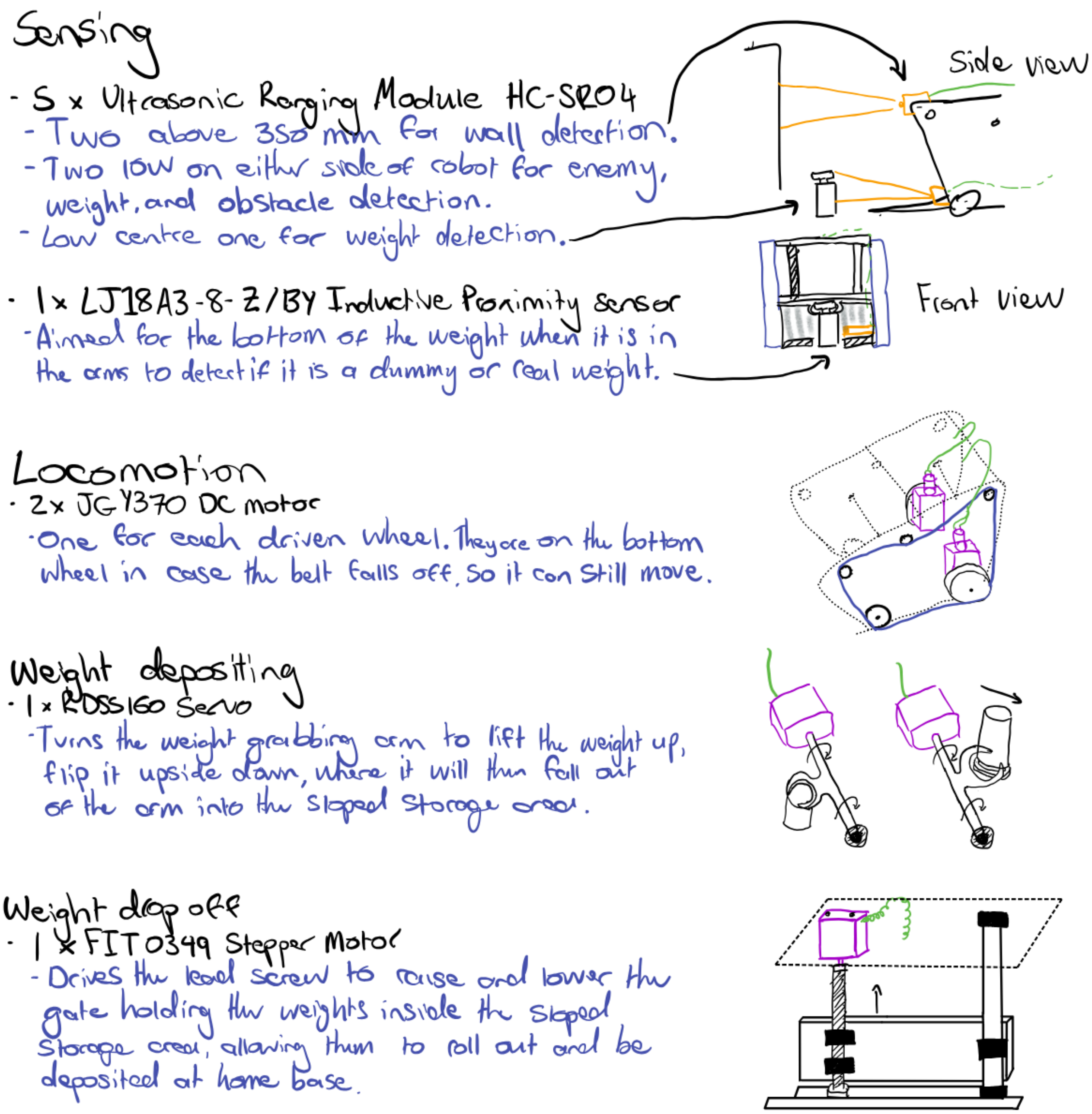

Figure 7. Description of key aspects of the design.

The robot's functionality relies on five ultrasonic sensors strategically positioned to detect walls, obstacles, weights, and other robots as described in Figure 7. Three of these sensors are positioned at the bottom of the robot. The two sensors flanking either side are specifically placed to identify weights and the sides of ramps. The sensor configuration allows the detection of ramps, wider than the robot but too low for the upper wall sensors to detect. Thus, if both bottom sensors are triggered while the upper ones are not, it indicates the presence of a ramp, and the robot can move to avoid it. Otherwise, these sensors function to detect weights and obstacles.

These ultrasonic sensors could potentially be a weakness as if a robot has an ultrasonic emitter, the sensors will be completely overwhelmed and not work correctly. Another concern was the servo motor possibly being unable to lift the 1 kg weight around and into the storage area. However, after testing it was found that even at a torque of 40 kg/cm it moved smoothly, and as the maximum load on the arm is 1 kg at < 10 cm, this once again this proved to not be an issue. However, because of the design of the arm, the snitch is effectively uncapturable by the robot and could get stuck in the weight guides.

Using the ultrasonic sensors, once the robot has detected an object that could be a weight, it will manoeuvre towards it. If the induction sensor identifies a weight, the weight depositing arm is activated. Subsequently, the arm rotates to elevate the weight and deposit it back into the sloped storage area. Once the robot has collected three weights or it is within 15 seconds of the two-minute time limit, it will navigate back to its 'home base' using the Inertial Measurement Unit (IMU). A diagram describing the decision-making process of the robot's movement is seen in Figure 8.

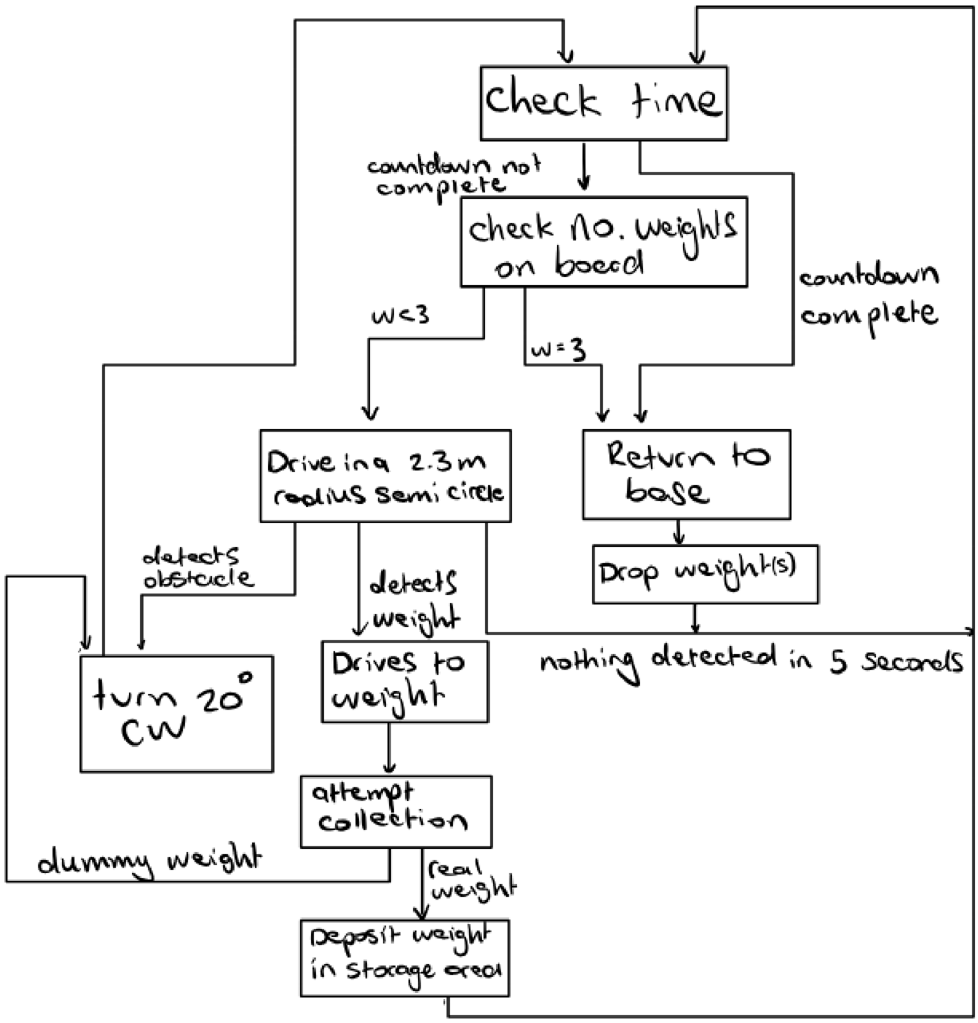

Figure 8. Finite state machine describing movement behaviour of 'garbage truck'.

Concept evaluation

For the concept evaluation, each concept was compared to each other. The main comparison was conducted using an evaluation matrix shown in Table 1. The design criteria and weights correspond to how important each criterion was deemed to be. All three of these concepts fulfil all the requirements specifications previously defined.

Table 1. Decision matrix for concept evaluation.

Criteria		**Concept 1: Mazerunner**			**Concept 2: The filter**			**Concept 3: Garbage truck**		
	Weight (1-10)	Details	Normalised score	Weighted score	Details	Normalised score	Weighted score	Details	Normalised score	Weighted score
Power consumption	3	9 sensors, 5 actuators	4	12	5 sensors, 2 actuators	7	21	6 sensors, 4 actuators	6	18
Reliability										
Ease of maintenance	7	Good	7	49	Average	5	35	Average	5	35
Toughness	6	Average	5	30	Average	5	30	Average	5	30
Redundancy	8	Very good	9	72	Below average	3	24	Below average	3	24
Movement										
Speed	4	Average	5	20	Good	7	28	Good	7	28
Rotation	8	Below average	3	24	Good	7	56	Good	7	56
Dexterity	7	Good	7	49	Good	7	49	Good	8	56
Collection speed	5	Ok	4	20	Very good	10	50	Below average	3	15
Obstacle detection										
Distance	3	12m front, 4m side	8	24	4m	8	24	4 m	8	24
Precision	7	3mm	9	63	3mm	9	63	~ 3mm	9	63
Measuring angle	5	15 deg	6	30	15 °	6	30	15°	6	30
General Navigation Algorithm	5	See Figure 2.	8	40	See Figure	6	30	See Figure 6.	8	40
Weight detection										
Distance	6	12m	9	24	4m	8	24	4 m	8	24
Precision	9	2%	7	81	~3mm	9	81	~ 3mm	9	81
Measuring angle	5	2.3 deg	8	30	15 deg	6	30	15°	6	30
cost	2	$10	5	10	$10	5	10	$5	8	16
Snitch capturability	3	Unlikely	4	12	Very unlikely	2	6	Impossible	0	0
Total				590			591			570

These concepts address different concerns of the competition in different ways. Concept 1 notably addresses the navigational issues of a complex arena through its multiple sensors. Requirements section 1.7 is focused on with this. Concept 2 notably addresses the need to reliably load the heavy weights through electromagnets, focusing on requirement 1.3. Concept 3 however is altogether a tried and tested conventional approach of finding, storing, and releasing heavy objects. Judging these was complex and required mechatronics techniques including the FOM table and concepts such as Reliability (in its own section).

The main differences between the concept designs were in the collection speed, power consumption and movement. Collection speed is important as there is two minutes to collect as many weights as possible. Power consumption is also very important to make sure the robot can last these two minutes. Finally, a manoeuvrable robot can positively contribute to the former two attributes. Concept 2 has massive advantages in these three important sections and so in terms of Figures of Merit concept 2 has the highest total score.

Conclusion and recommendations

For our final design, we chose to use Concept 2: "The Filter" due to its superior efficiency in weight collection, manoeuvrability, and filtering. Its electromagnet system allows seamless separation of target and dummy weights, optimizing collection speed and reliability. With fewer sensors and actuators, it is also more energy-efficient, ensuring sustained performance throughout the competition. Additionally, its robust navigation and state machine-based control system provide consistent and precise operation.

Concept 2 will be slightly adjusted with further research and testing, focusing on the optimal positioning of sensors, and implementing a mechanism to move the electromagnets up and down. This will involve adding a moving plate with lead screws to lift the electromagnets, addressing the issue of their very small range. It also addresses the issue of manoeuvring over small obstacles, as previously the robot would have been unable to do so while holding a weight. Additionally, a third electromagnet will be added to store up to three weights. Another important addition is an inductive proximity sensor to detect the difference between the dummy and real weights at intake. Without this, the dummy weights can be picked up by the electromagnets as they have a steel insert in the top. These refinements will enhance the robot's functionality and ensure it meets all competition requirements.

Contribution statement

Solomon

I contributed to this report more than just doing and proofreading my own section. I also wrote the section below the concept evaluation table, organising meetings for my team and I helped to make the robot when I could. To contribute my team's understanding of robocup robots, I asked the previous competition winners many questions.

Aeneas

In this report, I wrote the introduction, then in the group brainstorm I wrote down and then organised the ideas for the requirements specifications. I organised them into categories and deleted repeated or unnecessary requirements, while checking the rules to ensure no overlap. Additionally, I designed and wrote the description of concept 3: Garbage truck, created the concept evaluation table, filled in the concept evaluation table, and added to the concept 2 recommended adjustments in the conclusion. I also tested the motors, electromagnet, servo and assembled the frame and electrical drivers for the tests.

Oliver

In this report, I contributed by developing the design and description for Concept 2: "The Filter," writing the conclusion, and assisting with the scoring to determine the best concept to use. Additionally, I collaborated with my team to ensure the evaluation process was thorough and aligned with the competition requirements.