ENME301 Group 10 Robocup Concept Design Report

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Introduction

2024 Robocup is a competition between the third year Mechatronics Engineering cohort at the University of Canterbury. Teams will design and construct a fully autonomous robot which can navigate around the arena which contains obstacles and collect target weights. Target weights are a ferrous material with a standard shape with a mass of 0.5kg, 0.75kg, and 1kg each worth points depending on their mass. Fake weights are also positioned inside the arena which give negative points if on board the robot at the end of a round. If target weights are placed at the robots home base by the end of the round the weights will be worth double points.

The robot operations have four main components:

- Searching for weights
- Navigating to weights
- Collecting weights
- Returning weights to home

Robots which can complete those actions in a reliable efficient manner are most likely to win. Three concepts have been developed to meet the requirements below. Testing of select components was done to give a greater idea on some of the capabilities of select components, like the electromagnet. With this knowledge and knowledge about past designs from previous competitions it was discussed within the group to create various ideas which were turned into the concepts developed. This was done to create a wide variety of ideas instead of focusing on just one idea.

Requirements Specification

1. **TARGET CAPTURE AND MANAGEMENT**
    1.1. The robot shall collect assorted 0.5 kg, 0.75 kg, and 1 kg target weights.
        1.1.1. The robot should be aware of the quantity of targets weight onboard carrying at most three at once.
        1.1.2. The robot should identify metal target weights as opposed to plastic dummy weights to at least 80% accuracy.
    1.2. The robot should not be negatively impacted by catching the snitch.
    1.3. Nor should it actively attempt to catch the snitch.
    1.4. Up to 3 weights will be stored securely to prevent loss during movement.
    1.5. The storage mechanism shall allow weights to be removed from the robot for delivery to the home base.
    1.6. The robot should be aware of its location in the area.
        1.6.1. To distinguish its home base for weight deposit.
        1.6.2. To avoid picking up target weights from its own home base or opponent's base.
2. **IDENTIFICATION AND NAVIGATION**
    2.1. The robot shall effectively identify and navigate.
        2.1.1. Around walls and pipes as per rule specifications.
        2.1.2. Over speed bumps, ramps and home base rim as per rule specifications.
        2.1.3. Around opponent robots.
        2.1.4. Towards upright weights target or dummy.
    2.2. The robot should return to its home base within 20 seconds when required.
    2.3. The robot shall be able to travel at a speed of 0.3 m/s continually for 2 minutes.
    2.4. The robot shall remain functional after an upset event.
        2.4.1. Operation shall be possible after driving off platforms up to 100 mm in height.
        2.4.2. Operation shall be possible after collision with another robot or obstacle.
        2.4.3. The robot should not lose any components during operation unless they are designed to do so.
3. **STRUCTURAL AND ELECTRICAL ARCHITECTURE**
    3.1. The robot should be assembled and disassembled using hand tools only.
    3.2. All components should be replaceable or repairable within 20 minutes.
    3.3. The robot shall fit within a 400mm diameter bounding circle.
    3.4. The Teensy 4.0 should have its ports accessible when in an operational state for programming and serial debugging.
    3.5. The robot should have accessible controls for changing operation states.
4. **SAFTEY FEATURES**
    4.1. The robot shall have no sharp edges.
    4.2. The robot shall have a clearly accessible power cut-off button.
    4.3. The robot shall not have design features that are intentionally crafted to cause harm to an opponent's robot.

Proposed Concept 1 (Digby Eele)

Description

Concept 1 focuses on having a small footprint and the ability to drive over weights, this aims to prevent non-target weights getting stuck in front or under the robot. This design requires custom frame plates but uses only the given pulleys, motors and sensors. Small 3D printed parts will be used for actuator arms. I have drawn a basic CAD model for the purpose of confirming that packaging is possible in this small design and to design the belt path to the given length (880mm) shown in Figure 1. Sketches are used for conveying detail in positioning and choice of sensors / actuators.

Chassis and Drivetrain

Concept 1 uses a classical belt drive between 2 side plates shown in Figure 1. To reduce the footprint of the design custom plates with custom belt paths are used. The plates for each side are the same but are orientated different ways around, this offsets the motors allowing the width of the robot to be reduced to 219 mm and the length 281 mm. The drive belt will be positioned with the flat side of the belt down due to testing showing the flat side had far better traction.

The 143-rpm encoded motor will drive the belt on the flat side to ensure the best traction and be positioned to have a large surface area, this reduces slippage and will be crucial to the useability of the encoder data for ensuring precise navigation. There is a slot in one of the upper belt guides to allow tensioning.

The sides of the chassis will be held together by a slopped weight storage tray and a top plate to house the electronics.

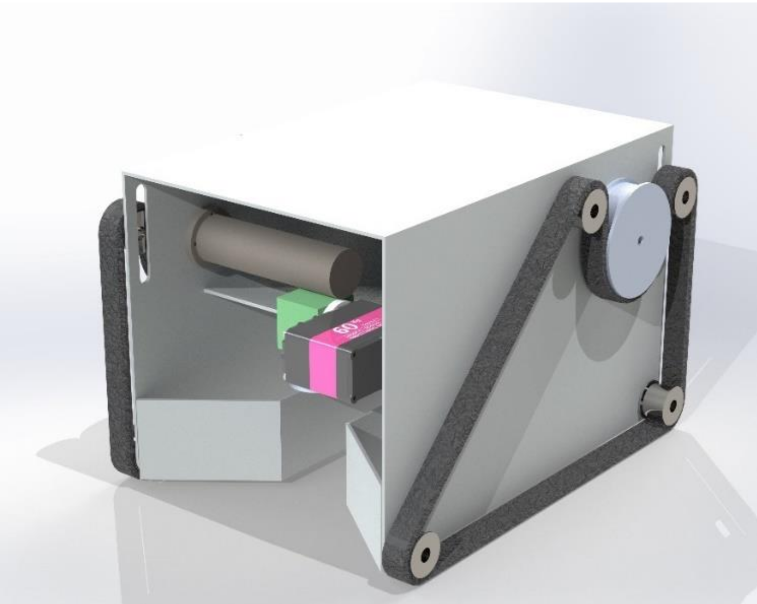

Figure 1 Basic Cad Drawing of Concept 1

Weight Collection and Release

For weight collection the robot will drive over the weight, centring it under the electromagnet that will be used to hold the top of a target weight. The electromagnet will be mounted with a 3D printed block to the large servo (RDS5160) as Shown in Figure 2. This will then be able to pivot weight up through a trap door (not shown in figures) where the weight is dropped and slides down the storage ramp.

Initial sketches had the targets weights being picked up on their side after being knocked over, which would have been desirable. After testing the electromagnet, it was deemed ineffectual due to the magnets inability to hold a 1kg cylindrical target weight through a rotation.

To release the weights the rear door is lifted with a smart servo and linkage. The door will be slid between 3d printed groves mounted to the side plates.

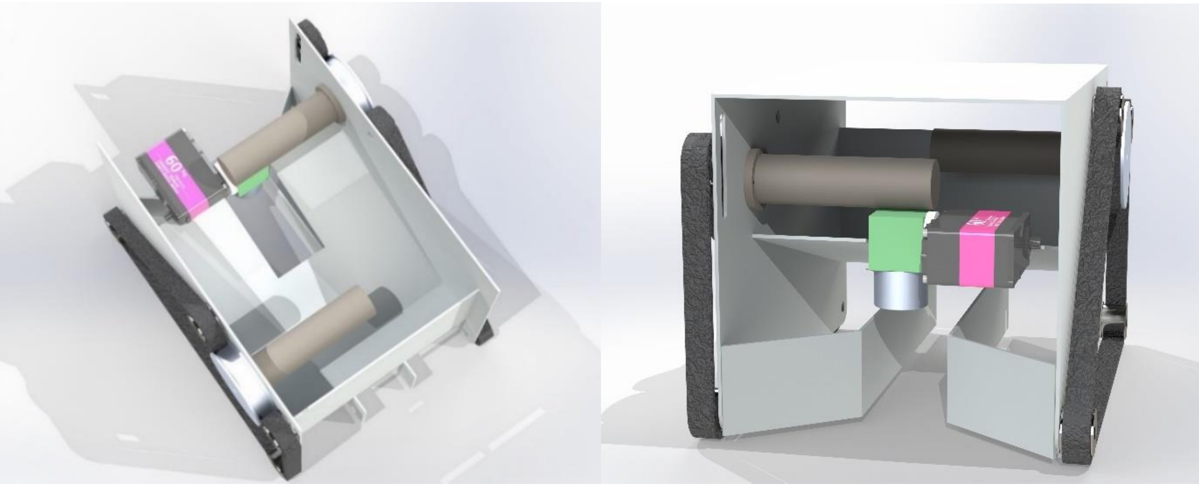

Figure 2 Basic Cad Drawing Showing Packaging and Collection

Sensors

Ultrasonic sensors will be used for general forward navigation therefore being positioned higher than any target weight or ramp Shown in Figure 3. They will be placed in a semi-circle fashion to gain directional information; this array will allow for distinction of different objects such as corners or poles and their relative positioning. Inferred sensors are shown in red and are placed along the side of the robot this will allow for wall distance and angle to be calculated.
For locating the target weight, a servo motor will rotate 2 time of flight (TOF) sensors to create a DIY 3D lidar sensor. By using 2 layers one at 60mm off the ground and the other above 70 mm it will allow for negating the 2 signals, to give a map of the standing up target weights in the arena. Individual TOF sensors could be added in locations that are deemed useful. TOF sensors have the narrowest field of view, and the highest accuracy so are best suited for the target weight detection.

For detecting if a weight is a target or a fake the inductive proximity sensor will used, if active due to metallic presence the weight is deemed a target. As specified in the rules fake weights could have metal embedded on top thus still able to be picked up with the electromagnet.

The colour sensor and IMU will also be used but their positioning is not critical. The colour sensor will be used to determine if the robot is on its own home base, or their opponents during play.

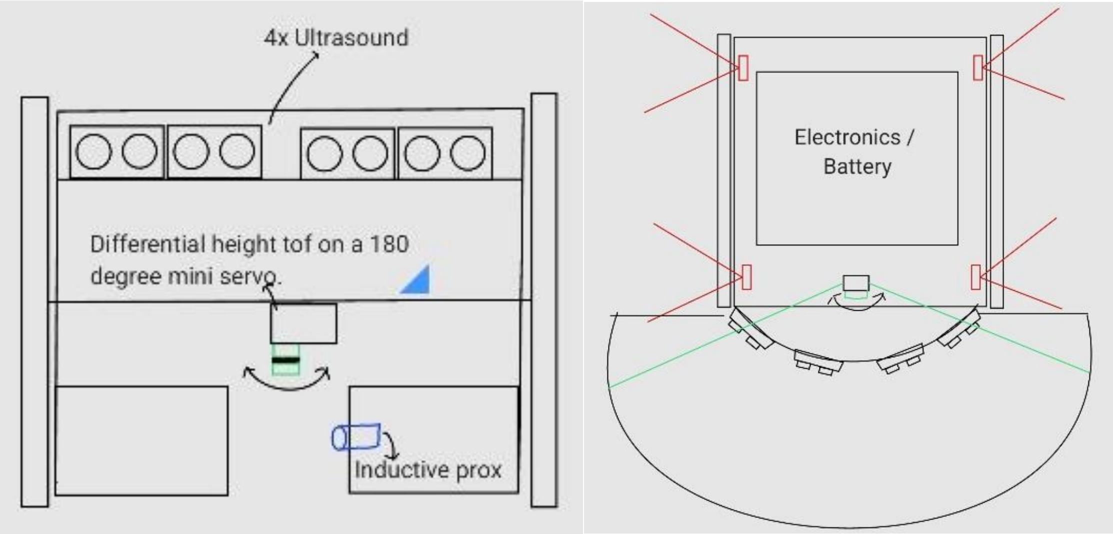

Figure 3 Sensor Layout Sketch

Proposed Concept 2 (Eric Kleiner)

Description

Concept 2 focuses on efficient collection, storage and sorting of the weights to reduce operational time pressure. The design requires 3D printing of the storage mechanism, and parts of the drive train. It also requires fabrication of the drive train guards. The key ideas are summarized in the sketch shown in Figure 4. The design tries to compromise between simplicity and more complicated concepts for efficient operation.

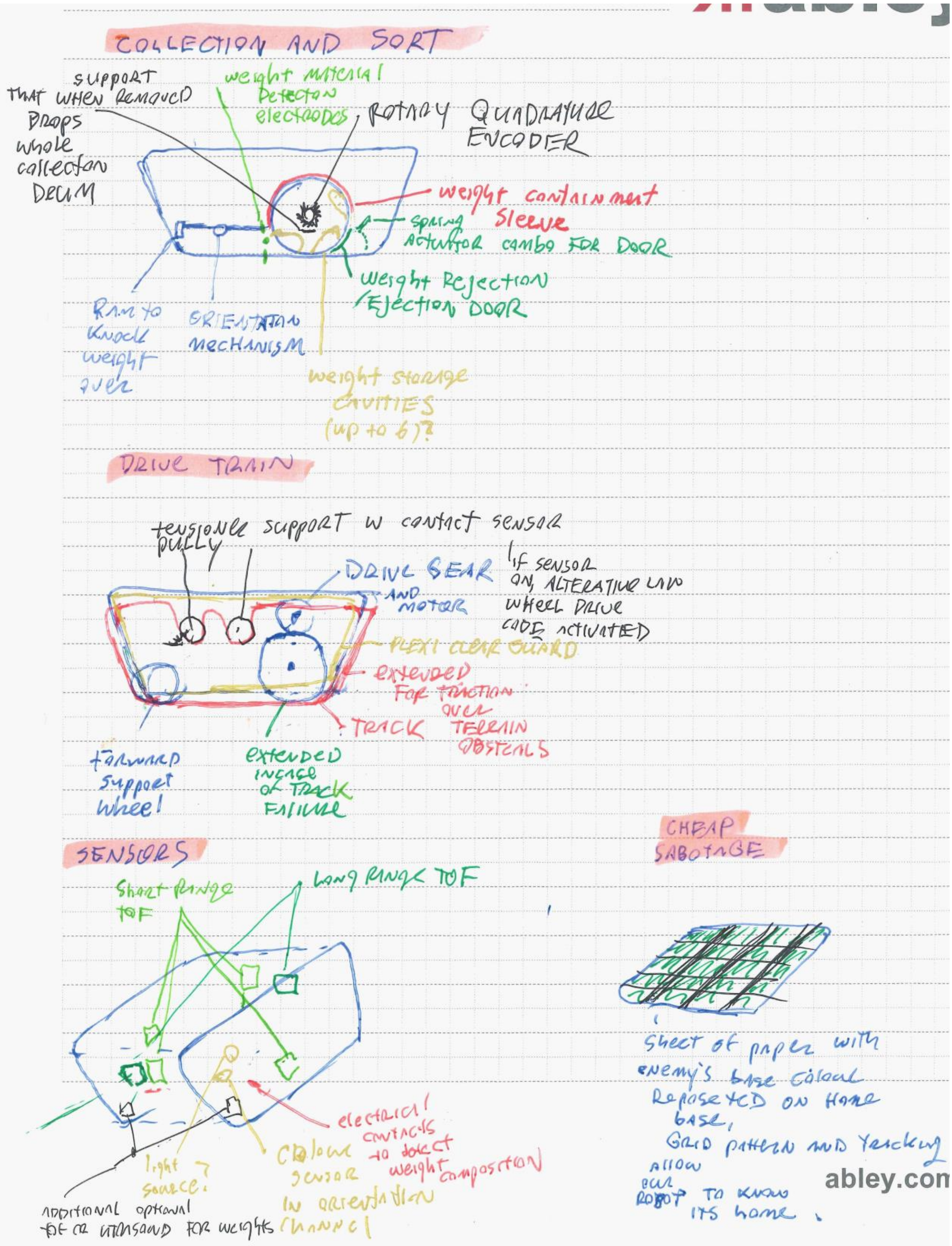

Figure 4: Concept overlay for drum storage-based robot.

Chassis and Drivetrain

The main chassis components provided in the competition will be used. If a smaller chassis is required, a custom chassis could be made from 3D printing. Tracks will be used for locomotion, with the track guides organized in a way that will allow operation if a track were to fail.

The drivetrain will be protected by a Plexi shield. This will help ensure that other robots or obstacles cannot interfere or tangle the drive train system. The tracks and its drive system will protrude slightly from the underside, front and back of the robot. The forwards and back protrusion of approximately 2 cm will allow for z axis traction on non-flat obstacles. The slight lower protrusion allows for the drive pulleys to function as a surrogate drive wheel should the track fail. A frictional coating on these pulleys will act as tyres to reduce vehicle slip. The drive motors will be positioned above the main rear track pulleys and will be driven by gearing. Tensioner pulleys will be used to ensure smooth operation.

Weight Collection and Release

First weights will be knocked over on their side by a bar that protrudes from the mouth of the robot. They will then be oriented lengthwise by their passage through a sorting channel as the robot moves forward. The channel will have either a protrusion or a spinning object with a decent friction coefficient to ensure proper lengthwise orientation. The weights will then enter a revolving collector/ storage device.

The collection/storage device will be akin to a revolver's barrel drum oriented sideways. Cut outs in the drum allow for the weights to be harvested and cradled for storage. The motor driven drum will rotate to scoop up the weights as the robot's forward momentum drives them in to the weight shaped cutouts. The drum will then rotate backwards and allow the next cutout to be ready for weight collection. The drum will be surrounded by a sleeve that ensures that the weights are contained. As the collected weight spins backwards a servo and spring trap door will open at the bottom of the sleeve. This allows for instant rejection of a dummy weight after detection, it additionally allows for the drum to spin and easily release all the collected weights at the robot's home base when the drum's storage is at capacity. The position of the drum will be tracked with the provided rotary encoder.

If required, it will be possible to drop the entire drum assembly onto the home base pad for rapid weight removal or added manoeuvrability. The whole drum unit will be held by a support that prevents the central axis of the drum from dropping.

Sensors

As weights are collected, they will pass by a pair of protruding electrical contacts, measuring the conductivity to assist in determining their material makeup. It will also act as a counter signal to tell the robot how many weights are onboard.

Home base detection and additional colour screening of weights will be done via the TCS3472 colour sensor. The sensor is placed in the forward weight sorting channel giving an optimal protected location for its dual-purpose roll.

Navigation is conducted with a combination of the provided long and short range TOF sensors on the front and back of the robot. These sensors will be mounted higher up on the chassis. Additional coverage is provided by two short range TOF sensors on the sides of the chassis. The data from the TOF sensor coverage can be compiled to provide a simplistic model of operating environment.

In the event that a track should fail, a limit switch would trigger if the spring-loaded tensioner pully hits its own mounting limit. This allows for the robot degrade control law to a wheel driven alternative for functional operation.

Proposed Concept 3 (Jack Edwards)

Description

Concept 3 also focuses on having a small footprint and the ability to drive over weights, this aims to prevent non-target weights from getting stuck in front or under the robot. This design requires custom frame plates but uses only the given pulleys, motors and sensors. Small 3D printed parts will be used for actuator arms and storage rails. Sketches have been used to help convey how the robot will be put together in terms of sensor and actuator placement and choice and general layout of the robot.

Chassis and Drivetrain

Concept 3 uses a classical belt drive between 2 side plates. To reduce the footprint of the design custom plates with custom belt paths are used. The plates for each side are the slightly different with the motors being offset to allow a reduced width of approximately 220mm and an approximate length of 320mm. The drive belt will be positioned with the flat side of the belt down due to testing showing the flat side had far better traction. The tracks will also have a shielding placed around them as to protect them from any unexpected collisions from other robots or walls.

The 143-rpm encoded motor will drive the belt on the flat side to ensure the best traction and be positioned to have a large surface area, this reduces slippage and will be crucial to the useability of the encoder data for ensuring precise navigation. There is a slot in the middle belt guides to allow for tensioning.

The sides of the chassis will be held together by structural beams near the top of the front and middle of the back with parts of a top tray also helping with electronics housed in the sides.

Weight Collection and Release

For weight collection the robot will drive over the weight, centring it for a claw positioned to pick up the weight from the angular grove. The claw will be mounted with a 3D printed arm to the large servo (RDS5160). This will then be able to pivot weight up through the robot where the weight slides down the storage rails which will be lined up with the claw.

To release the weights the gate at the end of the rails will be rotated outwards be another servo (HX12K). The gate and rails for the storage will be 3D printed and the rails will be attached to the top of the passageway walls.

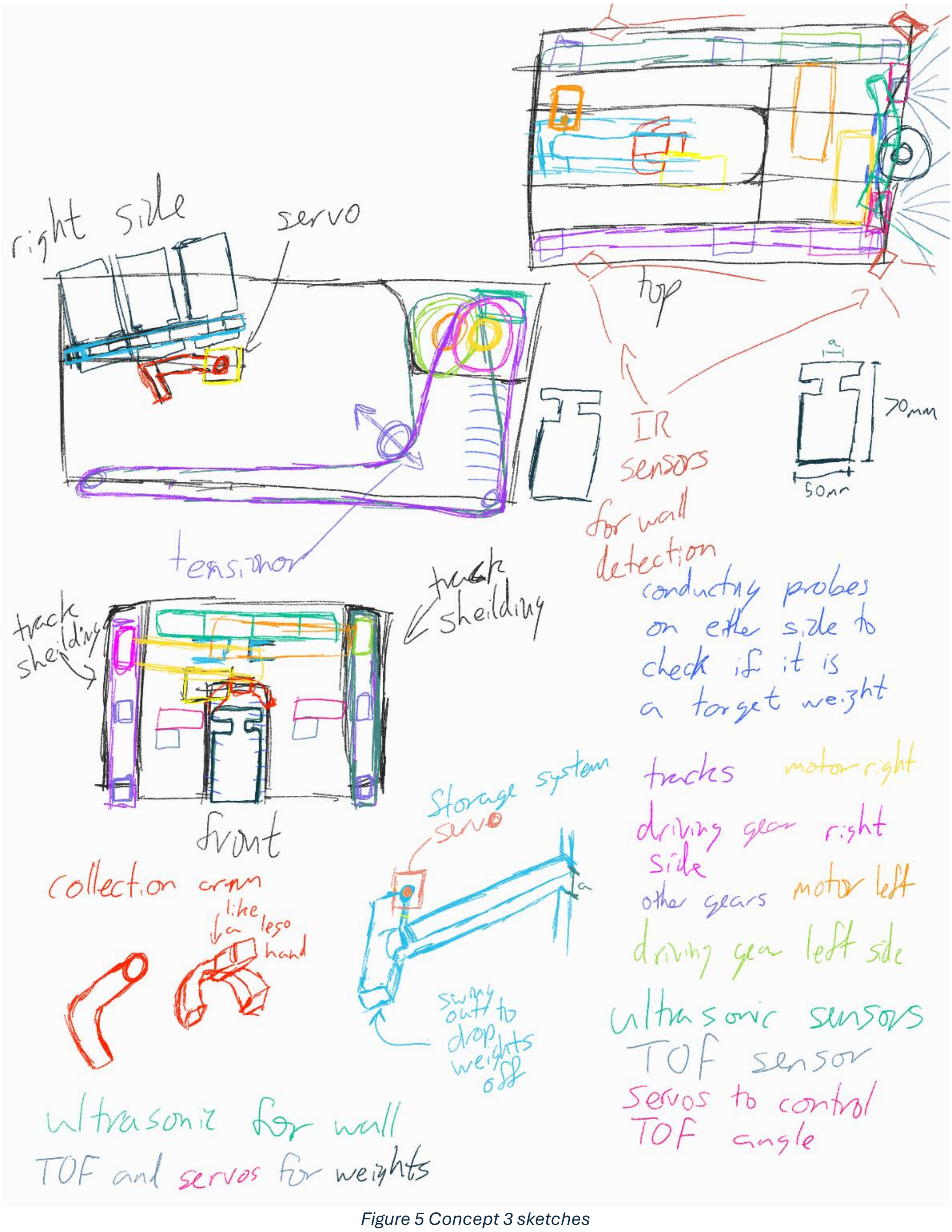

Figure 5 Concept 3 sketches

Sensors

Ultrasonic sensors will be used for general forward navigation therefore being positioned higher than any target weight or ramp. They will be placed in a semi-circle fashion to gain directional information; this array will allow for distinction of different objects such as corners or poles and their relative positioning. Inferred sensors are

shown in red-orange and are placed along the side of the robot this will allow for wall distance and angle to be calculated.
For locating the target weight, two servo motors will rotate a time of flight (TOF) sensor each to create a DIY 2D lidar sensor. By using 2 sensors it will allow for exact positioning of weights with them being at a height of 60mm which when compared to the ultrasonic sensors will give a map of all weights which are standing in the arena. More individual TOF sensors could be added in locations that are deemed useful. TOF sensors have the narrowest field of view, and the highest accuracy so are best suited for the target weight detection.

For detecting if a weight is a target or a fake a surface conductivity test will used, if active due to a conductive connection is made the weight is consider a target. As specified by the rules the fake weights are made with a nonconductive material on the outside meaning surface conductivity is the most sure-fire way of detecting if a weight is a target weight or not.

The colour sensor and IMU will also be used but their positioning is not critical. The colour sensor will be used to determine if the robot is on its own home base, or their opponents during play.

Concept Evaluation

Our figures of merit have been chosen from measurable requirements and the ability to construct and maintain our robot focusing on simplicity. These criteria were influenced by watching previous years rounds and noticing that the difference in performance was largely dependent on the software of the robot. Specifically, its ability to path find to weights avoid obstacles and return to its home base reliably. Therefore, the simplest fastest mechanical design to get functioning will give the greatest amount of time to refine software. Additionally, metrics that relate to the time of taken to get to the weight and pick it up are vital as this is a heavily time limited competition.

Figures of Merit Evaluation

Criteria	Weighting	Concept 1		Concept 2		Concept 3	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Ease of Construction							
Number of Kit Parts (excluding sensors and electronics)	-0.2	10	-2	5	-1	14	-2.8
Number of Parts not in Kit	-0.5	6	-3	6	-3	6	-3
Average Difficulty of Manufacture	-2	1	-2	2	-4	1	-2
Difficulty of Assembly	-1	2	-2	3	-3	2.5	-2.5
Repairability							
Complexity	-2	3	-6	4	-8	3.5	-7
Reliability	2	3	6	3	6	3	6
Agility							
Speed in (m/s)	8	0.5	4	0.5	4	0.5	4
Size (largest of width or length in metres)	-5	0.281	-1.4	0.320	-1.6	0.320	-1.6
Weight Collection							
Time to Collect (seconds)	-2	4	-8	1.5	-3	4	-8
Accuracy of Target Weight Detection	4	0.9	3.6	1	4	0.8	3.2
Accuracy of Weight Collection	4	0.7	2.8	1	4	0.8	3.2
Total			**-8**		**-5.6**		**-10.5**

Table 1 Figure of Merit Table

Concept 2 scores best on the figure of merit table, Table 1 due to its fast weight collection time and high target weight detection accuracy. This is a good general indication of this designs relative performance but there is plenty of space for improvement in our final design. Sensors and software have been left out of the table as these are not discission that need to be made yet as they are largely design independent. Some areas that could be improved in general is the ability to pick up weights that are already knocked over as only concept 2 can do this but at the cost of complexity. The ability to pick up weights that are against a wall or obstacle is a weak point of all these designs. Concept 2 uses some innovative methods for storing and collecting the weight that make it very fast not having to stop to secure the target weight with only a 1.5 second weight between collections. Concept 2 does have the highest complexity but due to the use of a 3d printed barrel prototyping can still be fast and effective. All of these designs have the ability to reject non target weights without having to reverse back simplifying programming.

Conclusion and Recommendations

The evaluation matrix gives a ranking of the three concepts with concept two scoring the highest mark of -5.6. This suggests that concept two is the best design to continue developing in detail. However, concept one was only 2.4 points lower than concept two with concept three only being 4.9 points lower than concept two. This shows that concept one is still a viable concept at this stage. Further design stages should be completed for these concepts before choosing a final concept.

The best approach would be to combine the best qualities from each concept in a cohesive manner. This can be done by adding concept two's sabotage method onto the other robots and potential adapting the other designs to be able to pick up weights when knocked over like concept two. The wall detection of concept one and three gives the most likely outcome to give accurate and quick analysis of the surrounding arena. The resulting design would result in a design that would be better then any concept by themselves.

Contributions

Digby Eele

- Concept 1
- Requirements
- Figures of Merit Table and Concept Evaluation
- Electromagnet and Sensor Testing

Jack Edwards

- Concept 3
- Introduction
- Conclusion and Recommendations

Eric Kleiner

- Concept 2
- Requirements
- Conclusion and Recommendations