Robocup
Conceptual Design Report

Group 4

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ENMT301

Mechatronics System Design

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Contents

Introduction

The 2025 Robocup Challenge is a project in which the 3rd year mechatronics cohort will design, test and compete against one another with autonomous robots in a double-elimination format. These robots will need to navigate a 2.4 x 4.9 metre arena filled with unknown obstacles in order to pick up target weights to gain points and then drop these off at the home base to double the points. However, only a maximum of 2 weights can be possessed by a robot at the end of the round. All while rejecting fake weights that will subtract points from the team if their robot picks them up. A special object called the “Snitch” will also be roaming the arena at high speeds (up to 7 m/s). But if picked up, it will grant three target weights worth of points, offering a major boon to the lucky team that manages to collect it.

This report will document the research, requirements of the robot and evaluation of some potential concepts. Research will occur by analysing past competitions, using the videos and statistics provided. Key events, as well as successful mechanisms and designs, will be recorded. Requirements will be generated based on the competition rules. Potential concepts will be brainstormed using a combination of research and requirements. These will be tested to compare the concepts and check the suitability of components. The requirements will then be used to evaluate the concepts and provide a recommended solution.

Research

For research, the 2024 Robocup competition was reviewed in its entirety. This is because there was only one rule change, that the maximum number of target weights on board decreased from three to two and the penalty for going over this limit was reduced from -2 to -1. In review of 2024, each video was watched, with the weights on board, weights at base, pickup mechanisms, distance travelled and notable features being recorded. Out of 67 rounds, rounds 4 and 59 were not included in the stats due to footage quality. Full results are found in Appendix A.

One notable feature of the 2024 Robocup was that out of the 34 robots competing, 33 (97%) of the robots used tracks. Robot number 33 used omnidirectional wheels as its form of movement. It did not win any rounds. The reason all competitors used tracks is believed to be due to the materials provided having a simple setup for tracks, as well as the added features of more traction and better stability. However, it was noted in Round 43, robot 31 had a track come off the bearings and motor, resulting in a loss of movement. A potential solution to this problem is to include an extra guide to stop the track from falling off, such as the ones used by the 2024 winners, robot number 1. This design is shown in Figure 1 and uses an interference fit to connect to the hex head bolts. This feature also doubles as protection for the robot in case of knocking into an obstacle or opponent.

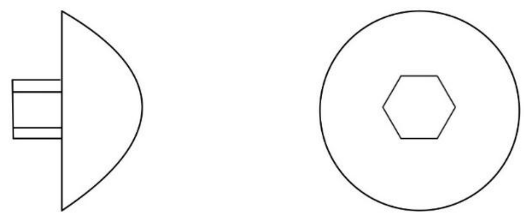

Figure 1: 2024 robot number 1's track derailment protection.

A key result from the 2024 Robocup was that out of the 65 rounds watched, the robot that travelled further won 53 of these rounds, resulting in an 81% win rate. It was also noted that the robot that travelled further in the first five seconds of the round won on 41 occasions, resulting in a 63% win rate. This means that the mobility of the robot is an important aspect in winning. However, robot number 2 was noted to be too quick in picking up weights, often colliding with them at a quick speed and then using its scoop too late, resulting in the weight bouncing off the front of the robot and rolling away. Finding the balance between speed around the course and the success rate of picking up weights will be an important factor in winning.

In round 32 of the 2024 Robocup, it was noticed that robot 11 might have had trouble getting past the dummy weight in a narrow channel. The layout of the arena is shown in Figure 2, and the only way to get to the far side of the arena is to go past the dummy weights. Robot 11's method to avoid the dummy weights was to sense that they weren't target weights and then drive around them. In this case, there was no possible room to go around the weights, so the robot continuously backed up and tried to go past the weight repetitively.

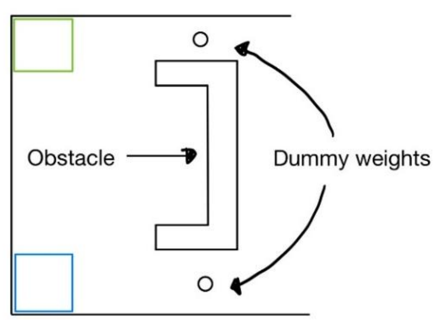

Figure 2: Arena layout for round 32.

Another notable design is seen in the 2020 competition on robot 20, which featured “legs” of a sort. This was done by having members with bearings on the end that were attached and reached down further than the base of the metal body of the robot, allowing for a buffer space of sorts between the tracks and the frame (Figure 3). This extra space allowed for the ability to handle larger disruptions in the terrain, like that which would be seen on a bump. These are most encountered on the initial bump in the arena, which borders the starting areas. The ramp also creates difficult terrain and was sometimes included in the obstacles for the arena. In the past, this ramp caused great issues for some robots, as tracks would deflect too much and cause the chassis to get caught on the surface. Thus, the extra clearance provided by this design feature provides an advantage in these cases.

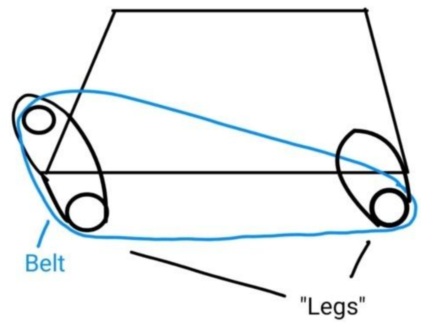

Figure 3: Extended Track Belt design

A notable feature of the 2019 RoboCup winner, specifically during Round 21, was the apparent use of a watchdog timer. Midway through the round, the robot became stuck on a ramp. After approximately five seconds of inactivity, the robot automatically reversed, freeing itself and allowing the round to continue. This behavior strongly suggests the implementation of a watchdog mechanism designed to detect when the robot is no longer making progress and initiate a recovery action. Several methods can be used to detect real time movement. These include the use of an accelerometer, downward facing optical sensors or a spring-loaded limit switch.

A common feature among all robots was the use of a storage system for collecting and retaining weights. While some teams implemented complex mechanisms, one effective design observed was a simple “open belly” configuration. In this approach, weights were dragged along the floor into an open cavity beneath the robot (Figure 4). This minimalist design proved highly reliable and efficient, as it reduced the number of moving parts and minimized the likelihood of mechanical failure. Additionally, once the weight was secured, a basic mechanical system often guided it into a designated storage area. This simplicity not only improved overall robustness but also reduced the robot’s weight. Reducing weight is an important consideration in the event of a tie-on points; in this situation the lighter robot wins the round. Despite these benefits, there is one major flaw in this approach. If the robot does not return the weights to “home” in time, the points will not be awarded, as the weights are still on the floor and technically not collected.

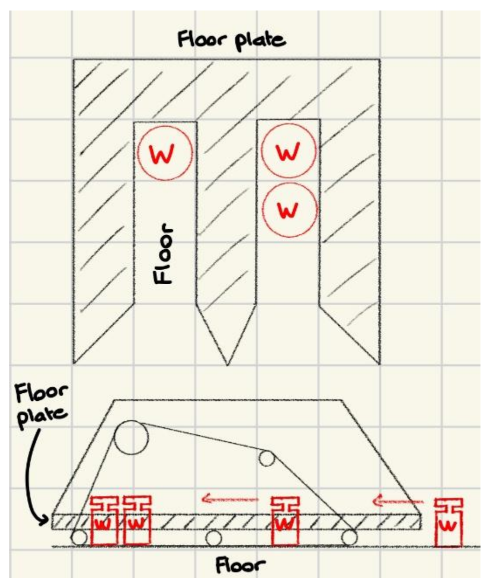

Figure 4: Open belly design

Requirements

Performance Requirements

1.1 The robot shall pick up weights of up to 1kg in weight.

1.2 The robot shall pick weights in all orientations.

1.3 The robot shall move the weights.

1.4 The robot shall be capable of dropping weights.

1.5 The robot should have a method of wall detection in at least three directions.

1.6 The robot should have the ability to move around the arena, avoiding obstacles, the opposition robot, walls, weights and the snitch.

1.7 The robot should not 'capture' any weights from:

- 1.7.1 its own base.
- 1.7.2 the opponent's base.

1.8 The robot shall be unable to drop a weight if it is considered 'on board'.

1.9 The robot shall be capable of travelling 4.9m in 20 seconds. **Rationale:** The arena length is 4.9m and the total round time is two minutes.

1.10 The robot shall be capable of turning within a 0.4m diameter circle. **Rationale:** The minimum gap between walls is 0.4m.

1.11 The robot shall be able to travel up a gradient of 30 degrees. **Rationale:** The arena has obstacles with a gradient of 30 degrees.

1.12 The robot shall be capable of travelling over a 25mm 'speed bump'. **Rationale:** The arena has 'speed bumps' with a profile of 25mm higher than the arena floor.

1.13 Weights shall not be picked up if in the other robot's home base. **Rationale:** Thieving robots incur a penalty that the weight is worth.

1.14 The robot should be capable of picking up the snitch.

1.15 The robot shall have storage for the snitch.

1.16 The robot shall not leave the arena during a round.

1.17 The robot shall have a 'watchdog timer' that stops repetitive functions from occurring if they occur for 10 seconds.

1.18 The robot shall have a method of dummy weight detection OR the robot shall have an 80% success rate of dropping the weights at the home base. **Rationale:** On board dummy weights have a penalty rate of 0.25, but there is no penalty for dropping dummy weights at the home base.

Non-performance based requirements.

2.1 The robot shall withstand being hit by the opposition robot or bumping into a wall.

2.2 The robot shall be modularized.

2.3 Wires shall be managed with tape or a drag chain and placed away from moving parts. **Rationale:** Ensures wires aren't disconnected.

2.4 The robot should take less than 45 minutes to assemble/ disassemble.

Proposed concepts

Concept Design One: Luka's Design

This design originally stemmed from the idea of how a train switches tracks; by actuating a movable section of the pathway, the object travelling it is rerouted. To facilitate this functionality and pick up weights of either type, a combine harvester is optimal as it can collect regardless of orientation. This provides flexibility when the object in question has been knocked over, which is likely. Combining the harvester with a funnel ensures the correct orientation of the weight once it has been collected. An inductive proximity sensor positioned to the side of the weight should be able to efficiently determine if the weight is made of plastic (dummy weight) or metal (target weight). After this has been determined the weight slides down a declined plane in the robot, the "track-switcher" will direct the weight either out the rear of the robot, or into a cavity to be held if it is a target weight. This cavity will have a bottom wall that can be rotated to release the weights onto the home-base.

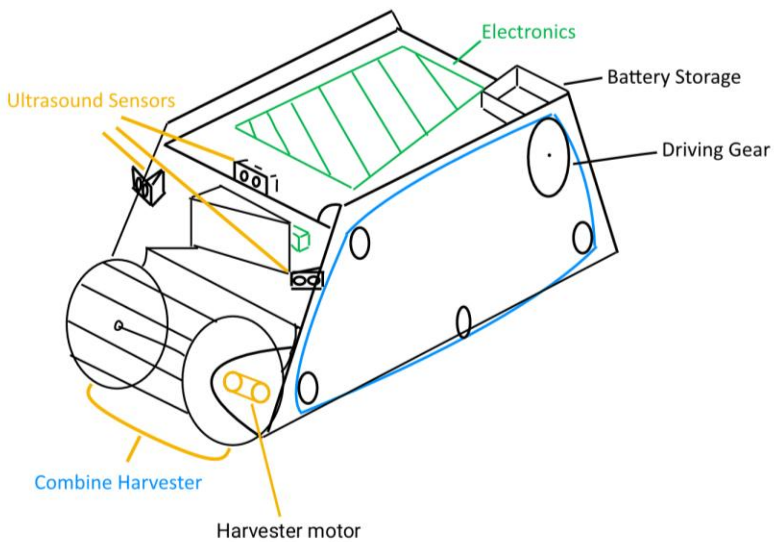

Figure 5: Isometric Design Overview (Not to scale)

An isometric view of the design is shown in Figure 5. The robot is propelled by belt tracks driven by motor-powered gears at the upper rear corners. This provides strong surface friction due to the large contact area with the ground. This increased surface area helps the robot maintain mobility even with incomplete contact with the ground. A significant advantage of belt tracks is either can be independently modulated to allow directional control, including "tank turning" where the robot pivots on its center, ensuring agility in tight spaces. A support bearing behind the track helps prevent deflection from pointed loads (e.g., a ramp or ledge), improving stability on uneven terrain and reducing the chance of getting stuck.

The shape of the robot is largely based on the default frame design provided by Julian Murphy, using the standard plates. Custom parts are added to mount sensors, construct the combine mechanism, and form the internal alignment wall.

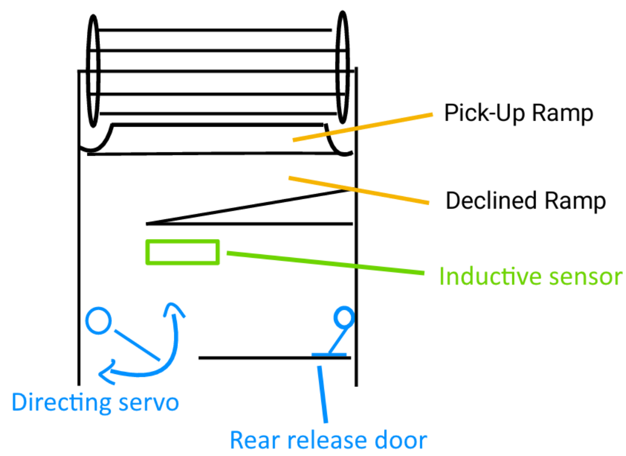

Figure 6: Birds-eye Cross-sectional View (Not to scale)

Weights are collected through a rotating drum with elastic crossbars, inspired by agricultural combine harvesters. As it rotates, it scoops up any contacted weight, target or dummy. The elastic crossbars can flex to accommodate awkward positions, improving pickup reliability, and in the case of a jam, provides enough give to reduce risk by bending or breaking instead of stressing the motors. Once a weight is caught, it's lifted onto a ramp and deposited onto the raised, declined floor of the robot. Once inside, the weight first encounters an angled alignment wall that guides the weight into the proper orientation for identification and routing. This area has the space to hold up to three weights at most, which is more than sufficient given the low probability of a high-density pickup.

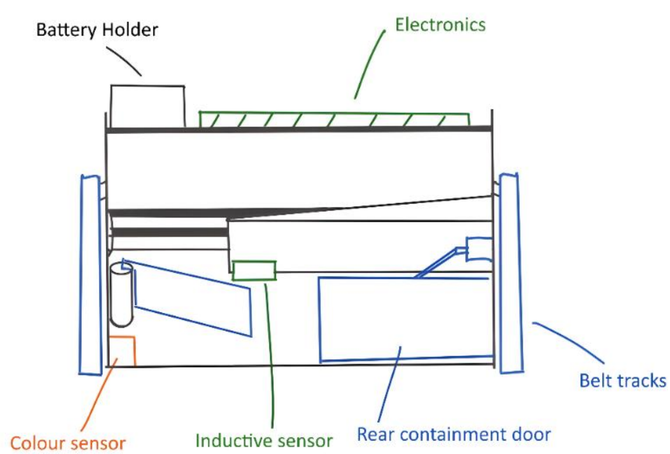

Figure 7: Rear View Diagram (Figure not to scale)

As a weight slides down the slope, it passes an inductive proximity sensor near its path. This sensor is only triggered by metal, and thus only by valid target weights. If undetected, the weight simply exits the robot through the rear. If triggered, the sensor sends a signal to a servo to move a barrier arm which redirects the weight into a storage cavity. This is sized to hold two target weights, matching competition rules. A final servo, is positioned to release the stored weights when actuated. This is triggered when the colour sensor detects the base colour as recorded during the beginning of the math.

The navigation of this design is done through the proven “follow-the-left-wall” maze strategy. This allows for wide arena coverage and embeds return-to-base in its path. Due to the nature of this design the range in which it can run into weights is limited to those close to a wall. This could cause the robot to not collect more weights after the first loop. Though the arena is small enough that this range covers the majority.

Concept Design Two: Hayden’s Design

This design incorporates a simple pickup mechanism to entirely focus on its movement and navigation, to maximize its weight picking up chances. Figure 8 shows the full robot layout and Figure 9 shows the functional architecture diagram.

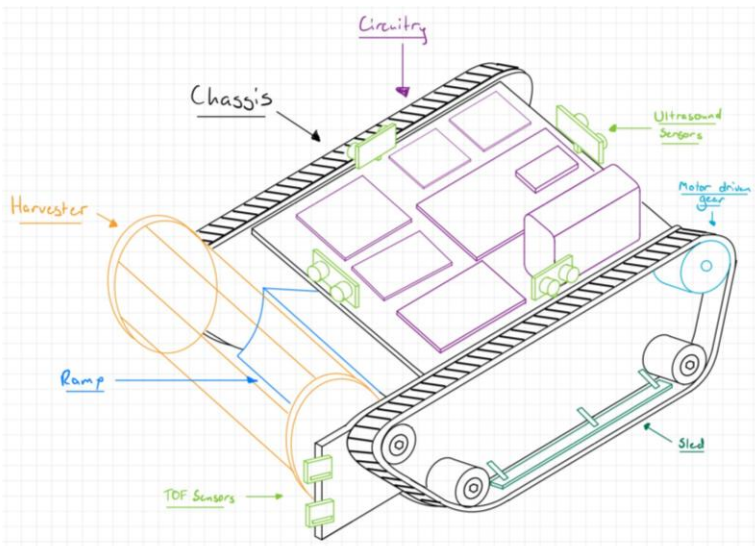

Figure 8: Sketch of robot (Hayden’s design).

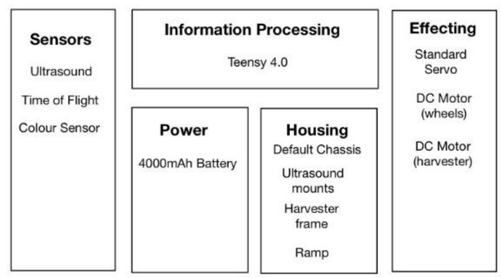

Figure 9: Functional Architecture diagram (Hayden’s design)

The default chassis is used due to its simplicity and ease of attaching the tracks. A PLA cover is placed on the track bearings, extending over the sides of the tracks. The extra protection that this will provide will ensure that the belts don’t slide off when under a high amount of force, resulting in the ability to ‘tank turn’. This means that the robot can turn on the spot, allowing the robot to escape enclosed spaces, whilst maximizing its size. A sled styled guide is also used to ensure tension consistently along the tracks.

This design doesn’t discriminate between weights due to its reliance on navigation. This means that the robot picks up all weights and relies on dropping them at its home base, because of the lack of penalty on dummy weights in the home base. However, to spot weights, two TOF sensors are placed at heights of 50cm and 100cm off the ground on each side of the robot and are used to identify weights. Detection is shown in Figure 10.

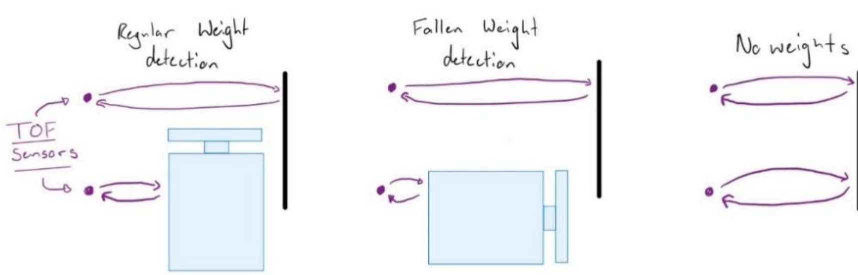

Figure 10: Weight detection using TOF sensors.

The harvester will use rubber bands as crossbars, due to the flexibility they provide. It will use a lifting force up a curved ramp and over a point, into the sloped storage backed by a door. The door can be actuated by a servo. The roof of this space is similarly sloped to provide space for the main motors of the robot. The opening is only 50cm high (Figure 11), accounting for the size of the snitch being 73cm, resulting in the snitch getting trapped on board while allowing the weights (being side on) to roll out. The gap between the center of the harvester and the ramp is ~80cm to allow for both the snitch and weights to be caught.

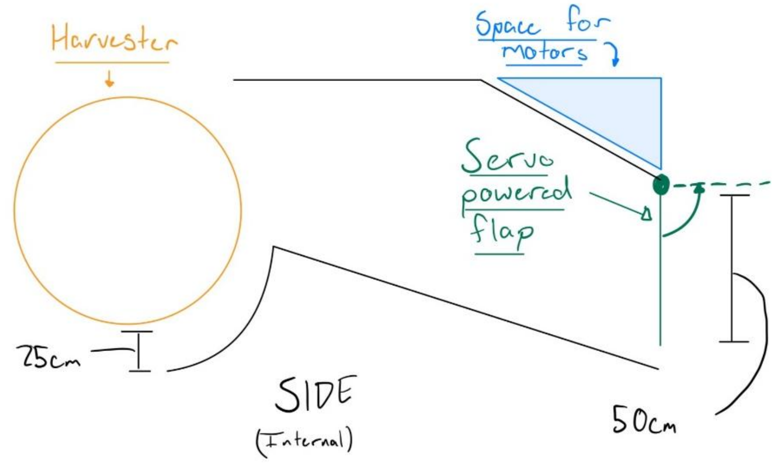

Figure 11: Side on view of the internal storage.

In this robot, a measurement wheel is centrally placed in the underbody of the robot. This is a custom-made castor wheel with two quadrature encoders built into it, in order to track the rotations of the wheel and the angle the wheel is on (Figure 12). This combination of tracking of the rotation and angle will allow the distance travelled to be calculated. The top rotation encoder records the angle and tracks it. With these two features combined, the motion of the robot can be recorded and relied upon for accurate robot tracking and navigation.

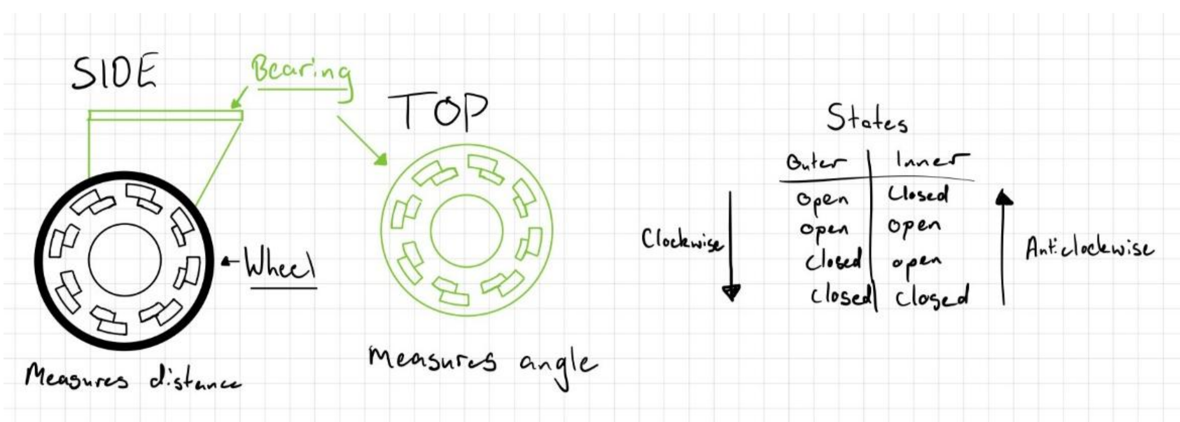

Figure 12: Sketches of the measurement wheel and results from encoder readings.

Robot navigation relies upon a coordinate-based system to track and store the location of the robot and surrounding obstacles. The arena will be segmented into sections and stored in the microcontroller as a nested array. Four ultrasound distance sensors are used in the four directions based on the robot, pointing forward, backward, left and right. Initial position can be identified by the starting positions surrounding obstacle conditions, allowing the robot to know its exact starting position and thus the dimensions of the main walls. Figure 13 shows the robot in a location on the map and shows the ultrasound sensor readings.

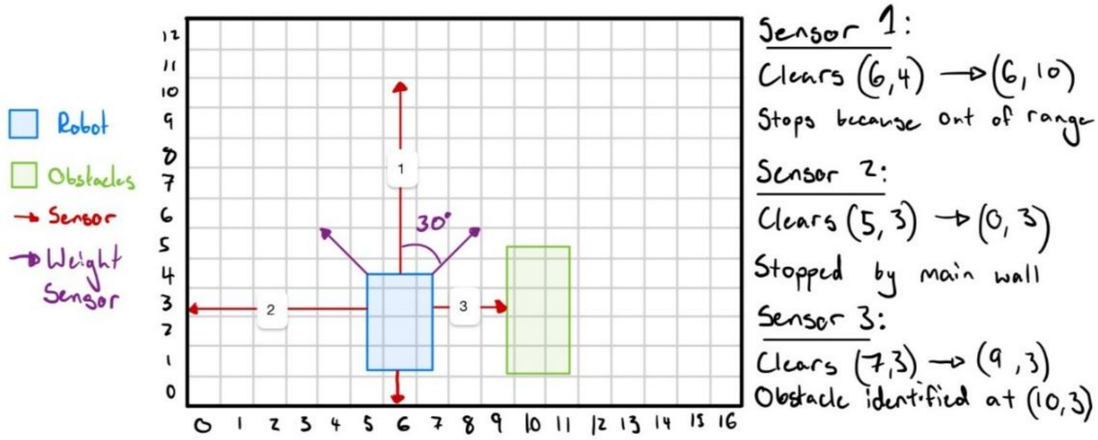

Figure 13: Robot obstacle identification.

Travel will follow a "hand on wall" method, where a wall will be followed (left if starting in the left corner, right if starting in the right corner). Initial corner identification is shown in Figure 14. Some examples of arena coverage (with no movement towards identified weights) on the 2024 arena layouts are shown in Figure 15.

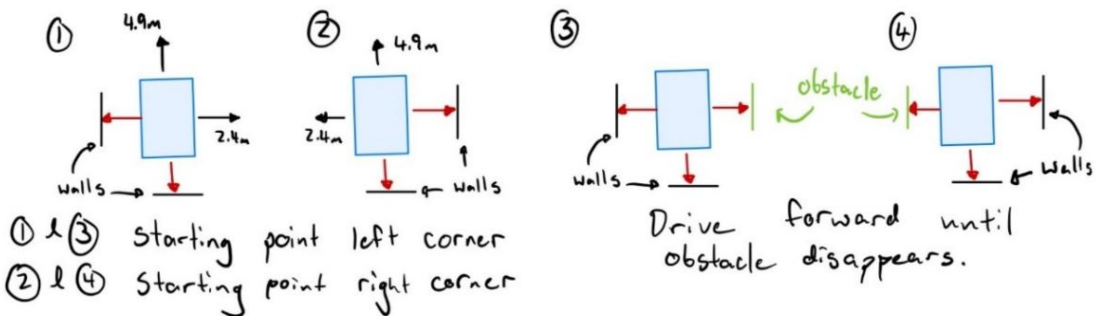

Figure 14: Home base corner identification.

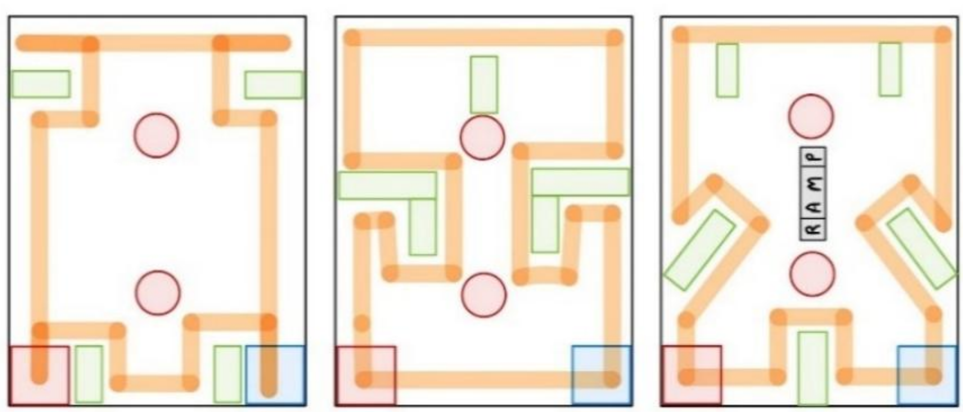

Figure 15: 2024 "hand on wall" navigation course coverage.

Concept Design Three: Conner’s Design

This robot features a front-mounted claw mechanism designed to identify and manage both real and fake weights. This claw system operates in four distinct modes: *searching*, *detecting*, *acceptance*, and *rejection*. Each claw arm is independently actuated by an individual motor, allowing for precise angular positioning based on the current mode. Figure 16 shows the robot's layout and claw design.

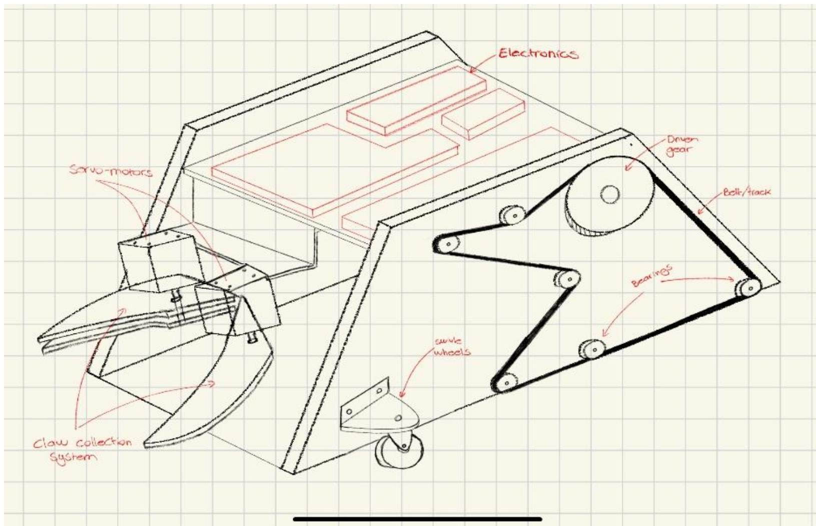

Figure 16: Isometric View of Conners Robot.

In *searching mode*, the claws are open in a fixed position. Once a weight’s encountered, the robot enters *detection mode*, where sensors determine whether the item is a real or dummy weight. If a dummy weight is detected, the robot switches to *rejection mode*, wherein the claws rotate outward to form a forward-facing wedge or “snow plough,” actively pushing the dummy weight aside. Following this, the system reverts to *searching mode* to resume searching. Conversely, when a real weight is detected, the robot transitions to *acceptance mode*.

In *acceptance mode*, the claws rotate inward continuously, guiding the weight up an internally sloped floor at the front of the chassis. Once over the crest of this incline, the weight slides down into an angled internal storage area that securely holds it for the remainder of the round. This passive ramp-based system minimizes the need for active sorting, reducing mechanical complexity while ensuring reliable collection. The position of the claw for each state can be seen in Figure 17.

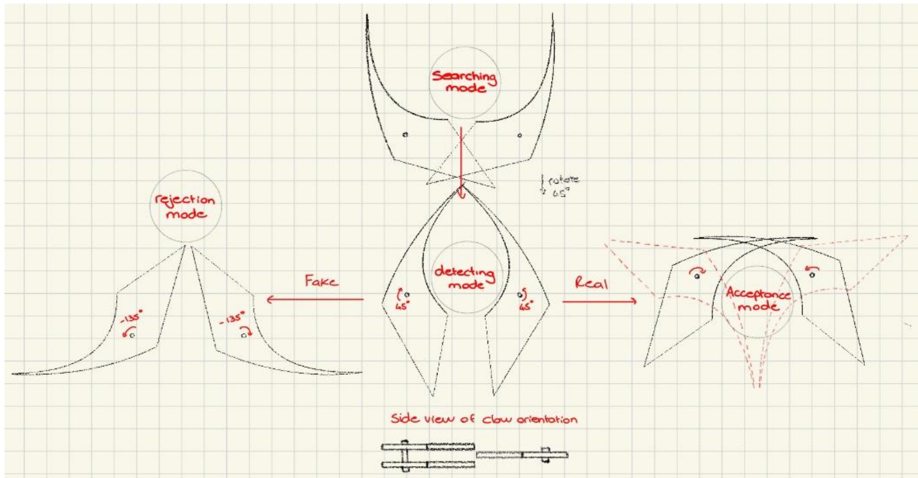

Figure 17: Claw orientation for each state/mode.

To transition from searching to detecting mode, an infrared (IR) sensor will be positioned between the claw controlling servo motors to identify when an object enters the claw area. In detecting mode, the robot distinguishes between real and fake weights. This is achieved using an inductive proximity sensor embedded within the angled ramp, which is constructed from PLA to prevent interference. This configuration enables fast and reliable classification of weights. The orientation and placement of both the IR and inductive sensor are shown in Figure 18.

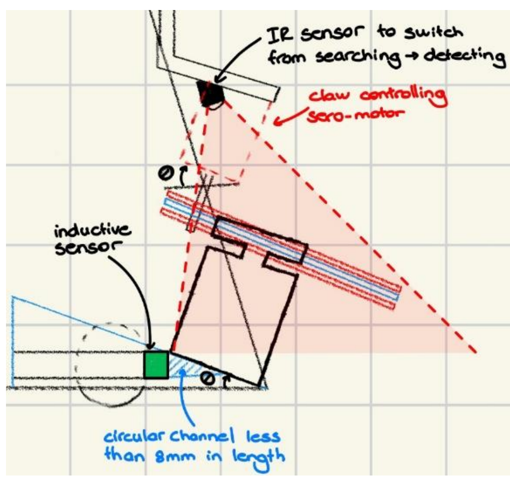

Figure 18: IR and inductive proximity sensor location.

For navigation, the robot will utilize Time-of-Flight (ToF) sensors to detect walls and maneuver through the course environment. These ToF sensors are positioned to face outward from multiple sides of the robot, allowing for accurate distance measurements to nearby walls and obstacles. By continuously polling these sensors, the robot can maintain a consistent distance from walls and adapt its path in real time to avoid collisions or becoming stuck. As a result of using a simplistic navigation strategy, the design does not include the functionality to return collected weights to the home zone. Instead, the robot prioritizes maximum weight collection in the time available. This method is effective, as the robot is designed to identify and ignore dummy weights, eliminating the risk of incurring penalties. Collected weights are retained within the chassis on a sloped internal floor, which naturally guides them toward the rear storage area during movement, requiring no additional mechanical handling.

Mobility is achieved using a small, tracked belt system at the rear of the robot, driven by a single motor per side and tensioned with six support bearings. This compact track system provides the necessary grip and drive force for moving over both smooth surfaces and obstacles in the course. For precise movement, particularly when operating in confined areas, the front end of the robot is equipped with free-spinning “shopping cart” style swivel wheels. This combination allows the robot to maintain a tight turning radius, improving precision during navigation and alignment for weight pickup. This too can be observed in the side view seen in Figure 19.

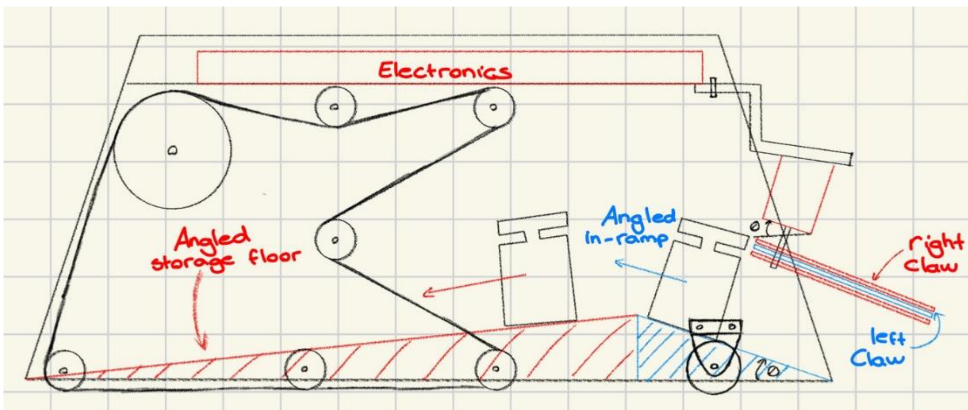

Figure 19: Side view

This design approach emphasizes simplicity, robustness, and intelligent decision-making when interacting with weights. By incorporating adaptive behavior through its claw system and a carefully angled internal structure, the robot efficiently handles both real and dummy weights without the need for complex sorting mechanisms within the robot. Movement precision and lack of weight drop-off mechanisms further contribute to the robot’s performance and reliability.

Results

Minimum Slope Angle

To test the angle for the internal slope, each weight was tested. The setup (Figure 20) used recycled sheets of laser cut MDF. These were stacked until the weights would slide down the surface. Both vertical and horizontal orientations were set up and tested. The results are shown in Table 1.

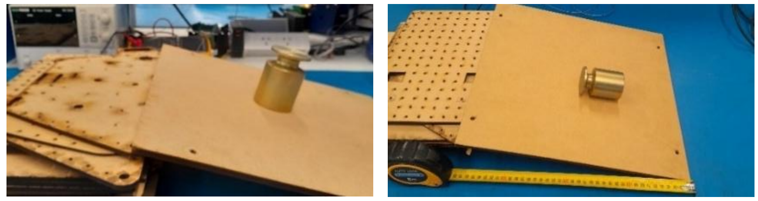

Figure 20: Testing set up for the weights on a slope. Left is testing the standing weights and right is the lying down weights.

Table 1: Resultant minimum angle for the weights to slide down an angled slope.

	Weight	**Degrees**
Standing Up	**0.5kg**	16.6
	0.75kg	13.7
	1kg	15.9
Lying sideways	**0.5kg**	14.7
	0.75kg	12.1
	1kg	11.1

From Table 1, the minimum angle for all standing up weights to slide down a slope is 16.6 degrees and the minimum angle for all sideways weights is 14.7 degrees. Note that his test was done using MDF and would differ if a different slope material were chosen. This test proves the importance that a sufficient angle, as all concepts use a sloped surface and need to fit this angled slope within the robot's length. Accounting for the length of the default chassis (200mm on the smaller side) and using all this length as a base, the minimum height required for the 16.6 degree angle would be 60mm, which makes these concepts feasible.

Inductive Sensor Testing

The Inductive sensor was used in both concepts one and three, and needed its range confirmed. To test this, each weight was placed on the bench, with the inductive sensor beside it. The weight was then carefully moved until the LED on the inductive sensor turned on. Results were recorded on both the curved edge and flat edges. The results of the test is shown in Table 2 with the testing configuration in Figure 21.

Figure 21: Inductive sensor range testing setup.

Table 2: Weight orientations and size, with inductive sensor range.

	0.5kg	**0.75kg**	**1kg**	**Minimum**
Curved	7.3mm	7.19mm	7.3mm	7.19mm
Flat	7.71mm	7.53mm	7.72mm	7.53mm

The experimental results differed from the expected 8mm the datasheet provided [1]. Once in this range, the results were consistent and reliable. Ranges less than the minimum of 7.19mm will provide accurate readings.

Belt Tension Test:

In previous years, robots in RoboCup with tank tracks often struggled with terrain, getting stuck as the belt tracks would deflect too much and cause the chassis of the robot to catch on bumps and ramps. This prompted testing of different belt layouts to counter this.

Five configurations were tested, four of which were based upon a base design of the track following the frame's perimeter using three bearings and a drive gear (Figures 22 to Figures 25). Primary variations included the addition of three more bearings. One of the bearings would increase the tension and the other two would provide extra support. With the fifth test using a "wild-card" configuration, deviating from the base design and pushing one of the corners inwards in an effort to more greatly increase tension (Figure 26).

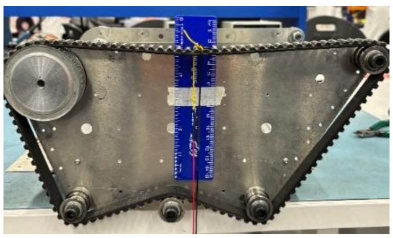

Figure 22: Belt Test 1
Extra bearing on suspended side increasing tension.

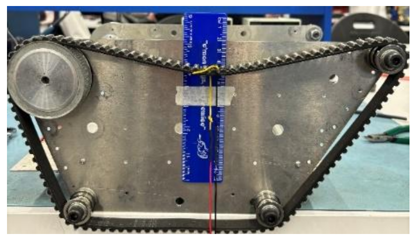

Figure 23: Belt Test 2
Simple base design.

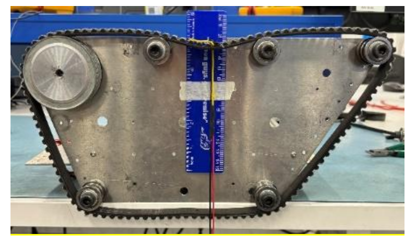

Figure 24: Belt Test 3
Two extra supporting bearings near loading site.

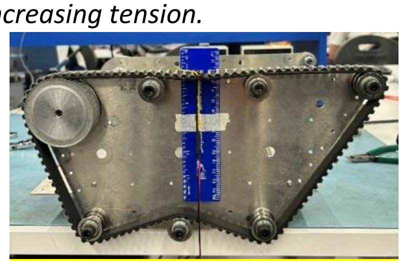

Figure 25: Belt Test 4
Two extra supporting bearings near loading site and another to increase tension.

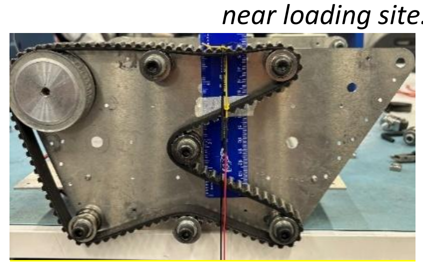

Figure 26: Belt Test 5
Zig-zag layout.

Table 3: Deflection in the belts, with a 1kg weight hanging down on the center of the belt.

Test	**Control (mm)**	**Deflection (mm)**	**Delta (mm)**	**Delta%**
1	16.0	23.5	7.5	46.9 %
2	11.0	42.0	31.0	281.8 %
3	11.0	24.0	13.0	118.2 %
4	15.0	17.0	2.0	13.3 %
5	14.0	19.0	5.0	35.7 %

The base case (test 2, Figure 23) unsurprisingly, featured the largest deflection, due to the low number of bearings. Adding a bearing to increase tension (test 1, Figure 22) had a much more substantial effect than adding two bearings to provide support to the track (test 3, Figure 24). However, it was the combination of both the tensioning and support bearings (test 4, Figure 25) that showed the lowest deflection with a delta% of 13.3%. Hence, a combination of the bearing types is required to provide significant tension.

Concept evaluation

A Field of Merit table (FOM table) was used to evaluate each concept (Table 4). Equations were made before the analysis began. The ratings in each concept were put through the equation to provide a scaled score. The scaled score used a scale factor, so that each criteria had an appropriate range. The scaled scores were summed up to produce an overall rating. Full justifications of the weightings can be found in Appendix B

Table 4: Field of Merit table.

Criteria		Concept 1			Concept 2			Concept 3		
	Weighting	Rating	Score	Total	Rating	Score	Total	Rating	Score	Total
Simplicity										
# - moving parts	0.4	4	1.6	2.44	4	1.6	3.5	4	1.6	3.05
# - sensors	0.2	3	0.6		8	1.6		6	1.2	
# - Structure components	0.01	24	0.24		30	0.3		25	0.25	
Eq: 5 - Total	Scaled score:	2.56			1.5			1.95		
Point acquisition										
P of dummy weight pickup	-0.02	0.1	-0.02	1.02	0.5	-0.01	0.67	0	0	0.96
P of weight pickup	0.92	1	0.92		0.5	0.46		1	0.92	
P of snitch pickup	0.09	0	0		0.2	0.02		0	0	
P of returning weight to base	0.39	0.3	0.12		0.5	0.20		0.1	0.04	
Eq: 7.1 * Total	Scaled score:	7.38			4.76			6.82		
Obstacle and Weight Detection										
# of TOF's	1	0	0	3	4	4	8	4	4	5
# of IRs	1	0	0		0	0		1	1	
# of ultrasounds	1	3	3		4	4		0	0	
Eq: 7/16 * Total	Scaled score:	1.31			3.5			2.19		
Movement										
Track length	0.4 – L	0.34	0.06	0.24	0.21	0.19	0.37	0.25	0.15	0.33
Track width	0.4 – W	0.22	0.18		0.22	0.18		0.22	0.18	
Eq: 20 * Total	Scaled score:	4.8			7.4			6.6		
Navigation										
Judgement call	Judgement	Poor	2	2	Good	5	5	Avg	3.5	3.5
Eq: Total	Scaled score:	2			5			3.5		
Overall rating:		18.05			22.16			21.06		

Concept one: Luka's design

This design has a middling level of mechanical complexity when compared to the other two designs. With a simple pick-up mechanism of a combine harvester, and a more interesting dummy weight rejection system utilizing a moving arm to direct dummy weights out, and target weights into storage. The robot relied upon a simple navigational system using three ultrasound sensors located above the level of weights. One in the middle to detect if it is about to collide into a wall or obstacle, and two on either side at an angle to help steer/ guide it through passages. Overall, this is a rather simple design with no special features. The simplicity should lead to reducing inevitable problems that come up in production and in use, as there are fewer components and functions to go wrong.

Interestingly, this design was the highest scoring in the point acquisition section. Due to the ability to pick up weights in any orientation and distinguish the dummy weights effectively.

Concept two: Hayden's design

This is the simplest design mechanically, but the most complex in its navigational system. The pickup mechanism of this design uses a simple combine harvester to lift the weights over a ramp and into the body of the robot to be stored. The focus of the design is heavily on the navigational system, using a method of mapping the arena to know the locations of the robot and its home base. This was done through a combination of measuring travel and using four sensors to detect the distance to any obstacles or walls. Weights would be detected through the use of two TOF sensors on each side. However, the robot is unable to reject or even determine dummy weights. Therefore, the quality of the robot lies heavily with the implementation of the designed navigational system.

Due to the significantly more advanced navigation algorithm, Concept Two received a high score in both navigation and obstacle detection. This was primarily due to the four TOF weight detection sensors and the four directional sensors providing the robot with a great range of detection.

Concept three: Conner's design

This design features the most mechanical complexity due to the multiple functions of the claw. Though novel in its design and versatility, this complexity could lead to increased difficulty in the creation of a successful rendition of this concept, in the production and assembly, and especially in the dimensions of this part. If done properly, however, this pickup mechanism could prove very effective.
Unfortunately, another problem lies in the fact that this robot does not have the ability to drop off weights, which lowers the ceiling for maximum point gain, instead focusing on gathering the target weights for the whole round.
Another key variance in this robot, as compared to the other two concepts, is its unique track design with a reduced length and unidirectional front wheels. Implemented to allow for a tighter turning circle to better navigate possible close confines. This feature could prove meaningless or a notable advantage purely depending on the arena layout and so is almost reliant on chance to prove its worth. But if nothing else is quite novel.

Concept three was the most well-rounded robot out of the proposed concepts, with no specific weaknesses. The use of a simple navigation algorithm, effective use of sensors and a reliable weight pickup detection method produced consistent results.

Conclusions and Recommendations

Following extensive research, design and evaluation of the three proposed concepts, it was clear that each design presented its own unique set of strengths, weaknesses and challenges because of different strategic approaches to the 2025 RoboCup competition.

Concept 1 (Luka's design) offers a balanced solution with moderate complexity. The harvester approach is a proven design as seen in previous years. This, coupled with a straightforward dummy weight rejection system, proves to be an effective, robust and realistic approach to this year's competition.

Concept 2 (Hayden's design) has a primary focus on navigation, featuring a lightweight and mechanically simple design that focuses on mapping the arena and ultimately maximizing mobility. Despite lacking the ability to detect dummy weights, this is mitigated by its superior navigation and ability to drop weights home, thus not incurring any penalties. This approach is both viable and an effective method to pursue.

Concept 3 (Conner's design) is the most mechanically ambitious, with a multi-mode claw system used to identify, classify and manage weights accordingly. Although this complexity introduces potential implementation and reliability issues, if done successfully, the robot will have precise control and management over any weights it encounters.

Therefore, when looking at the performance criteria and FOM analysis, Concept 2 is recommended for further development. This conclusion is drawn from a high overall score, a reliable and precise navigation system and simplicity of manufacturing. In addition to this, both Concepts 1 and 3 have valuable elements that can be incorporated into the final design to create a more competitive and well-rounded robot. An appealing approach would be incorporating the sorting system from Concept 1 into Concept 2. This would ensure reliable navigation, but in the unlikely event that the robot gets stuck with weights on board and can't return home, it will not be penalized for carrying dummy weights. Progressing further into the development process, it is vital to further explore and refine the features of these concepts with more in-depth testing and research. This will ensure smooth implementation and ultimately a successful robot.

References

[1] HEYI Electrical Solutions, “Inductive Proximity Sensor,” LJ18A3-8-Z/BY datasheet, March. 2017.

Appendices

Appendix A

See Submission

Appendix B

The order of the criteria from least important to most important was simplicity, then obstacle detection and navigation, then movement and lastly point acquisition. The range of results can be found below.

Simplicity (0-5): Least important. Complex robot doesn't result in a good robot. Helpful however for maintenance and debugging.

Point Acquisition (0-10): Achieving points is the key factor in winning, hence the highest weighting in the scoring system.

Obstacle and weight detection (0-7): Detection is an important factor for achieving higher scores, as weights can be found rather than randomly stumbling upon.

Movement (0-8): Is very important, as points can't be scored without movement. A moving robot can score points without other functions in use, hence the high rating.

Navigation (0-7): Navigation is an important factor for achieving higher scores, as both returning to base and exploring new areas can be achieved.

Simplicity equation:

$$S = 5 - (0.4x + 0.2y + 0.01z)$$

x = The number of actuators

y = The number of sensors

z = Structural components (frame, top plate, bearings, 3D printed ramps), excludes screws and electronic components. Estimation based.

Justification: Moving parts decrease the simplicity, as they are the most likely to cause issues if they have an error, hence the highest weighting. Sensors can have issues, but the robot will still be able to move (pickup weights). Structural components are unlikely to fail resulting in low weighting. Subtracting this result from five gives the values a suitable scaling for the evaluation.

	x	y	z	Result
Concept 1	4	3	24	2.56
Concept 2	4	8	30	1.5
Concept 3	4	6	25	1.95

Point Acquisition equation:

$$P = 7.1(-0.02w + 0.92x + 0.09y + 0.39z)$$

w = Probability of picking up a dummy weight

x = Probability of picking up a weight

y = Probability of picking up the snitch

z = Probability of returning weights to base

Justification: Weighting for each value is the probability of each category occurring in 2024. This is multiplied by the number of points scored from catching each item.

- Dummy weights on board: $0.07 \times 0.25 = 0.02$ (9/134 from 2024)

- Real weights on board: $0.92 \times 1 = 0.92$ (124/134 from 2024)

- Snitch: $0.03 \times 3 = 0.09$ (3/134 from 2024)

- Returned base weights: $0.19 \times 2 = 0.39$ (26/134 from 2024)

The scalability comes from perfect conditions (all perfect, except cannot pickup dummy weights). This resulted in 0.92+0.09+0.39 = 1.4, which gets scaled to the ideal max value of 10, resulting in a scale factor of 10/1.4 = 7.1

Weighting Justification:

	w	x	y	z	Result
Concept 1	0.1 can pick up the weights, but has a rejection method	1, if a weight is picked up, should retain it. Possibility of dropping it	0 can't pickup snitch	0.3 method to drop weights if correct conditions are met.	7.38
Concept 2	0.5 will pickup dummy, should drop at base	0.5 will pickup weights, should drop at base	0.2 can pickup snitch (not actively searching)	0.5 main focus is navigation so if a weight is picked up, should return to base	4.76
Concept 3	0 rejects dummy weights	1, can pickup weights efficiently	0 can't pickup snitch	0.1 no active method of returning weights to base	6.82

Obstacle and Weight Detection:

$$O = \frac{7}{16}(x + y + z)$$

x = Number of TOF sensors

y = Number of IR sensors

z = Number of ultrasound sensors

Justification: All sensors are believed to have similar reliability, resulting in all sensors having the same rating. This rating is then scaled to adjust it for its importance in the FOM table. The scaling comes from 7 / 16 (16 being the total number of sensors given (4 ultrasounds, 4 Time of Flights and 8 Infrareds) and 7 being the maximum weighting for scalability).

	x	y	z	Result
Concept 1	0	0	3	1.31
Concept 2	4	0	4	3.5
Concept 3	4	1	0	2.19

Movement Equation:

$$P = 20\big((0.4 - x) + (0.4 - y)\big)$$

X = Length of tracks touching the ground (m)

y = Width between the tracks (m)

Justification: 0.4m is the minimum width between obstacles and walls. This means that the further away from this length, that the robot is, the better turning radius it has, hence the subtracting from 0.4 the lengths are. It was noted that one concept castor wheels as well as the track. This was ignored due to the lack of motorization in the castor wheels. The scaling was determined based on the minimum size of a robot being 0.2 by 0.2, and the maximum rating being 8. This results in 8 / (0.2+0.2) equaling 20.

	x	y	Result
Concept 1	0.34	0.22	4.8
Concept 2	0.21	0.22	7.4
Concept 3	0.25	0.22	6.6

Navigation:

The navigation justification is based off a judgement, determined by the three authors. Rankings were set as:

No navigation mode= 0

Bad = 2

Average = 3.5

Good = 5

Perfect = 7

	Rating	Result
Concept 1	Poor	2
Concept 2	Good	5
Concept 3	Average	3.5

Concept 1 used three sensors to guide the robot away from obstacles. This means areas could be repetitively covered, hence the poor score. Concept 2 used a combination of mapping and wall following to produce good arena coverage and a direct route back to the home base, resulting in the good score. Concept 3 used a basic wall following algorithm to cover a decent amount of ground, therefore resulting in an average score.