RoboCup - Evaluation Report

ENMT301-Mechatronics System Design

University of Canterbury

Team 25

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Executive Summary

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1 Introduction

Over the course of the previous semester, an autonomous robot has been designed, built, and tested to ultimately compete in the 2023 UC RoboCup competition. Two previous reports have considered initial concepts of the robot and a detailed design that had been developed into a working prototype. Since then, the robot's design has been finished and participated in the competition. During the competition it won five rounds and lost two, getting knocked out in the semi-finals. This report will aim to give an overview of all the robot's subsystems and an evaluation of these against the specification of requirements. The robot will be compared to other robots that it faced during the competition to give an understanding of how it performed relative to other teams.

2 Design Description

2.1 Overview

Since the completion of the previous detailed design report several changes have been made to the robot. This was done to complete all areas of functionality for the competition. Some aspects that have changed include adding more sensors, a refined pickup mechanism, a colour sensor for home base detection, and further refinement of the navigation algorithm. Our design is broken down into several different functional groups. These include the chassis, pickup mechanism, autonomous navigation, weight detection, movement, and storage and release. The functional architecture for the robot can be seen below in Figure X.

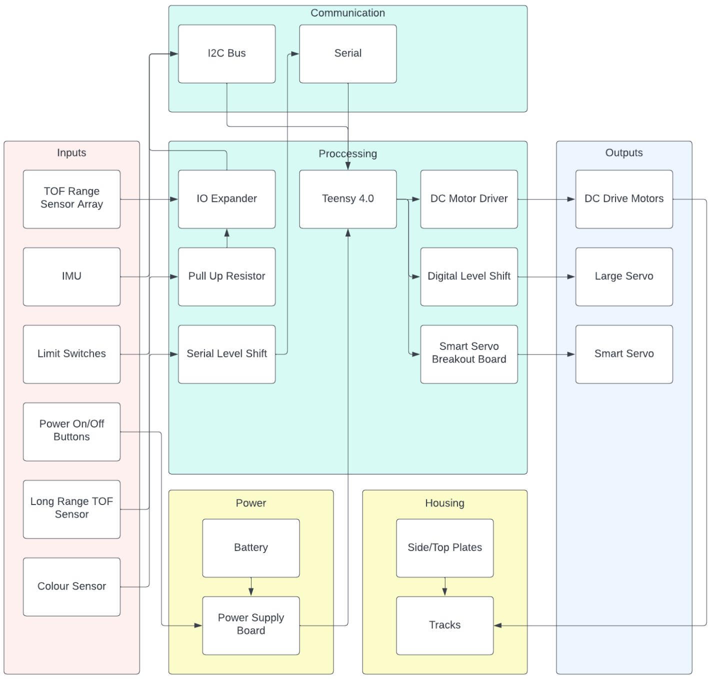


Figure X: The functional architecture of an autonomous robot.

2.2 Chassis

The chassis design was left unchanged from what was described in the design report. The chassis is built from the provided side plates and cross bars. This provides sufficient mounts for servos, sensors, and motors. The crossbars were screwed into the plates tightly to ensure the chassis had sufficient stiffness and robustness for competition.

2.3 Pickup Mechanism

The pickup mechanism was initially comprised of four parts, a funnel, a scoop, a backplate, and a ramp. The funnel knocks over all incoming weights, orienting them correctly in the process. When the weight hits the backplate the scoop lifts the weight from the ground, up the ramp, and into storage. Three major changes were made to this subsystem. Through further testing, it was occasionally found that a weight would jam between the scoop and the acrylic backplate. Over time, this weakened both components and caused both the scoop and backplate to fail. This issue was mitigated through three changes to the system. The infill of the scoop was increased from 5% to 25% this increased both the density and cross-sectional area, thus increasing the shear strength of the part. Additionally, the backplate was redesigned to allow weights to pass underneath. Figure XX shows the new backplate assembly.

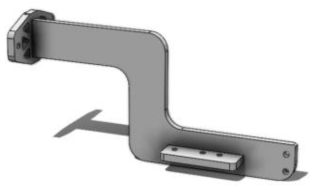


FIGURE XX: New Backplate Assembly

Another issue that surfaced during testing was that when a weight was picked up it would occasionally become hooked on the structural aluminium extrusion. When this happened, the weight would stay there until intervention. A small, guiding, triangular wedge was bolted to the extrusion to allow the weight to slide down instead of getting hooked. This new part worked without flaw in further testing. Figure XX shows the pickup mechanism with the addition of all new parts.

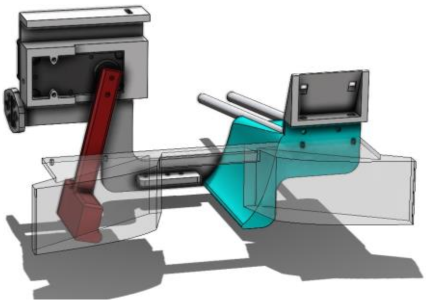


Figure XX: Pickup Subassembly

2.4 Navigation

One key design feature of the robot was that it must be able to navigate an unknown arena autonomously. To achieve this an array of time-of-flight range sensors and an IMU were used to provide data about the robot's position and orientation in relation to the arena. The number of sensors used by the robot was increased to eight from a previous design to remove blind spots. The sensor array can be seen in Figure X below.

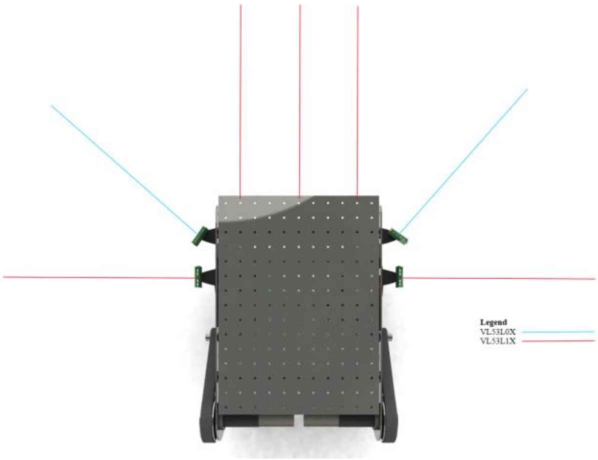


Figure X: The array of sensors used for navigation.

The navigation strategy used involved a combination of wall following and obstacle avoidance. To implement both strategies a finite state machine was used. The FSM, with its transition criteria, can be seen below in Figure x. To avoid obstacles the robot can turn 45 or 90 degrees in either direction. The decision on what angle the robot would turn was based on the readings of the three front sensors. If they were all similar it would turn 90 degrees, if there was a slope present then it would turn 45.

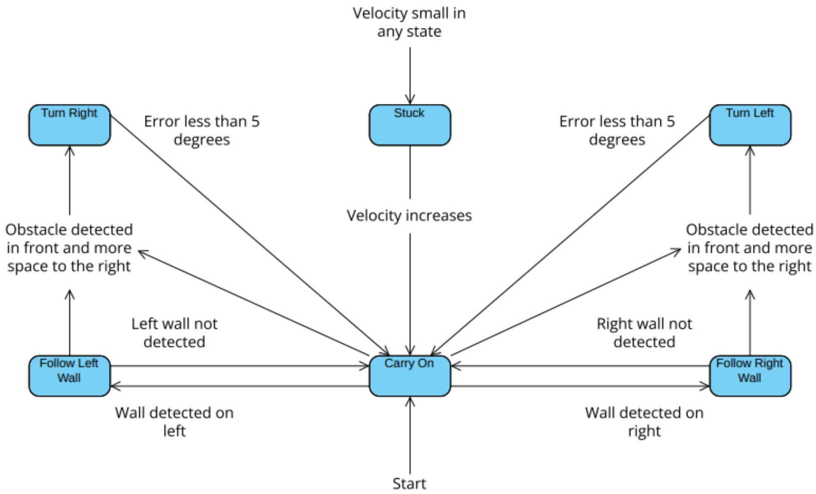


Figure X: The FSM for wall following navigation.

In order to implement wall following two cascaded control loops were used. The inner control loop was used to turn the robot to a reference angle using the IMU for feedback. The outer control loop used sensor readings to adjust the desired heading of the robot. These adjustments allowed for the robot to accurately follow walls around various arenas. The block diagram of these control systems can be seen below in Figure X.

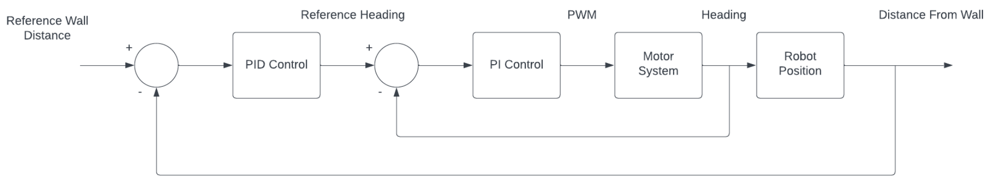


Figure X: A block diagram for the control systems used.

2.5 Movement

The movement system of the robot was largely untouched from the previous design outline in the detailed design report. The robot uses tracks powered by a DC motor to provide movement. Each of these tracks are spun around a drive wheel, flanged bearings, and rollers. The purpose of the rollers was to increase the torque to the ground as well as the amount of ground clearance the robot has. The only difference between the current design and the previous one is the location of the two bearings. These were changed to reduce the amount of slip that occurred while the robot was moving. The design can be seen below in Figure X.

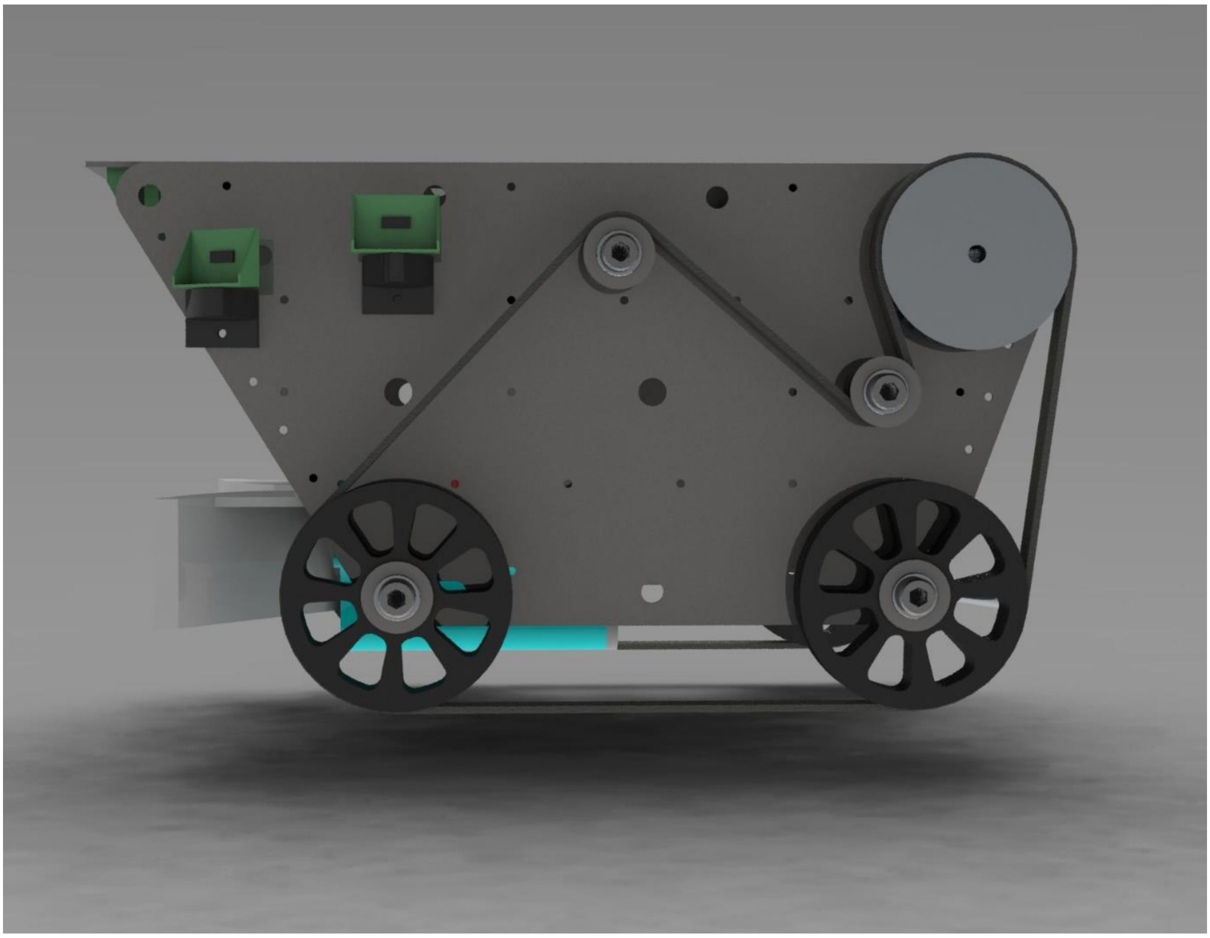


Figure X: The new track arrangement for a robot.

2.6 Storage/Release

The storage mechanism is very similar to the design represented in the detailed design report. Weights are stored on metal rails sloped down from the pickup ramp. This mechanism is visible in figure xx.

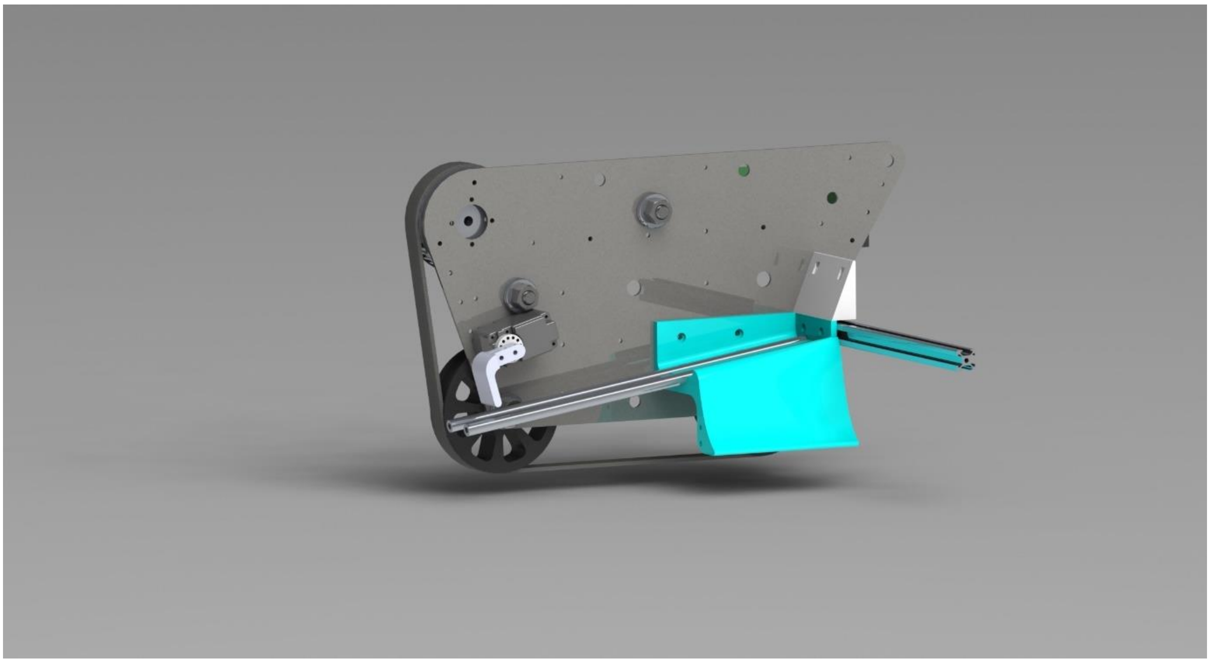


Figure X: The new storage system for a robot.

The only alteration made to the design was that the rods were cut be flush with the robots back plate. This increased the ground clearance, removed a potential sticking point, and made the robot more compact. The rods were also lubricated with silicone spray, reducing friction between the rods and the weights, and allowing easier sliding.

2.7 Software

A large part of the robot's capabilities came from the careful design of software on an embedded system. The robot was controlled by a Teensy 4.0 using the Arduino IDE to write C++ code. The code runs a timer-based scheduler using an inbuilt library. This operates four different tasks at desired frequencies. A flow chart of each of the tasks and their functions can be seen in Figure X below. The software has been updated since the previous design to include the extra features added. This includes the checking of the colour sensor, the implementation of more TOF sensors, and code for the release of weights via the smart servo. Another key feature that was added is the implementation of the blue button. This button will start the task scheduler on its first press and will perform a software reset on the next press.

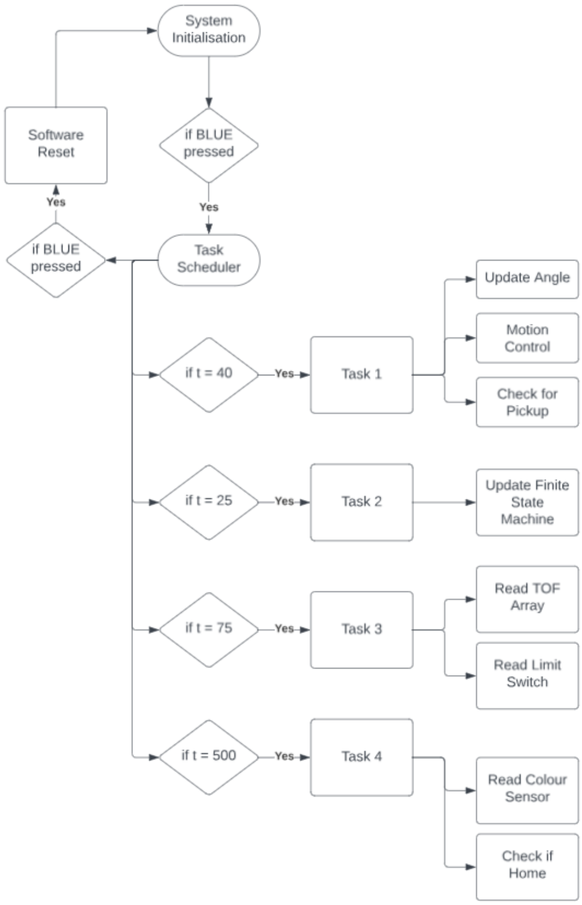


Figure X: The flow chart for the scheduler used.

3 Evaluation of Requirements Specifications

In the first conceptual report a specification of requirements was formed. These have been evaluated against the robot's performance in the competition. This gives an indication of the capabilities of the robot. Table XX presents a pass/fail for each requirement depending on how the robot performed in the competition.

Table XX: Relevant Requirements

Requirements	**Pass/Fail**
1.1 Functional	
1.1.1 The robot shall be able to pick up metal weights of differing mass (0.5, 0.75, and 1 kg).	Pass
1.1.2 The robot should be capable of storing three metal weights maximum.	Pass
1.1.3 The robot should distinguish between metal and plastic, dummy, weights.	Fail
1.1.4 The robot should have a mechanism to avoid capture of the bludger.	Pass
1.1.5 The robot shall have a width no larger than 350 mm.	Pass

1.1.6 The robot should have a ground clearance of greater than 25 mm.	Pass
1.1.7 The robot shall be capable of climbing a 30 % gradient with a maximum height of 100 mm	Pass
1.1.8 The robot should be able to distinguish between two base colours and store this information at the start of each round.	Pass
1.1.9 The robot should be capable of identifying and avoiding obstacles. These include the following: 1.1.9.1 Walls and cylinders. 1.1.9.2 The opponent robot.	Pass
1.1.10 The robot should be able to return to the home base and drop weights on arrival.	Pass
1.1.11 The robot shall not pick up weights in either base during the round.	Fail
1.2 Performance	
1.2.2 The robot should be able to travel at a minimum speed of 0.4 m/s when fully loaded with weights.	Fail
1.2.3 The robot should be able to identify and successfully pick up a weight within a time span of 25 seconds.	Pass
1.2.4 The pickup mechanism should have a success rate of greater than 90 percent during a round in competition.	Pass
1.2.5 The robot should be able to complete a full turn at any location in an arena.	Pass
1.3 Nonfunctional	
1.3.1 The robot shall be robust enough so that any collisions with an opponent robot will not cause permanent damage.	Pass
1.3.2 If a collision occurs, no components should be lost as a result.	Pass
1.3.3 Wiring should be secure enough to stay in place during a round.	Pass
1.3.4 The robot should be easy to assemble and disassemble within five minutes.	Fail
1.4 Constraints	
1.4.1 The robot should be made of supplied parts and bought parts within a $50 budget.	Pass
1.5 Operational	
1.5.1 The robot should not use a full battery within one round of the competition.	Pass
1.5.2 The robot should be able to have the same functionality independent of which side it starts from in the arena.	Pass
1.5.3 The robot should be easily repairable in between rounds within five minutes.	Pass

4 Evaluation of Subsystems

4.1 Chassis

The chassis held up without fault over the duration of the competition. It was sufficiently robust to survive collisions with wall or other robots, all external components such as sensors or tracks were also able to withstand the rigors of competition, and nothing came loose between rounds.

4.2 Pickup Mechanism

Throughout the competition, the pickup mechanism functioned without mechanical issues satisfying requirement 1.1.1. Though, during the first round, the scoop failed to activate once due to a malfunction with the limit switch. This issue was linked to the way the max-weight code was configured. Our robot was programmed to cease further pickups after the collection of three weights. The second weight that was collected hit the limit switch twice, fooling the system into believing it had already reached the three-weight limit. As a result, the robot couldn't pick up a third weight, which limited our overall performance in the round.

4.3 Navigation

During the competition we competed in seven rounds with a total of five different arena layouts. The different arenas that we competed in can be seen below in Figure X.

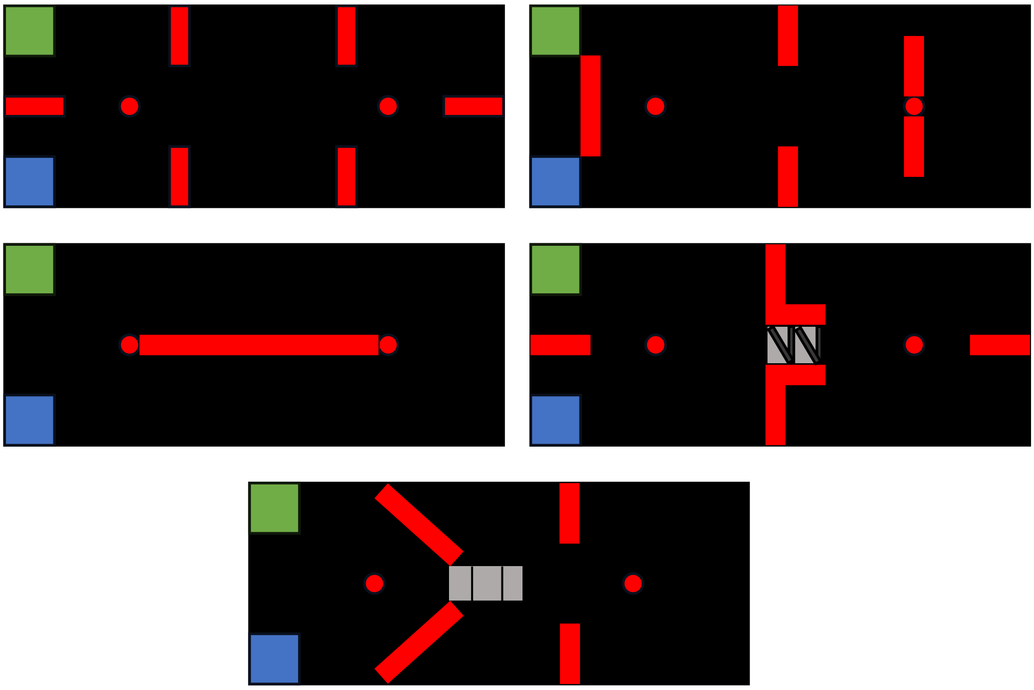


Figure X: Different arenas that we competed in during the competition.

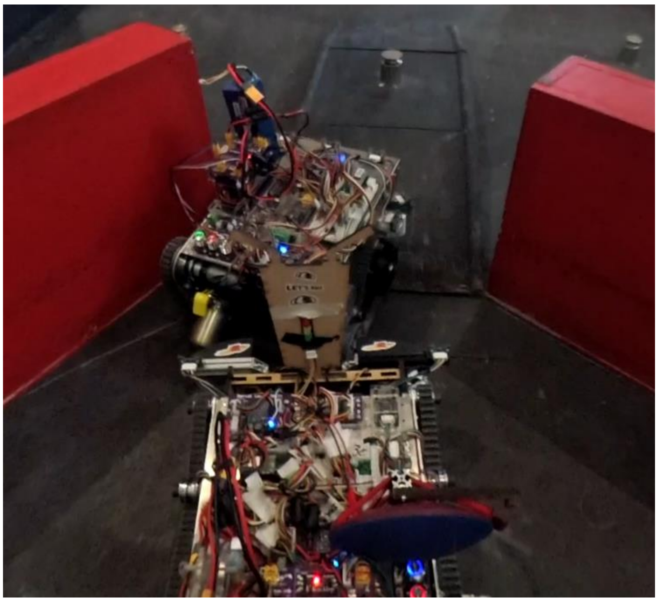
Generally speaking, the robot had robust navigation systems and so covered large areas of most of the arenas. Over the arenas shown in Figure X.1, X.2, and X.3 the robot achieved high levels of coverage during each round. From video inspection it was estimated that the robot covered 74% of the arena for these first three arena layouts. During the round with the arena seen in Figure X.4 there was a mechanical issue that caused the robot to stop moving once it was passed the speed bumps causing only 43% of the arena to be covered. This mechanical issue is evaluated in '6.5 Movement'. During testing a decision was made that the robot should avoid the ramp due to a potentially catastrophic failure occurring. This resulted in the robot only covering the arena before the ramp for the layout showed in Figure X.5. This resulted in low levels of area coverage for this arena of approximately 35%.

4.4 Movement

Overall, the movement of the robot was successful during the competition and testing. The setup generally allowed for the robot to travel at a sufficient speed while navigating the arena and moving over speed bumps. However, there were a few occasions where the system failed during the competition. These include the robot not being able to move over speed bumps while carrying three weights as well as the tracks losing tension with use. During round 63 the tracks lost tension and caused them to slip. This resulted in the robot not being able to move for the last half of this round.

4.5 Storage/Release

The storage system met requirement 1.1.2 of storing a maximum of three weights. It also successfully deposited weights at home in round 68, due to the colour sensor detecting the colour at home. This satisfies requirement 1.1.10. However, in round 70 the colour sensor was somehow triggered, causing the release of the only collected weight. The situation where the release was triggered is shown in figure xx. At this time the colour sensor was hanging off the edge of the ramp, while the robot was being pushed up. It's possible the colour sensor somehow detected the exact same colour values as the home base, triggering release. It's difficult to say for sure what was the cause of this issue without further testing to identify issues.



4.6 Software

The software written performed reliably during the competition. During the first round we competed in there was a bug present in the code that prevented the pickup mechanism from activating more than three times. This resulted in the robot not being able to pick up a weight that it otherwise would have. This was fixed after the first round and so the software performed reliably in the resulting rounds. Due to an increased number of tasks being performed by the CPU the software load has increased to a value of 0.281. The calculations for this can be seen in Table X below. As the total load is still significantly below the upper limit of 0.69, this is an acceptable value.

Table X: CPU loads of the Teensy 4.0 with the final code.

Tasks	T_k	$T_{desired}$	$F_{desired}$	L_k
Task 1	$2\ ms$	$40\ ms$	$25\ Hz$	0.05
Task 2	$13\ \mu s$	$50\ ms$	$20\ Hz$	$2.6e^{-4}$
Task 3	$8.3\ ms$	$75\ ms$	$13.333\ Hz$	0.111
Task 4	$60\ ms$	$500\ ms$	$2\ Hz$	0.12

5 Evaluation of Opposition

5.1 Team 27

5.1.1 Match Overview

We faced team 27 in round 72 where we were knocked out of the competition. During this round an arena was laid out where one real and one dummy weight were placed close to the home bases with the rest of the weights being only accessible by going over a ramp. Initially, our robot reached the real weight first but failed to pick it up because it was too close to the wall. Ultimately, the round was won by team 27 as they managed to push the real weight into its home base. During the competition this team averaged 1.3 kg of weights onboard and 0.55 kg of weights returned home at the end of each round. They made it to the final round of the competition coming second place overall. Team 27's robot can be seen below in Figure X.

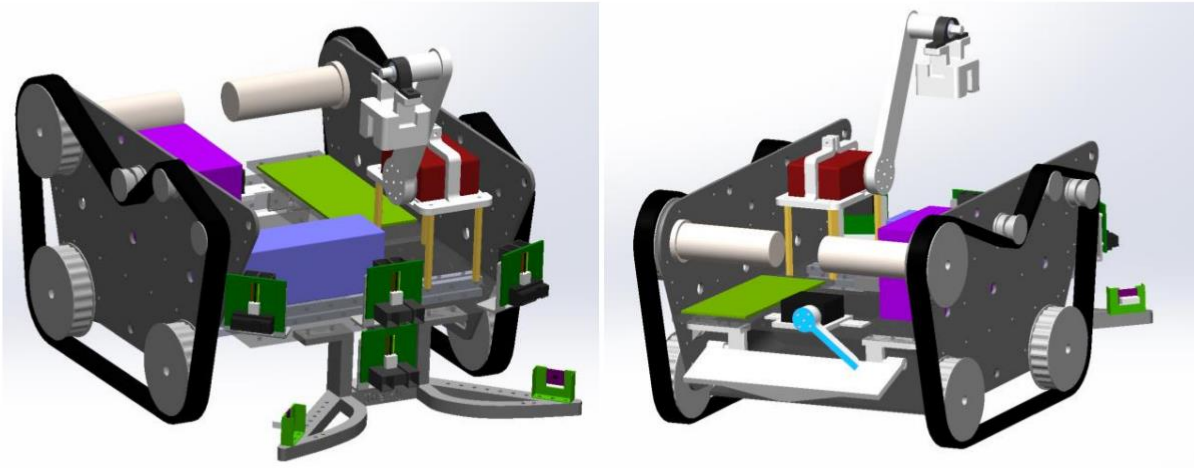


Figure X: Team 27's robot design.

5.1.2 Pickup Mechanism

Team 27 had an effective pickup mechanism that distinguished between real and dummy weights. The system involved a passive funnel and a crane arm with an electromagnet attached. As the robot navigated the arena it would use short range weight detection to tell if there was a weight directly in front of it. This weight detection was comprised of three High-Low sensor arrays that could distinguish obstacles and weights at a short distance in front of the robot. When a weight was detected, the robot would position itself so that the weight could be picked up. Once the weight was in place a crane arm with an electromagnet at the end would be lowered onto it by a large servo motor. Once the weight was in contact with the magnet the crane arm would lift it over the robot dropping it into a storage bay at the back of the robot. During the competition team 27 successfully picked up weights in most of their rounds. On average each pickup took 5.06 seconds from the time the crane arm started moving to the time that it had returned to its original position.

5.1.3 Drive Mechanism

The drive mechanism for team 27's robot was practically similar to the drive system employed by our robot. This involved the use of tracks driven by DC motors around a set of bearings and 3D printed rollers. The rollers that were in contact with the ground were 70 mm in diameter which allowed for increased torque to the ground as well as better ground clearance.

5.1.4 Navigation

Team 27 used a combination of wall following and obstacle avoidance to achieve autonomous navigation. An FSM was used to determine what actions the robot took based on what walls could be detected by the robot. It used three sensors; one directly forwards and two angled 45 degrees sideways to achieve this navigation. These three sensors would continuously check for the presence of a wall to the sides and in front of the robot. Based on what walls were present the robot would either turn or follow one of the walls. Wall following was achieved by a proportional controller from the sideways sensor, the control output from this would be added and subtracted from each of the motor values. This causes the robot to follow a wall at a set reference distance.

5.1.5 Return to Home

When team 27's robot returned to its home base it would determine if it had successfully returned to by verification with a colour sensor. If this verification was positive, it would complete a returned home routine. This involved the robot turning around and driving backwards before opening the storage bay and driving forwards. This change from driving backward to forwards caused the weights that the robot had on board to shift and fall onto the home base. The storage bay consisted of a sloped enclosure with a hinged door at the back of it. This hinged door could be opened with a servo allowing for weights to be dropped. This mechanism allowed for team 27 to score a greater number of points in each round due to the extra points gained from weights being returned home.

5.1.6 Comparison of Performance

Both robots had similar navigation principles of wall following and obstacle avoidance. However, the ways they were implemented differed slightly. Team 25 had a more general system that could cope with unpredicted arenas while team 27 attempted to predict the scenarios that might occur. However, this generally played to team 27's strength as their navigation was more reliable in standard arenas. The pickup mechanisms used differed largely. Team 27 used a crane arm that could only pickup metal weights while team 25's robot did not distinguish and picked up all weights. Team 25's pickup system relied on the robot being able to continue driving into a weight knocking it over. This made team 25's pickup faster and did not interrupt the navigation of the robot allowing it to continue without stopping. However, only picking up metal weights would often result in team 27 scoring higher as this optimised the use of storage space on the robot.

5.2 Team 38

5.2.1 Match Overview

We faced group 38 in round 63, with group 38 having five wins and one loss, significantly better than our two wins and one loss record. The arena positioned one 0.5kg weight directly in front of the robots start position, and this was the only weight we collected this round. Group 38 pushed this weight into a corner and was unable to retrieve it. Once both groups had interacted with the first weight in the first 20 seconds, groups 38's robot seemed to get stuck and would not leave the area, surrounding their start zone for the rest of the round. We managed to navigate the arena better, but our tracks had lost tension and were starting to slip. This limited exploration of the arena is why we did not collect another weight. At two minutes we won due to the 0.5kg weight collected early.

5.2.2 Pickup Mechanism

Group 38 employed a drastically different weight pickup system to us. Once a weight was detected and approached, a front mounted IR sensor would trigger collection once the weight was 30mm from the sensor. Two servo actuated arms would grasp the weight from either side. These ensured weights were centrally located, allowing an electromagnet on a crane style arm to reach down and accurately pick up the weight. This pickup method meant that any fake weights were unable to be collect as the electromagnet could not hold them, it also avoided collecting the bludger. Once successfully picked up the crane moved the weights up and back, where they are deposited into a rounded slide, which was gated to allow release of collected weights. In competition this mechanism seemed to be good at collecting weights, with few failed pickups, a notable failure being the round against us.

5.2.3 Drive Mechanism

The two robots used very different locomotion systems, with group 38 using two large rear mounted drive wheels and a central castor wheel at the front. All drive was supplied to the rear wheels, which were large enough to provide adequate ground clearance. The castor wheel had a smaller diameter but was lower to the ground. Group 38's robot encountered two issues with locomotion, firstly the castor wheel struggled to go over bumps of any size, such as the ridge surrounding the home areas. This caused their robot to take a long time to leave the starting zone. The other locomotion issue they faced was that their rear wheels would fall off. While this didn't occur when we faced them, their previous loss was due to a wheel falling off, this happened in two other rounds as well.

5.2.4 Navigation

Instead of wall following, group 38 focussed on detecting weights, driving to them, and collecting them. The robot used a high low sensor array to detect weights and would perform a spin, looking for either a weight or what the sensors said was the area with the freest space. If a weight was detected the robot would drive there and attempt collection, if no weight was detected the robot would drive in direction of most free space and spin again.

5.2.5 Return to Home

In none of their rounds did group 38 successfully return home and deposit weights. Though this may be because they never collected a full complement of three weights. The robot does have ultrasound sensors mounted on the side that could potentially be used for wall following and returning home. Their storage mechanism also allows for the release of weights once home, so it is likely some return to home functionality is present.

5.2.6 Comparison of performance

The two robots were very different in their design and had different philosophies about what would be needed to win the competition. While we focused on strong navigation around the arena and obstacles, group 38 focused on searching for weights and heading straight to them. This would benefit group 38 in arenas with many weights close to home base, but most arenas seemed to encourage exploration and had weights distributed further out. One factor Group 38 has over us was their inability to collect fake weights, while we would consistently collect fake weights when encountered. Group 38 also encountered many issues with their locomotion, being unable to navigate rough terrain, and losing wheels, while our locomotion was robust, not encountering any beyond slipping which was easily fixed between rounds. A major advantage we had over group 38 was our ability to return home, which earnt us many extra points over the tournament. However, group 38 was very successful winning five rounds, showing that ensuring collection of one weight was normally enough to win a round.

5.3 Team 9

5.3.1 Match Overview

We competed against Team 9 in round 30 of the competition. Their robot got itself trapped at the beginning and only managed to exit home base halfway through the round. Robot 9 did not collect any weights at any point in the round. Our robot picked up a total of four weights; we dropped off two real and a dummy to home base, while unintentionally pushing the fourth into Team 9's base. As we had a higher total mass of weights at home, we won the round.

The competing robot can be seen in Figure XX.

FIGURE XX: Team 9 Robot

5.3.2 Pickup Mechanism

Team 9 used a very different pickup mechanism to ours. Their design kept the weights upright and had no separate storage subassembly. Like our robot, Robot 9 utilized a high-low sensor to detect when a weight was in its pickup mechanism. The robot would then power a DC motor mounted at the rear of the robot and the front spikes would see-saw up; the robot would only retract this mechanism once a color sensor detected the robot was back at home. The average time taken for pickup was 2.03 seconds.

A large limitation of Robot 9 was that they could only collect one weight at a time. Having the ability to carry multiple weights would greatly benefit this team.

5.3.3 Drive Mechanism

The choice of drive mechanism in Team 9's robot was near-identical to ours, employing an unprotected bearing-mounted track system. The difference in driving lay in the fact that they did not use wheels to increase ground clearance. Although Team 9 never encountered this during the competition, the robot would most likely not be able to get over bumps or ramps.

5.3.4 Navigation

Team 9 used a wall-following algorithm to control the motion of the robot. They used two 45° sensors to measure upcoming objects, as well as two laterally mounted ultrasound sensors to aid with wall-following. This system seemed to work well overall, however, it may have benefitted from further refinement; it was clear the robot could not navigate well in tight spaces.

5.3.5 Return to Home

Like ours, their robot did not have return-to-home functionality. It relied on a colour sensor to detect when it stumbled upon home base again. This colour sensor had a 50% rate of success throughout the competition. Once the sensor accurately detected home, the mechanism took an average of 1.53 seconds to drop off the weight.

5.3.6 Comparison of Performance

Team 9's robot was relatively simple in terms of mechanical components. With only two separate movement elements, the tracks, and the pivoted collection mechanism. The advantages their robot had over ours were the addition of ultrasound sensors for longer range navigation and an array of high-low weight-detection sensors. However, these advantages were outweighed by their weak navigation system. Our robot outperformed Robot 9 in several key areas, most notably in the ability to pick up multiple weights and better navigation, ultimately leading to our victory in the round.

6 Post-Mortem Summary

The robot's performance throughout the competition highlighted several areas of potential improvement.

The most significant issue impacting the performance of the robot in Robocop was the inability to distinguish between real and dummy weights. 6 of the 14 weights we collected were dummy weights, comprising 43% of the weights collected. While our game strategy was to collect dummy weights, this hurt us in actual competition as dummy weights took up spaces that could have gone to real weights. In the initial design report use of conductance sensing to determine between metal and plastic weights was suggested and implementation of this would improve performance overall.

Another issue faced that caused the loss of round 53 to group 17 was that once the robot had reach internal weight capacity, the funnel design caused the robot to collect weights and push them around the arena. In the case of round 53, after reaching internal capacity the robot continued to follow the walls around, passing through the opponent's home area before it reached our home area. This led to the opponents having more weights in their home base, and win the round, despite group 17's robot not collecting anything that round. A more sensible strategy, particularly if metal weight identification was implemented, could have been to collect three weights and stop the robot, this was the strategy used by Group 5 who won the competition.

Rounds 68,70 and 72 were in an arena where all but one weight was across a ramp. In testing the robot was able to cross ramps if it lined up perfectly, but due to risks of misalignment, leading to the robot falling off the ramp a vertical incline limit of 15 degrees was placed. During testing this limit allowed the robot to climb the ramp if it was properly lined up but would stop the robot from falling off the edge is misaligned as it would trigger the robots stuck state and reverse. However, in competition the robot never successfully drove over the ramp, spending most of its time attempting to drive over before reversing. This led to some unexpected behaviour such as the release of weights from storage being triggered during an attempt at the ramp. More testing with a full load of weights and implementation of software control could likely get the robot consistently climbing the ramp, a feat no group achieved this year.

7 Conclusion

The concept of creating a simple yet effective design allowed time for many iterations, ultimately leading to a successful, semi-final qualifying design. Throughout the course the competition, the robot averaged 0.14kg of weights on-board and 1.14kg delivered back to home base.

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It was determined that for the robot to further succeed in future competitions, future developments would need to take place. Throughout the competition, a few obvious shortfalls were found; these included the lack of a high-low sensor array, the lack of dummy weight detection and the tendency for the robot to push weights into opponent's bases.

8 Contribution Statement

9 Appendix A – Bill of Materials

Part	Quantity	Material	Total Weight	Total Cost
Roller	4	3D Printed PLA	120 g	NA
Sensor Mount	2	3D Printed PLA	3.1 g	NA
Sensor Mount 45 degrees	2	3D Printed PLA	3.1 g	NA
Servo Mount	1	3D Printed PLA	29 g	NA
Scoop	1	3D Printed PLA	15 g	NA
Ramp	1	3D Printed PLA	86 g	NA
Funnel	1	3D Printed PLA	71 g	NA
Gate	1	3D Printed PLA	3.5 g	NA
Weight Front Buffer	1	3D Printed PLA	2.4 g	NA
Back Plate Assembly	1	Acrylic	32 g	NA
Robot Side plate	2	Aluminium Sheet metal	NA	NA
Robot Top plate	1	Aluminium Sheet metal	NA	NA
Drive Track Support Hardware	8	Mixed	NA	$24
Robot tracks – 880-8M	2	Rubber	NA	$100
Open beam aluminium profile	5	Aluminium	100 g	$25
8mm round bar	2	Aluminium	44 g	NA
DC Motor – 28PA51G	2	NA	NA	$140
Smart Servo – SG90	1	NA	NA	$58
Large Servo – RDS5160	1	NA	NA	$60
TOF I2C – VL53L0X	2	NA	NA	$10
TOF I2C - VL53L1X	6	NA	NA	$60
TOF Serial - TFmini	1	NA	NA	$50
Colour Sensor – TCS34725	1	NA	NA	$14
Limit Switch - SV-163-1C25	1	NA	NA	$0.5
Arduino Teensy	1	NA	NA	$60
Stop Go button	1	NA	NA	NA
Motor drive board	1	NA	NA	NA
Power supply board	1	NA	NA	NA
Digital level shift	1	NA	NA	NA
Smart servo breakout board	1	NA	NA	NA

Serial Level Shift	1	NA	NA	NA