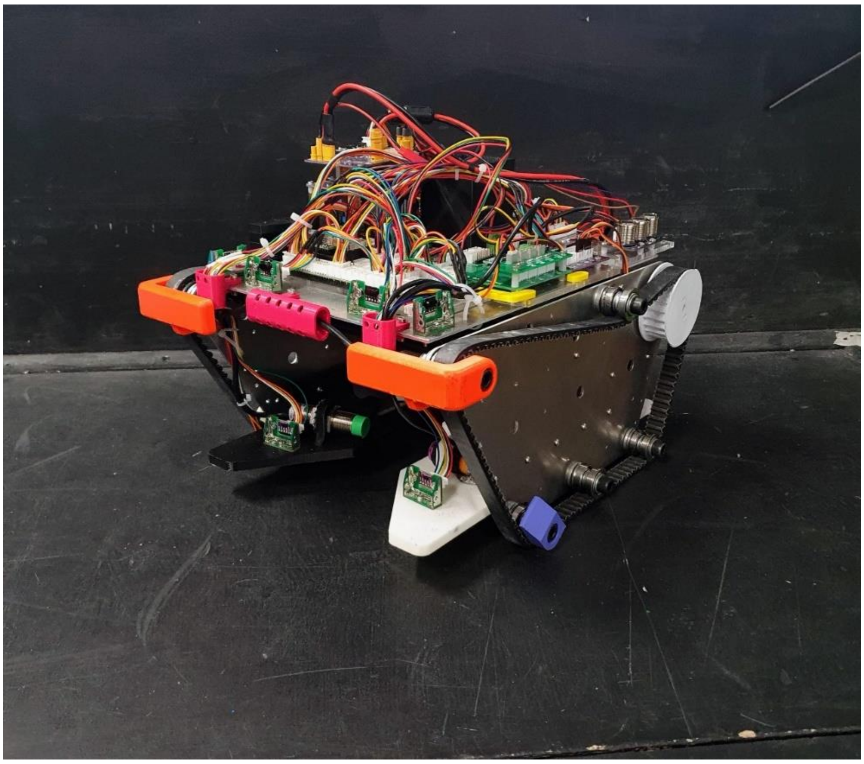

Design Evaluation Report

ENMT301 - 18/10/24

Group 4

Mark day

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Executive Summary

This report outlines the design, development, and competition performance of Group 4's robot built for the Robocup Competition. The main goal of the robot's design was to effectively navigate the arena, detecting and collecting target weights, while avoiding dummy weights and obstacles. The robot's design features included a tank drive system, a rail-based collection mechanism, and a navigation system that includes multiple time of flight (TOF) sensors for object detection.

Since the DDR report, there changes were made to subsystems. Changes to the drivetrain included the addition of front corner bumpers, lower track slides, and a custom 3D-printed main drive pulley. The target detection system was upgraded from ultrasonic sensors to TOF sensors, which significantly increased accuracy and speed in detecting weights, while the target collection mechanism was simplified.

In the Robocup competition, Group 4's robot was effective as it consistently collected weights in multiple rounds, securing 3rd place overall. The robot's strategy focused on quickly moving off its home base to collect target weights before the other teams, maximising the potential score. The robot's navigation system, which employed a combination of motor encoders and an IMU, enabled it to traverse the arena and return to its home base with minimal error.

One main issue was the weight disposal system, which struggled to consistently deposit weights within the home base, resulting in lost points during critical rounds. The robot also had difficulties when dealing with weights that were not in an upright position, as its collection mechanism was not able to handle tipped-over weights. Minor issues with the drivetrain occasionally caused the robot to get stuck on obstacles like poles and ramps, despite the improvements made during testing.

Cost analysis revealed that the robot remained within budget, with the total cost of additional components amounting to $43.20 NZD, compared to the allocated budget of $50. A full breakdown of the budget and bill of materials is provided in the appendix of the report.

Overall, the robot was deemed to be fit for purpose, successfully meeting most of its design requirements and performing competitively against other teams. The areas for future improvement identified in this report include developing a more reliable weight disposal mechanism, enhancing the robot's ability to handle tipped-over weights, and refining the navigation strategy to prevent it from getting stuck on obstacles. Addressing these issues would significantly increase the robot's reliability and performance in future competitions.

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1. Introduction

This report will discuss the Robocop competition and more precisely discuss Group 4 robot's performance in the competition with reference to robot design, game strategy and competitors.

Robocup is a competition between teams to build, construct and compete robots in one-on-one competitions. The competition consists of each team starting on a home base, then moving off into the playing field. In the field there are target weights, dummy weights, obstacles, poles and ramps. To score robots must collect target weights and score double if they get the weight back home. Dummy weights minus points if on board robots. There are two reports before this, Conceptual Design Report CDR which discuss different strategies and potential designs, and Detail Design Report DDR which discuss in detail Group 4s implementation of strategy and design.

2. Design Description

2.1 Overview

The design of the robot had some key improvements made to major components that would lead to the success of the robot in the competition (Figure 1). Changes were made to sub-systems such as the drivetrain, chassis, detection, collection and navigation. These changes were all made after the design report as the robot was going through extensive testing to iron out any flaws in the on-board systems. Some of these changes would occur between rounds of the competition due to issues occurring in rounds that had not been discovered yet. The results of these improvements would yield a robot that has greater reliability and simplicity which aligns with our objective from the detailed design report (DDR).

The final robot for the competition was a tank drive robot, navigated by moving into open spaces, collected weights using a rail system and detected weights with TOFs.

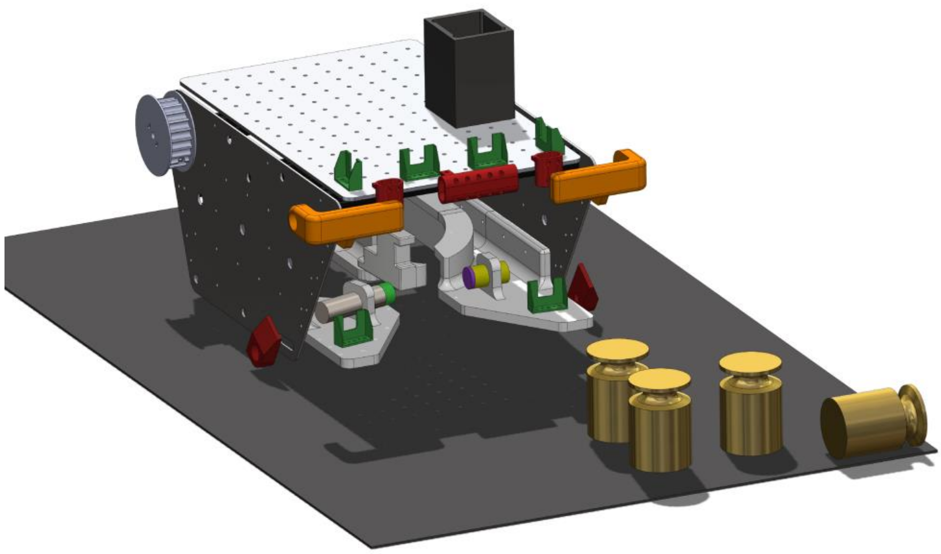

Figure 1: Group 4 finalised robot design.

2.2 Chassis and Drivetrain

The chassis and drivetrain of the robot made use of many components supplied in the Robocop kit. The robot chassis was kept simple by using the chassis plates, the standard geared DC motors with encoders, belts and bearings, and the black extrusions. All the major electronics were housed on the supplied alloy plate as the number of electronic components was kept to a minimum. By using supplied components for the drivetrain and chassis, this proved to decrease the time spent in design stage and allowed more time to be put into testing and development of other sub-systems of the robot. The function of the default components worked well for most parts of the requirements, but was not perfect, and minor changes had to be made to get the drivetrain running as smoothly as possible.

Three key improvements were made to the chassis and drivetrain; two were the addition of front corner bumpers and lower track slides and the third was a modification to the main drive pulley. The front bumpers (orange) seen in Figure 2, were an important step to allowing the robot to navigate the entire arena autonomously without getting stuck on any obstacle. This was important to achieve as one of the requirements from both earlier reports was that the robot shall not get stuck in a subsection of the arena (requirement 2.3) which includes getting stuck on obstacles. There were many occasions when the robot would approach a skinny vertical obstacle, such as the end of a wall, that was out of the field of view (FOV) of all the top time of flight (TOF) sensors. The obstacle would get caught in the section between the track and the cable management loop and the robot would continue to drive forward. This issue would lead the robot to violate requirement 1.4, the ability to drive home with weights, and 1.5, the robot shall be able to recognise walls in relation to itself. An important issue about getting stuck on obstacles is that most of the time it caused the tracks to slip on the ground, and because our navigation system was based on the encoder output from the motors, the virtual home position calculated on the robot would drift away from true home, therefore violating 1.4. The aim for the design of the bumpers was that if the robot were to hit the corner of an obstacle, the robot would slide off the obstacle as fast as possible and direct the obstacle to the closest TOF sensor so the navigation software could react. By doing this, it would minimise the amount of track slip and help towards achieving all the requirements and increasing reliability.

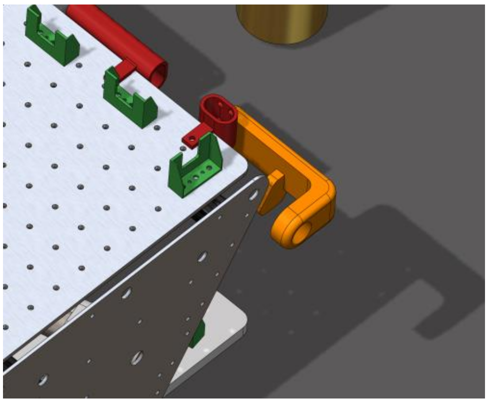

Figure 2: CAD assembly of the bumpers.

The lower track slides (Figure 3) were an addition made after the first round of the competition. A pole in the arena got caught on the cap screw holding the lower front track bearing causing the robot to rotate continuously around the pole. This caused similar requirement issues as mentioned above as the tracks slip and the robot was not able to navigate away from the obstacle. The slides provided an angled edge for the pole to slide off and the robot would be free to move on. Testing proved them to be successful and this issue never occurred again.

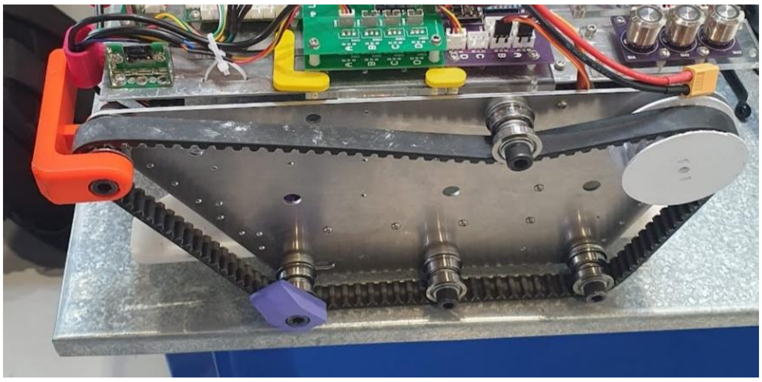

Figure 3: Implemented lower track slides (purple) and new drive pulley (white).

The third improvement was the 3D printed main drive pulleys (Figure 3) which included a better tooth design for the belts used. A common issue with the old aluminium pulleys was that the belts would slip on the pulley as the teeth were not the correct size for the belts. This only occurred when the robot was navigating bumps in the arena which applied more load on the pulleys. The slippage in the belts caused similar issues with virtual home drift so therefore required rectification. An IMU was onboard the robot but the absolute position from the IMU proved to have far less accuracy than when the encoders were reading correctly, so it was chosen to fix the slippage with all three improvements rather than changing the positioning system. This improvement was mentioned as further development in the DDR and was implemented successfully.

2.3 Target Collection

The collection system was designed to be as simple as possible while still having a high success rate. The weights are scanned for by the two lower TOF sensors, where the robot would then drive towards the weight until the weight is funnelled by the trays into the centre and stopped by the centre positioned gate. The weights are simply drafted by a 3D printed gate driven by a servo after they have been analysed as a target by an IR distance sensor and an inductive proximity sensor. The gate would move to either side and allow the weight to go to its designated position. If the weight was a dummy, then the robot leaves it to be expelled out the back, or a target is swept into the holding bay and up the rails to be lifted off the ground. The same rear gate and servo from the DDR were used at the rear of the holding bay to keep weights contained on the robot.

Two major changes were made to the collection system after the DDR, these were removing the combine harvester wheels and ultrasonic sensors and raising the holding bay rails so that the weights were lifted off the ground while contained on the robot. The final underbody of the robot can be seen in Figure 4. Removing the combines was mentioned as further development in the DDR due to their effectiveness, power consumption and complexity of electronics. They were found to be futile when collecting weights as they spanned the same distance as the funnel and making them wider would only cause them to catch on obstacles in the arena. Removing them made the robot as a whole more simple and allow focus to be put onto target detection and software.

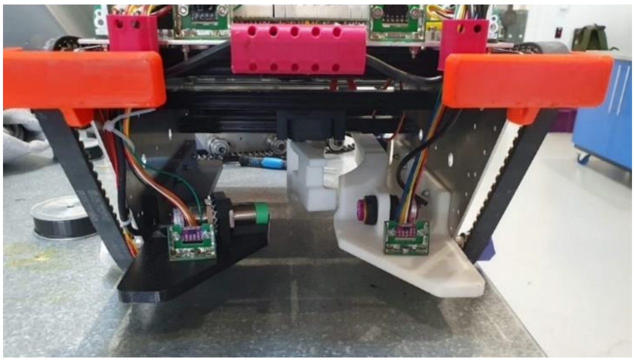

Figure 4: New TOF sensors and collection trays installed on the robot.

The other major change to lift the weights off the ground came from the robot's inability to drive when fully loaded (requirement 2.4). This occurred multiple times during testing as the weights in the holding bay dragging on the ground would catch on small inconsistencies in the arena floor bringing the robot to a halt. The rails were adjusted upwards with a small incline at the front to lift the weights ~8mm off the ground (Figure 5). This was just enough to clear all the bumps on the ground including the rails around the home bases in the arena and allowed the robot to drive freely and satisfy requirement 2.4. The downfall to this solution was that there weas no easy was to dispose the target weights from the robot into the home base. A solution to this was implemented in code where the robot would open the gate when home and drive forward abruptly, shunting the weights towards the back, slow down, reverse and abruptly drive forward again. This solution was used in the final design and through testing was found to be simple and effective.

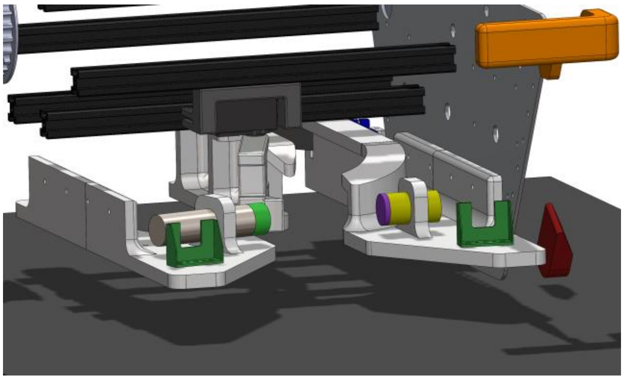

Figure 5: CAD of the raised holding bay and new gate to push the weights up the incline.

2.4 Target Detection

Target detection had significant changes between the DDR and race day. In early testing, the ultrasounds worked fine for target detection. However, this testing generally was done at a computer with the robot sitting on a desk. It is easy to simulate good results with sensors when testing is performed in a controlled environment such as this. Further testing was completed in full arenas with obstacles, and it was found, target detection was very temperamental. Therefore, a new design with time-of-flight sensors was proposed, shown in Figure 4. This new design featured an additional time-of-flight on the top of the robot and switched out the two ultrasound sensors closer to the ground for time-of-flight sensors. The angle of these sensors was analysed to find the optimal angle for the highest success rate (Figure 6). Rather than pointing the sensors outwards to detect weights to the side of the robot, they pointed directly forwards with the outer edges of the FOV to be parallel with the side of the robot. This limited the width of the detection area but allowed the robot to stay locked on to a weight for longer and direct the weight accurately into the centre of the funnel. Through testing this showed a much higher chance of collection versus having the TOF sensors angled outwards. The new angle of the sensors relied on enough movement from navigating the arena to scan for weights potentially out to the side of the robot. The short range TOF sensors gained significant accuracy and speed over the ultrasound sensors which improved the robot's function and reliability.

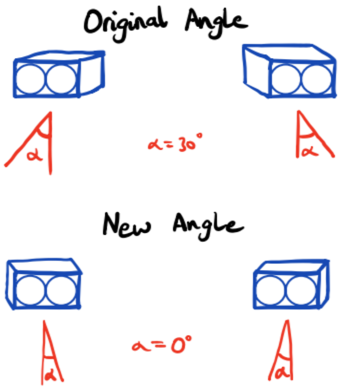

Figure 6: Angle of Target Detection Sensors

The new design also improved the ability to identify ramps. Previously, the ultrasounds would detect a ramp and identify it as a weight. It would then move into the weight collection state and get stuck on the ramp until the watchdog timer saved it. The new design checks if both bottom TOF see an object within 50mm and labels this as a ramp. This works since the sensors are now positioned parallel to each other, meaning they both would not detect a weight within this short distance.

2.5 Navigation

The Navigation for searching the playing field consisted of four TOF sensors on the top of the robot and two on the bottom. Two facing centre and two facing outwards on top as shown in Figure 7. The last two were used for the target collection sensors.

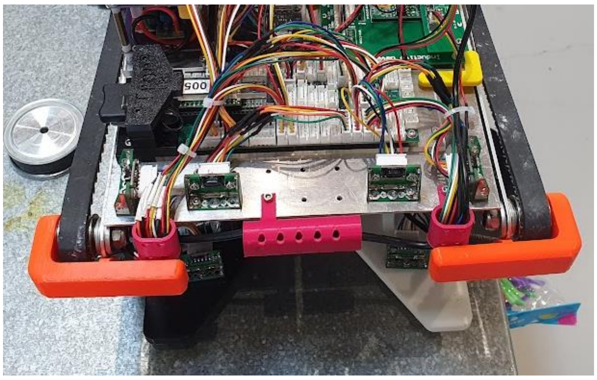

Figure 7: TOF sensor arrangement and front of robot.

This differed from the DDR report where the robot only used three on top and did not take advantage of the bottom two. The logic remains the same for majority of the functionality. Where the robot would travel forwards until it saw a wall then decide to turn the way which it saw the farthest out wall and keep turning until it no longer saw a wall right in front of it. Implementing the second centre top TOF consisted of returning the min between the two centre TOFs therefor kept the searching code the same. During testing of DDR, it was found that the robot could get stuck on the edges of walls. By implementing another TOF on top and pushing them further out increases the robot's ability to see wall edges.

The Navigation of the ramp was to not go on it. From Target Detection 2.4 the robot would avoid the ramp often. If the robot found itself on the ramp by checking the IMU angle it would back but and avoid it. This removed the ramp from play for the robot.

To navigate home the robot remembers its x, y position using the motor encoders and IMU and uses this to calculate the angle home. It then heads in that direction until it finds an obstacle. It then follows around the obstacle until it can turn back to the heading home. The navigation home differs from the DDR in it now waits longer before turning back to home after encountering an obstacle this was done to stop it turning into poles.

3. Results

3.1 Competition Performance Review

Group 4 key strategy was to move out of base and collect all three target weights before 80 seconds and before the other teams whilst avoiding dummies. Then returning all weights home doubling our points. Figure 8, is an diagram of the algorithm.

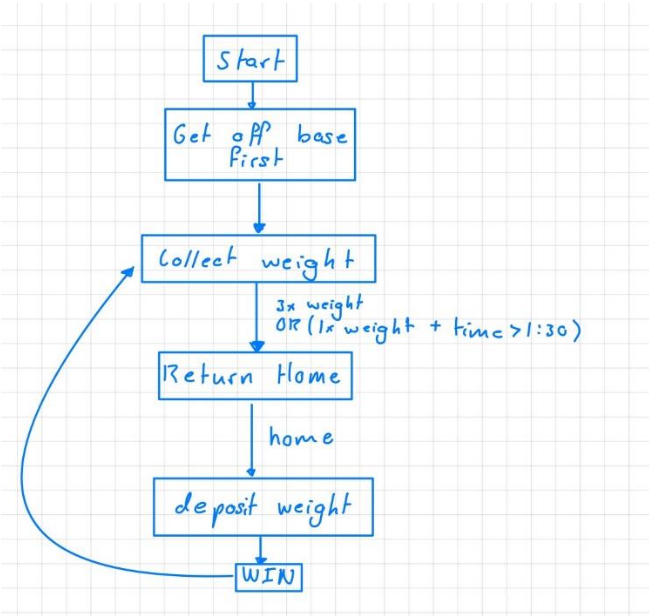

Figure 8: Competition strategy

The robot placed 3rd overall in the competition, which was due to the success of some systems, but the rounds lost were also due to the failure of other systems. The detection and collection systems worked well as the robot picked up at least one weight in all six competition rounds and satisfied requirement 1.10, 1.8 and 2.2. This was expected due to its very high success rate of picking up weights all throughout testing. The robot also successfully detected and ignored a dummy weight during one of the rounds which satisfied requirement 1.11. Other successful systems and requirements were the electronics and battery, the electronics never had issues such as cutting out and a battery could last nearly a full day of testing which fulfilled the performance requirement 2.1. The robot ran successfully when placed in multiple orientations in home base during testing and the last two rounds of competition.

There were many systems however that contributed to the loss of points for the first four rounds and to the loss of the last two rounds. The first two rounds the robot successfully picked up weights and then would get stuck in the arena. The first round, it was physically stuck on one of the poles from the track cap screw and the second round it was a software issue where it was locked on to the pole. Both prevented the robot from driving home but it won the round regardless. Both issues violated performance requirement 2.3 (do not get stuck) but were fixed after the second round. The case where the robot sensors got locked onto the pole is outlined in the FTA under software error, optimisation issue and then edge case error. A simple edge case was then implemented in code which solved this issue. The other case where the robot rotated around the pole is also outlined under the FTA where it was a mechanical error because the robot can't move because something was in the way. An issue that came across during testing was the robot getting stuck on the corner of the ramp, a simple software change allowed the bottom TOF's to detect it and navigate away from the ramp. To reduce the ability of the ramp causing more issues, an angle watchdog was implemented so if the robot's angle of attack was greater than 6 degrees at any point in time it would turn around. This proved effective as it never occurred during rounds.

The system that ultimately caused us to lose the last round was the weight disposal. Throughout testing the weight disposal had been reliable if the tracks did not slip somewhere in the arena. The weights would be disposed in the back corner of the base as expected and there were only minor adjustments made. However, during three of the rounds on the last day of the competition, a total of 4 weights collected were dropped off mere inches outside of home base because the robot thought it was home. This was not caused by tracks slipping as during these three rounds. The encoders had minimal error in the rounds where weights were dropped poorly as most the edge cases where the tracks would slip had already been dealt with. The failure of the disposal system caused a major loss in points and violated the requirements 1.3 and 1.14. This fault was not outlined in the FTA as it did not come under the category "robot fails to collect weight". The system failure was due to the poor strategy to drop the weights off at base but the reason for this strategy was ultimately the poor design of the weight storage. Since the weights had been lifted off the ground there was no designated method for dropping the weights off. If a method had been designed in tandem with the holding bay rather than after the fact, then the robot may have been able to deliver weights to inside the base.

A case that did not occur once during testing but happened twice during rounds was weights tipping over. The requirements originally specified that the robot shall be able to collect weights in any orientation, but when the design of the collection system was changed after the conceptual design report, this requirement became more overlooked as it never occurred. For the current design, the weight is required to be standing so that the rails of the holding bay can hook onto the weight and hold it. In round 5, a weight was knocked over in front of the robot and the robot continued to drive over top of it and its movement became impaired for the remainder of the round. This was unlucky and likely caused the round to be lost. This may have been able to be mitigated by allowing tipped over weights to slide under the centre to prevent getting stuck on top of it. A different occurrence happened in round 6 where one weight had been collected and the robot drove over the oppositions base rails and the weight caught on the rail and caused it to pop back out past the centre gate. This had also never occurred before but caused the weight to be dropped into the oppositions base and resulted in a loss.

3.2 Competitor 1 Review – Round 13

Round 13 was the first round for Group 4. Group 4 won the round with 2.25 points compared to 0 points from group 29's robot. Group 4 robot collected 3 weights at time 9, 21 and 31 seconds. Compared to group 29 who collected no weights. Neither team had weights at home. Group 29 and 4 both collected all weights they saw hence lost none. Neither team collected any dummy weights. Group 4 travelled 5700 mm more than group 29. Neither team returned home nor dropped weights home. Both teams became stuck during the round group 29 at 13 seconds and Group 4 at 46 seconds. Table 1 summarises all performance metrics of the round.

Table 1: Performance metrics of round 13.

PERFORMANCE METRIC	GROUP 4 ROBOT	OPPONENTS ROBOT GROUP 29
OFF HOME BASE	Yes	NO
WEIGHTS COLLECTED	3	0
WEIGHTS AT HOME	0	0
WEIGHTS SEEN	3	0
DUMMY WEIGHTS	0	0
WEIGHTS LOST	0	0
TIME BEFORE GETTING STUCK	46 s	13 s
DISTANCE TRAVELLED ESTIMATE	6000 mm	300 mm
RETURNED HOME	NO	NO

Ultimately won what Group 4 the round was collecting more weights than group 29, but this is a consequence of time before getting stuck and distance travelled. Group 4 spent 33 more seconds searching and collecting weights before being stuck whilst group 29 was stuck.

This comes from how to two robots navigate. Group 4 had better navigation than group 29. Group 4 kept a further distance from the walls avoiding edges of walls. Figure 9 shows group 29 hitting the edge of the wall.

Figure 9: Group 29 Robot stuck on wall

It should be noted that on green base, group 29's base, there was a broken part of the base barrier. This led robots to turn towards the broken part if one track went through the bump and the other track went over. This happened in the case of group 29 although the navigation system should've been able to deal with this edge case.

Group 4 navigation of moving into most free space and collection system allowed for the fastest collection of three weights in the round and competition. This proved to be advantageous in this round as there were only seven weights total. Another factor for fastest collection of three weights was Group 4's robot could be started before the count down and would only move after the blue power button was pressed. This gave it a five second advantage over group 29

A failure of Group 4 was the robot getting stuck on a pole while returning home. Figure 10 shows an annotated figure of the robot oscillating before the pole and then getting the belt stuck on the pole.

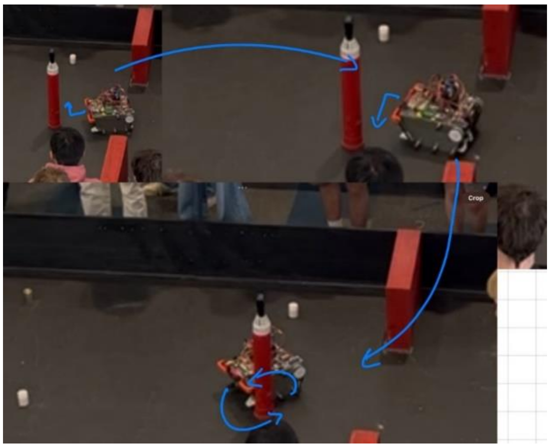

Figure 10: Annotated Robot Stuck on Pole

When returning home to robot drives in the direction home until an obstacle then drives around the obstacle. The pole being narrow caused the robot to not see it think it had gone pass it then turn back into it. See it and repeat trying to go around it. Eventually got close enough to get caught on it and spin indefinitely around it. The FTA discussed the potential of unexpected looping behaviours from code. A watchdog was included but as the robot thought it was moving home and it could not see the pole so it wasn't triggered.

It is hard to evaluate group 29 performance as they did not make it out of home. This is likely due to no TOFs facing outwards hence not being able to see to the side of the robot. It uses a machine learning method for searching. Wheels were the given setup. The way it collected weight was a strong point for it and held an advantage over Group 4. It used a combination of a metal laced ramp and a scope to grab weights and check if metal by passing a current through the weights. This has the potential to pick up multiple weights at a time unlike Group 4. In later rounds of the competition this feature proved important often winning rounds.

3.3 Competitor 2 Review – Round 63

In round 63 Group 4 competed against Group 1. Group 1's robot shown in Figure 11, featured a combine system with rotating rubber bands. It also featured a shorter wheelbase and a larger overall height. This system is beneficial for an instance where there are multiple weights close together as the combine can collect a lot of weights without necessarily sensing all of them. This would require a good dummy weight rejection system however this was not needed in this round as they didn't pick any dummy weights up.

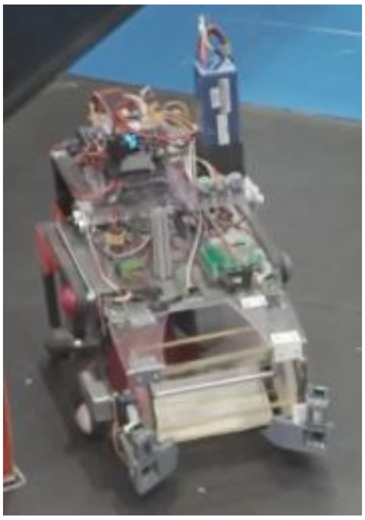

Figure 11: Group 1 Robot
(1st overall)

Group 1 won this round with 3.75 points while Group 4 achieved 0.75 points. Group 1 managed to get two weights to their home base contributing to all their large number of points. Group 4 had one weight on board the robot. At the start, both robots were facing towards each other with a weight in between. Group 4 was first off home base and collected the first weight. Group 1 collected their first weight at 60 s. A summary of performance metrics for round 63 is displayed in Table 2.

Table 2: Performance metrics of round 63.

PERFORMANCE METRIC	GROUP 4 ROBOT	OPPONENTS ROBOT GROUP 1
OFF HOME BASE	Yes	Yes
WEIGHTS COLLECTED	1	0
WEIGHTS AT HOME	0	2
WEIGHTS SEEN	2	2
DUMMY WEIGHTS	0	0
WEIGHTS LOST	1	0
TIME BEFORE GETTING STUCK	27 s	67 s
DISTANCE TRAVELLED ESTIMATE	3000 mm	4000 mm
RETURNED HOME	YES	YES
TIME TO FIRST WEIGHT	4 s	60 s

Group 4 tipped over the second weight as it was being collected, shown in Figure 12. Group 1 did not face this problem due to their combine system having the ability to collect tipped over weights. This is one of the main reasons Group 1 won this round as Group 4 was stuck in this way for most of the round. Group 1's robot was slightly faster than Group 4's robot despite being a larger robot and weighing more. This improved speed is due to a larger drive wheel allowing the robot to move faster. Group 1 also featured a good weight drop system with both their weights being dropped home successfully. The robot completed a 180 degree turn once reaching their base before tipping the weights into home in a smooth manner. Overall group 1 won this round due to their combine collection system and effective home drop system.

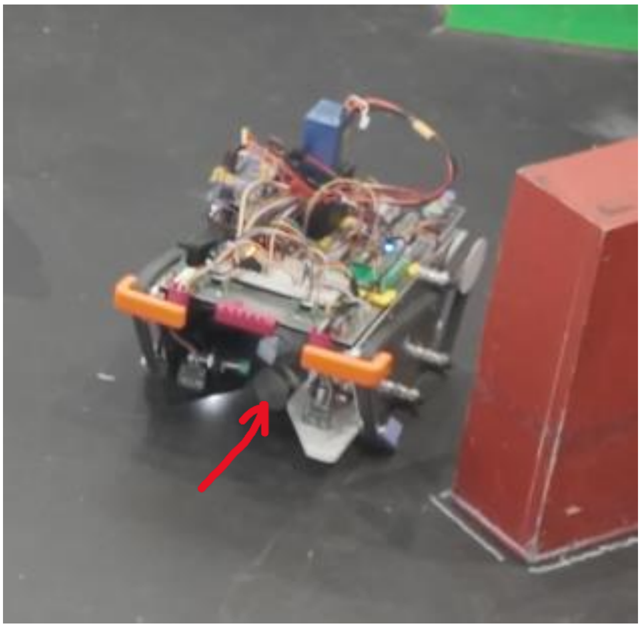

Figure 12: Round 63 Tipped Weight

3.4 Competitor 3 Review – Round 65

In round 65, Group 4 competed against group 13. Group 13 won the round with a score of 3.75 against Group 4 with a score of 0.75. Group 4 collected 3 weights over the round but unfortunately one weight fell out into group 13's base and another weight was dropped outside of home base. Group 13 collected 4 weights onboard, 3 target and one dummy. It took 20 seconds for group 13 to collect 3 targets and one dummy whereas it took 60 seconds for Group 4 to collect 3 target weights. The results of round 65 are summarised in Table 3.

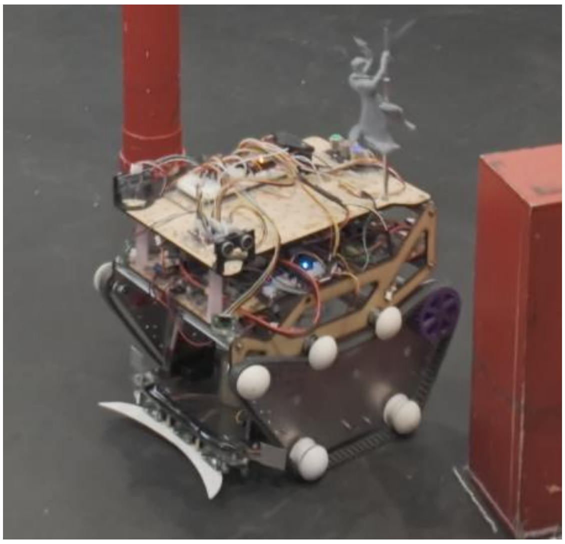

Figure 13: Group 13 robot (2nd overall)

Group 13's robot is shown in Figure 13. The drivetrain and chassis of group 13 was similar to Group 4 with one minor difference. Both robots used the standard chassis plates, extrusions, DC motors, 3D printed drive pulley and tracks, but group 13 used larger 3D printed bearing casings for the tracks to roll on. This gave the robot a height advantage to clear more obstacles and have less chance of getting stuck. Though neither robot got stuck in this round, the height difference could have been advantageous to Group 4 where the weight got caught on group 13's base and dropped the weight into their base.

Group 13's robot used a total of seven range finding sensors, two ultrasonic and five TOF sensors. The ultrasonic sensors and two long range TOF sensors were used for navigation and obstacle avoidance. The ultrasonic sensors were pointed directly outwards sideways and the TOF's were pointed forwards and out at an angle of 45 degrees. This configuration was evident as to why they often collided with obstacles head on and spent a portion of time sitting at an obstacle waiting for a watchdog timer. The sensor configuration of Group 4 was slightly better as the robot had better obstacle avoidance though this had little influence on the performance of both robots. The remaining three TOF sensors were the short-range version and were lined up along the bottom of the robot to detect weights. This gave the robot a large FOV for finding weights but due to the lack of forward-facing sensors above the lower TOF's, Group 4's strategy of comparing bottom sensors to top sensors to identify weights is not practical. Instead, the robot drives towards anything the lower sensors see. However, this method of detection did not limit the robot as it scored well.

It was evident that the motion control of group 13's robot used some form of PID control or smoothed motion as its movement around the arena was smooth with corners and straights, compared to Group 4 where motion was 'bang-bang'. This allowed group 13's robot to navigate through and beside obstacles smoother than Group 4's but still hit obstacles head on. It was also evident that group 13 could not return home as after their robot had collected 4 weights it stopped in an open area. Group 4's robot made it to home base but slightly misjudged and still dropped one weight outside of base therefore the advantages of making it home actually caused loss of points.

For collecting weights, group 13's robot utilised a U-shaped arm with an electro-magnet in the centre. The arm was controlled by two HX12 servos and could only pick up weights standing up with metal tops sitting directly in front of the centre TOF sensor. The weights would then be lifted on board and placed on a tray, but weights would not be checks weather they are a target or a dummy. This resulted in group 13 collecting a dummy weight so theoretically, Group 4's weight collection outperformed group 13's by collecting the same number of target weights. The advantage of Group 4's collection system was that penalties were applied for collected dummy weights but Group 4's deposit system and storage let it down by losing weights collected.

Table 3: Performance metrics of round 65.

PERFORMANCE METRIC	GROUP 4 ROBOT	OPPONENTS ROBOT GROUP 13
OFF HOME BASE	Yes	Yes
WEIGHTS COLLECTED	3	4
WEIGHTS AT HOME	0	1
WEIGHTS SEEN	4	5
DUMMY WEIGHTS	0	1
WEIGHTS LOST	2	0
TIME BEFORE GETTING STUCK	N/A	85 s
DISTANCE TRAVELLED ESTIMATE	12000 mm	9000 mm
RETURNED HOME	YES	NO
TIME TO FIRST WEIGHT	4 s	6 s

3.5 Post-mortem summary

From 3.1, the major flaw in the robot was the package delivery system for off-loading weights from the robot to home. Introducing a system where the robot does not have to move more than one turn once on home base would increase reliability and avoid dropping weights out of home. A screw that pushed the weights out the back could have been effective. Where the robot would just have to get home and turn around. This would have also been faster than the current method. Another method could be another the weights stored sloped down such that when the gates open, they slide out. This system working reliably would have helped the robot win more rounds. If the robot had deposited weights correctly in the competition, it would have achieved getting four weights in base across all rounds.

Another flaw was becoming stuck on fallen weights making the encoder and therefore the x, y position of the robot useless. Implementing a system such that it would not be stuck longer than 5 seconds would mitigate this. This could be integrating the IMU accelerometer data into the x, y positioning system. By doing so there would be two sensors taking odometry data and went they become unaligned, the robot is most likely stuck and should attempt to reverse. Another solution could be to allow fallen weights to slide under the robot by lifting the entire tray up. Therefore, it would not get stuck on them at all.

4. Conclusion

After completing the Robocup competition, the robot can be defined as 'fit for purpose' as it meets most of the requirement's specifications. However, the robot did not consistently pass functional requirements 1.3 and 1.9, while it did not pass performance requirement 2.3 during some rounds. All operational requirements, non-functional requirements and constraints were passed, see appendix B. Overall, the robot was successful as it placed 3rd in the competition winning four rounds. Requirements on pole obstacles would have improved performance.

The areas for improvement include fixing these functional and performance requirements which mostly occurred due to the robot getting stuck on poles and inability to pick up tipped over weights. The weight deposit system takes a lot of time and often pushes the weights off the home base. Further development time could have been spent on improving this system. It could be improved by a sloped ramp so that the weights fall out of the robot due to gravity. The current system has a lengthy move forward and backwards to shunt the weights out. There could also be a check for tipped over weights within code to move backwards and away if it is in the weight collection state for a certain amount of time.

We used 386 grams of PLA for 3D printing, but 300 grams of PLA was included in the budget. This resulted in an extra cost in PLA of $4.30 NZD. All parts designed were manufactured using 3D print except the main gate, this will be milled out of aluminium for strength as it provides a stronger mounting point to the servo. The aluminium has an approximate extra cost of $3.90 NZD. We used two extra TOF sensor (long-range) than what was provided, this had an extra cost of $20 NZD. Everything else is included in the budget. The total additional cost of the robot came out to $28.20 NZD which is well within the additional costs budget of $50. A full bill of materials can be found in appendix A.

Appendix

A. Bill of Materials

Part Description	Part Number	Cost per Unit ($ NZD)	Quantity	Additional Costs
Teensy 4.0 MCU	TEENSY40	23.80	1	
Chassis Plates			2	
Robot tracks	880-8M		2	
~~Drive Pulley~~			~~2~~	
Track Bearings			10	
Electrical Plate			1	
Aluminium Ex. 223.5mm			6	
Digital Level Shift			1	
Inductive Level Shift			1	
Encoder Board			1	
DC Motor Driver			~~2~~ 1	
Power Supply Module			1	
Power Buttons			1	
Colour Sensor	TCS34725	14.00	1	
~~Ultrasound Board~~		~~1.00~~	~~1~~	
~~Ultrasound Sensors~~	~~HC-SR04~~	~~1.80~~	~~2~~	
TOF sensor (Long)	VL53L1XV2	10.00	2+2	$20.00
TOF sensor (Short)	VL53L0XV2	5.00	2	
IMU Sensor	SEN0253	36.00	1	
Inductive Proximity	LJ18A	25.00	1	
Digital IR Sensor	SEN0019	6.00	1	
Servo	HX12K	14.00	1	
Servo	SG90	2.50	1	
DC Motor with encoder	28PA51G	70.00	2	
~~DC Motor 200RPM~~	~~SKU505979~~	~~15.00~~	~~2~~	
Aluminium Billet		$11.40 per 100x100x15mm	75x45x15mm	$3.90
PLA		0.05 per g	386 g	$4.30
			Total:	**$28.20**

B. Requirement Specifications

Functional	Description	Pass/fail
1.1	The Robot shall be able to recognise if it is at 'home' or in the playing arena	PASS
1.2	The Robot shall be able to distinguish between its home and its opponent's home.	PASS
1.3	If the Robot is positioned at its home and contains weights, it must place the weights on home.	FAIL
1.4	The Robot should return home once it contains three weights.	PASS
1.5	The Robot shall be able to recognise walls in relation to itself.	PASS
1.6	The Robot shall be able to traverse all the following obstacles:	PASS
1.6.1	Speedbumps of minimum 25mm high.	PASS
1.6.2	Ramps of minimum 100mm high and 30% gradient.	PASS
1.7	The Robot shall be no greater than 400 mm wide.	PASS
1.8	If the Robot detects a weight in the arena, it shall be able to move towards it successfully.	PASS
1.9	The Robot shall be able to collect weights placed in any orientation.	FAIL
1.10	The Robot shall only collect weights in the playing arena.	PASS
1.11	The robot should not collect fake weights.	PASS
1.12	The robot shall be able to collect weights against arena walls and obstacles.	PASS
1.13	Once identified The Robot should not interact with a dummy weight consecutively.	PASS
1.14	The Robot shall cash in weights before the end of the round.	PASS
Performance		
2.1	The Robots battery shall last for at minimum, 2 minutes.	PASS
2.2	The Robot shall be able to pick up a weight once it enters a picking up mode within 5 seconds.	PASS
2.3	The Robot shall not be stuck on in a subsection of the arena for more than 20 seconds	FAIL
2.4	The Robot shall be able to move at least 0.5 m/s whilst fully loaded.	PASS
Operational		
3.1	The Robot shall be robust enough to be hit by other robots.	PASS
3.2	The Robot shall operate in temps ranges of 5 – 40 °C.	PASS
3.3	The Robot shall function no matter the starting orientation and position.	PASS
Non-functional		
4.1	The Robot should have a mechanical modular design for easy assembly and repair.	PASS
4.2	The Robot should withstand collisions with other robots and obstacles.	PASS
Constraints		
5.1	The robot must not contain any more than 400 grams of 3D printed material.	PASS
5.2	The robot must not use any externally sourced parts (outside of university).	PASS