RoboCup
Design Evaluation Report

Group 4

Hayden Watson – 26781242

Luka Whitaker - 48420886

Conner Horn - 36757479

ENMT301

Mechatronics System Design

2025

University of Canterbury

Executive Summary

This report reflects Brendan's final design and performance, evaluating it against its initial requirements and the opposition. Overall, Brendan had a mixture of successes and failures. These successes included a first-round win with a score of 3.25, the collection of both a real and dummy weight, and the capture of the snitch. However, a key failure was the inability to escape the starting zone in two of the three matches, which resulted in lost time and missed weight collection opportunities.

Upon review of opposition robots (group 10, group 8 and group 26), key evaluations were made:

Group 10 had the same track layout design and used a crane for its weight collection mechanism. For navigation, they drove until the front sensors detected a wall or the weight sensor detected a weight. Crucially, Group 10 did not have a weight dropping method, resulting in a full boot and no chance of picking up more weights. However, the different navigation methods helped group 10's robot pick up 1.33 weights per round, a whole one weights more per round average than Brendan.

Group 8 features a comparable overall design, with a similar robot layout and collection mechanism. The main difference was that this robot featured a rotating segmented chamber for weight storage and release rather than Brendan's diverter and door system. There were significant issues with the navigation, which caused the robot to get stuck in a loop either spinning on the spot or stuck against a wall. This was likely the primary limit constraining greater advancement within the competition.

Group 26 was determined to be very similar in design, but with key differences in implementation of similar features, such as the movement and harvester speed. Although their harvester rotated 800% faster than Brendan's, it was the movement around the arena that was deemed to be the key to their success and ultimately winning round 58. Key differences in movement included a quicker robot (~48% quicker), thanks to a larger driver gear, and a superior bang-bang controller with hysteresis wall following navigation. This combination of both speed and superior navigation provided more opportunities for weight collection.

Overall, Brendan's inconsistency stemmed from multiple issues that were addressed with too little time to make significant changes. While the mechanical system was robust, the software was underdeveloped. Brendan's combine harvester, with a collection succession of 82% in testing, and "tank-like" movement were effective and sound, but only when the navigation was able to function correctly in the right conditions, an open environment void of many obstacles. As the competition rounds progressed and the arenas became more complex, Brendan was unable to keep up with the ever-complicating environment, as reflected by the results: a win, followed by two losses. This increasing complexity, alongside a lack of testing in complex situations, resulted in inadequate arena coverage (~15% in losing rounds) and ultimately fewer weight collection opportunities. The project highlights that a successful competition robot requires synergy between all areas of design and, in the case of Brendan, the mechanical and software systems should have been given equal energy and priority.

Table of Contents

1.0 Introduction

This report details the final evaluation of Group 4's robot, "Brendan", for the RoboCup competition. Building upon previous concepts and iterations as detailed in the Conceptual Design Report (CDR) [1] and Detailed Design Report (DDR) [2]. The goal for this project was to design and build a robot to compete in the competition, while being capable of moving using navigation, collecting and sorting weights, and doing all of which in an efficient and reliable manner. These requirements and their final implementation along with critiques and an overall evaluation of the robot and its capabilities on competition day are further detailed throughout subsequent sections. It also compares with opposition robots and evaluates potential improvements to the final design.

2.0 Design Description

The final design seen on competition day is the result of an iterative process of design, testing and refining that started on the day of initial conceptual design and ended the day of competition. The entire robot was built around 2 core features; movement and weight collection, both of which are detailed further in this report along with other key features such as navigation and weight management.

All code was organized by a scheduler, which used set frequencies to run through different modules. Sensors were updated at a fast rate with the motor movement algorithm updated at the same frequency. Servos were accessed less frequently due to the large time loads on the CPU and their occasional usage.

The watchdog timer was set up to implement if the conditions remained relatively consistent for a period of 10 seconds. If this occurred, the robot was set to move max speed forward until the forward or angled sensors picked up a wall close by, hopefully stepping over a lip or getting out of a loop.

2.1 Weight Collection

The collection mechanism is a combine harvester, driven by a 10 RPM motor, that uses a rotating "barrel" with 10mm rubber bands equally spaced out. Originally a crisscross pattern was used, but after further testing, this was changed to a uniform parallel pattern; this change is depicted in Figures 1 and 2. The motivation for this change was due to lack of ability to pick up the snitch and lack of tension to reliably move the weight up the ramp. See Appendix A for full testing.

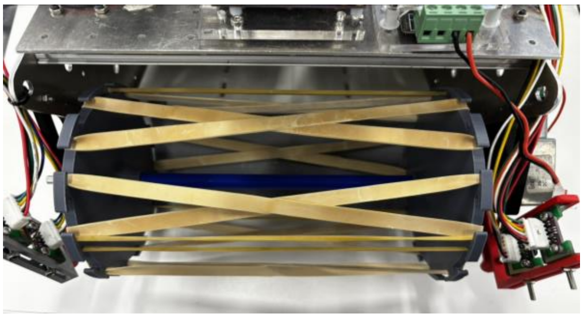


Figure 1 – The original crisscross pattern layout.

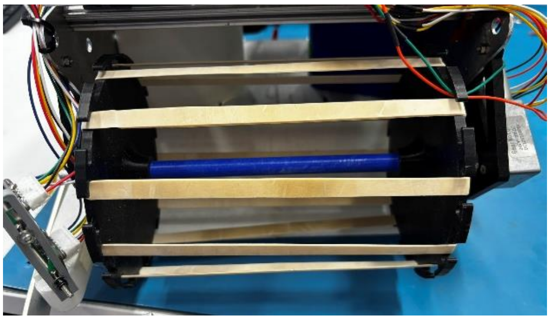
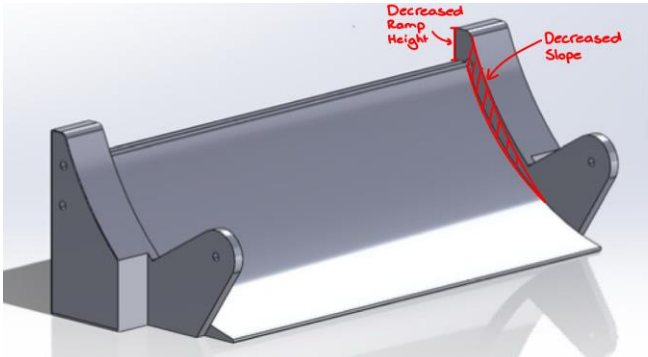


Figure 2 – The final pattern layout after testing.

Alongside the harvester itself, a key component of weight collection was the ramp used for entry into the robot's sorting system. Two key factors were considered for ramp design. The height of the ramp is a key element for the sorting system, as it was necessary that the weight was brought to a height that allowed for sufficient gravitational potential energy to be translated into kinetic energy and thus proceed with sorting. This, however, brought upon another design consideration, the steepness of the ramp. This took many iterations, and through trial and error, a suitable ramp steepness was determined. The combination of these design factors can be seen in Figure 3.

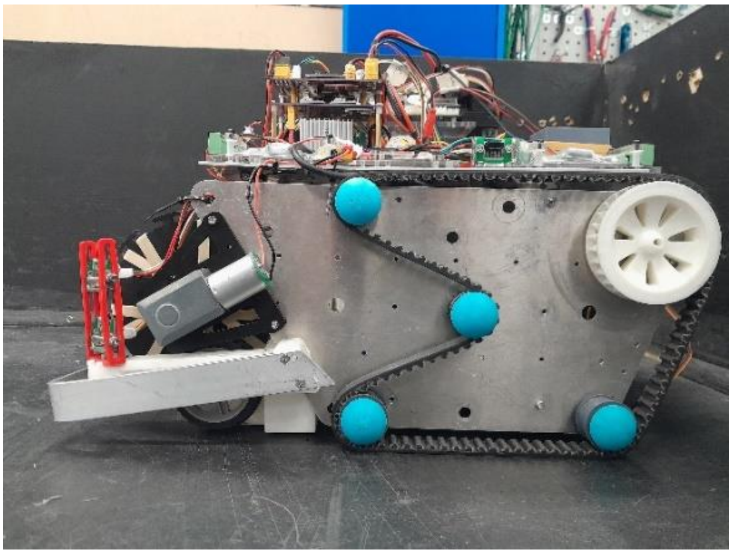
Figure 3 - Final ramp design with optimized height and slope



In addition to this, a unique feature that Brendan had compared to other robots of similar designs, was the front mounted wheels on the ramp to help in getting over obstacles. This kept a low ground clearance to aid in weight collection and overall traversal of the course. This feature too went through iterations to avoid getting caught on the harvester rubber bands, and the final design can be seen in Figure 3.

2.2 Locomotion

Locomotion for the robot involved a track arrangement to maximize the tension in the belts. Further increase in tension was added using spacers on some of the drive track supports and the design of a larger gear. Track protectors and guide rails were also added due to the regular catching of the bolts on the obstacles and walls. Figure 4 shows the arrangement of the track as well as the implementation of the track spacers, protectors and guide rails.



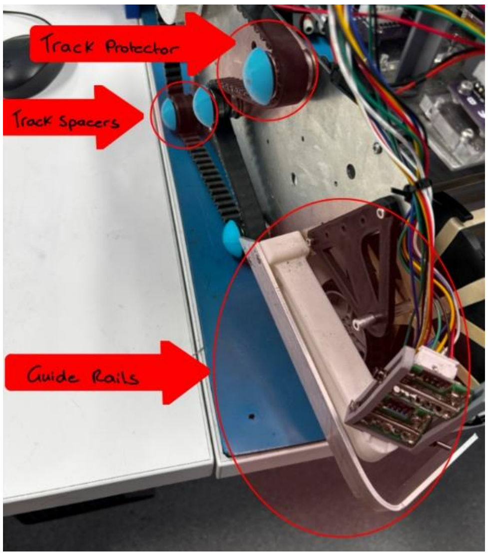


Figure 4 - Track arrangement (left) and track spacers, guide rails and track protectors (right) used in the final design

2.3 Navigation and Weight Detection

2.3.1 Sensor setup

There were seven location sensors set up on the robot: a Time of Flight (ToF) on each side for the wall detection, two ToFs on each side for the weight detection and an ultrasound on the front for obstacle detection. The arrangement is shown in Figure 5.

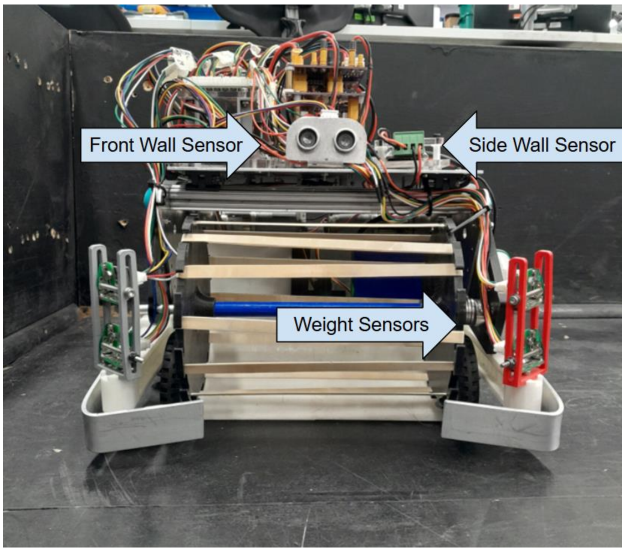


Figure 5 - Sensor arrangement on Brendan.

In addition to the sensor themselves, the mounting brackets also underwent further development. This was iterated to increase strength and develop fixed mounting positions at a 45-degree angle. The final cad model can be seen in Figure 6.

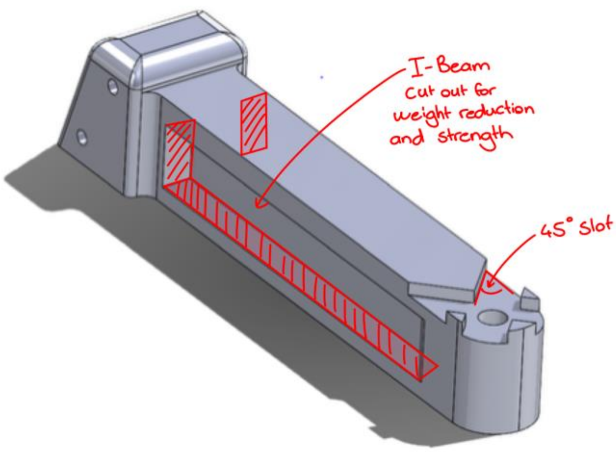


Figure 6 – The final sensor mount design with fixed 45-degree mounting slot.

2.3.2 Navigation Algorithm

The original matrix design concept was discarded due to the noise on the imu being more significant than expected, which resulted in an unreliable known location. The matrix design was replaced by a simpler wall following algorithm with an initial startup and then five different sequences depending on the sensor inputs. A full breakdown of the logic is shown in Figure 7.

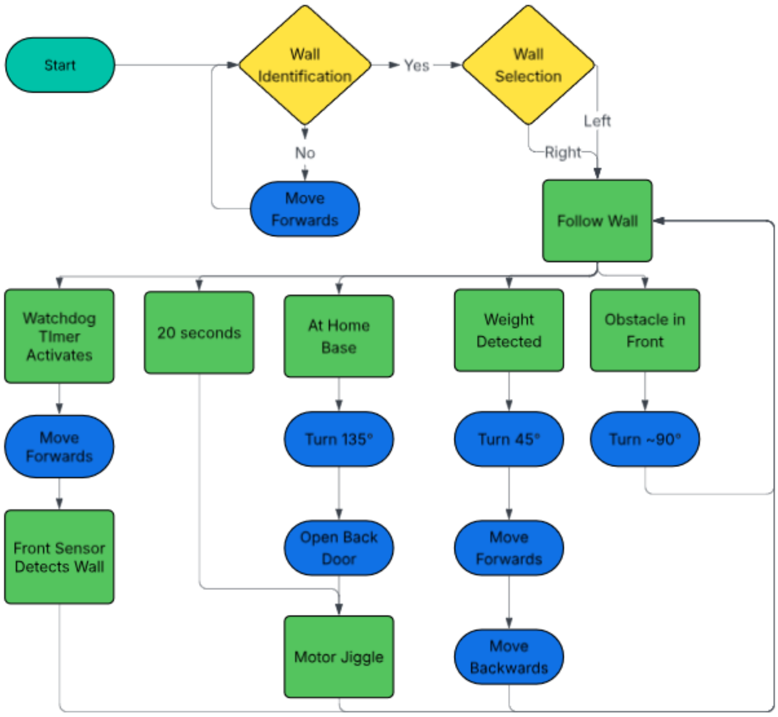


Figure 77 - Navigation algorithm diagram for Brendan

The startup involved determining which wall was going to be followed. This is shown as the wall identification decision node in Figure 7. This occurred by checking the side sensors to see if there was an initial wall on either side. If there was only one wall, then that wall was chosen to be followed. If there was a wall on both sides of the robot, then forward motion was carried out until one disappeared and then the remaining wall would be followed.

After this occurred, a wall following algorithm was created using a PD controller to maintain a constant distance from the wall. The parameter used to maintain the distance with the wall was determined using a combination of both the weight detection sensors and the side mounted sensors.

If there were any obstacles directly in front of the robot and these were picked up using the front sensor, then the robot did a skewed reverse in the direction of the wall it was following. The same thing occurred with the angled sensors.

A weight detection algorithm was added to control the motion if there was an identified weight. This was a hard coded sequence that involved turning the robot to 45 degrees and then moving the robot forward to the distance that the weight was seen from the sensor, and then a straight reverse to return to the robot's original position.

A watchdog timer and motor jiggle function were added to escape any loops or stop the robot from being stuck. The watchdog timer was set to activate if there was less than a 10cm change for 90% of all sensor readings for more than 10 seconds, resulting in forward motion until a wall was found. The motor jiggle activated every 20 seconds and moved the robot rapidly forwards and backwards.

Lastly, if the robot was identified to be on its starting square, the robot turned 135 degrees away from the wall and the back door opened. The robot then had a rapid sequence of driving forwards and backwards to drop any weights onboard.

2.4 Weight Management

An ultrasound sensor was added into the interior of the robot. This was to facilitate presence detection of both the dummy, and target weights. Initially a limit sensor was trialled but due to the small tolerance for the switch to be triggered in the channel in conjunction with the added resistance to the weight sliding, this idea was rejected. An ultrasound sensor was used for this purpose instead. The logic for the weight management system can be found in Figure 8.

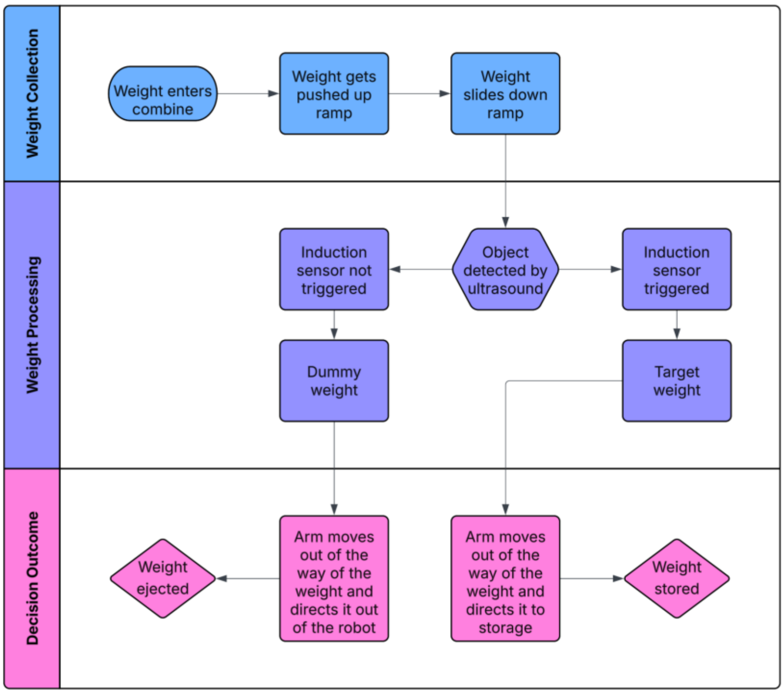


Figure 88 - Weight management logic diagram for Brendan

Figure 8 shows how weights are managed within the robot. In the weight processing stage when the weight is detected by the ultrasound sensor, if the inductive sensor is not triggered within a short amount of time, it is deemed a fake weight. If it is triggered, then it is deemed a target weight. This tells the servo motor to move the arm to the side to let the weight slide down the internal bed and then the motor swings back to help motivate it down faster. Figure 9 displays the three different operational modes.

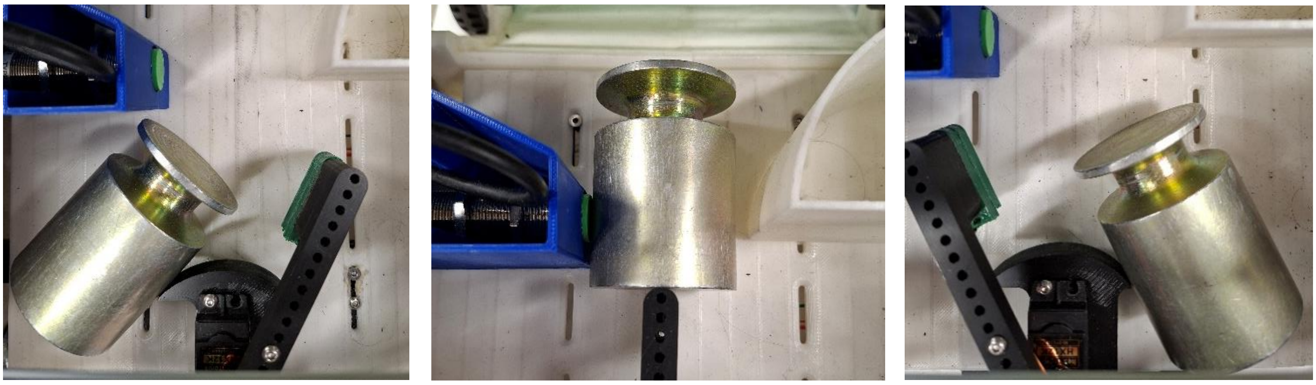


Figure 9 – The lever arm positions in dummy weight (left), weight determining (middle) and real weight (right) modes.

However, this detection system came with its own caveats due to this detection setup having a problematically large detection area. As sometimes weights might not fully be in position but still be detected and lead to errors in the logic. Primarily though this allows the implementation of the intended logic.

The switching arm is positioned up against the rear centre of the internal bed to best fulfil its' purpose of directing the weight. It is made up of three 3D printed parts, alongside the servo motor. The first of which is a mounting plate designed to be attached onto the internal bed through existing mounting slots. And then attach to the second part through an adjustable slot. This second part serves a couple purposes; both allowing the servo motor to be fixed in position, as well as having a contoured section on the front, to aid in directing sliding-weights to the sides. The third part is an arm attached to the top of the servo that stops and diverts the sliding weights to either side. Figure 10 shows the switching arm arrangement

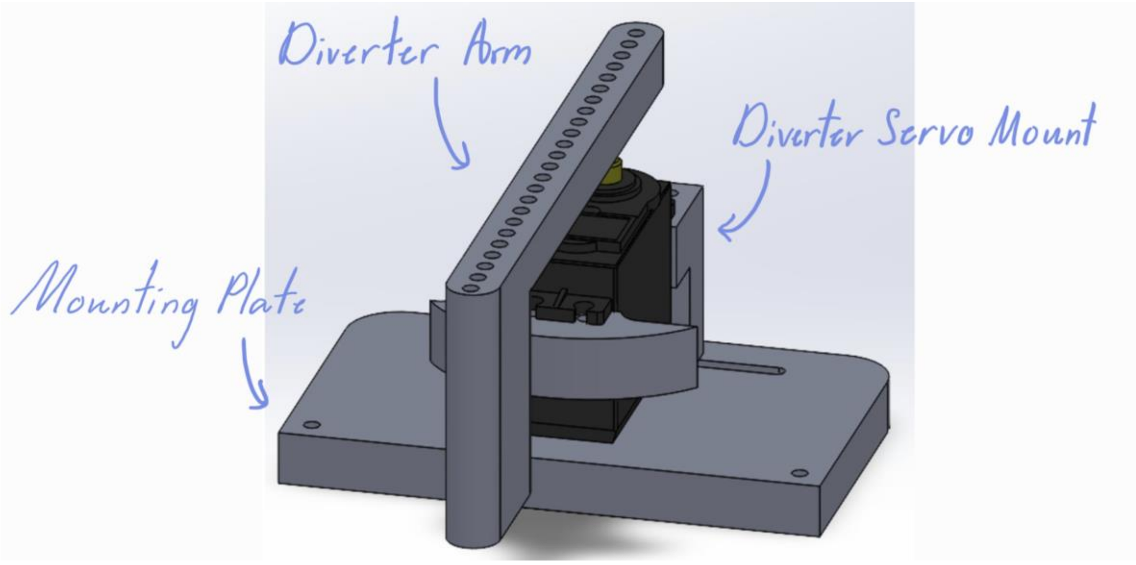


Figure 10 - Switching arm assembly for Brendan

The rear release door was also modified to be roughly half the length of the bed so as not to block any rejected dummy weights from exiting the robot while still holding the target weights. Figure 11 shows the final backdoor design.

Figure 11 – The final backdoor design for Brendan

3.0 Results and Evaluation

3.1 Competition review

Out of the three rounds participated in, Brendan won one and lost two. Overall, the robot picked up one dummy weight, one real 0.5kg weight and the snitch over the three rounds. This shows that the robot successfully completes requirements 1.3, 1.14 and 1.15 (“The robot shall move the weights.”, “The robot shall be capable of picking up the snitch” and “The robot shall have storage for the snitch.”). The full results table is shown in Table 1.

Table 1 - Results table, with scoring breakdown for Brendan

		Onboard (kg)						Base					
Round	**Competitors**	**Onboard Score weight (kg)**	**0.5**	**0.75**	**1**	**D**	**S**	**Base Score Weight (kg)**	**0.5**	**0.75**	**1**	**D**	**Winner**
Round 18	4	3.25	1			1	1	0					4
	10	1	2					0					
Round 39	4	0						0					8
	8	1.75		1	1			0					
Round 58	4	0						0					26
	26	1			1			0					

It was deemed that Brendan’s performance depended heavily on the arena coverage that it did. In round 18, Brendan managed to traverse ~50% of the arena and managed to pick up a real and a dummy weight as well as the snitch, winning the round. However, in rounds 39 and 58, coverage was very limited (~15%) for both. Figure 12 shows the estimated paths of the robot.

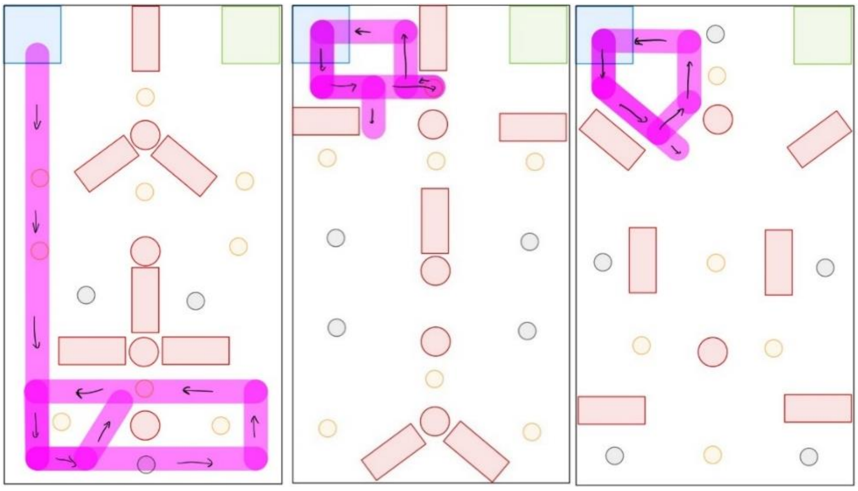


Figure 12 - Arena layouts and coverage that Brendan participated in.

Brendan also successfully completed requirement 1.7 (“The robot should not ‘capture’ any weights from: it’s own base or the opponent’s base”), by never reaching the oppositions base and never having weights at its own base to pick up. Additionally, to this, requirement 1.12 ("The robot shall be capable of travelling over a 15mm 'speed bump'"), which was successfully met by escaping the starting square.

In both cases, no weights were picked up. Although it was noted that one weight entered the harvester in rounds 18 and 39 with the robot failing to bring either of the weights on board. This gave a competition weight picking up success rate of 50% (2/4) which is significantly less than the 82% found in the DDR report. The sample size was small, resulting in a poor representation of Brendan's ability as well as the opposition robot causing interference when picking up weights.

An issue that occurred was the reliability of the weight detection algorithm. In round 18, the weight detection algorithm worked flawlessly, identifying and picking up one weight. In round 39 one weight was identified and entered the harvester but was spat back out. In this round there were also two times when the weight detection algorithm identified weights when they were not there. In round 58, the weight detection algorithm did not attempt to pick up any real weights but had six occasions of identifying weights that were not there. A potential future fix would be the implementation of some filter to reduce incorrect weight identifications.

The sorting mechanism did not get used during the competition. In round 18, the pickup of the snitch blocked the sorting mechanism as predicted, before any of the weights were picked up. This meant that the sorter was not used. In rounds 39 and 58, no weights were successfully put onboard the robot, therefore the sorter was redundant.

The watchdog timer and motor jiggle were usefully implemented, resulting in the robot never being constantly stuck in one spot for an entire round. In round 39, the watchdog timer was triggered three times to escape being stuck. In round 58, the robot escaped, getting stuck once through the motor jiggle. However, it was noted that this took 45 seconds to occur. A full breakdown of the time spent stuck and escape method is shown in Table 2. Although the watchdog timer successfully escaped loops and being stuck, it did not complete requirement 1.17 ("The robot shall have a 'watchdog timer' that stops repetitive functions from occurring if they occur for 10 seconds.") as it took longer than 10 seconds to activate on three of the five occasions.

Table 2 - Time spent stuck and method of escape for Brendan

Round	Time stuck	Escape Method	Total time
18	29.5 seconds	Motor Jiggle	29.5
39	10.5 seconds	Watchdog timer	43
	8.5 seconds	Watchdog timer	
	24 seconds	Watchdog timer	
58	45 seconds	Motor Jiggle	45
		Average	39.2

Although the robot never had any weights to drop at home, in rounds 39 and 58, the robot attempted to drop weights in the home base.

In round 18 and round 39, Brendan attempted climbing the vertical poles. This happened due to the harvester attempting to pick up the pole and the front half of the robot lifting off the ground, until the frontal sensor picked up an obstacle and forced the robot to reverse off of it. A potential solution to this could be to add a horizontal bar across the top of the harvester so that the bar hits the wall, and the harvester cannot touch the wall. Another solution would be to use the IMU to determine when there is a change in the vertical acceleration and implement a reverse if this occurs.

Other requirements met during the competition were 1.16 ("The robot shall not leave the arena during a round."), 1.5 ("The robot should have a method of wall detection in at least three directions."), 1.8 ("The robot shall be unable to drop a weight if it is considered 'on board'."), 2.1 ("The robot shall withstand being hit by the opposition robot or bumping into a wall."). 1.16 was achieved by never occurring. Requirement 1.5 was met as it had the sensor setup arrangement resulting in the three different sensor directions. Requirement 1.8 was successful as the robot never dropped any weights once they were on the ramp. 2.1 was successful due to taking no damage when being knocked by the walls or opponent in any of the rounds.

The other requirements completed are elaborated in Table 3. Appendix B contains the details of all requirement successes

Table 3 - Requirements met during competition by Brendan

Requirements	**Evaluation (Appendix C contains any extra testing)**
1.1 The robot shall pick up weights up to 1kg in weight.	As evaluated in the DDR report, this criterion was met.
1.2 The robot shall pick weights in all orientations.	As evaluated in the DDR report, this criterion was met.
1.4 The robot shall be capable of dropping weights.	Although it did not occur during a round, weights were dropped during trial runs.
1.9 The robot shall be capable of travelling 4.9m in 20 seconds.	As evaluated in the DDR report, this criterion was met.
1.10 The robot should be able to travel up a gradient of 30% (17 degrees)	Three simple ramp tests occurred, where the robot was capable of travelling up the ramp.
1.11 The robot shall be capable of escaping a three walled, 0.4m space	Similar to 1.10, the robot was put through three simple tests where it escaped the three wall design every time.
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	When the navigation algorithm changed to wall following, it was deemed that returning home reliably was unlikely, so dummy weight detection was included in the final design.
2.3 Wires shall be managed with tape or a drag chain and placed away from moving parts.	Cable ties were used to full effect, to ensure that the wires were safely managed.
2.4 The robot should take less than 45 minutes to assemble/ disassemble.	Robot disassembly occurred at the end of the project and took 41 minutes.

Requirement 1.6 ("The robot should have the ability to move around the arena, avoiding obstacles, the opposition robot, walls, weights and the snitch."), was deemed incomplete due to bumping into both obstacles and the opponent.

Requirement 2.2 ("The robot shall be modularized.") was also deemed not met. This was due to the bolts holding the ramp also required to go through the sensor arms and the aluminum protectors.

The required $50 budget was also met. The total cost on top of the components given was $32.6. The total bill of materials is shown in Appendix D with the non-given components shown in Appendix E.

3.2 Opposition analysis

Our three rounds were 18, 39, and 58, against teams 10, 8, and 26 respectively.

3.2.1 Group 10's "The Mothership"

3.2.1.1 Results

The Mothership was the first robot that Brendan competed against. The results of Team 10 are shown below in Table 4. They won one round and lost two.

Table 4 - Team 10's results

		Onboard (kg)						Base					
Round	Competitors	Onboard Score weight (kg)	0.5	0.75	1	D	S	Base Score Weight (kg)	0.5	0.75	1	D	Winner
Round 6	33	0						0					10
	10	1.75		1	1			0					
Round 18	4	3.25	1			1	1	0					4
	10	1	2					0					
Round 30	10	0						0					1
	1	1			1			0					

3.2.1.2 Weight collection

Team 10 used a crane for their robot using an electromagnet to pick and dump weights into their boot as shown in Figure 13, with the left side showing the overall robot design and the right side showing the crane and boot.

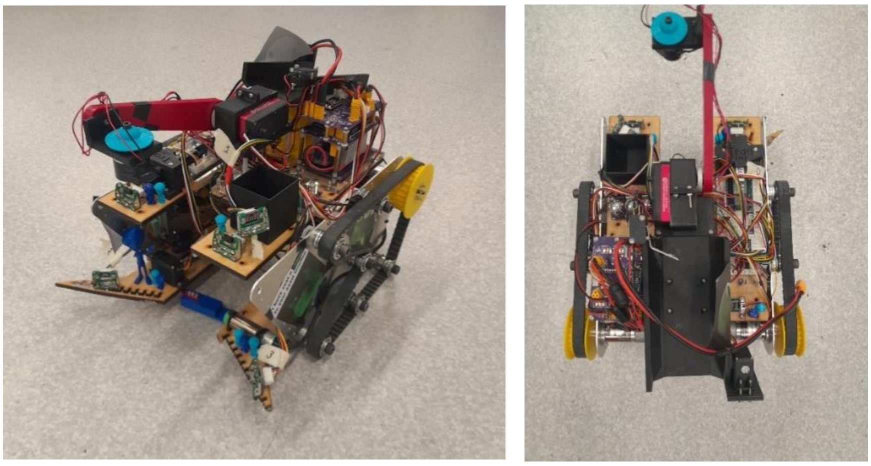


Figure 139 - Overall Mothership design (Left) and Crane and Boot of the Mothership (Right).

The crane method was reliable for picking up weights, and when a weight was within the arms, it never failed. This resulted in four total weights picked up across the rounds, an average of 1.33 real weights per round. In comparison to Brendan, which only picked up 0.33 real weights per round. This mechanism also never picked up any dummy weights, whereas Brendan picked up one across the three rounds. However, the lack of a snitch collection method meant that the Mothership never picked it up, despite the snitch hitting the front twice in the final round. A suitable pickup mechanism for this could have won the Motherships final round.

3.2.1.3 Locomotion

Unlike the weight collection mechanism, Team 10's robot had a near identical track setup to Brendan. The main difference being the extra drive track supports in the middle of the top and bottom. Figure 14 shows the comparison of tracks.

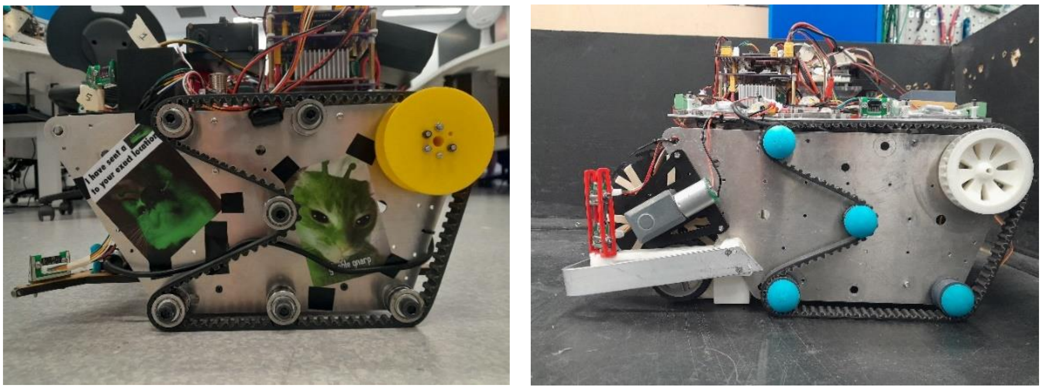


Figure 1014 - Track comparison between The Mothership (left) and Brendan (right).

A comparison made with the Mothership is the length of time stuck. The Mothership spent a long period of time stuck in Round 30, but this was due to a power issue. The average for time stationery for the Mothership was 20.5 seconds (full results in Appendix F), which in comparison to Brendan's 39.2 seconds is significantly shorter. This allowed for more arena exploration and therefore more weight picking up opportunities.

3.2.1.4 Navigation and Weight Detection

The Mothership used an obstacle detection method, where it travelled straight until one of three things happened: the angled wall sensor detected an obstacle closer than the threshold, the front wall picked up something below the threshold or the weight detectors found a weight. The angled wall sensors would result in a slow turn away from the wall, the frontal wall sensors would result in a 90 degree turn and the weight detectors would direct the Mothership towards the weight. The sensors used are shown in Figure 15.

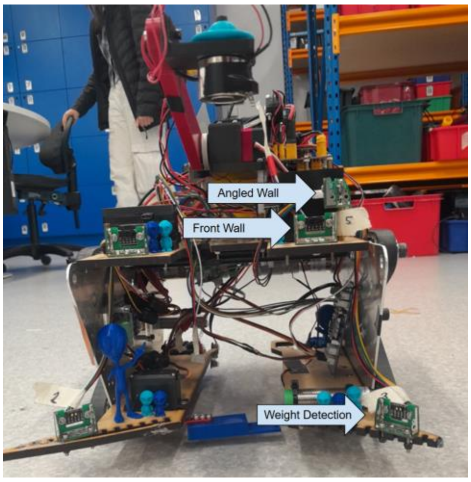


Figure 1115 - Sensor arrangement on The Mothership

This method, although simpler than Brendan's, resulted in better arena coverage, but no set method on returning home. This was a problem, as the Mothership returned to the home base in round 18 but did not attempt to deposit the weights it had onboard, therefore not doubling their points and not allowing for more weights to be collected.

3.2.2 Group 8

3.2.2.1 Results

Group 8's performance was admirable, with two wins and two losses in the same order. The compiled results of Group 8's rounds are featured in Table 5.

Table 5 - Group 8's Competition Results

		Onboard (kg)						Base					
Round	**Competitors**	**Onboard Score weight (kg)**	**0.5**	**0.75**	**1**	**D**	**S**	**Base Score Weight (kg)**	**0.5**	**0.75**	**1**	**D**	**Winner**
Round 19	30	1.5	2		1	2		0					8
	8	1	2					0					
Round 39	4	0						0					8
	8	1.75		1	1			0					
Round 61	8	0.75			1	1		0					12
	12	3					1	1	1				
Round 67	8	-0.25				1		0					24
	24	0						0					

3.2.2.2 Pickup mechanism

Similarly to our design, the robot of group 8 featured a combine-harvester type mechanism for weight collection. It functions so that when a weight encounters the crossbars (the material bridging between the sides of the combine), the weight gets pushed up a ramp and into the robot. The design features guidance arms out the front to help direct weights into the combine. The robot picked up a total number of 7 weights over the four rounds, 5 of which were real weights. Averaging gives 1.25 real weight collections per round. Which is approximately 3.8 times as many as Brendan's average of 0.33 weights. In round 39 the combine got jammed by a dummy weight being firmly lodged between the heat-shrink crossbar on the combine, and the ramp. Removing the possibility of any pickup from then on, for the remainder of the round. Figure 16 shows group 8's design.

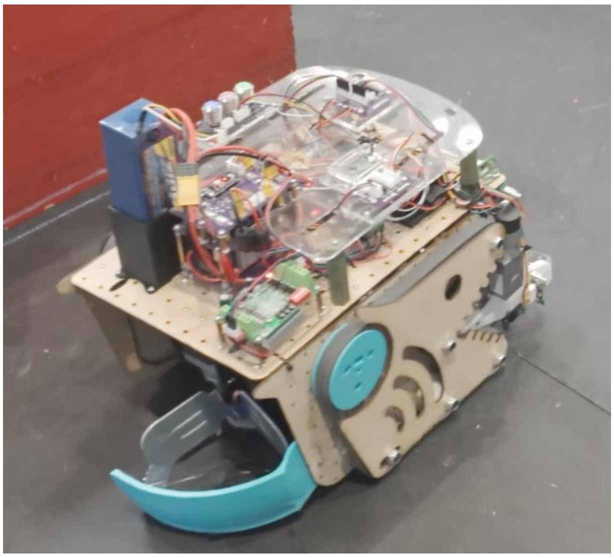


Figure 16 - Group 8's robot during competition.

3.2.2.3 Locomotion

Both robots used track-based locomotion with near identical layouts. The only difference being that Group 8's robot had a third bottom bearing to brace the belt. The belt layout had the same shape, both robots featuring sleeves on the bearings to increase radius and encourage greater clearance between the belt and the edge of the frame, as well as greater tension within the belt.

3.2.2.4 Navigation and Weight Management

Navigation seemed to be primarily obstacle-avoidance based, with no wall following or other navigation behaviours being observed, this strategy greatly simplifies control logic, and reducing sensor dependence, but at the cost of environmental awareness, and reduced robustness in recovery efforts if stuck. In Rounds 19 and 61 for instance this robot encountered some issues. It spent approximately 82% and 67% of the rounds (respectively) stuck spinning around on the spot, which is a significant issue causing no other weights to be collected and losing out on the possibility of gaining any points either by collection or drop off. In Round 39 however it spent no sizeable portion of the round stuck in a loop, so this was not always the case, and in this one it ended winning the round, indicating the loss in potential here.

Weight management for this robot utilised both a common detection approach of an induction sensor and internal funnelling-walls to help direct the collected weights, and then a segmented rotating chamber to hold the weights. This allowed for a single weight to be collected in each segment. Thus, helping reduce any jamming or blockage, and stopping any other un-wanted weights being collected, overall giving finer control. As well as having a simple release mechanism actuated by rotating the chamber until all collected weights are ejected.

3.2.3 Group 26

Brendan's final match was against Team 26's robot. This robot, like Brendan, utilized a combine harvester design but featured key differences in its drive system, harvester setup, and overall software approach, all of which are valuable for comparison. Team 26 competed in a total of 4 rounds, subsequently losing in the round after beating Brendan. The results of team 26 matches can be found below in Table 6.

Table 5 - Team 26's Results

		Onboard (kg)						Base					
Round	**Competitors**	**Onboard Score weight (kg)**	**0.5**	**0.75**	**1**	**D**	**S**	**Base Score Weight (kg)**	**0.5**	**0.75**	**1**	**D**	**Winner**
Round 11	13	1			1			0					13
	26	0.5	1					0					
Round 50	26	4			1		1	0					26
	31	0						1	1				
Round 58	4	0						0					26
	26	1			1			0					
Round 66	28	1.5	1		1			1	1				28
	26	0						0					

3.2.3.1 Weight Collection

As both robots used a combine harvester, there were many similarities in their approach to weight collection; however, there were also notable differences that affected the outcome. One of the most significant was the DC motor powering the harvester, specifically the difference in speed. Brendan used a 10 RPM motor, whereas Team 26 used a 90 RPM DC motor. This 800% increase in harvester speed resulted in a far more aggressive and rapid collection of weights. This was a viable option for Team 26 as their ramp had a less aggressive slope, meaning high torque was not a key factor. For Brendan, a more torque-based approach was chosen to overcome its steeper ramp and facilitate the collection of multiple weights.

Some similarities in the weight collection system included the harvester radius, with only a 2mm difference between them. Both harvesters used a uniform linear pattern of rubber bands to hook the weights. While neither robot was explicitly designed to collect the snitch, both could hold it if it happened to roll into the harvester. These similarities can be seen side by side in Figures 17 and 18.

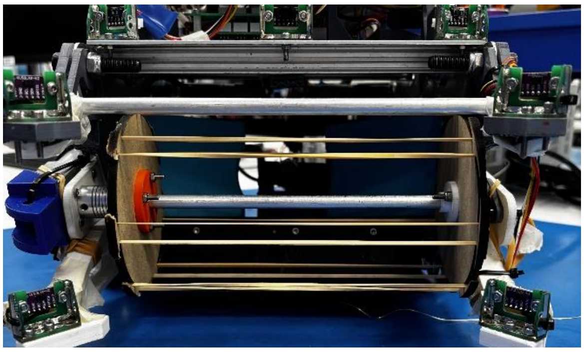


Figure 17 - Team 26's combine harvester layout.

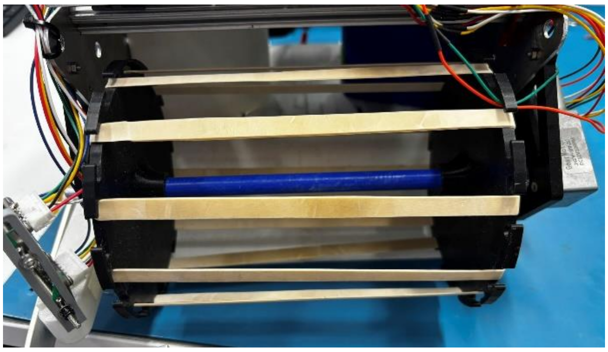


Figure 1128 – Brendan's combine harvester layout.

3.2.3.2 Locomotion

Both robots used the same motor setup and a very similar track layout for optimal tension as seen in Figure 19 and 20. The key distinction, however, was the size of the driver gear. Brendan used a 78mm diameter driver gear, as opposed to the 90mm gear used by Team 26. This change gave Team 26 a clear speed advantage. In testing, Brendan traversed the length of the course in 15.67 seconds, whereas Team 26 covered the same distance in just 10.71 seconds [3], conferring a 48% speed advantage.

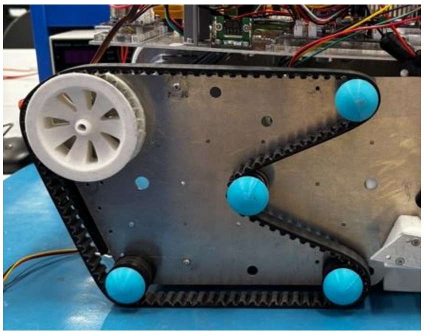


Figure 1319 - Brendan's locomotion setup.

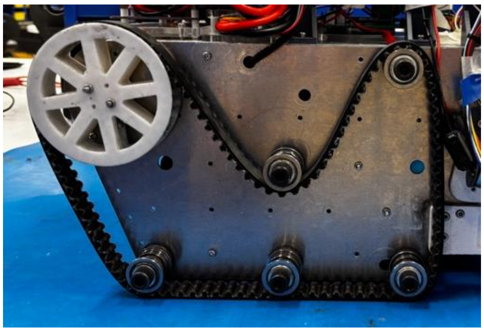


Figure 20 14 – Team 26's locomotion setup.

This speed difference played a key role in the round. Even if Brendan had not gotten stuck at the start and had detected the single weight at the same time as Team 26, it would not have reached the weight in time and it would have been collected by Team 26.

3.2.3.3 Navigation

Another key difference between the robots was the navigation logic. Where Brendan used a wall-following PD controller, Team 26 used a wall-following bang-bang controller with hysteresis. This resulted in a huge discrepancy in arena coverage. In its losing rounds, Brendan covered only ~15% of the arena, whereas Team 26 achieved 96.8% coverage in testing. This was by far the most critical difference between the two robots.

Despite having many similarities, Team 26 had a greater advantage on paper, mainly due to their superior speed and navigation. While other differences were design-specific and did not offer a clear advantage. The navigation supremacy of Team 26 allowed them to traverse the arena more effectively and at a higher speed. This increased their likelihood of detecting weights, ultimately winning them the round as seen in Round 58.

3.3 Post-Mortem Summary

The most significant limitation observed during competition was the robot's unreliable navigation. Particularly in non-linear and constrained environments seen in round 39 and 58. In round 58, despite the passage being wider than the robot (greater than two times its width). The robot became trapped within a small area around the home base, repeatedly turning and moving around within. This behavior appears linked to errors within the wall-following system, and fixed obstacle avoidance, which involved reversing and turning a set radius. A more refined navigation system able to reliably pass through smaller gaps, approximately the robot's width +3 cm on either side to allow for some small error. Without running into error-ridden obstacle avoidance behavior, would have enabled the robot to pass these issues and roam the rest of the arena thus creating more opportunities to collect weights.

A second improvement is a more dynamic navigation method to approach detected weights. Currently, detection triggers a hard-coded sequence, rotate, advance than reverse for a fixed duration. This lacks positional feedback and can result in misalignment. If the system instead calculates the distance using the ToF sensors that are used to detect the weights in the first place and uses IMU orientation data in conjunction with encoder information from the motors, the pickup process would have been significantly more reliable and precise. Thus, it would directly improve weight collection and overall success. The IMU sensors, particularly the front left sensors, occasionally spiked to 8m, which is a significant error and caused false detections of weights. This could be significantly reduced by implementing a moving window filter and a limit to reduce the impact of sudden spikes.

4.0 Conclusion

Ultimately, Brendan was a robot that was only partially fit for purpose. When looking at the final mechanical design alongside the initial conceptual design and requirements, the robot was a success. Its core subsystems, such as the combine harvester and "tank-like" locomotion, were both well-engineered, and this was shown in their effectiveness in competition. This was largely seen in the first round, where Brendan successfully collected a real weight, a dummy weight, and the snitch. This round, aside from the snitch jam that prevented sorting, demonstrated an ability to meet nearly all the design requirements in a single match. In addition to this successful round, the physical build quality and underlying concepts for weight collection and management were both conceptually sound and realistically achievable.

However, in competition, a critical flaw was exposed which ultimately undermined the working mechanical design: the navigation software. While the requirements were met in controlled testing, this did not suffice for the narrow and obstacle-littered competition arenas. The wall-following algorithm was fully functional in open spaces; however, in tight corners and corridors, failure occurred. This failure would often lead to the robot becoming stuck in a single place for long periods before the watchdog timer was triggered, and the robot could reposition itself. This software deficit was the primary cause of the losses in both rounds 39 and 58. Ultimately, it was revealed that although fit for purpose in testing, Brendan was not truly fit for purpose in a competition setting, and thus the primary goal of competing in the RoboCup competition was undermined.

Despite this, with further development time, particularly with an emphasis on software refinement alongside more realistic testing scenarios, we are certain that Brendan would be truly fit for purpose. This further development would involve an abandonment of the simple wall-following logic in favor of a more advanced path-finding algorithm, as implemented by other teams. This would allow for better weight detection as well as improved arena traversal. Alongside this, better sensor filtering would be key to eliminating "ghost" weight detections, thus improving overall reliability and efficiency. This project has highlighted the importance of time management as well as competency in all areas of design. This was most clear in the fact that a robust mechanical design cannot overcome the limitations of an underdeveloped navigation software system. The area with the largest room for improvement is the navigation system, which would be achieved through creating a smarter and more adaptable system that is able to match the mechanical robustness of the design, all of which would require greater time management skills to achieve.

References

[1] Horn, C., Watson, H. & Whitaker, L., (2025) *Robocup Conceptual Design Report*

[2] Horn, C., Watson, H. & Whitaker, L., (2025) *Robocup Detailed Design Report*

[3] Hinman, C., Vagg, W. & Smith, M., (2025) *Robocup Detailed Design Report*

Appendices

Appendix A

	Old layout	New layout
Snitch test 1	Fail	Pass
Snitch test 2	Pass	Pass
Snitch test 3	Fail	Fail
Snitch test 4	Pass	Pass
Snitch test 5	Fail	Pass

Appendix B

See page 21

Appendix C

1.4 The robot shall be capable of dropping weights.

Weights were picked up and robot shifted back to home square. The home routine was run.

Test number	Weights onboard	Weights dropped
Test 1	3	2
Test 2	2	2
Test 3	1	1

1.10 The robot should be able to travel up a gradient of 30% (17 degrees)

This test involved incrementing the gradient of the slope and validating if the robot could traverse up it, starting from 15 degrees.
Testing was stopped at 17 degrees as this meant it met requirement 1.1

Gradient	Success
15	Yes
16	Yes
17	Yes

1.11 The robot shall be capable of escaping a three walled, 0.4m space

The robot was placed in 0.4m enclosure and was tested to see if it could escape.

Test number	Escape success
Test 1	Yes
Test 2	Yes
Test 3	Yes
Test 4	Yes
Test 5	Yes

Appendix B

Requirement	Pass/ Fail	Justification
1.1 The robot shall pick up weights of up to 1kg in weight.	**Pass**	As shown in the DDR through testing, this requirement was successful
1.2 The robot shall pick weights in all orientations.	**Pass**	As shown in the DDR through testing, this requirement was successful
1.3 The robot shall move the weights.	**Pass**	As shown in round 18 weights were picked up, therefore being moved
1.4 The robot shall be capable of dropping weights.	**Pass**	Throughout trial runs, weights were consistently dropped
1.5 The robot should have a method of wall detection in at least three directions.	**Pass**	Final robot design involved sensors pointing in five different directions
1.6 The robot should have the ability to move around the arena, avoiding obstacles, the opposition robot, walls, weights and the snitch.	**Fail**	Collisions were made with opposition and walls, resulting in the failure of this requirement
1.7 The robot should not 'capture' any weights from: 1.7.1 its own base. 1.7.2 the opponent's base.	**Pass**	As shown in competition, no weights were picked up in Brendan's base or the oppositions
1.8 The robot shall be unable to drop a weight if it is considered 'on board'	**Pass**	As shown in competition, no weights were lost once they made it onto the bed
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.	**Pass**	Proven in the DDR through testing, this condition was met through testing
1.10 The robot shall be capable of escaping a three walled, 0.4m space	**Pass**	Three simple tests proved that the robot successfully escaped the three walls
1.11 The robot should be able to travel up a gradient of 30% (17 degrees).	**Pass**	Three simple tests proved that the robot got up a 30% slope
1.12 The robot shall be capable of travelling over a 15mm 'speed bump'	**Pass**	As proven in competition, exiting the starting square completes this requirement
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.	**Pass**	As shown in competition, no weights were picked up in the oppositions base
1.14 The robot should be capable of picking up the snitch.	**Pass**	As shown in competition, the snitch was picked up and stored successfully
1.15 The robot shall have storage for the snitch.	**Pass**	As shown in competition, the snitch was picked up and stored successfully
1.16 The robot shall not leave the arena during a round.	**Pass**	As shown in competition the robot did not leave the arena
1.17 The robot shall have a 'watchdog timer' that stops repetitive functions from occurring if they occur for 10 seconds.	**Fail**	Although a watchdog timer was implemented, it did not reliably activate within 10 seconds of the robot becoming stuck.
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.	**Pass**	As the navigation algorithm changed to the wall following method, the reliability was reduced, and the decision was made to include a dummy weight detector.
2.1 The robot shall withstand being hit by the opposition robot or bumping into a wall.	**Pass**	No parts were damaged when collisions with the wall and opposition
2.2 The robot shall be modularized.	**Fail**	Parts were assembled for multiple sections, such as ramp and sensors arm
2.3 Wires shall be managed with tape or a drag chain and placed away from moving parts. **Rationale:** Ensures wires aren't disconnected.	**Pass**	Cable ties were used to full effect, and no wires were pulled apart during the competition
2.4 The robot should take less than 45 minutes to assemble/ disassemble.	**Pass**	As proven by the final disassembly of 41 minutes

Appendix D

Component	Part number	Weight(g)	Qty	Cost ($)	Total ($)
Sensors					
Ultrasound IO Board	HC-SR04	-	2	1	2
ToF – Short	VL53L0XV2	-	4	5	20
ToF – Long	VL53L1XV2	-	2	10	20
IMU	SEN0253	-	1	36	36
Inductive Proximity	-	-	1	25	25
Color Sensor	TCS34725	-	1	14	14
Actuators					
10RPM DC Motor	SKU365231	-	1	15	15
143RPM DC Motor with encoder	28PA51G	-	2	70	140
Standard Servo	HX12K	-	2	14	28
Drivers and Electronics					
Power Supply	-	-	1	40	40
Microcontroller Board	Teensy 4.0	-	1	80	80
Ultrasound Driver	-	-	1	10	10
Motor Driver	DFR0513	-	2	20	40
Inductive level shift board	-	-	1	10	10
Digital level shift board	-	-	1	10	10
Stop go buttons	-	-	1	10	10
Hardware					
Robot side plate	-	-	2	4	8
Robot top plate	-	-	1	4	4
Aluminium profile 220mm	-	-	4	10	40
Main drive pulley belt	-	-	2	5	10
Aluminium ultrasound cutout	-	-	1	2.5	2.5
Drive track support	-	-	8	3	24
Servo arm long 25T Aluminium	-	-	2	2.2	4.4
Aluminium 3mm rod	-	-	1	3	3
Aluminium 25mm x 3mm x 300mm	-	-	2	4	8
Shaft coupler	-	-	1	3	3
Power wires	-	-	3	0.1	0.3
3 pin cables	-	-	3	0.2	0.6
4 pin cables	-	-	8	0.2	1.6
5 pin cables	-	-	2	0.2	0.4
6 pin cables	-	-	6	0.2	1.2
8 pin cables	-	-	2	0.2	0.4
Power Cables	-	-	5	0.5	2.5
Rubber bands	-	-	7	0.15	1.05
Cable ties	-	-	8	0.2	1.6
Assorted nuts	-	-	30	0.05	1.5
Assorted fasteners	-	-	77	0.05	3.85

PLA					
Backdoor	-	33.87	1	0.05	1.6935
Bottom bracket	-	26.39	1	0.05	1.3195
Diverter	-	12.56	1	0.05	0.628
Back door servo mount	-	12.55	1	0.05	0.6275
Battery holder	-	20.15	1	0.05	1.0075
Track spacer	-	4.665	4	0.05	0.933
Front sensor mount	-	12.09	2	0.05	1.209
Combine disc	-	40.63	2	0.05	4.063
Ramp	-	102.56	1	0.05	5.128
200m bed	-	115.96	1	0.05	5.798
Combine centre rod	-	6.51	1	0.05	0.3255
Combine mount	-	9.62	1	0.05	0.481
DC motor mount	-	17.02	1	0.05	0.851
Sensor elevator	-	2.765	2	0.05	0.2765
Belt protectors	-	1.9	8	0.05	0.76
Diverter servo mount	-	9.71	1	0.05	0.4855
Feeder left	-	46.7	1	0.05	2.335
Feeder right	-	52.7	1	0.05	2.635
				Total	652.4565

Appendix E

Component	Part number	Weight(g)	Qty	Cost ($)	Total ($)
ToF - Short	VL53L0XV2	-	2	5	10
Servo arm long 25T Aluminium	-	-	1	2.2	2.2
Aluminium 3mm rod	-	-	1	3	3
Aluminium 25mm x 3mm x 300mm	-	-	2	4	8
Rubber bands	-	-	7	0.15	1.05
Cable ties	-	-	8	0.2	1.6
Assorted nuts	-	-	30	0.05	1.5
Assorted fasteners	-	-	77	0.05	3.85
PLA	-	28.35	1	0.05	1.4175
				Total	32.6175

Appendix F

Round number	Time stuck
Round 6	8 sec
Round 18	0 sec
Round 30	53.5 sec