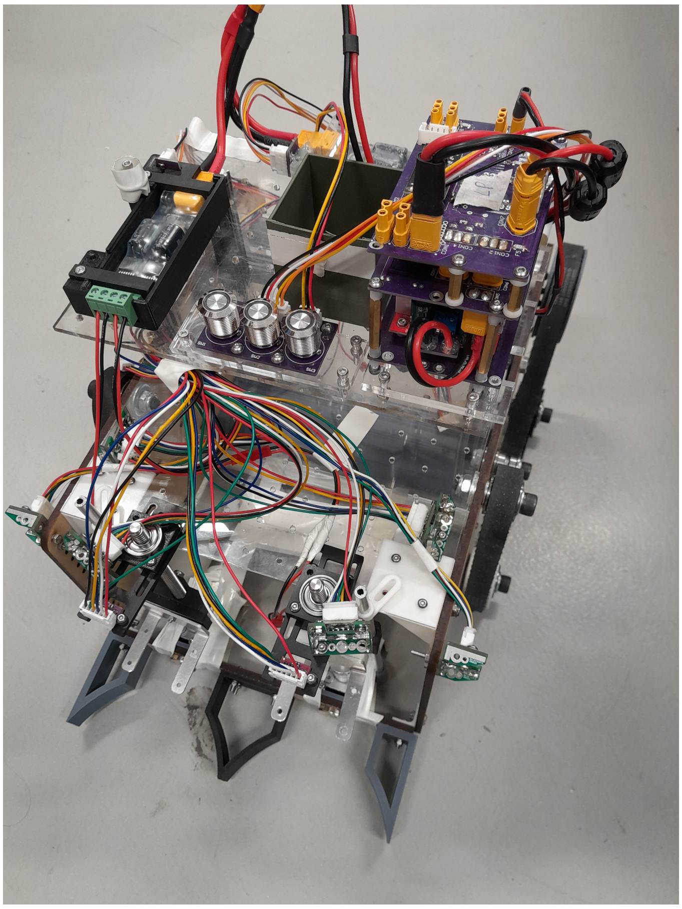
Robocup Design Evaluation Report

ENMT301



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Executive Summary

This report presents a comprehensive evaluation of Pole Dancer, an autonomous robot developed for the 2025 ENMT301 RoboCup competition. The project required designing a robot capable of independently navigating an arena, identifying metallic target weights, collecting them, and returning to base while avoiding obstacles and dummy weights. The final design featured a dual-forklift magnetic pickup mechanism, tracked chassis, and a modular software architecture built around scheduler-driven state machines for navigation, pickup, and control.

Quantitative performance analysis confirmed the robot met most functional requirements, including reliable pickup of 1 kg weights, autonomous obstacle avoidance, and consistent operation under competition conditions. However, mechanical limitations - particularly low ground clearance - caused repeated base-lip entrapment, which restricted performance despite stable control logic. Comparative evaluation against three competitor teams highlighted that simpler mechanical layouts paired with robust sensing often outperformed heavier or over-engineered systems.

The report concludes that Pole Dancer was fit for purpose in testing and partially fit in competition, with its main weaknesses being mechanical rather than algorithmic. Recommendations for improvement include increased chassis clearance, closed-loop motor control, non-blocking task scheduling, and refined sensor calibration to enhance responsiveness and reliability in future iterations.

1 Introduction

This report reviews the final design and performance of our robot developed for the 2025 Robocup competition. The challenge involved building an autonomous robot that could navigate an arena, collect metallic weights, and return them to base for points. Robots also competed to intercept a roaming "snitch" for bonus points, while avoiding dummy weights and obstacles throughout the round.

Our robot, Pole Dancer, was first introduced in the Conceptual Design Report (CPR) and refined through the Design Progress Report (DPR). The final design uses a double forklift-style magnetic pickup system mounted to a tracked chassis. The magnet remains permanently active and attracts metallic weights as the robot drives into them. When contact is made, the robot reverses, dragging the weight backward. If the weight follows, confirming that it is metallic, the forks are raised and the weight is considered collected. This is compared to dummy weights which remain in place when the robot reverses after contact, so are ignored. This sequence provided a simple and reliable way to collect real weights without requiring additional discrimination sensors or complex logic.

The robot navigates the arena using a random-movement routine. It drives forward for variable intervals, changes direction periodically, and uses Time-of-Flight (TOF) sensors to detect and avoid walls. This behavior allows for wide coverage of the arena with minimal computational overhead, while maintaining consistent obstacle avoidance.

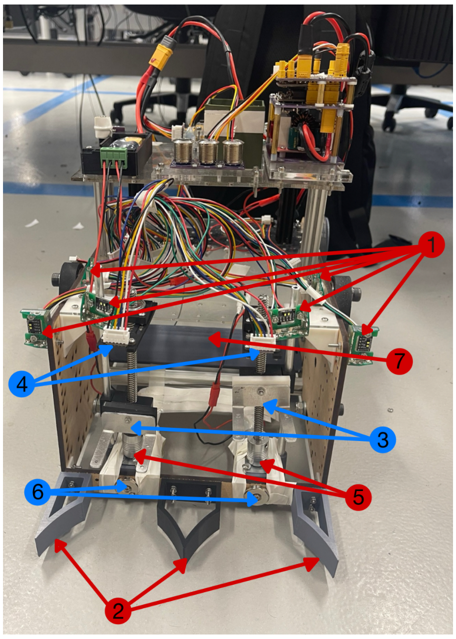
This report evaluates how the design performed both in testing and in competition. It outlines the final mechanical, electrical and software updates since the previous report and assesses the system's reliability, speed, and scoring performance against the original design requirements. The competition results are also compared with other teams to highlight which design choices were the most effective.

Finally, the report discusses key observations and lessons learned from the competition, identifying areas where the pickup system, control logic, and navigation could be refined to improve overall consistency and performance in future iterations.

2 Design Description

2.1 Design Overview

The final design, with key parts labelled, is shown in Figure 1. Its mechanical construction employed the same strategies of robust simplicity as outlined in the DPR, but featured some improvements and redesigns, which shall be outlined subsequently.



1) TOF sensors for obstacle detection
2) Weight guides
3) Forklift arm lead screw attachment for weight collection
4) TOF sensors for weight detection
5) DC motors for lead screw
6) Permanent magnets for weight collection
7) Ramp for snitch collection

Figure 1: Picture of final robot and design overview (note: as another group on the day needed it, no CPU board is shown in the picture. See Figure 3 for placement information).

Additionally, the high-level functional architecture of the robot is shown in Figure 2.

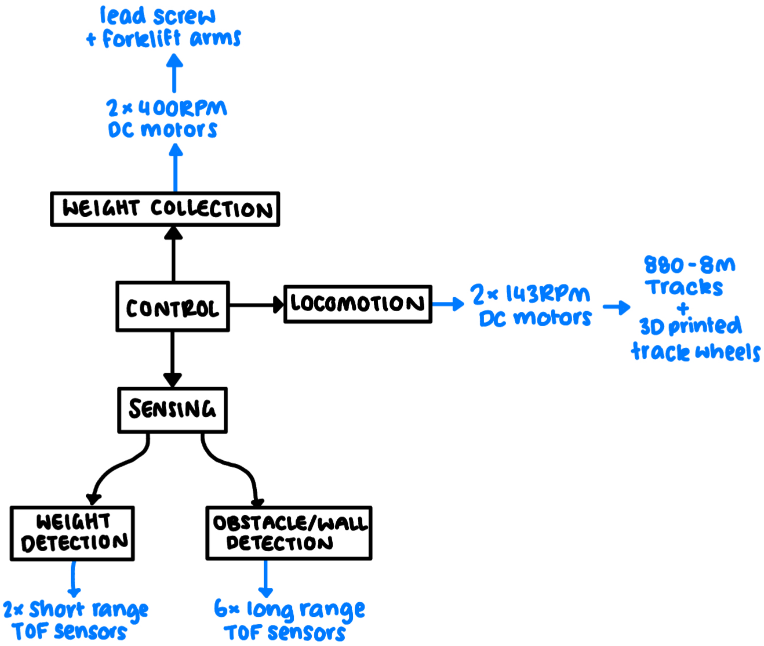


Figure 2: High-level functional architecture diagram.

The top plate housed the electrical components required to operate the robot. The final physical architecture of the top plate is shown in Figure 3.

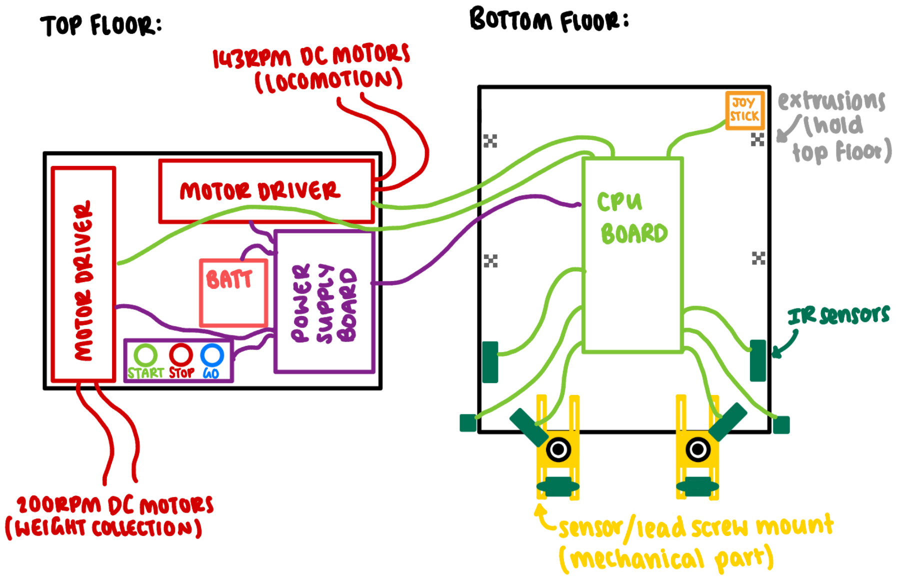
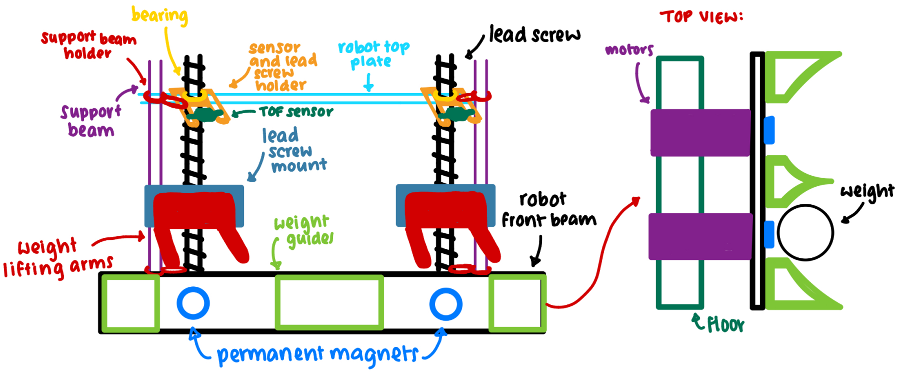


Figure 3: Top plate physical architecture.

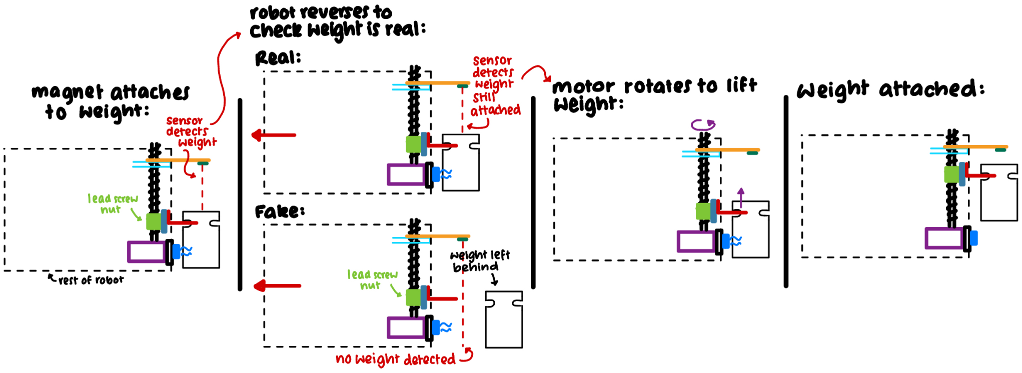
2.2 Mechanical Design Developments

2.2.1 Weight Collection

The weight collection system has changed significantly since the DPR, as further testing of the original design revealed notable issues. The magnetic pick up system proved insufficient in reliably picking up weights, as it was not strong enough and the magnets could not be positioned low enough to work for all weight orientations. Furthermore, the servo motors used to move the magnet holder arms (to release weights) could not rotate a full 360◦ and thus could not pull the arms back enough to release weights. Further design progress to ensure the robot met the requirements of weights being considered on board (being off the ground and lifted with the robot when picked up) was also proving difficult. Thus, a new design was implemented, which kept the same concepts of magnets and front storage (to maintain the benefits of the original design of simple weight sorting and storage) but was more robust and catered to the requirements of the project. Figure 4 shows all the components of the new system (Figure 4a), along with how the mechanism works (Figure 4b).



(a) Drawing of the new weight collection mechanism.



(b) Diagram of how the mechanism works.

Figure 4: New weight collection mechanism design overview.

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As shown in the figure, the new design uses a forklift mechanism, realised using a lead screw, to pick up weights. The lead screws are actuated by 200rpm DC motors. A photo of the new design is shown in Figure 5.

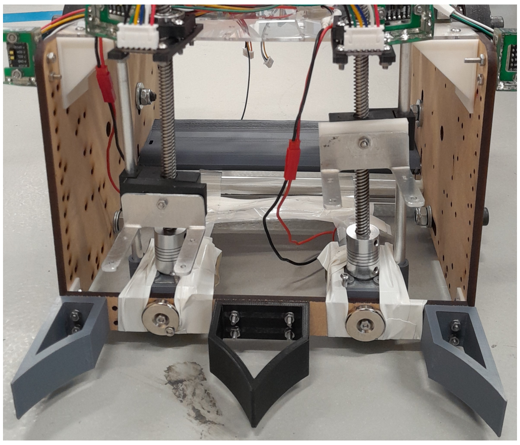


Figure 5: Photo of the weight collection system used in the final design.

The weight lifting arms (red in Figure 4a) were repurposed IR sensor backings. This meant a new piece did not have to be designed. Furthermore, the backing is metal and thus much stronger than anything that could have been designed, as the materials used in the manufacturing processes available were limited.

The magnets (blue) help align the weight with the pick up mechanism, as well as sort fake from wheel weights using the method outlined in Figure 4b. Weight alignment is further improved using the weight guides (light green). The insides have been hollowed to save on material.

The support beam (purple) is an aluminium rod and makes sure the lead screw nut does not inadvertently turn, interfering with the weight lifting arms. It connects to the motor mount via a small attachment sleeve.

The lead screw mount (cyan) connects the weight lifting arm and support beam to the lead screw nut. The CAD model of the designed 3D printed part is shown in Figure 6. The part was designed to have the screws and nuts sit flush with the surface, allowing the arms and lead screw nut to connect to it, which both have flat backings.

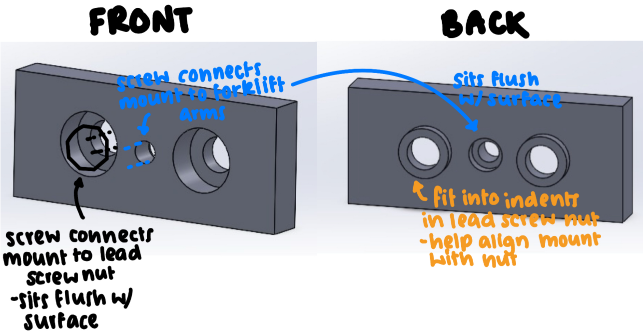


Figure 6: CAD model of the lead screw mount, front and back view.

The bearing (yellow) supports the lead screw. Its ability to freely rotate while fixed allows the lead screw to be held in place, but still spin.

The sensor mount (orange) is shown in Figure 7. It was designed with long slots so its position was easily adjusted, thus the weight detection sensors could be precisely aligned with the weights. The long slots also doubled as connections for the bearing mount and support beam supports, and one of the obstacle detection sensors. This multifunctional design saved on space and material.

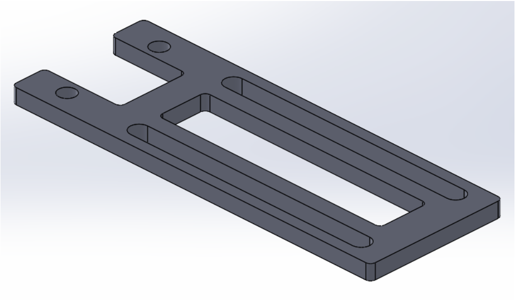


Figure 7: CAD model of the sensor mount.

2.2.2 Track Layout

As discussed in the DPR, the DC motors for track driving were moved to the top of the robot to make room for the snitch collection system. The new track layout is shown in Figure 8.

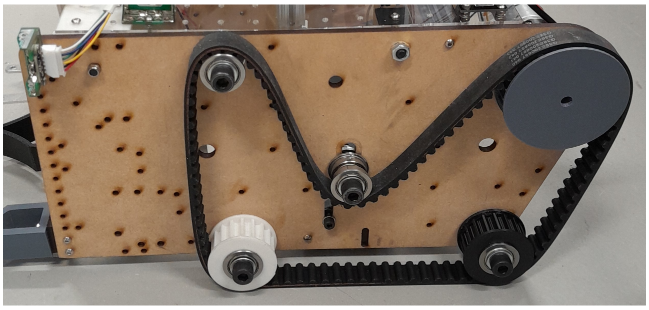


Figure 8: Track layout with DC motors at the top.

2.2.3 Snitch Catcher

Aspirations of implementing a snitch catcher were also discussed in the DPR. The design used was similar to that proposed in the DPR, and is shown in Figure 9.

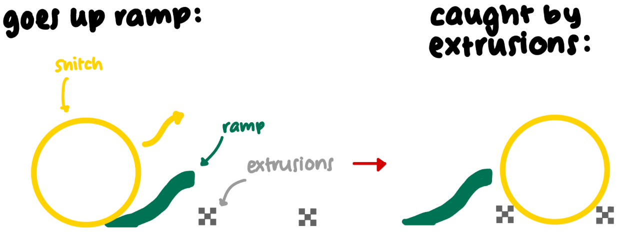


Figure 9: Snitch catcher system.

The ramp was connected to the robot side plates with one screw on each side (at the top of the ramp) so that the bottom could lift up to get over any obstacles. Extrusions were used as they were deemed to be easier to implement and less bulky than a floor, but provided the same outcome. On the day, sticky tape was lined over the extrusions for extra security.

2.3 Software Design Developments

The software for *Pole Dancer* underwent a major redevelopment following Report 2. The original version had implemented map-based navigation and predictive pickup logic, but this complexity made tuning and debugging impractical under real conditions. The final software instead prioritised modularity, reliability, and simplicity, resulting in a robust and easily adjustable control system that complemented the robot's mechanical improvements.

The final software controlled all onboard subsystems—sensor readout, navigation, motor control, and the forklift mechanism—through a modular Arduino-based framework. Configuration parameters such as motor speeds, task intervals, and sensor thresholds were centralised in *config.cpp*, allowing fast field tuning and ensuring consistency between testing and competition setups. This approach proved valuable when re-calibrating sensor thresholds during competition rounds.

The core control architecture followed a layered state-machine hierarchy (Figure 10), consisting of the *RobotStateMachine*, *NavigationStateMachine*, and *PickupStateMachine*. Additional control checks, including *CALIBRATION*, *EMERGENCY_STOP*, and *END_ROUND*, were implemented as transition-level conditions between the main state machines rather than as standalone state machines. Each layer managed a specific subsystem, with clear entry and exit conditions to ensure predictable transitions. The system operated under a scheduler-based task structure using the *TaskScheduler* library, which replaced the continuous loop logic of earlier prototypes. Sensor reading, fusion, navigation, and motor updates were executed at fixed intervals, maintaining real-time responsiveness without blocking delays.

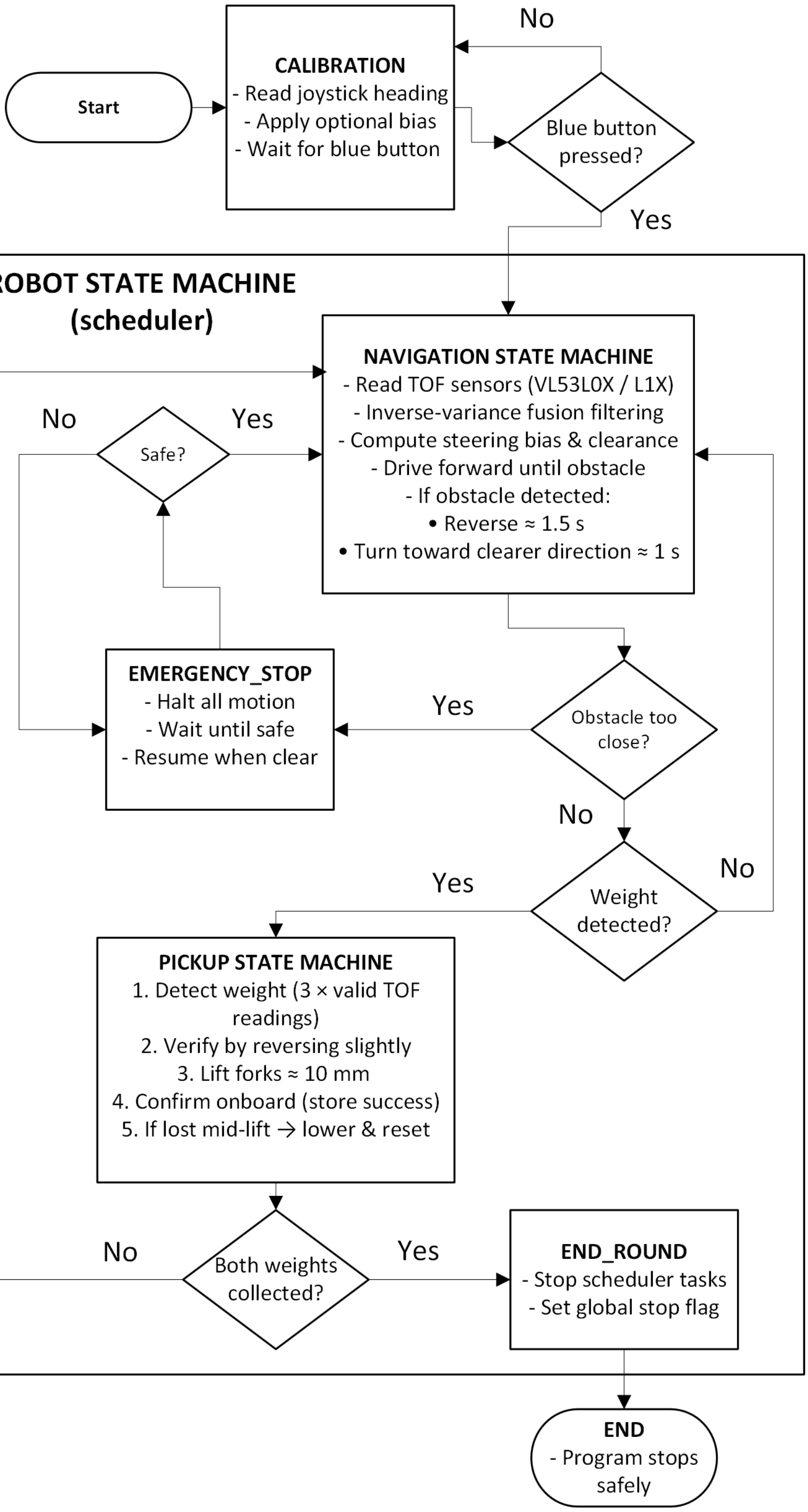


Figure 10: Top-level state machine showing the robot's main operational modes.

The Time-of-Flight (TOF) subsystem, comprising VL53L0X and VL53L1X sensors, provided continuous distance readings for obstacle and weight detection. A lightweight fusion layer combined the forward-facing sensor data using inverse-variance weighting to smooth noise and correct minor bias. The resulting outputs—forward clearance, side distances, and steering bias—allowed the robot to maintain smooth, stable navigation without oscillations. This biasing method enabled gradual course corrections instead of abrupt turns, producing consistent path coverage across the arena.

Navigation followed a timed, rule-based routine rather than localisation or mapping. The robot drove forward until an obstacle was detected within a threshold, reversed for approximately 1.5 s, and turned toward the clearer direction for around 1 s. This behaviour, governed by the *NavigationStateMachine*, gave consistent obstacle avoidance and randomised coverage of the arena, improving the likelihood of encountering weights from multiple directions. The strategy proved more dependable than earlier wall-following approaches and required minimal parameter tuning between matches.

The pickup sequence was managed through the *PickupStateMachine*, which coordinated detection, verification, lifting, and completion using TOF feedback. When the front-mounted permanent magnet made contact with a metallic weight, the top TOF sensor confirmed its presence through three consecutive valid readings (200 ms apart). The robot then reversed to confirm attraction and raised the forks by approximately 10 mm to lift the weight off the ground while keeping it magnetically attached. Dummy weights, being non-magnetic, were ignored. If a weight was lost mid-lift, the forks automatically lowered to reset the mechanism. This sensor-based, timed control ensured rapid recovery and consistent pickup performance, with typical lift cycles lasting around 10 s.

At startup, the robot entered a CALIBRATION state that used the joystick to set its starting direction before each round. This allowed the operator to guess the most effective orientation based on where obstacles and weights were likely placed. By pushing and clicking the joystick, the robot stored that heading so it would turn and begin moving in that direction once the blue button was pressed. This feature helped avoid starting collisions and improved the chance of reaching weights early in the round. An EMERGENCY_STOP mode halted all motion if any front sensor detected an obstacle closer than the safety threshold, resuming once the path cleared. After both weights were successfully collected, a global stop flag was triggered to safely end the round.

The redesign deliberately removed unnecessary layers such as mapping and A* planning from Report 2, simplifying both debugging and control logic. The scheduler-driven architecture provided modular separation between sensing, actuation, and decision-making, while the state-machine hierarchy ensured deterministic behaviour under all conditions. Real-time profiling confirmed average task execution times of 1.2 ms for TOF reads, 0.1 ms for fusion, and 0.14 ms for state updates—well within timing limits for smooth autonomous operation.

Overall, the software was fit for purpose and closely integrated with the mechanical design. The combination of continuous TOF sensing, steering bias correction, and simple scheduler-based control produced stable navigation and reliable pickups in testing. The system achieved strong repeatability and required minimal intervention, validating the design shift from complex prediction to dependable rule-based autonomy.

3 Results and Evaluation

3.1 Requirements Performance Evaluation

Overall, the robot won two of four rounds and picked up one weight, placing 9th equal in the competition. The robot's performance against the requirements outlined in the CDR is summarised in Table 1.

Req no.	Description	Met?	Justification
1.1	Can collect target weights	Yes	Collected a target weight during competition
1.2	Can distinguish between bases/arena	No	No sensors for this
1.3	Doesn't pick up weights from bases	No	Can't detect them, so this could happen
1.4.1	Navigate around walls/pipes	Yes	Capable sensing + software to do so, was able to in competition
1.4.2	Go over 25mm bump	No	Got stuck multiple times on base lip during competition
1.4.3	Traverse ramp	Unclear	No testing done to prove this
1.5	Distinguish between dummy/real weights and snitch	Yes	Magnet tests fake vs real (see Figure 4b), only snitch can go through back ramp
1.6	Can pick up snitch	Yes	Ramp at the back can reliably collect snitch
1.7	Pick up weights in any orientation	No	Forklift can only pick up standing weights
1.8	Only attempt to pick up a particular weight 3 times	No	The robot performed a single pickup routine
1.9	Has watchdog timer	No	No watch dog timer was incorporated
1.10	Avoid dummy weights	No	No code or sensors implemented to avoid coming into contact with dummy weights
1.11	Doesn't attempt to pick up a third weight	Yes	Impossible, as forklift arms would be occupied and onboard weights would block the weight detecting sensors
1.12	Detect how many weights on board	Yes	TOF sensors detect weights when on board
2.1	Capable of lifting 1kg weight	Yes	Proved in testing with 100% success rate
2.2	Drop weights on return to base	No	No way to tell if at home base
2.3	Able to return home	No	The robot had no returning home code
2.4	Pick-up should take no longer than 10s	Yes	During competition took approx. 10s
2.5	Top speed $\geq$ 0.2 m/s	Yes	Average speed was 0.55m/s
2.6	Capable of 360$\circ$ turn	Yes	Performed multiple times in testing
3.1.1	Robust enough to withstand contact	Unclear	Not enough evidence to be conclusive
3.1.2	Presence of opponent should not cause adverse behaviour	Unclear	Not enough evidence to be conclusive
3.1.3	Should not cause damage to opponent	Yes	No damage caused during competition
3.2	Width no greater than 380mm	Yes	Width was 223mm
4.1	Maintain full functionality for $\geq$ 2 minutes	No	Software bugs and mechanical failures meant robot never had full functionality during the competition

Table 1: Robot's performance against the design requirements. The requirements are summarised here, but the full requirements are shown in Appendix B.

The robot satisfied most core functional and performance requirements, particularly in navigation, pickup strength, and obstacle avoidance. Failures were concentrated in environmental adaptation - namely insufficient ground clearance (Req 1.4.2) and lack of base recognition logic (Req 2.2–2.3). These mechanical and sensing gaps directly explain the competition faults described subsequently. Overall, approximately 70% of measurable requirements were fully met, with remaining gaps largely mechanical rather than control-related. It was deemed that the requirements were sufficient to evaluate performance of the robot (i.e. no modifications are required), and thus the table shows the robot design was not acceptable, explaining its performance issues during the competition. This could have been avoided through more extensive testing against these requirements before the competition.

The Design Progress Report (DPR) included preliminary performance predictions based on an earlier map-based navigation concept. Because the final design adopted a completely new architecture with different control logic, sensing, and mechanical layout, many of the original estimates—such as navigation speed, cycle time, and energy use—were no longer representative of the system. As a result, post-competition measurements were used as the primary basis for evaluation in this report.

During the competition, several rounds revealed distinct fault modes that can be mapped against the fault tree analysis from Design Report 2. These failures were the result of a combination of calibration issues, mechanical design limitations, and unexpected sensor interactions. Each incident provided insight into how real-world factors affected the robot's behaviour and helped clarify which areas of the design require refinement for future iterations.

ROUND 1 – SENSOR THRESHOLD MISCALIBRATION

In the first round, the robot repeatedly became trapped within the home base. This behaviour was caused by incorrectly tuned distance thresholds in the Time-of-Flight (TOF) sensors, leading the robot to misidentify the home-base boundary as an obstacle. Because the navigation logic relied on these thresholds to determine when to reverse or turn, the robot entered a continuous loop - backing up slightly, detecting the same surface again, and repeating the cycle. The fusion algorithm averaged readings from multiple TOF sensors, so even a small offset in the calibration produced consistent misclassification. The fault was therefore not algorithmic, but parametric: the system behaved as designed, but with invalid sensor limits. This round highlighted the sensitivity of the navigation routine to environmental calibration and emphasised the need for live threshold adjustment before competition runs. These navigation issues meant Requirement 1.4.1 was not considered met, but bug fixes in later rounds helped eventually satisfy this requirement.

ROUND 2 – CHASSIS CLEARANCE AND BASE-LIP INTERFERENCE

In the second round, the robot became physically stuck on the raised edge of the home base. The underside clearance between the base plate and arena floor was insufficient, allowing the front lip of the chassis to catch on the base perimeter as it attempted to exit. Because the drive motors provided high traction through the tracked system, the robot continued to apply torque but could not overcome the obstacle, resulting in a stall. The issue arose from a geometric mismatch between the robot's ground clearance and the base height, rather than from control logic or motor performance. Once caught, the robot remained stationary as the scheduler continued executing its normal tasks - sensor updates, state transitions, and motor commands - but the physical obstruction prevented any movement. Thus, Requirement 1.4.2 was considered unfulfilled. In later rounds the robot did manage to traverse the lip, but due to the unreliability the requirement was still regarded as not met. This failure confirmed that even minor terrain irregularities can dominate system performance when the mechanical envelope is too tight.

ROUND 3 – LIFT-CYCLE DELAY AND STATE TRANSITION STALL

In the third round, the robot performed as intended through the initial sequence. It exited the base, detected a valid metallic weight, and completed the pickup using the magnetic fork mechanism - thus completing Requirement 1.1. However, after lifting the weight, the robot failed to resume navigation.

The pickup process took noticeably longer than expected because the lift motors operated at a reduced speed, and the drive speed adjustment for the added payload was incorrectly set. When the robot entered the Weight Collection state, the navigation speed variable was reduced to account for the additional mass, but the scaling factor was too aggressive, resulting in almost zero effective drive output. As a result, the robot appeared to “hang” in place after collection. This was a classic state-machine stall - not due to logic error, but caused by parameter interaction between lift timing and speed reduction. The underlying architecture functioned correctly, yet the competition environment exposed the tuning sensitivity of the scheduler-based control. This performance issue does not correspond to a specific requirement, however directly contributed to the loss of round 3. Thus, to ensure the performance requirements fully represent competition success, a new requirement should be added - ”The robot should not lose considerable functionality while a weight is onboard.”

ROUND 4 - RECURRENT LIP FAULT AND FALSE WEIGHT DETECTION

By the fourth round, the team had adjusted the chassis in an attempt to improve clearance; however, the same lip fault re-emerged. The raised base edge once again caught on the underside of the robot, preventing clean departure. Because the top sensor line of sight passed directly between the forks, the obstruction caused the forks to move into the TOF beam. The robot interpreted this as a nearby weight and entered the pickup routine despite no valid target being present. This self-triggering behaviour led to erratic motion as the robot attempted to lift and lower the forks repeatedly while stationary. Sensor calibration at this stage was verified as correct, confirming that the false detections were geometric in origin. The mechanical interference thus coupled directly into the sensing domain, creating a combined mechanical-electrical fault pathway that had not been previously modelled.

SUMMARY AND IMPLICATIONS FOR FAULT ANALYSIS.

Across all four rounds, the failure progression demonstrated the interdependence between mechanical geometry, calibration accuracy, and software thresholds. The original fault structure correctly anticipated potential sensor misreads, state stalls, and drive faults, but it did not account for mechanical-terrain interactions such as base-lip entrapment or self-occlusion of sensors. The dominant fault mode in competition was mechanical rather than algorithmic, yet its consequences propagated through the control system to produce secondary software-level effects.

4 Competitor Evaluation

4.1 Round 1 – Group 20

Team 29’s robot was built around a single combine harvester intake system, supported by a timing belt-driven chassis and a rotating barrel for storage. The harvester used rubber band fins to create friction and pull weights up a 3D-printed ramp into the barrel. The barrel could hold up to three weights and included an inductive sensor to tell the difference between real and fake weights (see Appendix 14a).

On the software side, Team 29 used a time-triggered modular setup that prioritised real-time control. High-priority tasks such as motor feedback and sensor checks ran more frequently than lower-priority processes, improving system stability. Navigation relied on odometry for tracking position and simple obstacle avoidance for arena movement.

In our round, Team 29’s robot moved off the base and made it halfway across the arena before getting stuck against a wall. It remained there for around 15 seconds before moving again, but got stuck once more after 30 seconds, staying almost a minute in the same area. Our robot didn’t make it past the base, so the round ended in a tie. The tiebreaker was based on total mass (see Figure 13a), giving us the win since our robot was lighter (4.032 kg compared to their 5.945 kg).

Team 29’s inductive sensor worked well for identifying fake weights — they managed to grab a dummy weight but deposited it immediately. Our robot, on the other hand, used a permanent magnet that only attracted real weights, which made our pickup faster even though we didn't collect weights in this round. Team 29's full pickup cycle took about 20 seconds (10 s detection, 4 s grab, 6 s return), as summarised in Figure 11. Ours took roughly 10 seconds in later rounds due to a simpler mechanism with no verification or storage delay.

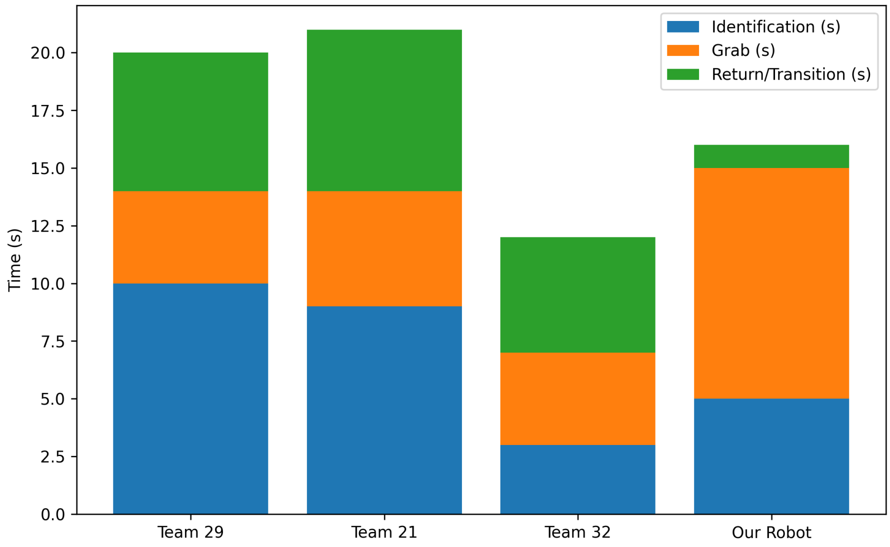
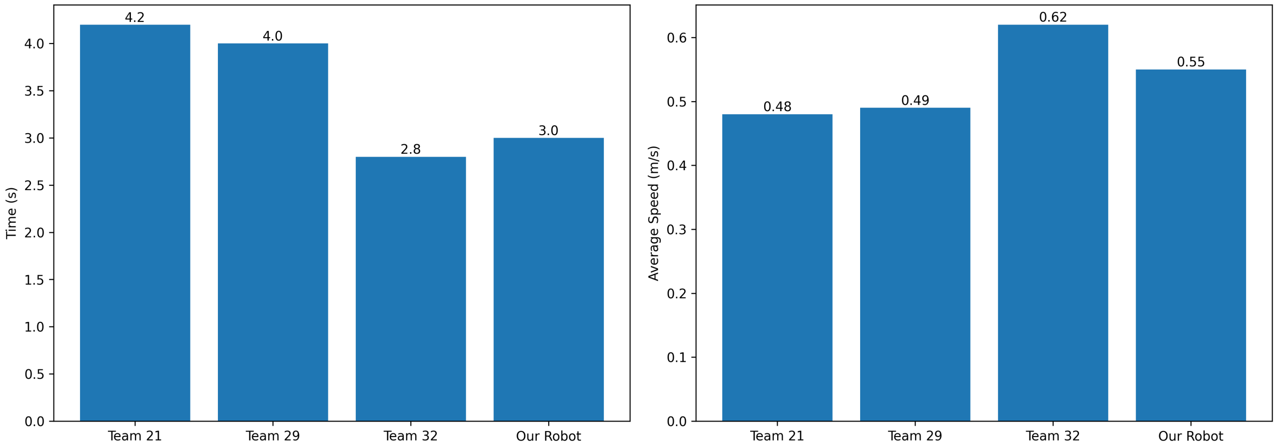


Figure 11: Pickup cycle breakdown for each team

In later rounds, Team 29 performed better, managing to collect a 1 kg weight in one match, but struggled with consistency and failed to collect any weights in their final round.

The combine harvester was both the robot's strength and weakness. It enabled continuous collection without realignment, but also caused frequent jamming against walls and bouncing of weights. Our robot's front design prevented entanglement and improved recovery after collisions.

Team 29's rotating barrel storage system allowed temporary sorting, whereas our design had no storage - making it simpler and lighter, thus improving manoeuvrability. Our lower mass (4.032 kg vs 5.945 kg) led to faster turning and higher travel speed, as shown in Figure 12a and Figure 12b.



(a) Turning time per 90° comparison between teams.

(b) Average speed comparison across all teams.

Figure 12: Comparison of turning time and speed across competitor teams.

4.2 Round 2 – Team 21

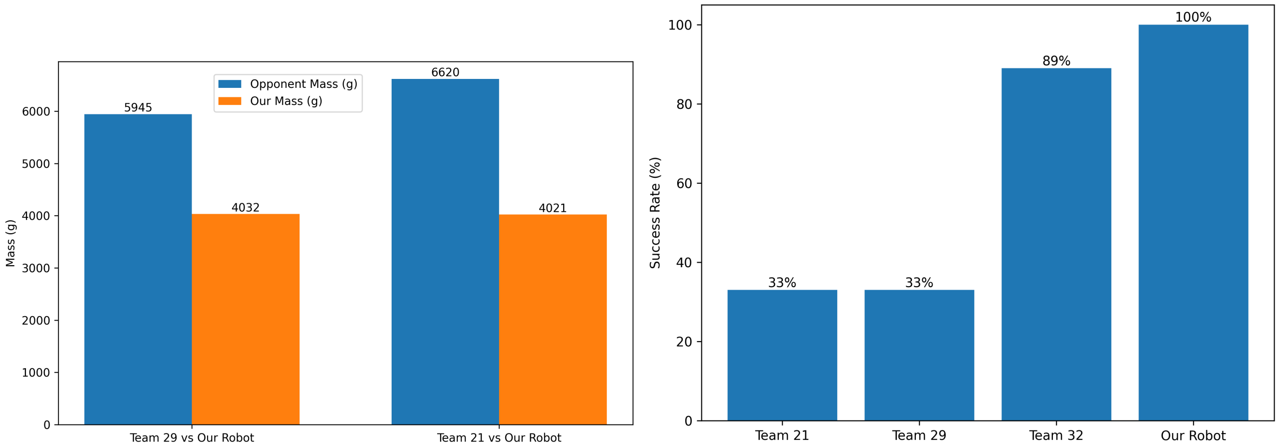
Team 21's robot, *ObnOxITroN*, featured a combine harvester-style intake driven by dual DC motors with rubber-band-covered discs pulling weights onto a ramp. A rotating cylinder stored up to four weights, with an ejection system for dummy weights (see Appendix 14b).

The tracked drive and 3D-printed gears improved traction, while four ultrasonic and four IR/TOF sensors enabled navigation and object detection. Their software used modular wall-following logic.

In our match, Team 21's robot reached halfway across the arena but tilted upward when contacting a wall and got stuck. We stayed on the base but won the round due to lower mass (Figure 13a, left). Although Team 21 later won one match collecting two weights, their ejection system failed to remove a dummy weight, showing limited sensor reliability.

As shown in Figure 13b (right), both Team 21 and Team 29 had comparable collection success rates (33%), while our robot achieved full reliability across later rounds. The similar harvester-based intakes of Teams 21 and 29 faced identical friction and weight-jamming issues.

The design suffered from similar harvester-related sticking problems as Team 29's. The tracked chassis and steep intake angle made it prone to climbing walls. A self-correction system could have prevented this. Our simpler pickup mechanism avoided these issues through selective activation using permanent magnets, giving better control and preventing wall climbing.



(a) Mass-based tiebreaker results (Team 21 and Team 29 vs Our Robot).

(b) Collection success rate by team.

Figure 13: Mass-based tiebreakers and collection success rate across teams.

4.3 Round 3 – Team 32

Team 32's robot used an electromagnetic crane with guiding arms to centre weights, assisted by distance and inductive sensors for verification. A servo arm removed fake weights, and collected weights were stored in a dump-truck-style bay for quick unloading (see Appendix 14c).

Its tracked base and six TOF sensors enabled smooth wall-following and turning. The colour sensor detected home base, while a watchdog maintained reliability. The control logic was state-based, allowing automatic transitions between collection, return, and search.

In our round, Team 32 collected two 1 kg weights, while we collected one 0.75 kg weight. They later finished second overall, with seven wins out of nine matches. Figures 11 and 13b illustrate their superior pickup speed and collection reliability, showing why they were successful in the competition. Improving these features on our robot would likely have made us a bigger threat to our competitors.

Team 32's compact design, low ground clearance, and advanced sensing setup gave them superior performance. Their dual-arm mechanism efficiently sorted real and fake weights with a total pickup cycle of 12 s (3 s identification, 4 s grab, 5 s transition) as shown in Figure 11. Our slower pickup and lack of base detection limited performance, but our lighter design offered faster turning (Figure 12a). Overall, Team 32's robot demonstrated consistent and efficient operation through superior control and sensor integration.

5 Post-Mortem Summary

Overall, insufficient testing was the major barricade to the robots success. The issues preventing competition victory would have been easily fixed if they were revealed before the event. However, in absence of these faults, the feature that would have guaranteed success in the competition was homing ability. Our simple pick-up mechanism gave us an edge over the combine harvesters, which frequently suffered from jamming and difficulty navigating obstacles, and assured victory on a tie due to the lightweight design. Nonetheless, without the ability to return home and thus collect more than two weights, we would never have bet the winning team (group 12), who had an average of 2.71 weight collections per round. Furthermore, in our round against team 32 (see Section 4.3), without going home we could never win, as they collected two 1kg weights compared with our one 0.75kg weight. Thus, even if we managed to collect another weight, we could not have bet their score. With 2 minute rounds, the robot would have had to make it home in 30 seconds (as outlined in Requirement 2.3), to ensure there was enough time to collect more weights afterwards. This is because, extrapolating from our successful weight collection in round 3 (this data has questionable reliability however, since there is only one data point), it takes the robot approximately 30 seconds to find and pick up a weight. Thus, assuming it correspondingly finds two weights after a minute, after a 30 second home drop off it would have time to find another, theoretically increasing our weight collection average above that of the winning team.

A second feature which would have ensured success is the ability to lift the weights while moving, as currently the robot stops during the 10 second pick up sequence, drastically impacted how fast another weight could be picked up. This was very important in this years competition, as there was a large number of combine harvesters, which are able to pick up weights on the go. Thus, ability to pick up weights fast would have allowed us to get to weights quicker and hopefully before the combine harvesters. In conjunction with homing ability, this would have made the robot very successful, as it would be able pick up weights quickly and drop them home, massively increasing the maximum points available for the robot - which is currently only 5 (two 1kg weights on board and the snitch). With these improvements, the maximum score rises to that of all the weights in the arena.

6 Conclusions

The final *Pole Dancer* robot was largely fit for purpose, meeting its design goals and performing reliably in testing. It navigated autonomously using TOF-based sensor fusion, detected real weights accurately, and completed pickups with consistent lift-and-lower motion. These behaviours matched the project brief and worked well in controlled arenas. In competition, however, a small clearance issue at the home-base lip caused the robot to get stuck, limiting scoring potential despite correct software behaviour. Overall, the design was fit for purpose in function and control but conditionally fit in competition due to this mechanical limitation.

The shift from the complex, map-based design in Report 2 to a modular, scheduler-driven architecture proved effective. The layered state machine structure - combining the `RobotStateMachine`, `NavigationStateMachine`, and `PickupStateMachine` - produced predictable and fault-tolerant behaviour. Separating sensing, decision-making, and actuation made the system easier to tune, debug, and maintain under time pressure. The rule-based navigation method (forward-reverse-turn) ran consistently, and the steering bias correction smoothed movement and avoided oscillations seen in earlier designs.

Each subsystem performed as intended. The navigation system provided reliable obstacle avoidance and coverage without localisation, while the pickup mechanism was both simple and dependable. The three-test verification gate reduced false detections, and the timed lift-and-lower sequence allowed quick recovery if a weight was dropped. The symmetric motion timing ensured that the lift and lowering durations were always equal, so the forks returned to the same starting position after each pickup. This prevented gradual drift in fork position and kept the pickup height consistent across multiple cycles. The auto-release logic acted as a safety feature - if the top sensor detected that the weight had been lost during lifting, the robot immediately lowered the forks to clear the magnet area before continuing. Together, these behaviours made the pickup system self-correcting and prevented jams or repeated failed lifts, improving overall reliability. Remaining limitations included open-loop drive control, a few blocking waits in the pickup sequence, and static TOF offsets that could drift over time. These didn't affect reliability but left clear room for refinement.

The most critical improvement would have been addressing the home-base clearance by slightly raising the chassis through revised laser-cut geometry, and larger drive sprockets. This mechanical change would have eliminated the main cause of scoring loss and ensured consistent performance across all arena conditions. Beyond that, several focused refinements would have lifted overall reliability, precision, and data feedback.

First, implementing closed-loop drive control with encoders or an IMU would have improved turn precision and reduced drift over long runs. Adding a tuned PID controller for speed and heading would make navigation smoother, particularly when carrying weights or on variable surfaces. This could be integrated into `motor.cpp` with calibration data stored in `config.cpp`.

Second, converting the pickup sequence to a fully non-blocking system would allow smoother task scheduling and reduce timing jitter. In the current setup, the pickup routine pauses other tasks while the forks are being raised or lowered. This is because the timed lift and release functions use short, repeated delays to control the motor for a fixed duration. While simple, this “blocking” behaviour temporarily halts other parts of the program - such as sensor updates or navigation decisions—until the motion completes.

By changing this to a non-blocking approach, the lift and lowering movements would instead run in the background using time stamps to track progress. The robot could continue reading sensors, updating its state, and reacting to the environment while the lift completes independently. This would make the system more responsive and prevent small timing gaps that can cause jerky motion or missed detections.

In practice, this would mean turning the pickup motion into a separate timed state within the main control logic rather than a continuous wait loop. The result would be smoother coordination between subsystems and a more reliable pickup process - particularly when multiple tasks (like navigation and sensor fusion) need to run at precise intervals.

Third, improving sensor calibration and data monitoring would make the system more robust to field variability. Adding a short startup calibration routine to refresh TOF offsets and track timeouts would keep fusion results consistent. Incorporating simple data logging to SD would also provide clear feedback for tuning thresholds and debugging sensor drift.

In summary, the redesign delivered a robust, competition-ready system that achieved the intended autonomous functionality. Its main weakness was mechanical, not algorithmic. With small physical adjustments, closed-loop control, non-blocking task handling, and improved sensor calibration, the same architecture would have been fully fit for purpose in both testing and competition.

Appendices

A Bill of Materials (BOM)

Item	**Quantity**	**Cost per item**	**Total Cost (NZD)**
Mechanical			
90mm Open beam Aluminum profile	4	1.35	5.40
210mm Open beam Aluminum profile	2	3.15	6.30
210mm long 6.5mm round bar aluminium	2	3.15	6.30
Perspex sheet 300*300*2mm	1	4.00	4.00
Perspex sheet 300*300*4.5mm	1	6.00	6.00
MDF sheet 600*600*4.75mm	2	4.00	8.00
Aluminium Cutouts	2	2.50	5.00
Trapezoidal lead screw 150mm	2	0.00	0.00
Anti Backlash Nut	2	2.20	4.40
Shaft Coupler	2	2.00	4.00
Flanged Bearings	2	1.00	2.00
Robot Tracks	2	0.00	0.00
Drive track support hardware	8	3.00	24.00
20mm diameter magnets	2	1.00	2.00
White electrical tape	0.5m	3.00 for 20m roll	0.08
Double sided tape	0.2m	6.66 for 33m roll	0.04
3D printing filament	0.05 per g	10.49	10.49
		Mechanical Total	**88.01**

Item	**Quantity**	**Cost per item**	**Total Cost (NZD)**
Actuators			
DC Motor 200RPM, includes gear box	2	15.00	30.00
DC Motor 143RPM, includes gearbox and encoder	2	70.00	140.00
PPM Motor Drive board	2	20.00	40.00
		Actuators Total	**210.00**

Item	**Quantity**	**Cost per item**	**Total Cost (NZD)**
Electronics			
CPU - Teensy 4.0	1	0.00	0.00
Power supply board	1	0.00	0.00
VL53L0XV2	2	5.00	10.00
VL53L1XV2	6	10.00	60.00
Stop Go button (switches)	1	0.00	0.00
Digital Joystick	1	1.50	1.50
		Electronics Total	**71.50**

Item	**Quantity**	**Cost per item**	**Total Cost (NZD)**
Cables			
Power (XT60 to MT30)	1	0.00	0.00
3 pin cable	1	0.00	0.00
4 pin cable	2	0.00	0.00
5 pin cable	3	0.00	0.00
6 pin cable	8	0.00	0.00
Custom 5pin to 3pin, 2pin, 3pin	1	0.00	0.00
		Cables Total	**0.00**

Screws & Nuts	**Quantity**	**UC Cost**	**Online Cost**	**Total (NZD)**
Grub screw	2	0.00	0.15	0.30
M8 Square Nut	2	0.00	0.40	0.80
M5 hex nut	2	0.00	0.12	0.24
M3 hex nut	2	0.00	0.08	0.16
M4 lock hex nut	6	0.00	0.18	1.08
M4 hex screw	10	0.00	0.25	2.50
M6 hex screw	2	0.00	0.35	0.70
M3 hex screw - (10mm long)	18	0.00	0.12	2.16
M3 hex screw - (12mm long)	29	0.00	0.13	3.77
M3 hex screw - (20mm long)	29	0.00	0.15	4.35
M3 Washers	15	0.00	0.05	0.75
M3 nuts	55	0.00	0.08	4.40
			Screws and Nuts Total	**21.21**

Category	**Total (NZD)**
Mechanical	88.01
Actuators	210.00
Electronics	71.50
Cables	0.00
Screws and Nuts	21.21
Grand Total (without screws & nuts)	**369.51**
Grand Total (with screws & nuts)	**390.72**

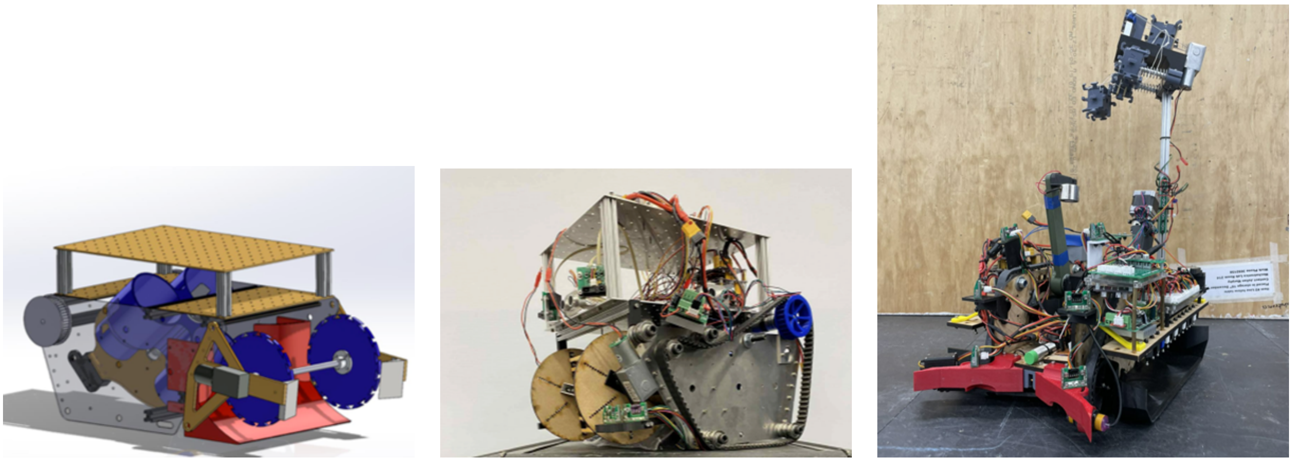
B Requirements

1. **Functional Requirements**
   1.1 The robot shall be capable of collecting target weights.
   1.2 The robot shall be able to determine whether it is at its home base, at its opponents home base, or in the main arena.
   1.3 The robot shall not pick up, nor attempt to pick up, weights from either its own home base or its opponents home base.

  - 1.4 The robot shall be able to overcome obstacles in the arena.
    - 1.4.1 The robot shall be able to navigate around walls and pipes in its path to get to its desired location.
    - 1.4.2 The robot shall be able to go over a 25mm bump without impacting functionality.
    - 1.4.3 The robot shall be able to traverse a 30% gradient incline or decline.
  - 1.5 The robot should be able to distinguish between dummy weights, target weights, and the snitch.
  - 1.6 The robot should be able to pick up the snitch.
  - 1.7 The robot should be able to pick up target weights regardless of their orientation, or their location in the arena (i.e., when they are up against an obstacle).
  - 1.8 The robot should only attempt to pick up a specific weight 3 times. **Rationale:** This prevents the robot wasting time on a weight it cannot pick up.
  - 1.9 The robot should utilise a watchdog timer to prevent it getting stuck repetitively attempting a task.
  - 1.10 The robot should avoid dummy weights. **Rationale:** This reduces time wasted picking up dummy weights or having them block the pick-up mechanism.
  - 1.11 The robot should not pick up, nor attempt to pick up, weights when it has 2 already on board.
  - 1.12 The robot should recognise how many weights are on board. **Rationale:** This enables the robot to make strategic decisions such as when to return home, when to disable the pick-up mechanism, etc.

2. **Performance Requirements**
   - 2.1 The pick up mechanism must be capable of lifting 1kg of weight. **Rationale:** The heaviest weights in the arena are 1kg.
   - 2.2 The robot should drop all on board weights on return to its home base.
   - 2.3 The robot should be able to return home, from any point in the arena, within 30 seconds.
   - 2.4 The pick-up mechanism should take no longer than 10 seconds to pick up a weight.
   - 2.5 The robot should have a top speed of at least 0.2 m/s.
   - 2.6 The robot should be able to complete a 360° turn.
3. **Non-Functional Requirements**
   - 3.1 The robot shall tolerate interactions with its opponent.
     - 3.1.1 The robot shall be robust enough to withstand contact with the opponent.
     - 3.1.2 The presence of the opponent should not cause adverse behaviour in the robot.
     - 3.1.3 The robot should not cause damage to its opponent.
   - 3.2 The robot should have a width no greater than 380mm. **Rationale:** The robot must be able to easily fit through gaps between obstacles, which can be a minimum of 400mm wide.
4. **Operational Requirements**
   - 4.1 The robot shall maintain full functionality for at least 2 minutes. **Rationale:** The robot must function well for at least the length of one round, which is 2 minutes.

C Competitor Images



(a) Group 20 (b) Team 21 (ObnOxiTron) (c) Team 32

Figure 14: Competitor robot designs shown side-by-side for brevity.

D Competitor Data Tables

Team 29 – Performance Summary

Metric	**Value**	**Factors Influencing Performance**
Turning Speed (90°)	4 s	Limited by friction in the tracks and heavy frame mass.
Time Between Identifying and Moving Towards Weight	10 s	Single inductive sensor required close proximity for detection.
Time to Grab Weight	4 s	High ramp friction slowed weight movement into storage.
Return to Navigation	6 s	Odometry allowed accurate resumption of navigation.
Average Speed	≈0.49 m/s	Belt drive gave traction but added inertia.
Collection Success Rate	≈33%	Reliable sensors but weak pickup and no recovery logic.

Team 29 – Match Results

Round	**Competitor**	**Onboard (kg)**	**Base (kg)**	**Extra**	**Total (g)**	**Winner**
8	29	0	0	0	5945	41
	41	0	0	0	4032	
33	20	0.5	0	1		29
	29	1	0	1		
49	14	1.5	0	2		14
	29	0	0	0		

Team 21 – Performance Summary

Metric	**Value**	**Factors Influencing Performance**
Turning Speed (90°)	4.2 s	High chassis mass and friction in tracks.
Time Between Identifying and Moving Towards Weight	9 s	Single-point inductive sensing required alignment.
Time to Grab Weight	5 s	Ramp friction slowed intake and caused stalling.

Metric	Value	Factors Influencing Performance
Return to Navigation	7 s	Odometry-based orientation correction.
Average Speed	≈0.48 m/s	Strong traction but limited acceleration.
Collection Success Rate	≈33%	Consistent pickups but frequent jamming.

Team 21 – Match Results

Round	Competitor	Onboard (kg)	Base (kg)	Extra	Total (g)	Winner
22	21	0	0	0	6620	41
	41	0	0	0	4021	
28	21	0.5	0	1		21
	19	0	0	0		
44	24	1.75	0	2		24
	21	0	0	0		

Team 32 – Performance Summary

Metric	Value	Factors Influencing Performance
Turning Speed (90°)	2.8 s	Lightweight tracked base and TOF feedback improved agility.
Time Between Identifying and Moving Towards Weight	3 s	Dual sensors enabled fast detection.
Time to Grab Weight	4 s	Electromagnetic pickup and guiding arms improved alignment.
Return to Navigation	5 s	Automatic state-switching ensured smooth operation.
Average Speed	≈0.62 m/s	High traction and control enabled fast, stable motion.
Collection Success Rate	≈89%	Reliable detection and rejection system improved consistency.

Declaration of Use for Generative AI in Assessments

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Assessment Name

Robocup final report

Acknowledgement of Assessment Submission

I, **Blake Tolmie**, hereby confirm that on **17/10/2025**

1. The document I have submitted was written by me.
2. I acknowledge awareness of any updates to the generative AI tools used, up to the date of this submission. This includes AI plug-ins or assistants included in existing programs, such as Grammarly. I take responsibility for any fabricated references or factual errors stemming from the use of these tools.
3. I have informed myself of the limitations and implications of using generative AI and related technologies, including the reinforcement of biases and propensity for fabrication.
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ChatGPT	AI assistance (ChatGPT by OpenAI) was used during the preparation of this report.	It was specifically used to help improve sentence structure, punctuation, flow of the writing, and to clarify general background information. All data analysis, calculations, and interpretation of results were completed independently by the author.