Delft Mercurians Team Description Paper RoboCup 2026

The Delft Mercurians

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Abstract. This paper goes over the progress the Delft Mercurians team has made in the past year in terms of robot design and development, to compete in RoboCup Small Sized League division B. The paper presents the hardware, embedded-electrical, and software aspects of the robot as well as the research done into curved kicking.

1 Introduction

Delft Mercurians is a multidisciplinary RoboCup Small Size League team based in Delft, the Netherlands, which debuted in Robocup 2024 and now aims to participate in Robocup 2026 in division B of the Small Size League [1–3]. The team was founded in September 2022 by members of the Robotics Students Association (RSA) and is made up of robotics enthusiasts and students of the Technical University of Delft. Currently, the team consists of 15 active part time members divided into three departments: Hardware, Embectrical[1], and Software. This paper will outline the integral components that each department has worked on, with an emphasis on describing their innovations.

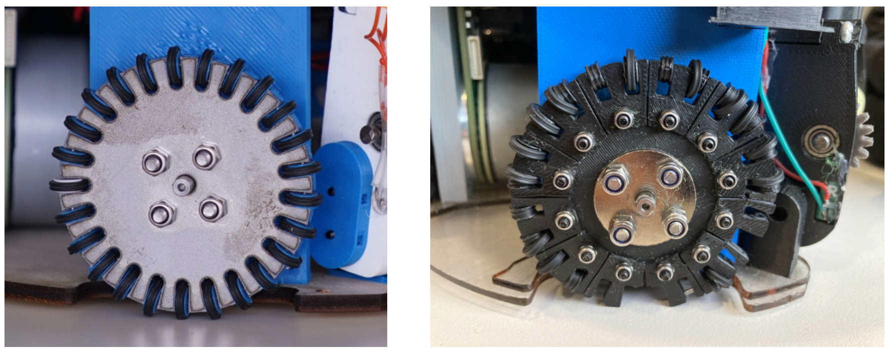
2 Hardware

The focus for this year's competition is a major rework and homologation of the entire hardware concept. Every component will receive minor tweaks to improve assembly and maintenance. One of two components that will receive a major rework this year is the dribbler: currently the motion is largely rotational, whereas

[1] Embectrical is a concatenation of the words embedded and electrical. This term was adopted from the Project MARCH Dream Team based in Delft.

the new design will feature a larger degree of linear vertical motion. The second major project for this year is a complete redesign of the wheels, switching to a novel concept with a low number of custom cast subwheels. This will be the focus for the rest of this chapter.

2.1 Wheels



(a) 2024 Wheel Design (b) 2025 Wheel Design

Fig. 1: Previous wheel designs

Past Designs Review The previous Delft Mercurians wheel concept consisted of a single flat plate with many small wheels around its edge, as seen in Figure 1a [1] and Figure 1b [2]. In the 2024 version, the centre wheel was made up of three layers, two layers of laser cut sheet metal, and a 3D printed sheet in between. A steel wire was used as the axle for the smaller subwheels, consisting of 3D printed cores each with a rubber X-ring around it. This design has some major flaws:

1. The X-rings often slipped off the sub-wheel cores during the matches, jamming up the central wheel making it harder to spin.
2. The X-rings often wore out and broke off during matches, littering the field. The sub-wheel can still spin but can no longer transfer any torque from the motor to the ground due to the lack of grip.
3. Felt fibres got stuck between the subwheels and the central wheel, causing jams and accelerated wear and tear of the subwheels.
4. The wheels had to be completely removed from the robot and then disassembled to be repaired. This process is lengthy and difficult, making it impossible during or between matches.
5. The gaps between the subwheels cause an inconsistent ride height, resulting in strong vibrations for the robot.

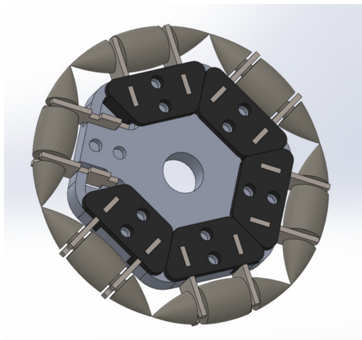
The 2025 redesign focused on addressing the reliability and manufacturability problems of the 2024 design. This was achieved by dividing the central wheel into segments, each carrying 2 subwheels. It was now possible to repair the wheels between matches by swapping out the sub-segments in the wheels, resulting in better performance in the competition. However, the 3D printed nature of the sub-segments resulted in a new flaw: The sub-segments broke easily due to excessive force, fatigue, or by getting stuck on the felt. Furthermore, the subwheel design stayed effectively identical, thus the first 3 flaws carried over into the 2025 version.

2026 Design Options The 2026 wheel redesign aims to solve all the problems identified in the previous designs. To achieve this, the design must consist of as few subwheels as possible. Additionally, the main body will be made from plate steel or CNC machined aluminium instead of 3D printing for added strength. Two plausible concepts were identified for the new design: holding the subwheels by the end of their axles as used by The Bots [4], and splitting the subwheels and holding them along their axis, inspired by the Kamami OW-001 [5]. The latter allows for smaller gaps between the subwheels and is being developed further.

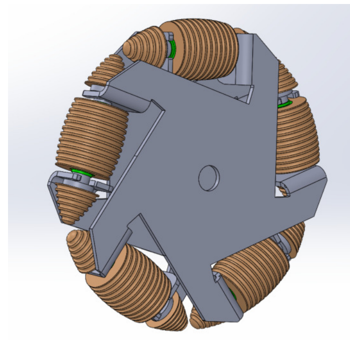
From the aforementioned concepts, two concrete wheel concepts were made: a solid hub with spokes and two separate sheet metal hubs, shown in Figure 2a and Figure 2b respectively. Each design uses polyurethane (beige) overcast steel axles (green) as subwheels with groves to improve traction [4]. The first solid hub and spoke design consists of four parts: a central CNC machined aluminium hub (grey), 3D printed mounting blocks (black), laser cut sheet metal tabs (light beige), and the subwheels. This design is manufacturable in house but is extremely time-consuming. The major challenge is the interface between the laser cut sheet metal tabs and the sub-wheel axles. This interface needs to be tight enough to prevent the wheels from detaching yet offer low friction.

Alternatively, the central wheel can be made from two pieces of sheet metal as in the second design. The construction is much simpler, making it easy to repair and more reliable. The major challenge here is the manufacturability of the parts. Bending equipment and lots of experience are required to manufacture the parts at the desired the precision, neither of which the team has. Furthermore, the sheer quantity of parts to produce, at least 336 parts for seven robots including spares, makes it impossible to achieve by hand in the given time-frame. Hence, either (semi)automated processes must be used, or the number of parts per wheel must be kept at a minimum. However, that would drastically drive up the cost to produce these wheels.

Another concern in the design is the size of the tabs that hold the subwheels; the small size might not be manufacturable or strong enough, they are much smaller and flatter compared to most other omni-directional wheels. Their small



(a) Solid Hub and Spoke



(b) Sheet metal hub

Fig. 2: Current wheel designs

size also prevents the use of bearings to allow smooth spinning of the wheels, and the friction between the laser cut tabs and PTFE bushings used in the subwheels has yet to be tested. Fortunately, the team is currently working with a sheet metal manufacturer to design a version that they can produce at the desired precision and quantity.

3 Embectrical

The electronics in this year's robot were largely redesigned to improve the reliability, which was a major issue in the previous competition. Furthermore, the use of time-of-flight sensors was evaluated as a way to precisely detect the ball when it is close to the robot.

3.1 New PCBs

All of the PCBs in the robot are being redesigned for this year's competition, to improve reliability and add new features.

On the kicker board, a safety discharge circuit has been added to improve safety. Figure 3 shows the schematic of this circuit. The capacitor discharges through a constant-current regulator whenever the microcontroller loses power or when the discharge button is pressed, using a normally-closed solid-state relay. A second regulator with a lower current setting is connected to an LED to indicate when there is high voltage in the circuit, even if the robot has no power. This circuit works even if the kicker coil is disconnected or broken.

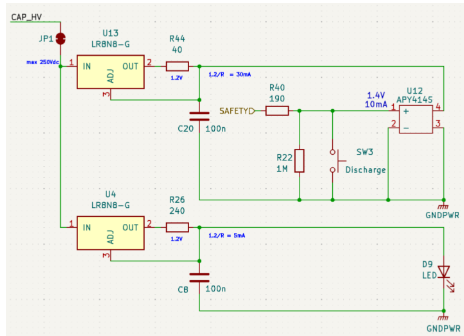


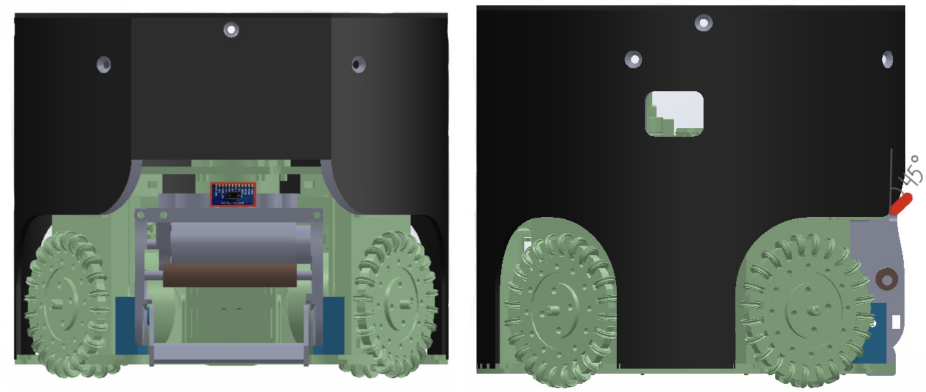
Fig. 3: Schematic of the kicker board safety discharge circuit

The powerboards connect all of the electronics in the robot together and include the main microcontroller. A small display and some buttons have been added to show the status of the robot and execute self-tests, as done by the TIGERs team [6]. The IMU is also changing. The exact model to use is still under evaluation, with the current options being the BNO055 or ICM-20948. It will also be placed higher up in the robot to avoid electrical interference from the kicker. The modular motor drivers now use standard pin headers and sockets to improve reliability. During the 2025 competition, pins on the previous connectors frequently broke off.

3.2 Time-of-Flight sensors

Knowing the precise position of the ball when it is near the robot can significantly improve dribbler control and decision-making during close-range play. Teams such as the TIGERs have attempted to use an IR scan array for this [6]. The VL53L8cx time-of-flight (ToF) sensor is a promising alternative. It outputs an 8x8 grid with distance measurements up to 400 cm and a field of view of 45-degrees [7].

On the team's robots, the ToF sensor is placed 8.5 cm above the ground and positioned above the kicker as seen in Figure 4a, at a 45-degree angle. As shown in Figure 5, when the ToF is tilted at a 45-degree angle, the ball can be detected at distances ranging from 3.5 cm to 20.52 cm from the robot. This configuration results in a blind spot between 0 and 3.5 cm in front of the robot.



(a) Position ToF (b) Angle ToF

Fig. 4: vl53l8cx

Since the distance from the ToF to the ground is known for each zone, objects in front of the robot and their position can be detected by deviations from the expected distance measurements. The robot may encounter three types of objects: a ball, another robot, or a wall. A robot or a wall has a larger vertical profile than the ball and will therefore be detected across more ToF zones. In contrast, the ball only affects measurements in the lower zones of the ToF sensor. Consequently, if deviations are observed exclusively in the lower zones, the object will most likely be the ball.

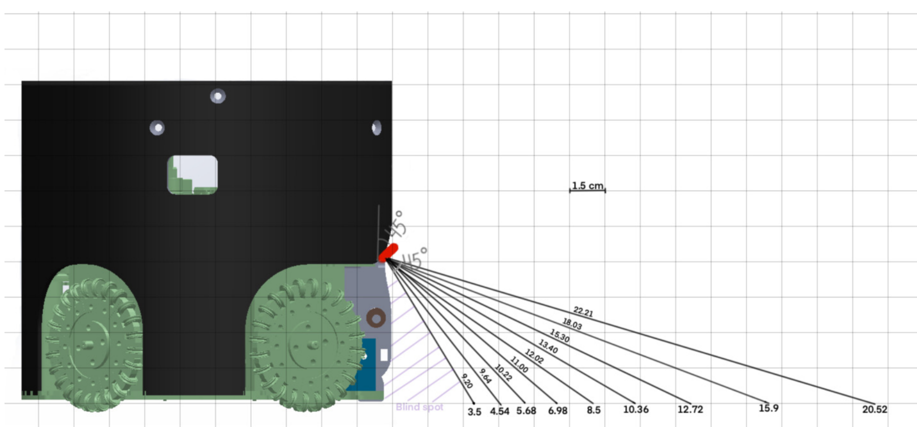


Fig. 5: 2D side view of FoV

4 Software

Following the 2025 competition, the team has continued refining our open source framework Dies [1, 2, 8] while exploring new approaches to strategy architecture. The main area of research this year has been rethinking the strategy layer.

4.1 Strategy Architecture: Concerto

Last year's behaviour tree architecture provided structure and debuggability, but as strategies grew more complex, limitations emerged in coordinating multi-robot sequences while maintaining good field coverage. This led to the development of an experimental two-layer strategy system termed Concerto, currently under evaluation.

Existing Strategy Patterns The dominant strategy architecture in SSL is the Skills-Tactics-Plays (STP) hierarchy, where plays select tactics that invoke skills [9–11]. While effective, this structure often intermixes continuous positioning concerns with discrete coordination logic. An experimental architecture, Concerto, was made as an attempt to create a cleaner separation between the two: a Formation layer that continuously optimizes all robot positions through a scoring function, and a Plays layer that temporarily claims robots for scripted sequences. This pattern has conceptual precedents—notably in CMDragons' zone-based coordination [9], TIGERs Mannheim's persistent plays [10], and ZJUNlict's FSM-based Play Module [11]—but it is being investigated whether explicit architectural separation yields practical benefits in development velocity and debugging clarity.

Core Observation Robot soccer exhibits two distinct modes of play that require different control paradigms. The first mode is continuous positioning, which involves maintaining defensive coverage, marking opponents, and staying open for passes. This mode is parallel, optimization-based, and runs constantly. The second mode is discrete sequences, which involves executing coordinated actions like passing plays or set pieces. This mode is sequential, script-like, and triggered by specific game states.

Two-Layer Design Concerto separates these concerns into two simultaneously running layers.

The Formation layer manages all robots by default using a continuous scoring function that evaluates field positions. Each robot is assigned to the highest-scoring unoccupied position, which shifts dynamically as the game state changes. This provides sensible default behaviour for defensive coverage and general field presence.

The Plays layer consists of scripted sequences of coordinated actions involving one or more robots. When trigger conditions are met, a Play activates and claims the robots it needs, temporarily removing them from Formation control. When the Play completes or fails, claimed robots return to Formation. Robots not claimed by a Play continue under Formation control throughout.

This separation allows positioning logic and play logic to be developed and tested independently, with Formation providing graceful fallback behaviour when Plays fail or are not applicable.

The system is still in early development and evaluation. Results from testing will inform whether this architecture is adopted for competition.

5 Curved kicking

Multi-directional kicking was tested by UBC Thunderbots in 2011 [12], OP-AmP in 2013 and 2017 [13], and RoboTeam Twente in 2018 [14]. In 2019 the OP-AmP team had the idea of combining this mechanism with the backspin created by the dribbler [15], which results in the ball following a curved trajectory. The year after, the KIKS team also described a curved kicking mechanism [16]. For such a kick, the roll direction must be at an angle compared to the kick direction, as shown in Figure 6. To change the kick angle, both OP-AmP and KIKS change the angle of the solenoid in the robot. The main downside of this approach is the size constraint: leaving space in the robot for moving the solenoid can be quite challenging and is difficult to combine with the other systems in the robot.

5.1 Implementation on the robot

It is possible to achieve curved kicks by rotating the robot just before the kick, without a rotating solenoid. If this is done fast enough, the axis of rotation of the ball will remain the same as before the rotation, but the kick angle will correspond to the direction the robot is pointing in after the rotation. An example of this is included in the TDP Video and Figure 7.

While this means that curved kicks can be achieved without any hardware modifications in the robot, it likely results in higher variability compared to a rotating

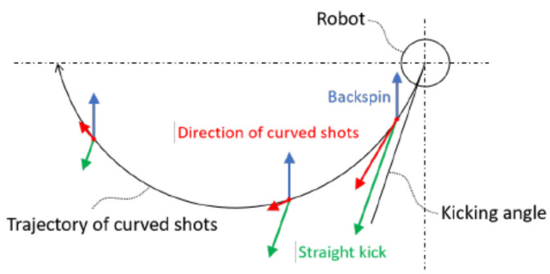


Fig. 6: Behaviour of curved shots, from the 2019 OP-AmP TDP [15]

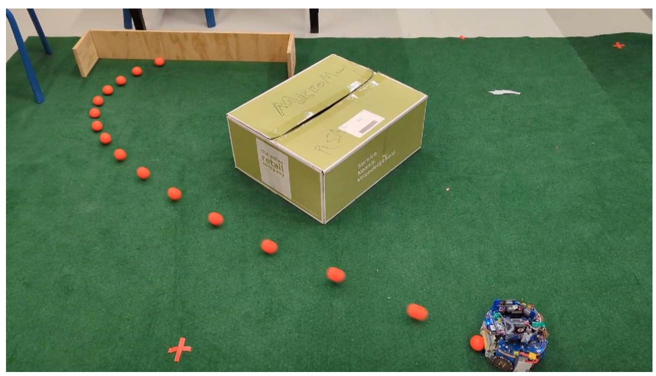


Fig. 7: Video of a curved kick with an unmodified robot (edited into a single image)

kicker. As the robot rotates, the ball's roll direction will slightly change. Furthermore, to kick as quickly as possible, the robot kicks while it is still rotating. This means that the kick angle is also less precise than if the robot stopped rotating before kicking, but it also results in fewer failed kicks.

5.2 Modeling

In order to use curved kicks in a RoboCup game, the software should be able to determine the kick parameters (kick speed, kick angle and ball rotation speed) for a desired trajectory, which is defined with an x-intercept (where the ball crosses the axis of the dribbler again) and maximum y coordinate.

The *pool tool* library from Evan Kiefl was used to simulate the trajectory of the ball [17]. While the main goal of this tool is to accurately simulate the physics of a pool game, there is a close similarity to the conditions of Robocup SSL.

Initial tests were conducted with a test setup where the angle of the kicker can be manually changed. The trajectories were recorded from above, as can be seen in Figure 8. An example of the model's output compared to the recorded trajectory can be found in Figure 9, with a rolling friction of 0.22. In these cases, it predicts the path with an error less than 20 mm for the x-intercept and less than 50 mm for the maximum y.

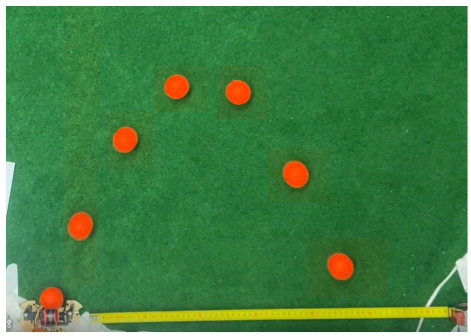
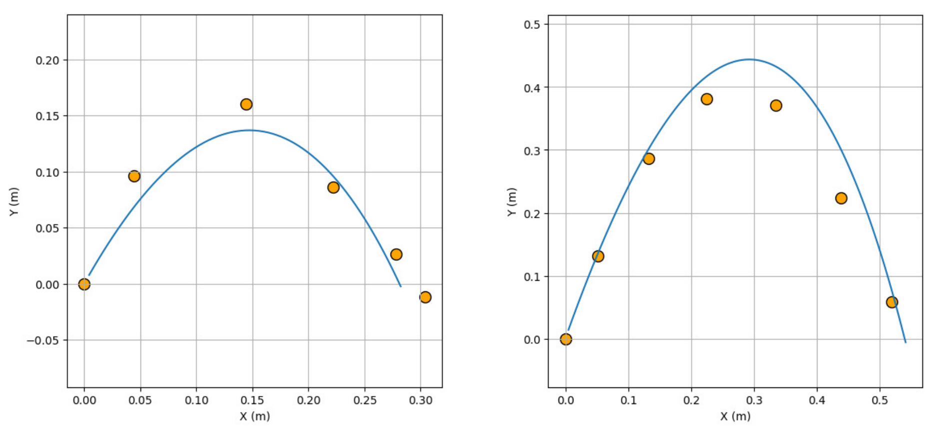


Fig. 8: Video of a curved kick with the test setup (edited into a single image). kick speed: 1.4 m/s, dribbler rotational velocity: 3750 rpm, kick angle: 19.57 deg



(a) kick speed: 0.9 m/s, dribbler rotational velocity: 3750 rpm, kick angle: 29.35 deg

(b) kick speed: 1.5 m/s, dribbler rotational velocity: 3750 rpm, kick angle: 19.57 deg

Fig. 9: Comparison of ball positions with model predictions

A dataset was created that evenly distributes the initial kick speed, kick angle and ball rotation speed and includes the results of the simulation for each point (x-intercept, maximum y). Kick parameters can be selected from this table such that they lead to a path that is the most similar to the target trajectory. Using this approach to get the ball to the desired point leads to near perfect matches, with an average difference from the desired location of less than 10 mm between the simulation and target.

There are limitations to this approach. The rolling friction must be tuned for each type of felt, which requires a lengthy calibration process prior to competition. The simulation also does not perform well at high kick speeds or when the balls do not follow a path that crosses the x-axis again (such as for a slight curve).

The model will likely not yet be used in the 2026 competition. Instead, there will be some predefined positions from which the robots will attempt curved kicks towards the goal with predetermined parameters, such as in Figure 10. In the future, the team hopes to achieve these kicks from any position on the field with a trajectory that avoids opponent robots, using the model. This could also be extended to curved passes between robots.

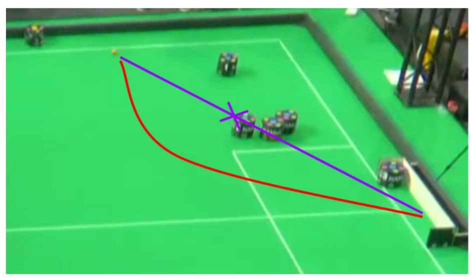


Fig. 10: Example case from the 2024 competition where a curved kick can be used to score a goal [18]

6 Conclusion

Over the past year, the team has revisited every subsystem based on lessons learned from last year's competition, leading to significant improvements in the overall design. Several of these updates have already been implemented, with additional changes still in progress.

The team has made substantial improvements across all aspects of the robot, and they are confident these upgrades will significantly enhance on-field performance and provide a competitive edge during the competition. Furthermore, Delft Mercurians will continue with SSL beyond the planned phase-out of the Small Size League from the international RoboCup event after 2027.

7 Acknowledgements

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