# Warthog Robotics SSL Team Description Paper for RoboCup 2026

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**Abstract.** This paper presents the Warthog Robotics Lyra project and the key improvements made to this RoboCup Soccer Small Size League initiative over the past year. The research and development cycle included various hardware improvements, with a new robot project and auxiliary test devices. On the software side, handling robot heterogeneity was explored.

**Keywords:** Heterogeneous Robots · Inertial Measurement Unit · ESD Protection · Test Devices

## 1 Introduction

Warthog Robotics is a research and development Robotics group from the University of São Paulo at São Carlos. The group consists of over 100 members from several knowledge areas, such as Computer Science and Electrical, Mechatronics, and Computer Engineering, and develops Robotics technologies in various areas, applying most of them at Robotics competitions. After more than ten years without participating in RoboCup due to budget limitations, the team was able to participate in RoboCup 2025, securing third place in SSL Division B. In local competitions, Warthog Robotics SSL Team secured second place in 2025 *Competição Brasileira de Robótica* and fourth place in the 2024 edition.

Warthog Robotics' latest software improvements are detailed in Section 2.1, with an approach focused on heterogeneous robots integration. Hardware improvements were also implemented with a new designed robot, including mechanical and electronics upgrades, as described in Sections 3.1 and 3.2. Furthermore, two auxiliary test devices were designed and are discussed in Sections 4.1 and 4.2.

## 2 Software Improvements

The software improvements described in Section 2.1 presents the integration between two different robots: a low-cost project, called Team B, and Warthog

Robotics' main team, called Team A. This system was able to compete in the *Competição Brasileira de Robótica* and RoboCup 2025 previously mentioned.

### 2.1 Handling Robot Heterogeneity in Software

Due to hardware issues and a lack of reserve robots from Team A, it became necessary to play a match with a heterogeneous team, composed of Team A and B robots. In the context of software development, the main difference between both models is controllability. The low-cost robot control loop does not employ odometry, relying exclusively on vision feedback, while the main team robot uses encoder feedback to close the control loop. This difference is significant to require a new layer of abstraction for high-level control in our AI package and a new module for role assignment that is able to accommodate a heterogeneous team.

**Control Abstraction Layer** To support these differences in controllability, we implemented a new abstraction layer to encapsulate the state of the specific control algorithm of each platform. We defined an interface containing basic motion primitives, which are implemented according to each robot model. For Team A robots, we employ a Proportional–Integral–Derivative (PID) controller (where the integral term was tuned to zero) that tries to minimize the Euclidean distance error from the origin to the target position. In contrast, the low-cost robot required a full PID controller (all constants were tuned to non-zero values) and the addition of a feedforward term to the control loop to overcome static friction and initial inertia. This feedforward component consists of a tunable constant that is applied only when the system detects a change in direction or the start of movement.

**Role Assignment** In practice, a lack of precision was noticed in low-cost robots, suggesting the necessity of a module dedicated to role assignment of different robot models. This precision deficit was mostly prevalent in ball manipulation tasks; specifically, during free kicks, the robot's jittery motion frequently caused double-touch fouls. To mitigate this problem, we implemented a priority system that would attempt to assign low-cost robots to support roles, such as barriers and markers. We determined that for these roles positioning is important, but finer motion control is not as critical as in ball-centric tasks. This approach would free up main team robots to take on all ball-interaction tasks.

### 2.2 New Player Behaviors

Due to constant hardware problems with the old Team A robot version, Warthog Robotics used to play with 4 to 3 robots in the majority of the game time. But with the new low-cost, described in last year's TDP [2], and Team A, described in Section 3, versions, it was possible to play with 6 robots with reliability in the last year's *Competição Brasileira de Robótica*. Therefore, it was possible to develop new robot behaviors in order to unlock the potential of the full-size team.

The main focus was on developing the passing skill. The main attacking formation is composed of three players: the main attacker, that is constantly trying to reach out for the ball, the attacker assistant, that shadows the main attacker's movement and looks for possible rebounds, and the pass receiver, that positions for a possible pass in case a shot on goal is not possible. The currently developed pass receiver positioning heuristic is simple: there is a pre-defined set of points in the field and the receiver decides the best one based on the ball, enemy, and allied robots' positions. Then, in case the main striker has no clear angle to make a goal shot, he looks for a pass opportunity. Also, the pass was enabled in *freekick* and *kickoff* situations, which greatly improved the team's ability to take advantage of those recurrent game events.

## 3 Hardware Improvements

This section presents all hardware improvements made to the Warthog Robotics SSL project over the past year. The previous Team A consisted of robots that were more than ten years old and had begun to show signs of aging, making an upgrade necessary. All developed work is a continuation of last year's TDP [2], where the low-cost SSL team was developed. This project worked as a sandbox, serving as a development platform. For this year, all the validated ideas, such as new motor drivers and board-to-board connections, were introduced on Team A, in addition to new improvements. Section 3.1 describes the new mechanics project, while Section 3.2 describes the new electronics projects.

### 3.1 Robot Mechanics

The robot uses 4 direct current (DC) motors from Faulhaber, model 2342S012CR [1], that transmit the rotation for the omnidirectional wheels using a 6:1 stainless steel gear system. The entire system is powered by a three-cell LiPo battery, with a capacity of 5200mAh. The mechanical project can be divided into three layers: the top for the Printed Circuit Boards (PCBs), the middle for the battery, and the bottom for the solenoid and the powertrain, as shown in Figure 1.

At the bottom, the transmission system and motorization remain the same as last year's used in the A team, but they are now spaced further apart, allowing more space for a future second solenoid. Except for the wheel bearing support, the wheel axis, and the transmission gears, all the bottom layer is composed of 3D printed parts, printed in black acrylonitrile butadiene styrene (ABS).

In the middle, the battery is placed between two walls, keeping it fixed during the robot's movement. The base of the middle layer acts as a guide to the cables that come up from the bottom layer. At the top, the PCBs are placed and fixed with screws and nuts, receiving the cable connections from the motorization system and the solenoid.

Finally, the cover is also 3D printed and fixed with neodymium magnets to the robot's body. At the low-cost robot developed over the past year, the cover was also 3D printed, but the result wasn't satisfactory, since the blob fixing region presented problems caused by the 3D printed supports. For this year, this issue was solved by developing a cover with an opening at the blob region and an exclusive component to attach the blobs, which is fixed to the underside of the cover with magnets. The solution solves the support problem and reduces the rework after the print.

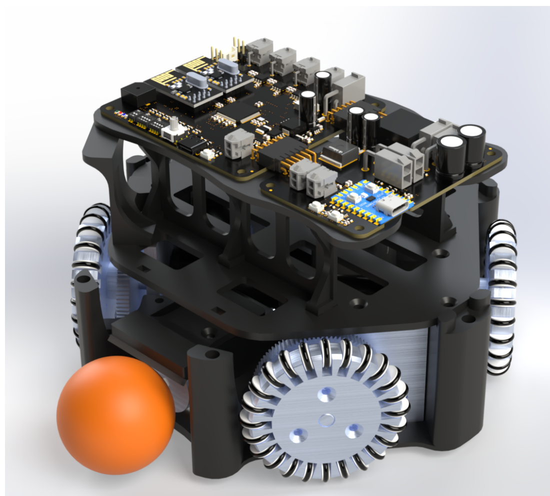

Fig. 1: 3D rendering of the internal parts of the robot. The robot is divided into three main layers: the kicker and the powertrain at the bottom, the battery in the middle, and the PCBs at the top. At the bottom, the wheels and the wheel brackets are shown in silver color.

### 3.2 Robot Electronics

The robot's electronic system consists of two PCBs: the first one for communication, data processing, and motor driver control, called MainBoard, and the second one for boost converter and kick actuation, called KickBoard.

The development focused on producing durable, reliable, and robust boards. Hence, the design incorporates protection components against Electrostatic Discharges (ESD) and short circuits, as well as features that enable future upgrades to the robot without requiring a redesign.

**MainBoard** Like the previous robots of Warthog Robotics' team, the MainBoard receives the group's WRMagic protocol command data via an nRF24L01+

[6] radio module, enabling its interchangeability with the other existing robots that use the same protocol, allowing a heterogeneous team of robots. The radio information is sent via Serial Peripheral Interface (SPI) to the microcontroller PIC32MK1024MCM100 [4], which processes the data and uses it to control motor driver and kicking capacitor voltage regulation systems, sending Pulse Width Modulation (PWM) signals and managing the user interface functionalities.

This current version of Warthog Robotics' Team A uses the DRV8231DDAR H-bridge to drive the 2342S012CR Faulhaber DC motors [1]. This component was validated in Team B last year's competitions, which used A2-102-S DC motors from Microred [5]. Both motor models present the same nominal operating voltage of 12 V and a stall current compatible with the component. The last H-bridge model used by the main team was the STMicroelectronics L298N, but due to its large Pin Through Hole (PTH) package and the need to add external freewheeling diodes to the project, it occupied a lot of space on the PCB. The new model, in contrast, has a Surface Mounted Device (SMD) package and internal freewheeling diodes, ensuring better use of space on the PCB.

In addition, the MainBoard incorporates the electronics required for a future implementation of a roller, using the same H-bridge used for the locomotion motors. However, this functionality has not yet been implemented in either the robot's firmware or mechanical design.

The user interfaces are composed of debug Light Emitting Diodes (LEDs) and a buzzer for robot status indication, like the old set of PCBs of the Warthog Robotics Team A. In this new version, a SD card connector has been added, enabling the logging of robot information during matches and testing through SPI communication.

Furthermore, although not yet implemented in the firmware, the board includes an ICM-42670-P Inertial Measurement Unit (IMU) from TDK InvenSense [9], which integrates a three-axis gyroscope and a three-axis accelerometer. The IMU is capable of measuring the robot's linear acceleration and angular velocity, enabling future enhancements in rigid-body control and, consequently, improving its locomotion. Furthermore, the component is positioned in the center of the XY plane of the robot, which assists in linear acceleration measurements, reducing noise caused by misinterpreted rotational accelerations.

Regarding electrical protection, one of the primary failures observed in the previous boards was the occurrence of short circuits on at least one of the power supply lines: the battery voltage, 5 V or 3.3 V. Therefore, one approach adopted to mitigate this issue was the implementation of resettable fuses, properly designed considering the normal operating current that each voltage line supports.

Moreover, a USB-C connector was added to the MainBoard to facilitate firmware flashing by enabling the microcontroller's USB bootloader function. Therefore, after the first flashing of the firmware, the microcontroller's flasher (called Pickit) is no longer needed for reprogramming. Another important function of the USB interface is the possibility of serial communication between the board and a computer during code development and testing, for example, allowing code debugging log. Figure 2 shows the MainBoard top view.

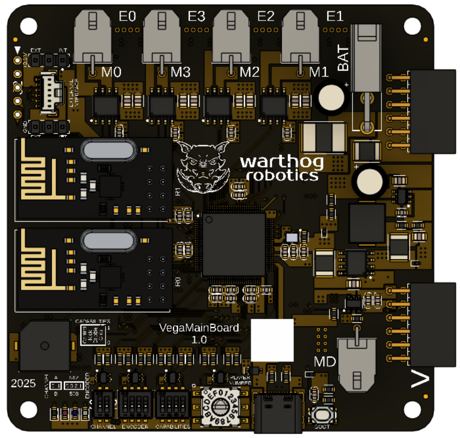


Fig. 2: 3D rendering of Warthog Robotics' MainBoard top view. On top, with M0 to M3 subtitles, four Micro-Fit connectors supply the motors; on the bottom, the MD subtitle indicates the connector for the dribbler motor; the one Mini-Fit connector on the MainBoard is the battery connector, with BAT subtitle; on the left, two nRF24L01+ radio modules; on the center, the microcontroller.

**KickBoard** The KickBoard role is to control the robot's kick system, being responsible for increasing the battery voltage up to 180 V using a discrete boost converter, storing the charge in two 2200 µF capacitors and discharging it on a solenoid actuator, performing the kick when requested.

For this year, a new PCB for the kick system was developed. The previous version from the Team A's KickBoard was a handmade PCB, which increased low-level problems, such as oxidation and cold solder joints. Furthermore, communication failures between the MainBoard and the KickBoard happened frequently, caused by an imperfect cable connection assembly. This new version was built and assembled by a specialized company and presents a board-to-board connection between the MainBoard, which improves hardness when compared to the previous version.

In addition, the new KickBoard has a dedicated microcontroller, an RP2040 [8] embedded on the RP2040-Zero module, from Waveshare [10]. This microcontroller was chosen based on its practicality, since your utilization doesn't require auxiliary supply and flash circuits. RP2040 brings more modularity to the project, allowing independent control of the boost circuit. The utilization of Waveshare's module is optional, i.e., the boost circuit control and the solenoid drives can also be established by the PIC32 [4] from the MainBoard or by the RP2040, allowing a backwards compatibility with the low-cost robot KickBoard.

In legacy previous versions, the KickBoard was exposed to constant ESD closer to user interfaces, such as connectors and buttons. These discharges frequently caused damage in ESD-sensitive components, since not all of them have on-chip protection, and those that have are typically only made large enough to protect against smaller ESD events present during IC handling, and not against high-voltage ESD pulses present at the system-level [3]. To solve this problem, transient voltage suppressor (TVS) diodes were placed next to the user interfaces and ESD-sensitive components. The chosen model was the NUP4114 from OnSemi [7].

Although not yet used, the KickBoard has a connection for a second solenoid, enabling a future ship kick project without electronics changes. Furthermore, with the reduction in the available PCB space for component placement, some of them were changed to their SMD versions, such as the power resistors from the manual discharging circuit. Finally, to group all robots' kick systems, the infrared circuit that detects the ball at the kick position was replaced, from the MainBoard to the KickBoard. Figure 3 shows the 3D rendering top view of the KickBoard.

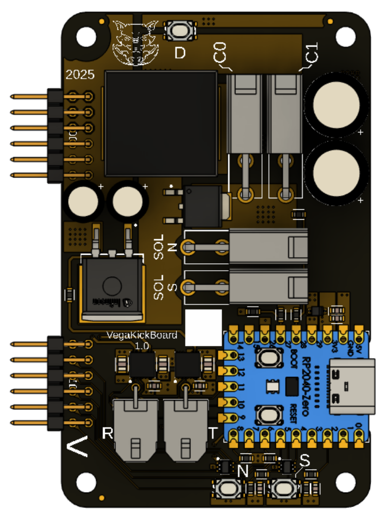


Fig. 3: 3D rendering of Warthog Robotics' KickBoard top view. On the right in blue color, the RP2040-Zero Module; on the top with C0 and C1 subtitles, the Mini-Fit connectors from the capacitors; on the right with SOL N and SOL S, the Mini-Fit connectors from the solenoids; on the bottom with R and T subtitles, the Micro-Fit connectors from the infrared system; on the left, both board-to-board connectors.

## 4 Test Devices

This section presents the test devices developed by Warthog Robotics. The test devices (or JIGs) provide practicality in the testing and debugging process. Section 4.1 presents the Radio Test Board, a JIG that validates nRF24L01+ radio modules, and Section 4.2 presents the DC Motor Test Board, a JIG that validates the assembly and operation of E4T Miniature Encoders on Faulhaber motors.

### 4.1 Radio Test Board

The Radio Test Board was developed to test nRF24L01+ radio modules. With a storage full of modules without correct validation, this JIG became necessary, providing practicality during the debug process. This board checks if the module presents short circuit and validates the sending and receiving messages.

For the short circuit test, the Device Under Test (DUT) is connected to a header and, if it's short-circuited, a red led turns on. To validate the communication, a reference radio is required, ideally a new one, to establish back-and-forth communication with the DUT. The DUT is connected to another header, and if it's able to receive and send messages, it's considered approved. The result of the test is printed on an Organic Light-Emitting Diode (OLED) display. Figure 4 shows the 3D rendering of the Radio Test Board.

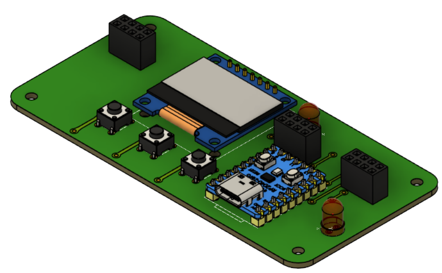

Fig. 4: 3D rendering of Radio Test Board isometric view. On the middle of the board, the OLED display; the top left header is for the reference module; the bottom right header is for the short circuit test; the header between the others is for the back-and-forth communication test; below the display, three buttons for interface navigation.

### 4.2 DC Motor Test Board

The Faulhaber 2342S012CR motors present in Team A robots have been in use for several years. Over time, some of the native encoders coupled to these motors have exhibited failures and stopped operating correctly, requiring their replacement or maintenance. However, this process is highly delicate and, if not performed properly, the device may realize inaccurate velocity measurements of the motor, which impairs the robot's control loop and consequently its locomotion.

Therefore, the purpose of the DC Motor Test Board is to evaluate basic operating conditions of motors and their respective encoders after maintenance, such as testing the power supply of both devices, checking for encoder short circuits, turning the red LED on if it's on, and the reliability of the encoder's response, displaying results in real time on an OLED display. Figure 5 shows the 3D rendering of the DC Motor Test Board.

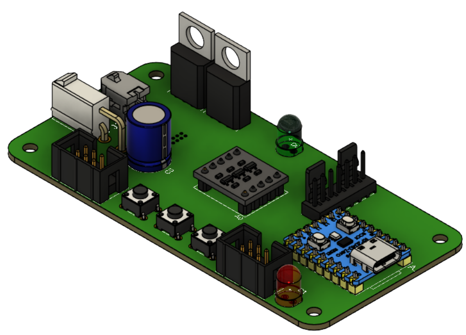

Fig. 5: 3D rendering of DC Motor Test Board isometric view. The top-right KK 254 Wire-to-Board Header is for the OLED display connection; the one Micro-Fit connector supplies the motor; the one Mini-Fit connector supplies the board; the bottom-left Insulation-Displacement Connector (IDC) header is used for encoder test; the bottom-right IDC header is used for encoder short circuit test; on the bottom, three buttons for user interface navigation.

## 5 Conclusions and Future Work

Warthog Robotics' latest software improvements consisted mainly of different approaches for heterogeneous robots integration, with a new control abstraction layer and a role assignment based on the robot's mechanical features. Furthermore, improvements in hardware were based on a new robot project, including the redesign of the mechanical project, new PCBs for kick control (KickBoard), external communication, and motor control (MainBoard). In addition, two test devices were developed as facilitators to validate the nRF24L01+ radio modules and the encoder's assembly.

In terms of software, the focus will be on high-level motion control and navigation using a path-tracking approach based on a dual PID system. By correcting cross-track and longitudinal errors, this method is expected to improve accuracy on following planned paths and contrasts with our current approach, which greedily steers the robot towards the next possible direction using a reactive planner.

Finally, a new mechanical system is currently being developed, with new wheel brackets and a dynamic ball damper, aiming to get more free space in the bottom layer of the robot and enhance the ball reception in passing plays, respectively. New features such as chip-kick and ball roller shall be integrated into the project.

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