Atena Team: RoboCup@Work Team Description Paper 2025

Giovanni Santos, João Henrique Aléssio, Matheus Paiva, Pedro Diniz, and Vinicius Gustierrez

SEMEAR Group
São Carlos School of Engineering of the University of São Paulo (EESC-USP)[⋆⋆⋆]
Department of Mechanical Engineering (SEM)[†]
13566-590 São Carlos - SP, Brazil
semear@eesc.usp.br
https://atenateam.squarespace.com

Abstract. This paper describes the approach of the Atena Team to RoboCup@Work 2025, detailing the robot's hardware, software, navigation systems, task planning strategies and mechanisms. The system includes omnidirectional navigation, vision-based object recognition, and a custom gripper for efficient manipulation in a modern and smart industrial setting. The document also highlights the team's history and the recent improvements and future directions of the project.

Keywords: RoboCup@Work · ROS · SCARA · YOLO.

1 Introduction

1.1 RoboCup@Work

RoboCup@Work [1] is a league of the RoboCup competition that challenges teams to develop smart robotic solutions for industrial environments, promoting worldwide research and development that enables the use of innovative autonomous mobile robots with advanced manipulators for applications in factories, warehouses and more.

Such applications include complex tasks ranging from manufacturing, automation, and parts handling, which are promoted and defined by the competition in a set of tests [2] carried out inside a large arena environment with obstacles as well as platforms, shelves and bins that include objects such as nuts, bolts, drill tips and metal extrusion profiles.

1.2 RoboCup@Work Brazil 2024

In the Brazilian RoboCup@Work 2024 competition, teams had the opportunity to participate in the country's first edition of the category. As this was the first

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⋆⋆⋆ https://eesc.usp.br/en/

† http://www.sem.eesc.usp.br/index.php/pt/ (in Portuguese)

year for the modality on the national stage, the organizers opted for a simplified version of the international challenges, allowing competitors to familiarize themselves with the event dynamics without the additional complexity of global tests. The arena used can be viewed in Figure 1, and the official document in English can be found in [3].

The arena was designed to simulate a real industrial environment, but with a focus on practical, straightforward tasks. Robots had to perform manipulation and transportation operations with adapted objects—April Tag Tagged Cubes (ATTCs)—to be retrieved or positioned onto tables, shelves, and containers that were specially arranged to delimit the service and manipulation areas, as well as a stacking area on the tarpaulin for precision placement tests.

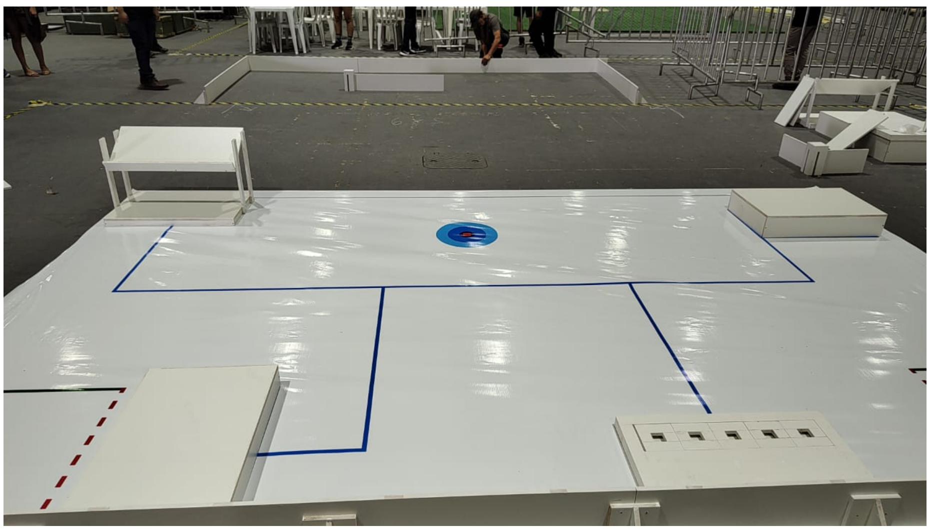


Fig. 1: Arena used for RoboCup@Work Brazil 2024

Although the international RoboCup@Work competition adopts more rigorous standards and more complex challenges, such as the integration of virtual obstacles and tests requiring advanced coordination between navigation and manipulation, the Brazilian edition served as a gateway for new teams. Even in its simplified form, it imposed fundamental requirements, such as navigation and object manipulation in dynamic scenarios, challenging teams with varied tests throughout the event.

This pioneering experience not only boosted the development and training of local teams but also laid the foundation for future editions, in which the challenges can evolve to increasingly align with international demands over the years.

1.3 Atena Team

Atena Team is the international branch of the SEMEAR Group[1], a student-led robotics group from EESC-USP founded by two mechatronics engineering students in 2010. Today, the group consists of more than 130 members, including our coordinating professor Marcelo Becker and students from many fields of engineering and computer science.

The members are subdivided into four separate technical cores that develop projects ranging from autonomous to controlled and aerial to terrestrial robots.

Our core, the Autonomous Mobile Robots Core, is the current winner of the Brazilian category of the competition, held for the first time in the country at the Petrobras Brazilian Robotics Competition 2024 (CBR)[2], and is in the process of qualifying for its first time competing in the international RoboCup@Work 2025, having also won several editions of the national IEEE Open[3] and participated in many national events such as RoboCore Experience (RCX)[4] and RSM Challenge[5].

The multidisciplinary team that is working in the project for RoboCup@Work is focused and motivated to learn about cutting-edge robotics and conduct research and development to achieve optimized manipulation, navigation, locomotion, localization and mapping for our robot, in addition to being able to contribute to the development of robotics and Industry 4.0 both nationally and worldwide.

2 Robot Platform

As an overview of the platform planned and developed by the team itself utilizing components both purchased and obtained through partnerships and sponsorships, as well as manufactured parts, the robot (see Figures 2 and 3) consists of four main subdivisions:

- Parallel robotic gripper with an onboard Logitech C270 camera for object identification and navigation
- Ball screw [4] elevator with arm attachment for the gripper
- Elevator base for arm rotation with an embedded Intel RealSense D435i for distance measurement, robot-base alignment and navigation
- Chassis for organizing electronic components and storing collected objects
- Aluminum extrusion base with DC motors, Mecanum wheels and distance sensors

[1] https://semear.eesc.usp.br (in Portuguese)
[2] https://cbr.robocup.org.br (English translation available)
[3] https://lars-larc2024.ucsp.edu.pe/rules/Rules_IEEE_OPEN_2023_en_V1.pdf
[4] https://www.robocoreexperience.com/en
[5] https://servidor.rsmvirtual.com.br/rsmchallenge/ (in Portuguese)

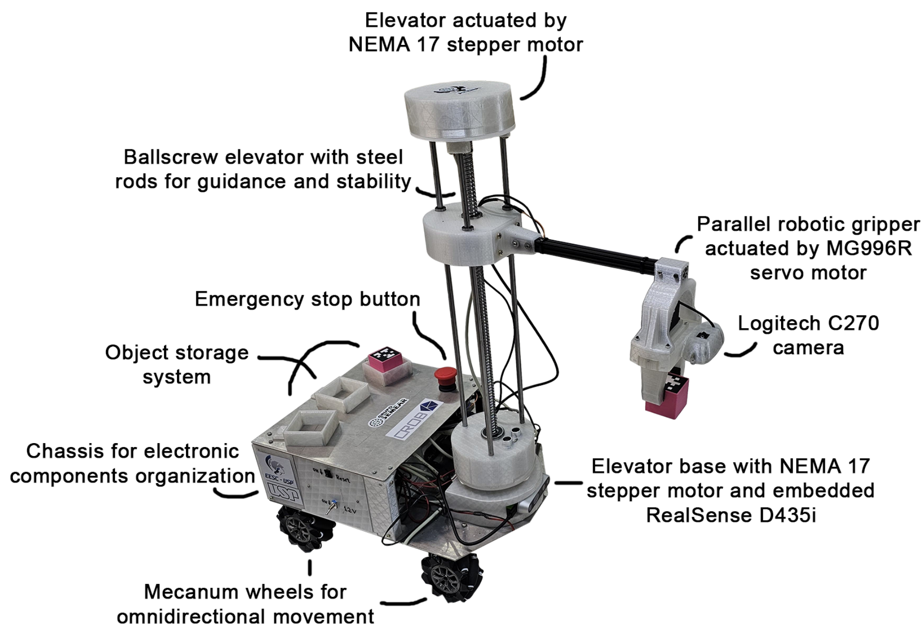


Fig. 2: Atena Team robot platform overview.

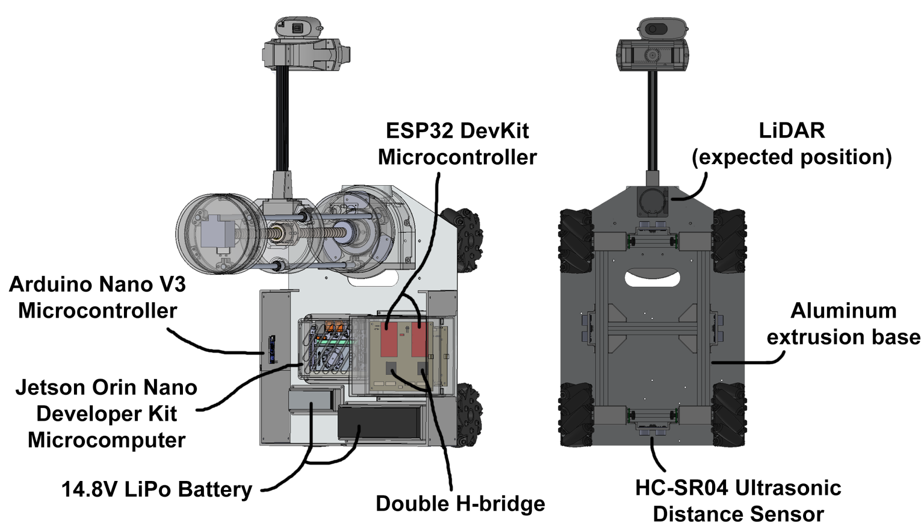


Fig. 3: Atena Team robot platform overview (top and bottom view) in SOLID-WORKS.

2.1 Mechanical systems

Our robot platform was constructed using 2 mm aluminum sheets, cut-out aluminum profiles, and 3D printed PETG and TPU components [5], ensuring a balance between rigidity, durability, and modularity.

The aluminum structure provides a strong and lightweight chassis, while 3D printed components — produced via Fused Deposition Modelling (FDM) — allow for the rapid prototyping and customization of various parts, including functional and final components, supports, couplings, and housings.

Locomotion: The robot utilizes a four-wheel omnidirectional drive system consisting of 96 mm diameter Mecanum wheels [6], each independently powered by a DC motor. This configuration enables the robot to perform holonomic movements, allowing it to navigate freely in all directions, including forward, backward, sideways, and diagonal translations, as well as in-place rotations. This movement versatility is particularly advantageous for precisely aligning with workstations and object compartments within the competition arena.

Component organization: The robot's electronic components and wiring are mounted using 3D-printed PETG supports, designed to fix and organize cables, preventing tangling and ensuring efficient heat dissipation. Additionally, snap-fit 3D-printed walls enclose the electronics compartment, offering easy access for maintenance and troubleshooting.

Robotic arm: A custom-built SCARA-inspired 2-DoF robotic arm [7] was developed and mounted on the chassis, designed to access three object compartments positioned radially at a 20° separation from each other. The combination of the omnidirectional base and the SCARA mechanism enables effective object retrieval and placement without requiring complex inverse kinematics, ensuring fast and precise manipulation.

- *Elevator base:* Being screwed to the chassis, the elevator based is a 3D-printed PETG structure that houses the NEMA 17 required for the rotating joint, as well as the Intel RealSense D435i used for distance measurement, robot-base alignment and navigation (see Figure 4a).
- *Rotating joint:* The elevator system, which vertically extends the arm's reach, is mounted on a rotating joint supported by a deep groove ball bearing[6] and two thrust ball bearings[7]. This arrangement provides structural stability and reduces friction, allowing smooth and controlled rotation of the manipulator.

[6] https://www.skf.com/group/products/rolling-bearings/ball-bearings/deep-groove-ball-bearings

[7] https://www.skf.com/group/products/rolling-bearings/ball-bearings/thrust-ball-bearings

- *Elevator mechanism:* The cylindrical joint of the elevator utilizes a ball screw drive - offering efficient vertical motion -, three 8 mm diameter steel rods with linear ball bearings - providing a stable motion - and a 3D-printed PETG elevator mounted to the ball screw nut.
  The arm itself, made of aluminum extrusion, is attached to the elevator platform using a custom 3D-printed removable coupler, allowing quick disassembly and maintenance.
- *Parallel robotic gripper:* The robot features a parallel robotic gripper capable of lifting objects up to 2.5 kg. The gripper incorporates a Logitech C270 camera (see Figure 4b), enclosed in a custom 3D-printed case, providing real-time visual feedback for object recognition and grasping as well as navigation. The gripper's force and opening width are optimized via programming and vision for securely handling objects of various shapes.

2.2 Electrical and eletronics systems

(a) Intel RealSense D435i depth camera.

(b) Logitech C270 camera.

Fig. 4: Currently implemented cameras.

The robot's actuators, sensors, and processing units are powered and controlled through a multi-layered electronic system, ensuring precise movement, real-time processing, and reliable communication, utilizing three main custom-made printed circuit boards (PCBs).

Actuators: The following motors are used to drive the robot's locomotion and manipulation systems (see Figure 5):

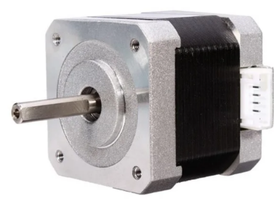
Locomotion:

- 4 Pololu 9.7:1 HP 12V DC motors, each with 1030 RPM nominal angular velocity, 3.2 kgf·cm stall torque and 48 CPR encoders for precise motion tracking and feedback control

Manipulation:

– 2 NEMA 17 stepper motors (one for rotation, one for vertical motion), each with 4.2 kgf·cm stall torque
– 1 MG996R servo motor with 11 kgf·cm stall torque at 6V used to open and close the parallel robotic gripper

(a) Polulu 9.7:1 HP 12V DC motor with encoder.



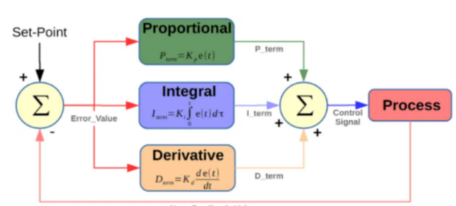
(b) NEMA 17 stepper motor.

(c) MG996R servo motor.

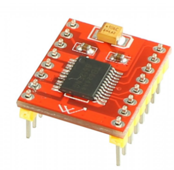
Fig. 5: Currently implemented actuators.

Locomotion control: Each DC motor includes a 48 CPR encoder for precise rotation measurement. Each of the two ESP32 DevKit microcontrollers (Figure 6a) receive encoder signals and execute PID calculations(Figure 6b), which fine-tune velocity and trajectory tracking. A system with two double H-bridge drivers (Figure 6c) controls motor speed and direction, allowing precise navigation, error correction, and smooth acceleration/deceleration.

(a) ESP32 DevKit microcontroller.



(b) PID controller.



(c) Double H-bridge driver.

Fig. 6: Locomotion control systems.

Computing unit: The Jetson Orin Nano Developer Kit serves as the central processing unit of the robot, responsible for:

- High-level decision-making, processing sensor data, and executing navigation and object recognition algorithms.
- Running ROS (Robot Operating System) to handle inter-module communication.
- Image processing and computer vision.
- Interfacing with microcontrollers (ESP32 and Arduino Nano V3) to coordinate motor control and sensor input.

Fig. 7: Jetson Orin Nano Developer Kit microcomputer.

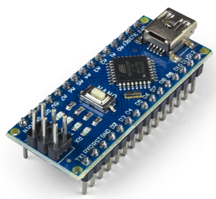
Auxiliary microcontroller system: An Arduino Nano V3 microcontroller, interfaced with the Jetson Orin Nano, handles (see Figure 8):

- Driving the MG996R servo motor and the two NEMA 17 stepper motors (utilizing two A4988 stepper motor drivers) with PWM signals.
- Processing data from four HC-SR04 ultrasonic distance sensors, used for obstacle detection and collision avoidance.

Power supply system: The robot is powered by three Lithium Polymer (LiPo) batteries (see Figure 9), each supplying different systems and components, utilizing appropriate step-down regulators for each application.

The two 14.8V (4-cell) LiPo batteries supply power to the four DC motors for locomotion and the two stepper motors for the movement of the robotic arm, while the 7.4V (2-cell) LiPo battery provides power to both the Jetson Orin Nano and the two ESP32 microcontrollers.

Providing energy from its USB ports, the Jetson Orin Nano powers both cameras, the Arduino Nano V3 microcontroller and, for a future implementation, a LiDAR sensor.



(a) Arduino Nano V3 microcontroller.

(b) A4988 stepper motor driver.

(c) HC-SR04 ultrasonic distance sensor.

Fig. 8: Auxiliary microcontroller system.

(a) 14.8V 5200 mAh LiPo battery.

(b) 14.8V 1300 mAh LiPo battery.

(c) 7.4V 6000 mAh LiPo battery.

Fig. 9: Batteries utilized in our robot.

Regarding the microcontrollers, the two ESP32 supply power to both H-bridge drivers, while the Arduino Nano V3 does the same to the MG996R servo motor, the two A4988 stepper motor drivers and the four HC-SR04 sensors.

3 Software Description

This section presents the overall software architecture adopted by the team during the 2024 competition – the first of @Work category in Brazil – based on the ROS Noetic middleware [8]. The model adopts a modular approach, inspired by the Model-View-Controller pattern [9], with the following components:

- **Driver:** Responsible for interfacing directly with sensors and actuators, collecting raw data to be processed by the other layers.
- **Model:** Contains the data processing algorithms applied to the data obtained in the Driver module.
- **Controller:** Manages the execution of commands, covering the control of the different subsystems.
- **Brain:** Layer responsible for decision-making and task planning.

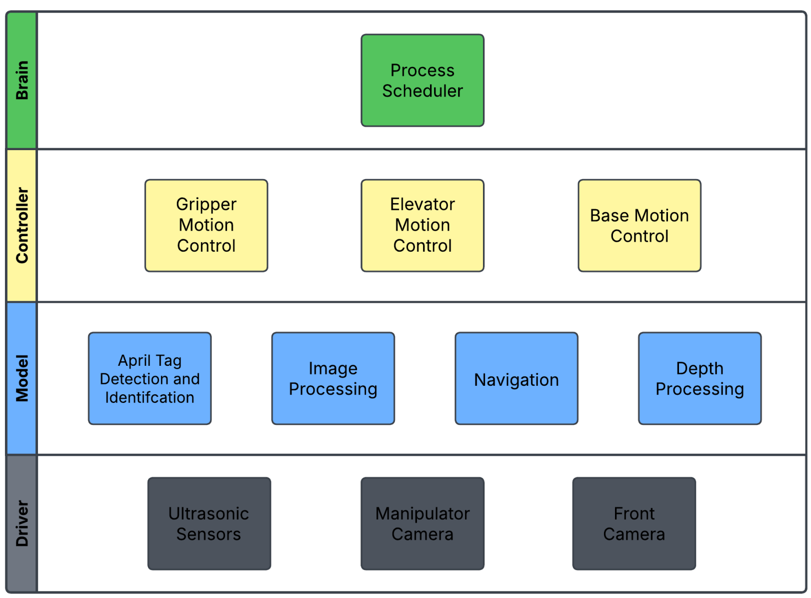


Fig. 10: Software Architecture

Figure 10 illustrates these modules. The system runs on ROS Noetic[8], operating on Ubuntu 20.04 on a Jetson Nano, and uses topics for inter-node communication, allowing non-blocking message exchange and continuous state monitoring.

3.1 Driver

The Driver is the link that connects the raw sensor data to the robot's processing and control modules. It collects and integrates information from the cameras and sensors, enabling the Scheduler to coordinate the actions of the controllers responsible for manipulation, navigation, and base movement.

RGB Manipulator Camera: The Logitech C270 (see Figure 4b) provides an overhead and detailed view of the objects manipulated by the robot, as well as the manipulation areas within the challenge arena.

Front Camera: The Intel RealSense D435i (see Figure 4a), equipped with RealSense technology, performs depth detection, mapping the environment in front of the robot to avoid collisions and generate a "depth map" crucial for the navigation stage.

Ultrasonic Sensors: The four HC-SR04 sensors placed on the robot's base (see Figure 3) monitor the proximity of lateral and rear structures, providing real-time information about obstacle distances. This data enables fine adjustments in locomotion, especially in environments with a high density of obstacles.

3.2 Model

The Model is responsible for transforming the raw data captured by the Driver into useful information for decision-making and for performing navigation between service areas. It operates on four main fronts: image processing[10], April Tag identification[11], depth analysis, and navigation.

Furthermore, our models encompass all the algorithms used to tackle the challenges of the tasks in the @Work league, covering essential functions such as navigation and perception. These algorithms are fundamental for the robot to interpret the environment and execute the necessary actions autonomously and accurately.

During the 2024 @Work competition, the objects used were April Tag Tagged Cubes (ATTCs)[11] for identification. The manipulation tasks required handling cubes with specific colors and IDs, necessitating robust image processing alongside accurate April Tag detection and handling. An example of these cubes is shown in Figure 11.

April Tag: It uses the ROS April Tag package[12] to process the overhead image and identify the tags present in the scene, extracting essential data such as the tag's centroid position and its identification, which is crucial for object localization and robot alignment. The information is published on a specific topic

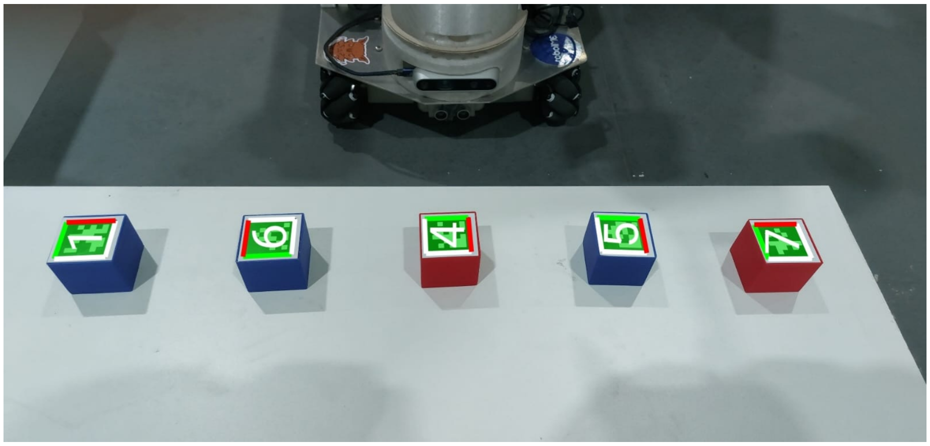
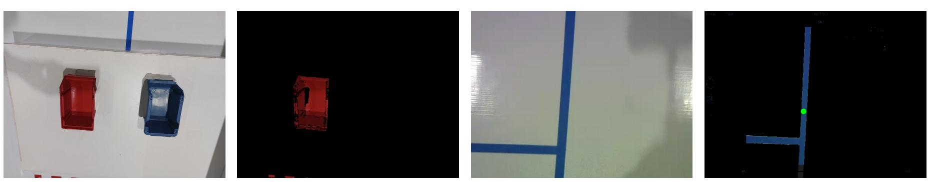


Fig. 11: April Tag Tagged Cubes (ATTCs) used in the RoboCup@Work Brazil 2024 tournament

and accessed by higher-level modules.

Image Processing: It analyzes the overhead image to extract relevant features of the environment, such as identifying the colors of cubes and delivery areas, as well as segmenting floor regions to use reference lines.



(a) Raw container image (b) Red container isolated (c) Top camera view (d) Isolated line and centroid

Fig. 12: Application of image processing for service area identification and navigation line detection.

Navigation: The robot's navigation was performed using the landmarks available in the @Work 2024 Tournament arena in Brazil, where a continuous line interconnected all the service areas, as seen in Figure 13. Due to the limited time until the event, the chosen solution was to use image processing from the overhead camera to extract not only the specific navigation line—using color segmentation and ROI (Region of Interest)[13]—but also to count the intersections encountered. This approach allows the system to publish specific commands on dedicated topics, enabling the execution of precise maneuvers (e.g., "turn right at two intersections"). In this way, the Brain determines which route should be taken and sends the corresponding command to the navigation node, which executes the trajectory and returns a confirmation message. Additionally, the navigation algorithm integrates depth image data to detect and avoid obstacles without interfering with the main trajectory.

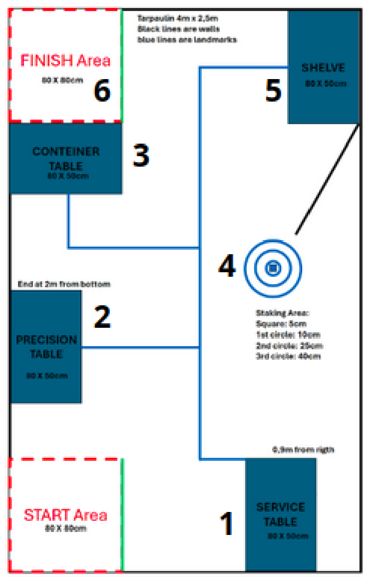


Fig. 13: Map of the @Work 2024 Tournament arena, illustrating the service areas interconnected by the navigation line.

Depth Analysis: It captures and interprets the depth image provided by the front RealSense camera, enabling the evaluation of distances and dimensions of objects and surfaces. The image generated by the depth matrix is published on a specific topic and analyzed by higher-level modules.

3.3 Control Module: ROS Command Integration

The robot's control implementation is divided into three modules, each operating through the publication of specific topics in ROS, allowing for precise and coordinated operation:

Gripper Control: Performed via a custom ROS topic and message that sends the desired position to the servo motor responsible for closing the gripper, ensuring precise object manipulation.

Elevator Control: Operates through a dedicated topic, where the necessary parameters for the stepper motor are published. For example, to perform an ascent, the system can send a command specifying a rotation angle of 8000 degrees and an applied voltage, ensuring controlled movements.

Base Control: Managed via messages of type `geometry_msgs/Twist`[14], which contain the linear and angular velocity information. A Hardware Interface converts these commands for the PID controllers [15] of each motor, ensuring stability and precision in locomotion with the Omniwheels used in the project.

3.4 Brain: Task Management and Scheduling

The Brain layer is responsible for planning, coordinating, and scheduling tasks for the robot, using the ROS package `smach` [16]. For each challenge proposed during the competition days, a specific scheduler was developed, responsible for:

- Scheduling processes according to the requirements of each environmental scenario.
- Publishing custom messages on designated topics to trigger subprocesses (e.g., searching for a block with a specific ID or manipulating it).
- Waiting for the confirmation of each subtask's completion, allowing safe transitions to the next stage.

This modular approach enables efficient code centralization, where each function or challenge can be developed, tested, and reused independently. Thus, implementing a new challenge does not require rewriting the entire control logic, but merely defining or adjusting states and transitions in the state machine. The communication between the architecture's components is shown in figure 10

The use of a state machine, implemented with SMACH, allows for defining states such as `TASK1`, `TASK2`, etc., and establishing transitions based on the feedback received from the ROS topics. For example, for the task of searching for a block with a specific ID, the scheduler publishes a message on the corresponding topic and, upon receiving confirmation, proceeds to the next state, which may involve alignment or object manipulation.

4 Focus and Relevance

There are a wide range of industrial applications for autonomous mobile manipulation, and our work focuses on advancing research and education in both the manufacturing and logistics domains.

Industry impact:
Our platform contributes to the evolving landscape of Industry 4.0 by demonstrating how mobile robots can optimize parts handling, streamline logistics, and

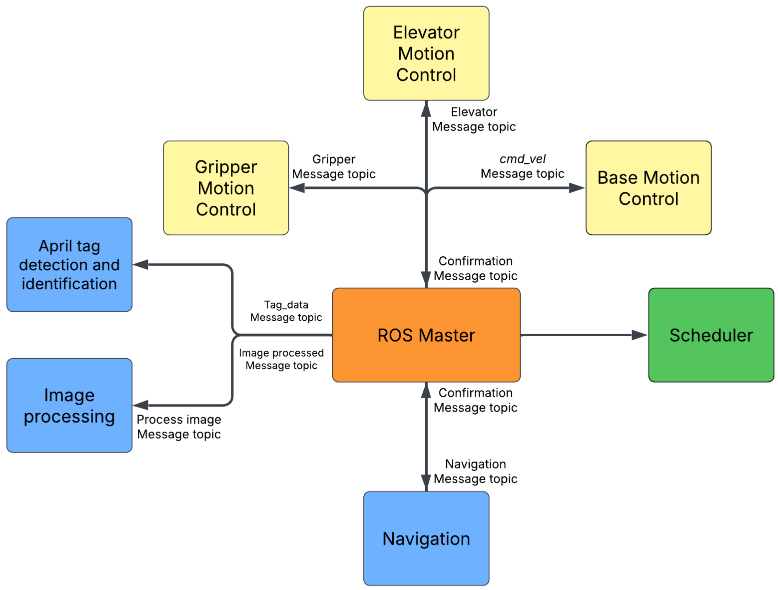


Fig. 14: Software framework based on ROS.

enhance operational efficiency in modern factories and warehouses. By showcasing our technology at events such as RoboCup@Work 2025, we illustrate the tangible benefits of integrating autonomous systems into industrial processes. Our collaborations with industry partners and sponsors further reinforce our commitment to providing smart automation solutions that meet current industrial challenges.

Research and development:
Our current and future research aims at developing adaptive multi-robot systems capable of autonomously operating in complex and dynamic environments. We focus on advanced techniques in dynamic path planning, where both high-level and low-level traffic rules are not only pre-programmed but also generated in real-time based on the robots' experiences. In addition, we address key safety issues, particularly in scenarios involving close human-robot interactions, ensuring our systems operate safely and efficiently.

Educational outreach:
Participation in RoboCup@Work 2025 not only drives technical innovation but also serves as a powerful educational tool. Our projects challenge engineering students to apply their theoretical knowledge in real-world scenarios, motivating them to push their boundaries and acquire new skills. Moreover, through community outreach initiatives—such as demonstrations in schools and interactive

events—we aim to inspire young minds and showcase the transformative impact of robotics on everyday life.

Online material:
For a closer look at our platform in action, please watch our Qualification Video for RoboCup@Work 2025 on YouTube[8] and visit our website and GitHub repository[9], where all related software and project documentation are available.

5 Conclusion and Future Work

This work presents Atena@Work's easy-to-control, robust, and modular system that integrates advanced techniques in navigation, manipulation, and perception for industrial applications. The results shown and applied in competitions such as the Petrobras Brazilian Robotics Competition 2024 demonstrate the system's viability and efficiency, as well as its adaptability to various scenarios.

Looking ahead, our future work will focus on several key improvements. For the international RoboCup@Work 2025 competition, we are actively implementing advanced navigation capabilities using the ROS Navigation Stack[17], adopting a dynamic mapping[18] approach rather than relying solely on static maps, as was demonstrated in the 2024 national challenge. This will allow us to apply and utilize sensors such as LiDARs, employed in many of our past projects, and additional cameras to detect and pinpoint service areas and obstacles such as virtual walls, as well as optimizing the mecanum wheel modelling for more agile and efficient locomotion.

In addition, with greater generalization and adaptability in the manipulation of objects during competition challenges in mind, we are enhancing our manipulation module to achieve more robust and reliable retrieval, storage and placement. We are also developing a comprehensive perception pipeline that leverages classical YOLO neural networks for object detection and recognition[19]. These initiatives, combined with further optimization of algorithm performance and improved communication between system modules, will contribute to a more efficient and resilient robotic platform.

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We are also grateful to the sponsors and partners of the Autonomous Mobile Robotics Core and SEMEAR Group for the financial support, which was of immeasurable help in obtaining components, as well as prototyping and building the robot.

[8] https://youtu.be/U3LXDnhjJSY
[9] https://github.com/Grupo-SEMEAR-USP/Work_2024

We would also like to express our gratitude towards the league chair of RoboCup@Work Brazil 2024, Carlos Cadamuro, and the team at CBR Petrobras 2024 for the spectacular work on bringing this category to our country.

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