RoboHub Eindhoven: RoboCup@Work Team Description Paper 2025

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Abstract. This paper presents the RoboHub Eindhoven team's submission for the RoboCup@Work World Championship 2025. It provides an overview of the current state of our robot platform, as well as the team structure behind its development. We describe the key components of our hardware platform, the design of our software framework, and the technical challenges we address in the areas of navigation, object recognition, and manipulation. Additionally, we outline our ongoing and future research directions and discuss how our work relates to the broader context of industrial automation and mobile manipulation applications.

Keywords: ROS2 · synthetic data generation · Ufactory lite6 · Groot2 behaviour tree · nVidia ISAAC AI vision · IMU.

1 Introduction

RoboHub Eindhoven is a dynamic team of motivated students, teachers, and professionals working together to develop innovative solutions in the field of robotics. We are part of the Engineering Department at Fontys University of Applied Sciences and are continuously challenging ourselves to push the boundaries of autonomous robotic systems. Our mission is not only to advance robotics but also to share our knowledge and inspire others. To achieve this, we actively collaborate with companies that support our vision and technology.

With RoboHub Eindhoven, we participate in the RoboCup@Work league with our dedicated team, focusing on the industrial application of autonomous robots. Our team is made up of a multidisciplinary group of students, complemented by participants from our Adaptive Robotics Minor, and guided by experienced RoboCup coaches. Together, we combine expertise from various backgrounds to develop, test, and refine our robot systems.

In addition to competing, we run an educational outreach project around our robot platform. Through this initiative, we aim to inspire non-technical students to engage with technology, encouraging them to learn how to create, program, and collaborate with robots.

Our journey started in 2017, and since then, we have participated in multiple editions of the RoboCup German Open. Initially, we competed with a KUKA YouBot[1], but after its discontinuation, we transitioned to new platforms. In 2018, we competed with a prototype of the Probotics Packman platform[2] combined with a UR3 manipulator[3]. From 2019 onwards, we introduced our own custom-designed platform, Sui^2, also equipped with an UR3 manipulator.

In 2021, we began developing the next generation of our competition robot, which made its debut in the 2023 championship. For the 2024 season, we competed with a streamlined version of this robot, which we further developed and improved for the 2025 season.

To support our long-term growth and increase our independence, we established RoboHub Eindhoven as an official non-profit foundation, registered with the Dutch Kamer van Koophandel. This step allows us to strengthen our organizational structure and expand our impact.

Additionally, we have established a collaboration with Auryn Robotics to further develop behavior tree technologies and share resources that benefit the wider robotics community. This partnership supports our mission to promote open-source solutions, particularly in ROS2 and beyond. We are also actively exploring advanced AI-vision techniques, including NVIDIA Isaac ROS, to enhance 3D perception capabilities. As part of this effort, we are developing synthetic data generation pipelines that we plan to release as open-source resources.

By collaborating with both academic and industry partners, we aim to accelerate innovation in robotics while reinforcing our educational mission, empowering the next generation of engineers and technologists.

2 Description of the hardware

Our current robot design, named SLE3K, is a streamlined evolution of our 2023 competition robot, SLICK. The name "SLE3K" reflects both its sleek design and the fact that it is the third competition robot developed by RoboHub Eindhoven.

The robot features a custom-designed sheet metal frame, specifically engineered to provide easy access to internal components. The top plate can be opened quickly, simplifying maintenance and hardware adjustments during development and competitions.

[1] http://youbot-store.com
[2] https://probotics-agv.eu
[3] https://www.universal-robots.com

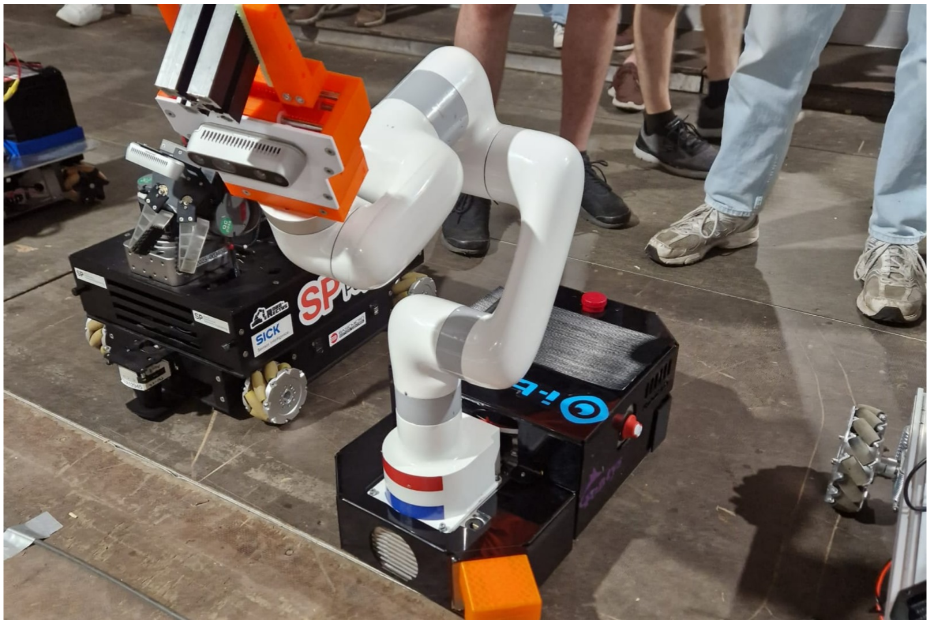

Fig. 1. SLE3K robot at the 2024 competition.

To move, SLE3K utilizes Maxon EC45 flat BLDC motors[4]. These motors are equipped with integrated gearbox reduction and encoders, making them an ideal match for the Maxon EPOS4 motor controllers. Their compact and efficient design offers both reliability and precision.

The manipulator we have selected is the UFactory Lite6 robotic arm[5]. This arm provides high-quality performance at a very competitive price point. Its size and payload capacity make it an excellent fit for the RoboCup@Work competition. A key advantage of the Lite6 is that it does not require an external control box, which reduces the robot's overall footprint and simplifies the hardware setup.

A visual representation of SLE3K's design, as used in the 2024 RoboCup, is shown in Figure 1.

The entire robot system is controlled by an NVIDIA Jetson Orin NX, provided by Forecr[6]. This compact yet powerful computing platform manages the complete control architecture, keeping the hardware configuration streamlined. The Jetson Orin NX features a CAN bus interface used to communicate with the motor controllers and offers sufficient computing power to handle navigation,

[4] https://www.maxongroup.com/
[5] https://www.ufactory.cc
[6] https://www.forecr.io/

perception, and vision-based tasks effectively.

To provide a complete overview of the interconnections within the SLE3K platform, we have created a detailed hardware schematic that outlines the main components and their communication interfaces. This schematic visualizes how power, data, and control signals are distributed throughout the robot, including internal systems like motor controllers, fans, and sensors, as well as external devices such as the LiDAR units and robotic arm. The schematic highlights

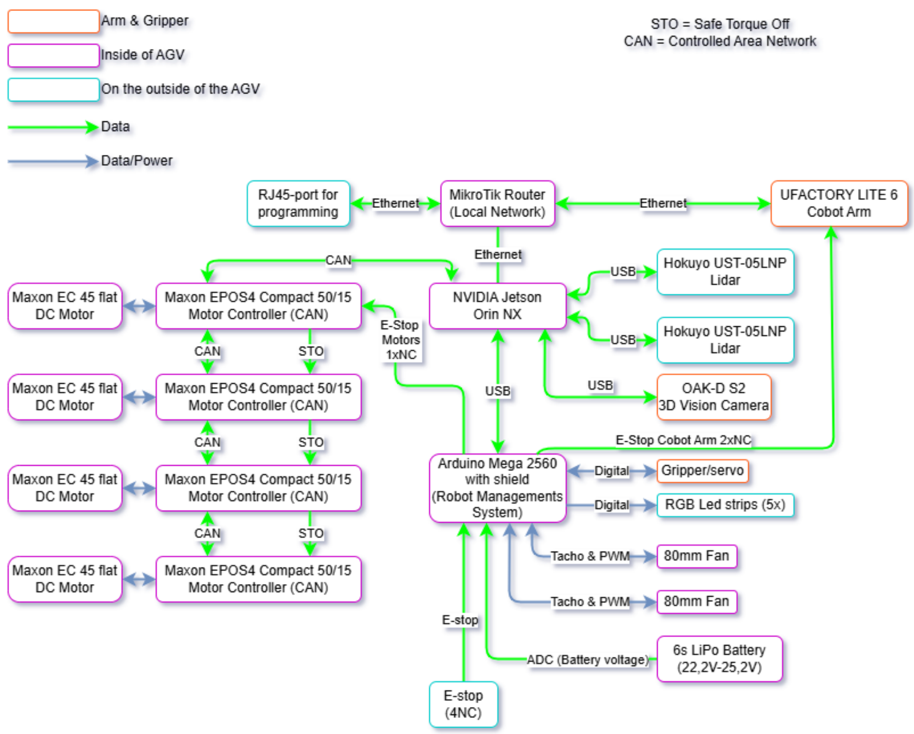

Fig. 2. Hardware schematic of the SLE3K platform, showing component interconnections.

several key aspects of the system:

- The use of CAN bus for motor controller communication and synchronization.
- USB and Ethernet links between the Jetson Orin NX and external sensors.
- A dedicated Arduino Mega 2560 for managing system-level components such as emergency stops, fan control, and LED feedback.
- Centralized control and monitoring via the NVIDIA Jetson, which serves as the core processing unit.

This modular architecture improves reliability, supports maintainability, and allows for scalable system upgrades as development progresses.

3 Description of the software

Our software stack includes both high-level and low-level control systems, as well as software for sensor and actuator processing and system monitoring.

High-level Control: For the high-level control of the robot, we utilize the Robot Operating System 2 (ROS2) [2]. ROS2 provides a comprehensive framework that includes a wide range of useful tools, hardware abstraction layers, and an efficient message-passing system. It enables modular software development by organizing functionality into independent components, called nodes. These nodes operate autonomously and communicate with each other via topics, using a one-to-many subscriber model based on the TCP/IP protocol. This architecture allows for scalable, flexible, and reliable communication between various parts of the robot's software stack.

ROS2 and Groot2 behaviour tree: Over the past two seasons, our team has primarily focused on rewriting and modernizing our software stack. This effort was driven by the decision to migrate from ROS1 to ROS2, ensuring compatibility with the current Referee Box communication system used in the RoboCup@Work competition. As part of this transition, we successfully implemented communication bridges between ROS1 and ROS2 during the migration phase.

One of the key changes in this software overhaul was the replacement of our original state machine approach with a behavior-tree-based control structure. We adopted the BehaviorTree.CPP library alongside its visual editor Groot2[7]. This shift offers multiple advantages:

- Modularity and reusability: Behaviors are implemented as small, self-contained nodes that can be easily reused across different tasks.
- Ease of debugging: The visual interface in Groot2 simplifies the process of tracking and modifying the execution flow.
- Scalability: Expanding the robot's functionality, such as adding new tasks or reacting to dynamic sensor inputs, can be done more easily compared to the monolithic structure of traditional state machines.

An example of our behavior tree setup in Groot2 is shown in Figure 3.

Additionally, through a collaboration with the developers of BehaviorTree.CPP,

[7] https://www.behaviortree.dev/groot/

we are currently piloting the Groot2 PRO version. This advanced version provides extended logging capabilities and an improved user interface, which we are evaluating to see how it can further streamline our development process. Our goal is not only to improve our own workflow but also to assess whether this approach could be beneficial for other teams competing in the RoboCup@Work league.

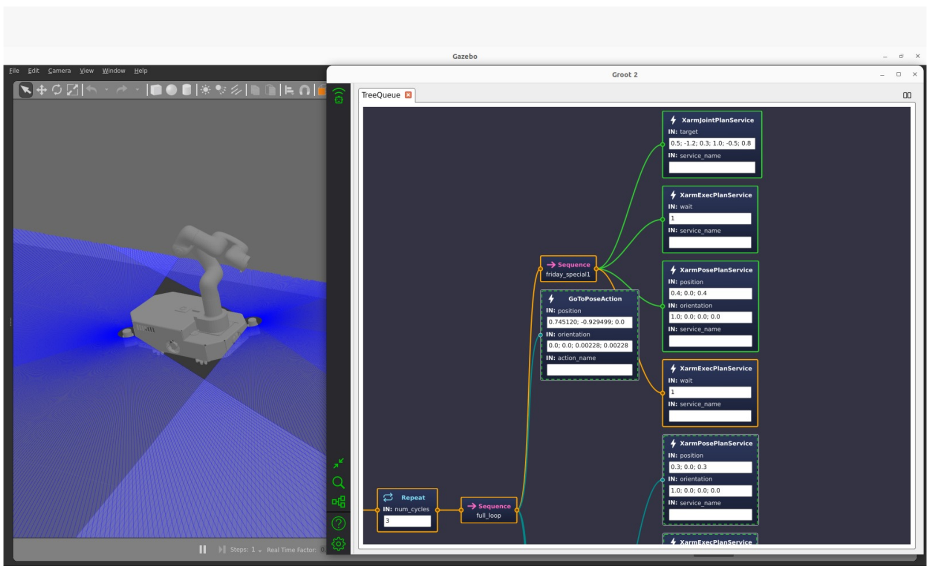

Fig. 3. Groot2 behaviour tree example.

Field Oriented Control: Field Oriented Control (FOC) is an advanced technique used to control three-phase motors, such as the brushless DC (BLDC) motors implemented in our SLE3K platform. Unlike conventional BLDC motor drivers, which often generate torque ripple due to their commutation methods, FOC drivers apply sinusoidal currents to the motor windings. This approach effectively eliminates unwanted torque ripple, resulting in smoother and more precise motor behavior.

The FOC algorithm continuously monitors the rotor position to ensure that the applied torque is always maximized. It does this by dynamically adjusting the magnetic field orientation in sync with the rotor's position. As a result, the system can minimize current consumption by only applying higher currents when necessary, such as during acceleration or when external forces are encountered. This leads to stable, coordinated motion while reducing energy consumption and limiting heat development in the motors.

In our implementation, the FOC algorithm includes a closed-loop PID controller with a third-order position profile to manage smooth acceleration and deceleration. These features make FOC particularly well-suited for use in Autonomous Guided Vehicles (AGVs), such as our robot platform, as they enable precise position control, improve operational efficiency, and contribute to an energy-saving and reliable system.

Containerization: Starting this year, we have adopted the use of Docker[8] to manage our development environment. By distributing our ROS2 environment and related tools as a set of Docker containers, we simplify version management and ensure that all team members work with the correct software packages and versions. This approach offers several key advantages:

- Streamlined onboarding: New contributors can quickly set up an identical development environment without dealing with dependency conflicts.
- Reproducibility: We can easily recreate the exact software stack used during development, testing, or competition.

By standardizing our software environment, we improve our internal development workflow.

Localization and Navigation: For localization, SLE3K is equipped with two Hokuyo LiDAR sensors. The raw LiDAR data is processed within the ROS2 framework to enable robust and accurate localization in the competition environment. For motion planning and control, SLE3K utilizes the Nav2 MPPI controller[9], which is the successor to the traditional TEB planner. This controller is particularly well-suited to our platform, as it efficiently supports the motion control of omnidirectional robots like SLE3K.

In addition to high-level path planning, we have implemented low-level acceleration smoothing to improve the controllability and smoothness of the robot's movement. To further enhance navigation accuracy, an Inertial Measurement Unit (IMU) has been integrated into the system. The IMU data is fused with LiDAR-based localization, improving overall movement precision and ensuring more stable navigation performance.

nVidia ISAAC AI vision: This year, we have started integrating the NVIDIA Isaac AI Vision framework[10] into our software stack. Leveraging the computing power of the NVIDIA Jetson Orin NX, the implementation of this

[8] https://hub.docker.com/
[9] https://docs.nav2.org/configuration/packages/configuring-mppic.html
[10] https://developer.nvidia.com/isaac

package has been straightforward and allows us to benefit from real-time 3D object detection and pose estimation.

Specifically, we utilize NVIDIA's DOPE (Deep Object Pose Estimation) pipeline [11] to improve the accuracy of detecting an object's position and orientation relative to the robot. Unlike traditional 2D vision systems, DOPE operates directly on 3D model inputs, which enables precise estimation of both the object's pose and its distance from the manipulator. This 3D-aware approach significantly reduces common edge cases and errors associated with purely 2D detection methods, leading to more stable and reliable object classification and localization.

To further enhance the performance of our vision pipeline, we plan to develop a synthetic dataset of industrial test objects. This dataset will include a variety of shapes, colors, and textures to ensure robustness and adaptability to real-world conditions. Our intention is to make this dataset open source, providing other teams and the broader robotics community with a resource to replicate, validate, or expand upon our vision workflows.

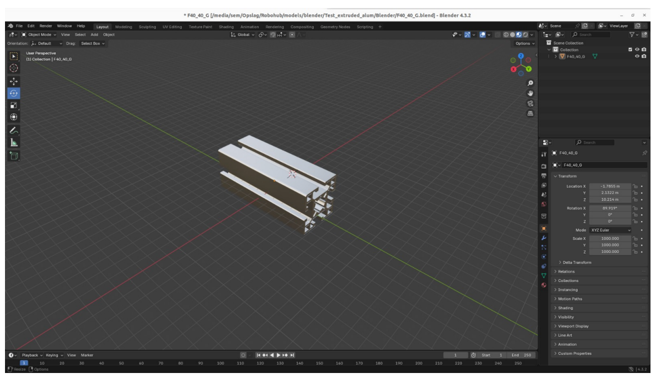

Fig. 4. ISAAC AI vision.

Barrier detection: In addition to object detection, we have developed a barrier tape detection system that allows the robot to identify and localize lines on the ground within its own coordinate frame. This feature is intended to improve situational awareness and assist with navigation in dynamic environments. The detection is performed using the main camera mounted on the robot's gripper, which is oriented towards the ground during driving.

At this stage, the system is configured to detect barrier tape lines only in the robot's forward driving direction. While the robot is capable of driving in reverse, detection in that direction is currently not supported. To address this

[11] https://developer.nvidia.com/isaac

limitation, a rear-facing camera may be considered in future developments. For now, the implementation focuses on using a single forward-facing camera to simplify development and validation.

4 Focus and Relevance

There are numerous industrial applications for autonomous mobile manipulation; within our education and research activities, we primarily focus on applications in the manufacturing and logistics domains.

Industry: We actively contribute to the ambitions outlined in the Dutch Smart Industry Agenda[12], which aims to drive innovation and digital transformation within the manufacturing and logistics sectors. As part of this effort, we collaborate with various industry partners and use our mobile manipulation platform as a showcase to demonstrate how logistics and manufacturing companies can benefit from the deployment of autonomous mobile robots in warehouses and on factory floors.

In addition, we are involved in several research projects funded by the Dutch government, working in close collaboration with industry stakeholders. One such project is the Fieldlab Flexible Manufacturing, which focuses on integrating mobile manipulation robots into flexible manufacturing lines. In this project, robots are used to deliver parts just-in-time to specific (automated) assembly stations, contributing to a more efficient and adaptive production process. These activities are closely aligned with the principles of Industry 4.0 [5], emphasizing flexibility, automation, and intelligent manufacturing systems.

Research: Our current and future research efforts are focused on several key directions, all aimed at advancing the capabilities of adaptive multi-robot systems that can operate autonomously in complex and dynamic environments. One of our primary objectives is to develop systems where multiple robots can collaboratively perform industrial tasks, such as navigating within a shared warehouse and efficiently transporting parts. In these scenarios, robots will be able to exchange products during transport and optimize their behavior based on the overall system performance.

Additionally, we are investigating advanced methods for smart and dynamic path planning, where navigation strategies are not only pre-programmed but also evolve based on the robot's experience and environmental knowledge. This includes the development of both high-level and low-level traffic rules that can adapt to changing conditions in real time.

[12] https://www.smartindustry.nl/english/

Another important aspect of our research focuses on robot safety and the development of systems that enable natural and intuitive interaction between humans and robots. By addressing these safety and interaction challenges, we aim to facilitate the seamless integration of mobile manipulation robots into real-world industrial environments.

First step in automation: Taking the first step toward automation can be challenging and, for many companies, even intimidating, especially when it is unclear where to begin. At RoboHub Eindhoven, we aim to make this first step more accessible and approachable by supporting companies through small-scale projects. This support may include providing advice, conducting a pre-study, developing a proof of concept, or performing practical experiments to demonstrate the potential of automation.

By working with us, companies can explore these initial steps in automation in a cost-effective and low-threshold manner, without the overhead often associated with large industrial service providers. Our focus is specifically on guiding companies through this first phase. Once a clear foundation has been established, we can recommend reliable and experienced partners to assist in the next stages of their automation journey.

Education: One of the primary goals of our participation in the RoboCup competition is to motivate and challenge our engineering students to reach a higher, more professional level in their education. Working on such a complex and multidisciplinary project encourages students to apply their existing knowledge while pushing their boundaries to acquire new skills and solve real-world problems. This hands-on experience fosters both technical expertise and teamwork.

In addition to the core team, we currently involve interns and three different student project groups in the development of our robot platform. Beyond our efforts in the RoboCup@Work league, we are also preparing to compete in the 2026 RoboCup Small Size League (SSL). The first prototypes of these SSL robots have already been built, and development is actively ongoing to bring them to a competitive level.

5 Future work

For this year, our team has identified several key development goals that need to be completed:

Software Goals

- Finalize the newly developed 3D vision system based on the NVIDIA Isaac AI Vision framework.

Fig. 5. SSL robot prototype.

– Complete the implementation of the barrier tape detection and collision avoidance system.
– Fully integrate the Groot2 behavior tree for high-level task control.

Hardware Goals

– Design and implement a new gripper.
– Redesign the hardware layout and wiring to improve maintainability and reliability.
– Develop a new AGV cover design.
– Implement a new suspension system to enhance stability and handling.

We are planning to publish detailed documentation and insights on this robot during the summer period. Furthermore, we are always happy to answer any questions related to our project. If other teams are interested in developing their own mobile manipulation platform, we are open to sharing our knowledge and supporting their development efforts.

Online Material: Videos showcasing our platform in action are available on our YouTube channel[13]. Additional information about our team, projects, and activities can be found on the RoboHub Eindhoven website[14]. Furthermore, all software developed by our team is published and maintained on our GitHub repository[15], making it accessible to the broader robotics community.

[13] https://www.youtube.com/channel/UCQkpwno0b1QEp96Wy66yLPQ
[14] http://robohub-eindhoven.nl
[15] https://github.com/robohubeindhoven

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