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MoMo: An Open-Source Modular Mobile Robot Research Platform

Mobile robots have evolved beyond transportation to serve diverse research and industrial tasks. This work addresses the need for flexible robotic platforms by introducing MoMo, a modular mobile robot featuring a mecanum drive system and a modular electrical connector. The platform supports various research modules, such as actuators and sensors, enabling experiments across multiple use cases. MoMo, implemented in ROS 2, accommodates payloads up to 105 kg and offers a cost-efficient solution compared to commercial platforms. The purpose of this work is to document the design of the modular platform and its implementation, facilitating collaboration and knowledge exchange within the robotics community. Future developments include expanding the versatility of the platform through additional top modules like mobile manipulation systems, demonstrating adaptability and practicality across diverse research domains.

Keywords: *mobile robot, open-source, mecanum drive, omnidirectional robot, modular design.*

1. INTRODUCTION

In the first decades of their existence, mobile robots were primarily applied for transportation tasks and as mobile workstations [1]. Recent applications show a broader variety of use cases for mobile robots in research and industry. Present research examples include a robot-based picking principle featuring a mobile robot with a gripper [2], gas leakage detection using several gas sensors and a LiDAR [3], an ergonomic load carrier equipped with a lifting mechanism [4], and a book inventory robot equipped with an RFID reader and a camera [5]. All these examples have one thing in common: the need for a mobile robotic platform to which researchers can flexibly attach additional hardware. Commercially available robotic research platforms are expensive and offer limited customizability.

Another approach to meeting budget constraints could be the modularity and multi-use of robotic platforms [3]. Some hardware parts like computers, motors, motor controllers, and batteries are always required and are the most expensive components for mobile robots, which must perform intensive computational tasks, carry high payloads, or accelerate quickly. As sensors and actuators can vary across research project demands, mounting specialized components directly onto the base of the robot using screws and connecting power and data cables manually is impractical. Transitioning between setups necessitates a cumbersome disassembly and reassembly process. This drives the development of a concept for a flexible and modular mobile robotics research platform, allowing research organizations to conduct experiments across multiple use cases using a single modular platform. Based on the outlined concept, *MoMo* has been developed. The modular mobile robot features a mecanum drive system and a modular electrical connector to simplify the attachment of diverse research modules consisting of actuators and sensors.

The main contribution of this work is the documentation of the systematic design and implementation of the modular mobile robotics research platform, offering a cost-efficient and customizable approach to carry out research in several use cases using a single robot base. The process includes a requirement analysis, an open-source assembly manual regarding mechanical and electronic components, a list of parts and components, a CAD model, ROS 2 software and driver packages, and a budget calculation regarding required parts and components.

This work is structured as follows: The next section compares the platform to other robotic platforms available. Sections 4 and 5 present the modular concept and implementation. In section 6, an exemplary top module demonstrates the functionality of the concept and the implemented design. This work closes with a conclusion and outlook for future research.

2. RELATED WORKS

This section briefly overviews commercially available and open-source platforms to the scientific community and compares state-of-the-art omnidirectional robotic research platforms. The platforms are compared in terms of payload, drive system, weight, open-source availability, ROS integration, speed, runtime, charging time, and customization effort. To ensure comparability, only platforms with a minimum payload capacity of 50 kg are considered. The specifications of the platforms are compared in Table 3 at the end of the paper.

URANUS, the first omnidirectional robotic research platform, was proposed in the 80s and features a

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mecanum drive system and a top plate to mount optional hardware. The mechanics, electronics, and pseudo-code of the control are documented by Blackwell [6]. Since then, the robotics industry has evolved, and ROS has become the state-of-the-art framework for modern robot software research and development with many open-source packages. ROS 2 [7] surpasses ROS 1 due to its advanced communication architecture, enhanced security features, real-time processing capabilities, and superior support for multi-robot systems, rendering it more suitable for sophisticated and scalable robotics applications. There is a lack of open-source mobile robot research platforms capable of carrying large payloads, which is why Nwankwo et al. propose an open-source mobile robot using ROS 1 with a differential drive system that provides a maximum payload of 90 kg and costs less than $1500 [8]. There are some advantages to using commercially available mobile robots. Platforms like the Robotnik RB-STEEL [9] offer various sensor and actor configurations and optional accessories. Commercially available platforms typically have safety certifications and IP ratings, which further justifies their use in industrial research environments. The only commercially available omnidirectional robotic research platform matching the payload requirement with open-source code is the Clearpath Ridgeback, which costs 48000 € and only supports ROS 1 [10]. The AgileX robots [9][10] and the Husarion Panther [11] do not cost as much money and run ROS 2 software, but the code is not open-source. To the knowledge of the authors, there is no mecanum drive mobile robotic platform available with building instruction and open-source software and no open-source robot with building instruction running ROS 2. None of the available platforms come with a modular connector limiting the multi-use of the same base.

3. REQUIREMENT ANALYSIS

At the beginning of the design process for the modular mobile robot research platform, a requirement analysis is conducted by consulting with other researchers and technicians in the field of robotics. This chapter derives, classifies, and quantifies the requirements for a mobile robotic research platform. The quantifiable requirements are summarized at the end of the chapter in Table 2. Due to space constraints, additional requirements are only described in the text. Each requirement was classified as either a minimum requirement (M), a fixed requirement (F), a goal (G), or a wish (W). The requirements can be grouped into operating conditions, geometry requirements, computer specifications, ergonomics and usability, battery requirements, and efforts regarding costs and time.

The robot must operate indoors in a lab environment at room temperature, with non-condensing humidity levels and relatively low dust, vibration, and shock (F).

The PC of the robot should have at least 512 GB of storage for recording extensive data sets containing high-dimensional data such as images or point clouds (M). The processor should have at least four cores and a clock speed of 2.5 GHz to ensure smooth processing of multiple tasks simultaneously, such as data processing and real-time control (M). There should be at least 8 GB of RAM for demanding tasks like machine learning (M). The robot should run Ubuntu 22.04 and ROS 2, the latest version of the Robot Operating System, offering improved performance over ROS 1 (F).

Ergonomics and usability requirements are essential for encouraging researchers to build and use the platform. The robot base should be easily extendable by custom-built top modules (F). The platform should allow a fast and easy switch of sensors and actuators in order to promote the multi-use of the platform (F). The modules should be capable of being manually attached and detached by one person (F). There should be a user manual and documentation on manufacturing and assembling the robot and what to consider when designing a custom top module (F). A small built-in display on the robot, LED stripes, and a built-in speaker would further enhance the usability (W). The robot should be able to be lifted for maintenance by two people. This requires the maximum weight of the robot not to extend 60 kg to be in accordance with the German occupational health and safety law (F).

The base of the robot should be able to carry loads of up to 100 kg (G). A minimum weight of 20 kg allows the robot to serve as a counterweight for top modules equipped with a gripper.

Geometry requirements ensure the stable and efficient operation of the robot. The height of the base of the robot should be between 20 cm and 40 cm to fit all components while keeping a low center of mass (F). The base should be 50 cm to 70 cm wide because a broader base increases stability, especially when the robot is carrying a load or performing movements that could shift its center of mass (F). The center of gravity should be as low as possible to minimize the risk of tipping over, especially during sudden stops or directional changes (F). The length-to-width ratio should be balanced to ensure the robot can navigate through typical doorways and tight spaces. From experience, a 60 to 100-cm length should be appropriate (F).

Kinematics requirements ensure the safe and flexible movement of the robot. To investigate robotics use cases where robots can drive relatively fast, the goal for the maximum speed should be 2 m/s (G). This should be done using appropriate safety precautions, such as restricting access to the experiment area. The stopping distance must be 0.5 m to prevent collisions (F), which requires an acceleration of 4 m/s^2 for a speed of 2 m/s. An omnidirectional drive system improves maneuverability and flexibility and allows experimentation with different movement strategies (F). Positioning accuracy with a maximum error of 1 cm or 1 degree allows conducting experiments where accuracy is required (G).

Battery requirements ensure an adequate power supply to all electronic hardware components for the desired runtime, which is 14 hours (G). This allows different research teams to conduct experiments with the same base platform throughout the entire workday, which starts at 6:00 and ends at 20:00. The charging time should be less than 10 hours to fully charge the robot before the start of the next working day (M). The battery should be able to supply at least 50 A at 24 V to supply four motors

Table 1. List of Requirements

Requirement	**Value**	**Type**
Storage	512 GB SSD	M
Processor	> 2.5 GHz, > 4 cores	M
Memory (RAM)	8 GB DDR4	M
Min. weight	20 kg	F
Max. weight	60 kg	F
Payload capacity	100 kg	G
Max. speed	2 m/s	G
Max. acceleration	4 m/s^2	G
Runtime	14 h	M
Charging Time	< 10 h	M
Battery Current/Voltage	50 A / 24 V	M/F
Battery Capacity	50 Ah	M
Maximum Costs	15000 €	G
Construction Time	4 weeks	G

(each 10 A), LiDAR sensors (1-2 A), and a gripper (2A) with power. The battery capacity of the robot should be large enough to allow 14 hours of continuous operation (M).

Cost and time requirements ensure the feasibility of research teams adapting the robot platform. To explain the use of this platform as opposed to commercially available robots, the off-the-shelf parts and materials should cost less than 15000€ (G). The manufacturing methods should only entail lathe, milling, drilling, cutting using a circular saw, and 3D printing, as many technical universities can access the machines required for these methods (F). The assembly should only need standard tools. Manufacturing and assembly should take a maximum of four weeks for one person working full-time (G).

4. MODULAR CONCEPT

The MoMo platform is designed to provide flexibility and adaptability for robotics research, particularly in indoor environments. This section details the foundational base platform of MoMo and the specific functionalities introduced by the modular attachments.

The base platform of MoMo forms the foundational unit equipped to support both autonomous and remote-controlled operations. Central to its operation is the onboard computer, which processes all data inputs from the robot and its modules. This computer is pivotal for tasks such as navigation, communication, and integration of module functionalities. Mobility is facilitated by a drive system consisting of four independently powered omnidirectional wheels. This mecanum drive system allows the base to move fluidly in any direction, providing versatile navigation capabilities within complex indoor environments.

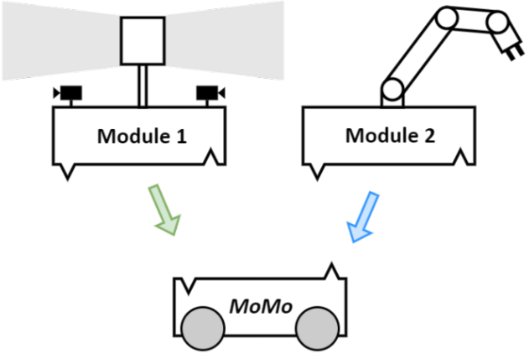

Figure 1. The modular concept allows the flexible attachment of different top modules.

The MoMo platform supports the integration of various top-mounted modules, each tailored for specific tasks. Figure 1 shows an example of a sensing module (Module 1) equipped with sensors such as LiDAR and cameras for tasks requiring environmental perception, spatial mapping, and obstacle detection. Module 2 includes a robotic arm for interacting with the environment, suitable for tasks involving object manipulation like picking and moving.

Modules connect to the base platform through a standardized interface that ensures mechanical and electronic compatibility. This setup facilitates power and data integration between the onboard computer and the attached top module. The design allows different modules to be mounted and unmounted within seconds, enhancing operational efficiency. This quick-change capability reduces downtime and enables researchers to switch between different experimental setups rapidly.

Additionally, this modular approach results in a substantial reduction of hardware costs for research organizations. Instead of investing in multiple specialized robots, organizations can leverage the versatility of the modular system, which can be reconfigured to meet diverse experimental needs.

5. IMPLEMENTATION

This chapter gives an overview of how hardware and software components are implemented. Complete assembly and manufacturing instructions are available in the GitHub repository [13].

5.1 Hardware

The following section describes how the hardware of the base platform is implemented. The official documentation provides a complete list of all hardware components with a link to a supplier. Figure 2 provides an overview of the most essential hardware components.

The frame of the robot is built using 30 mm aluminum profiles. Mounted on the robot are 203 mm mecanum wheels (12), each actuated by a 15 Nm motor-gear combination. Most electronic components are mounted on the inside wall onto the aluminum frame. This makes them easily accessible if a component must be replaced or connected. The main PC (6) is an industry mainboard with an Intel i9 12900T processor and 64 GB of RAM.

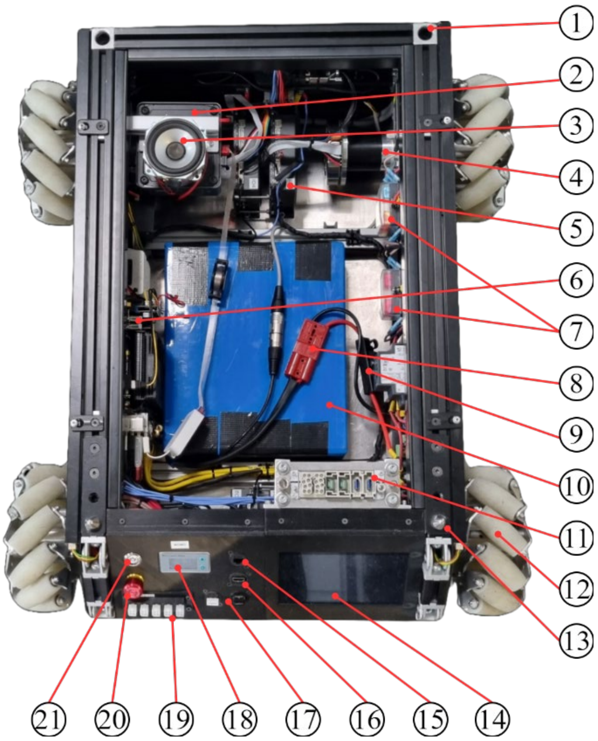

Figure 2: Centering hole (1), control PC (2), speaker (3), motor (4), motor controller (5), main PC (6), fuses (7), power supply (8), battery fuse (9), battery (10), modular connector (11), centering cone (12), mecanum wheel (13), display (14), ethernet port (15), HDMI port (16), USB ports (17), voltage display (18), *Micro-Fit* sockets (19), emergency stop (20), power button (21)

The main PC runs Ubuntu 22.04 with ROS 2 Humble. An Intel NUC serves as a control PC (2), sending velocity commands to the motor drivers (5). In the center of the robot, a 1440 Wh Li-ion battery (10) is placed. A battery fuse (9) is connected to the power supply (8). A battery monitor (not visible) allows voltage to be displayed (18). The user is warned using the built-in speaker (3) when the voltage is below a certain threshold. Eventually, the robot shuts down automatically to prevent a deep discharge from the battery. Multiple fuses (7) are installed to avoid damage from overcurrent and thus add to the safety of the robot. To allow the researcher to easily interface with the robot, a display (14) is connected to the main PC, as well as ports for USB (17), ethernet (15), HDMI (16), and 4-pole Micro-Fit sockets (20). Besides the emergency stop (20) on the robot, there is also a remote-controlled emergency stop. Both emergency stops interrupt the electrical connection to the motors. Two centering cones (13) are mounted to the top of the robot in the front corners. In the back corners are holes (1) in which the centering cones of a top module are inserted.

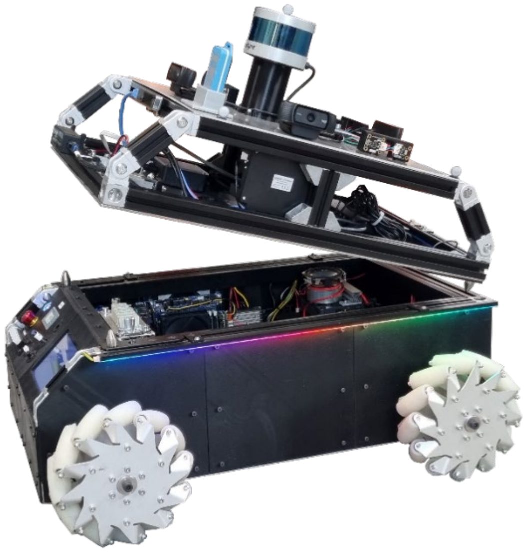

Figure 3. Docking of a top-module

Table 3. Specifications of the base platform

Specification	Value
Length × Width × Height	0.76 m × 0.64 m × 0.26 m
Weight (w.o. top module)	45 kg
Maximum Payload	105 kg
Maximum Speed	1.5 m/s
Acceleration	3 m/s^2
Operating System	Ubuntu 22.04 + ROS 2
Runtime	30 h
Charging Time	15 h
Battery Capacity	1440 Wh
Communication Interfaces	Bluetooth, Wi-Fi, Ethernet, USB, HDMI
Safety Features	Emergency Stop, Battery Voltage Monitor

Figure 3 shows the docking of a top module. Centering cones in the corners perform a pre-centering, ensuring a robust coupling of the electrical connector (11). Table 3 summarizes the most critical specifications. The speed and acceleration are measured using an infrared light-based motion-capturing system. The maximum payload is determined by subtracting the weight of the base platform from the maximum load of wheels.

5.2 Software

This section details the design and implementation of the software for the MoMo research platform. It features a description of the architecture and the control package, which ensures robust motion control, odometry calculation, and velocity limiting.

Figure 4 shows a high-level view of the software structure. The robot uses two separate PCs to handle different tasks. The main PC runs ROS 2 Humble on Ubuntu 22.04 and is responsible for high-level control and computationally demanding tasks. It communicates with sensors and actuators of top modules and stores data.

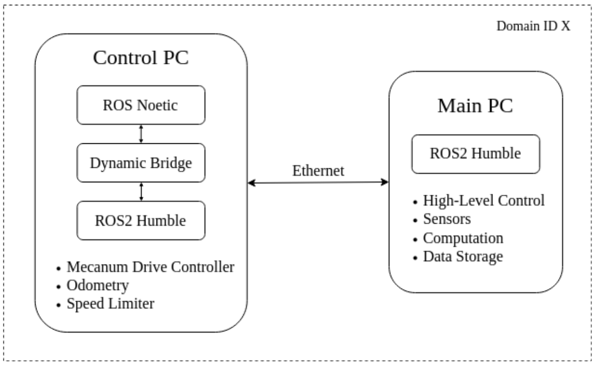

Figure 4. Dual-PC Software Setup

A control PC is employed which is running ROS Noetic and ROS 2 Humble on Ubuntu 20.04. The control PC receives velocity commands for the robot on a ROS 2 topic through an ethernet connection from the main PC. Setting a unique domain ID prevents interference from other PCs in the local network. A dynamic bridge allows seamless data exchange between the ROS Noetic and ROS 2 Humble environments. The control PC runs the mecanum drive controller, which converts velocity commands into individual wheel velocities. The control PC also calculates and publishes odometry data for localization and navigation. The odometry module continuously updates the pose of the robot using wheel encoders. This real-time feedback is essential for autonomous navigation. The speed limiter ensures safe operation by enforcing velocity, acceleration, and jerk limits on the movement.

6. EXEMPLARY USE CASE

The autonomous navigation of mobile robots depends largely on reliable localization systems. Various environmental influences such as direct sunlight, reflection, map ambiguity, the movement of the robot, or dynamic obstacles can disrupt localization systems and jeopardize process reliability. A monitoring software will be developed and evaluated using data-driven models to detect and monitor these faults. The aim is to control the localization quality during operation, identify errors, and make adjustments to ensure the safety and efficiency of the robots. This includes collecting relevant environmental data, creating models to estimate the uncertainty of the robot pose, and using synthetic and real-world sensor data for modeling. The models are validated experimentally to ensure transferability to real application scenarios. The perception and localization module that will be used for data collection and validation is shown in Figure 5. The module is equipped with reflective markers (1) that a motion-capturing system uses to track the movement of the robot. Four light sensors (3) and four webcams (4) are mounted on the robot. Additional sensors are a 360-degree LiDAR (2), a tracking camera (6), and a depth camera (8). This research project utilizes some hardware that is very use-case-specific. The modular connector (7) allows mounting the localization module in seconds, enabling flexible cooperation with researchers requiring a different top module. The transmission of the motors allows accurate positioning and flexible kinematics, making it possible to investigate localization performance for various types of movements.

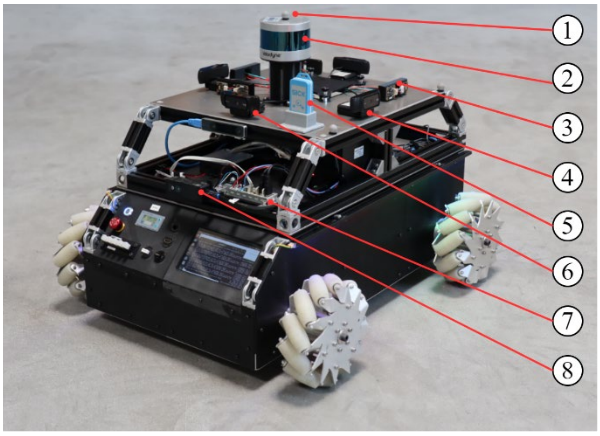

Figure 5. Perception and localization top-module mounted on the MoMo platform

7. CONCLUSION

This work illustrates the development process, concept, and implementation of an omnidirectional mobile robotics research platform. This novel platform represents the first open-source omnidirectional robotics research platform with building instructions available. Furthermore, the modular approach of the platform enables researchers to perform multiple research activities and use cases on a single platform by allowing them to switch between use case-specific top-mounted modules within seconds. The modules are connected to the platform using a modular connector consisting of standardized interfaces providing the necessary ports.

All information needed to build the platform is provided via a continuously updated and improved open-source GitHub repository. The repository contains documentation regarding the required hardware and software components, complete assembly and manufacturing instructions, and packages for the robot.

Future research will focus on developing and integrating new top modules. Upcoming activities include creating modules for mobile manipulation, picking, and transportation tasks. Additionally, the construction of the platform and implementation will be continuously improved and refined.

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Table 3. Overview of existing omnidirectional research platforms with payloads above 50 kg

Robot	Price	Runtime	Charging Time	Open-source	Payload	ROS version	Weight	Speed
AgileX Ranger Mini 3.0 [11]	Upon request to vendors	7-8 hours	1.5 hours	No	120 kg	ROS 1 & 2	75 kg	2 m/s
AgileX Scout Mini [12]	8100 €	20 km	1.5 hours	No	50 kg	ROS 1 & 2	48 kg	2.8 m/s
Clearpath Ridgeback [10]	48000 €	15 hours	8 hours	Yes	100 kg	ROS 1	135 kg	1.1 m/s
Husarion Panther [14]	20000 €	3.5 to 8 hours	1 hour	No	100 kg	ROS 1 & 2	55 kg	2 m/s
Robotnik RB-STEEL [9]	Upon request to vendors	6 hours	-	No	250 kg	ROS 1	105 kg	3.0 m/s
MoMo [13]	12500 €	30 hours	15 hours	Yes	100 kg	ROS 1 & 2	45 kg	1.5 m/s