Mountaineers@Work
Team Description Paper 2025

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Abstract. This paper details Mountaineers@Work, West Virginia University's team for the Robocup@Work competition 2025. As a first-year participant, our team presents a robot built upon a commercial robot platform, which was adapted to increase its performance and satisfy the competition's needs. Besides presenting the robot's hardware and software, the paper also discusses the performance of our robot in the execution of some Robotcup@Work tests. This discussion is complemented by a accompanying video. The presented results indicate our robot's promising potential for a strong performance at the RoboCup 2025 competition in Brazil.

Keywords: Robocup@Work · Autonomous Mobile Manipulation · Industrial Automation.

1 Introduction

This paper presents Mountaineers@Work's efforts to create a competitive robotic system for the Robotcup@Work league. The Mountaineers@Work team is composed of West Virginia University undergraduate students in Mechanical, Aerospace, and Electrical Engineering. Most team members are fulfilling their senior design capstone project requirements by preparing a robot for the competition. Given the variety of options available at the university, these students' participation highlights their strong motivation to explore industrial robotics and the Robocup@Work challenge.

The team started their work in August 2024 with the Pickerbot Pro robot[1] from Roboworks and dedicated two school semesters to preparing the robot for competition. Throughout this period, many changes were made to the system's hardware to enhance functionality and performance. A major priority of the group was to ensure the safe operation of the robot. Additionally, substantial effort was invested in software development to integrate all of the components. This was not an easy task for a team without any software-focused students.

[1] https://www.roboworks.net/store/p/pickerbotpro

With some persistence and occasional tips from more experienced faculty and students, they were able to accomplish their goals. The next sections describe our robot's hardware and software. We also discuss some of our tests. The paper starts by introducing our university and the context behind our efforts.

1.1 WVU Robotics

West Virginia University (WVU) is a public land-grant research university with its main campus in Morgantown, West Virginia, United States. Since West Virginia is the only state of the country that resides entirely in the Appalachian Mountains, WVU is known as the "Mountaineers", which is also the name of our athletics and robotics teams. WVU offers more than 350 bachelor's, master's, doctoral, and professional degree programs throughout 13 colleges and schools. One of these colleges is the Benjamin M. Statler College of Engineering & Mineral Resources, which is the home of WVU Robotics[2].

Over the past decade, the WVU robotics program has experienced significant growth, evolving into a leader in robotics education and research. The program has expanded its faculty from three to nine members and now engages over 120 students in cutting-edge robotics projects. This growth is complemented by enhancements in research and educational facilities, providing students with state-of-the-art resources to explore various aspects of robotics engineering. WVU places a strong emphasis on experiential learning and student leadership, fostering a hands-on approach that has led to a distinguished record in robotics competitions. Student teams have won ten competitions and placed top three in nine other competitions. This includes winning NASA Centennial Challenges three times between 2014 to 2016 with a cumulative prize of $855,000, the first place finish at the international University Rover Challenge in 2023 (among 104 total teams from 15 countries), along with the winning of RASC-AL Moon to Mars Ice and Prospecting Challenge in 2019, NASA Mars Ice Challenge in 2017, NASA Robotic Mining Competition in 2014, and NASA/NIA RASC-AL Exploration Robo-Ops Student Challenge in 2014.

Building on this success, WVU launched a Bachelor of Science program in Robotics Engineering in the fall of 2024. This four-year degree program offers an interdisciplinary curriculum that integrates mechanical systems, computer science, and engineering principles. Students engage in hands-on learning through courses in mobile robotics, robotic manipulators, and autonomy, among others. The program culminates in a yearlong capstone project, preparing graduates for careers in industries such as aerospace, defense, transportation, healthcare, manufacturing, and agriculture. Additionally, WVU Robotics is extending its impact beyond the university by enhancing K-12 outreach programs, hosting robotics competitions, and offering summer research opportunities to inspire the next generation of engineers. WVU Robotics' inaugural participation in the Robocup@Home league highlights our ambition to extend our impact beyond the borders of our state and nation.

[2] https://robotics.wvu.edu/

1.2 Research Interest

West Virginia University (WVU) is one of only 187 colleges and universities in the U.S. to attain a ranking of R1, or very high research activity, according to the Carnegie Classification of Institutions of Higher Education. WVU conducts research in many areas, including cancer, neuroscience, energy, mathematics, artificial intelligence, and robotics. At least four active robotics research labs exist at WVU: Interactive Robotics Laboratory (IRL), Navigation Laboratory (NavLab), Neuro-Mechanical Intelligence Laboratory (NeuroMINT), and Field and Aerial Robotics Laboratory (FARO), which is led by the faculty advisor of the Mountaineers@Work competition team. The FARO laboratory[3] develops robotics systems that operate outside the research labs, in applications that range from mine inspection to space exploration. Current projects include the development of autonomous drones for tri-dimensional (3D) mapping of tailing dams [15] and 3D reconstruction of underground stone mines [13], and the navigation of aerobots in the atmosphere of Venus [8]. In these projects, the main research areas are motion planning [3, 11], including landing of aerial vehicles [4, 1], localization [2], robot cooperation [9], and system development and integration [10]. Industrial robotics is not a traditional research area in the lab, but some work has been done and new research proposals are being submitted on this subject, with a special focus on teaching manipulators by demonstrations [14]. It is important to mention that we recently inaugurated a Robotic Manipulators laboratory containing state-of-the-art industrial robots to be used in education and research. This lab is currently supporting an industrial robotics senior design course and a senior-level robotics manipulators course.

2 Hardware

This section describes the physical components of our competition robot, GBB8, which is shown in Figure 1. Components included on GBB8 are located in Table 1

2.1 Mobile base mechanical hardware

Our competition robot is based on the PickerBot Pro robot from Roboworks. The mobile base was designed to work efficiently in a factory. Since this environment includes narrow passageways, having a robot that can move in every direction without turning is essential. This is done with four mecanum wheels powered by DC motors that can work together to move forward and backward as well as in any other direction without changing the heading of the robot. These wheels use several rollers mounted at an angle on the wheels to allow the wheels to rotate in opposite directions thus generating a lateral movement. Working with the mecanum wheels is the robot's suspension system. The robot does have the ability to include eight different springs but after testing different springs we chose to replace them with rigid links that provide no damping to the mobile

[3] https://farolab.wvu.edu/

Fig. 1: Mountaineers@Work Mobile Manipulator Robot 2025: GBB8

base, as shown in the left side of Figure 2. As the robot performs in a factory setting with a smooth driving surface, the absence of springs will not harm the performance of the robot.

The robot is built using two-centimeter extruded t-slot bars as the frame. We replaced the original metal plate with a clear 1/4-inch plexiglass top plate. The frame provides the ability to modulate and change the robot as needed quickly and efficiently, as seen with the sensors that are mounted to the frame, which include two LIDARs and an RGBD camera. The RGBD camera is mounted above the robot via t-slot bars protruding from the back of the robot. The Plexiglass top plate allows for quick access into the internals of the robot as well as ease of viewing of the hardware should a problem arise. This top plate was also designed for ease of disassembly and for the ability to allow modularization. A closer view of the robot chassis with its main components is shown in right side of Figure 2

Table 1: List of main components on GBB8.

Robot Component	Description
LiDARs	Two Leishen M10 LS planar LiDAR's mounted on the front and back of the robot. These LIDAR's provide a maximum detection range of 30m at a 12Hz rotational scanning frequency.
Camera	Intel Realsense D435i with RGBD capabilities.
Manipulator	Unitree Z1 manipulator arm with 6 degrees of freedom and a custom parallel gripper.
Computer	NVIDIA Jetson Orin NX 8GB. and 128GB SSD.
Motors	Four 24V/20W Wheeltec DC Motors with 500PPR Encoder and planetary gear with 1:71 ratio.
Motor Control and IMU	STM32 Control Board with precise motor control and inertial measurements.
Batteries	Two 24V KOBALT batteries connected in parallel with an ideal diode attached to each positive terminal. Together their total power capacity is 192 Wh.

2.2 Mobile base electrical hardware

The robot was engineered to work in an industrial environment, capable of tackling the unique challenges associated with this environment. Due to the demanding needs of a factory floor, a robot that can be powered independently for an extended period of time is essential to be able to complete tasks. To this end, the commercial robot was modified to include two 24V, 4Ah batteries that supply the power for the onboard electronics. Having two batteries allows for "hot swapping", which permits continuous activity for the robot. This is an important addition made by the team that can translate into an industrial setting where manufacturing operations must run continuously.

Additionally, the robot now contains many different fuses and protective equipment to protect the sensitive onboard hardware, including the computer and the manipulator arm. The wires and fuses are sized appropriately according to the National Electric Code (NEC) along with the International Electrotechnical Commission (IEC). To accomplish this, the team referenced the rated ampacity of conductors using the American Wire Gauge (AWG) system in combination with the cross-sectional area of the conductors. An emergency stop switch was installed to allow the arm and the base to be quickly shut down if necessary. This emergency stop was an addition that not only allowed for the team's safety but also aligned with industry and competition standards for the mobile equipment.

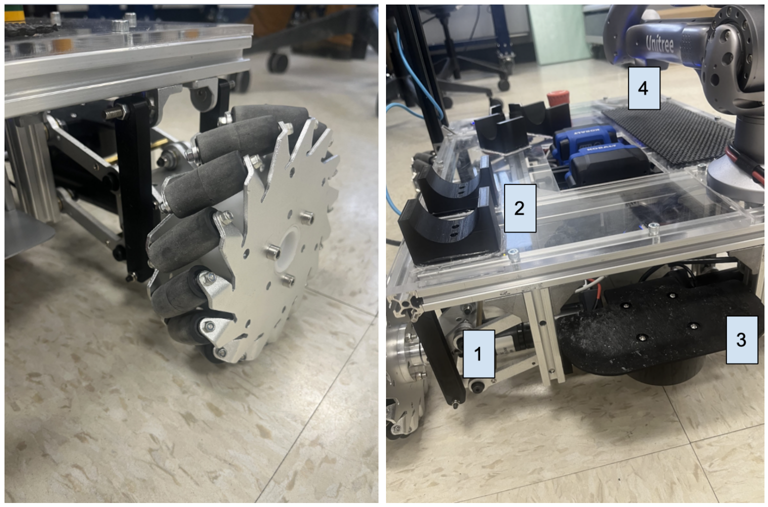


Fig. 2: Mecanum wheels and the 3D-printed rigid "suspension" links on the left and front view of the robot with (1) suspension, (2) object trays, (3) LiDAR mount, and (4) object platform on the right.

2.3 Manipulator

The PickerBot Pro robot came with the Unitree Z1 Pro manipulator from Unitree Robotics[4], which can be seen in Figure 3. There were no modifications made to the manipulator itself, but the end-effector was changed from the original, a large one-sided pinched-based pickup design, to a dual parallel motion pick up design. The original end-effector was changed because the large size would make it difficult to manipulate smaller competition parts and the one-sided motion struggled with precise drop-off of parts. The new design was entirely created in CAD models and then 3D printed out of mostly polylactic acid (PLA) with a small portion of resin-based thermoplastic polyurethane (TPU). The final model for the gripper can be seen on the right side of Figure 3. By attaching a gear to the original gripper's motor, which can rotate 90 degrees, and using a transition gear allowed two equally sized gears to rotate in opposite directions, both with a range of 108 degrees, with their contact about the center line. The gears were then used to drive a four-bar mechanism, similar to how windshield wipers work, to facilitate the closing of the end-effector. The use of the original motor allowed us to control the gripper using the manipulator SDK provided by Unitree, avoiding the need for external cables and specialized software. Figure 4 shows the process of the end-effector when transitioning from the open to the closed position.

[4] https://shop.unitree.com/products/unitree-z1

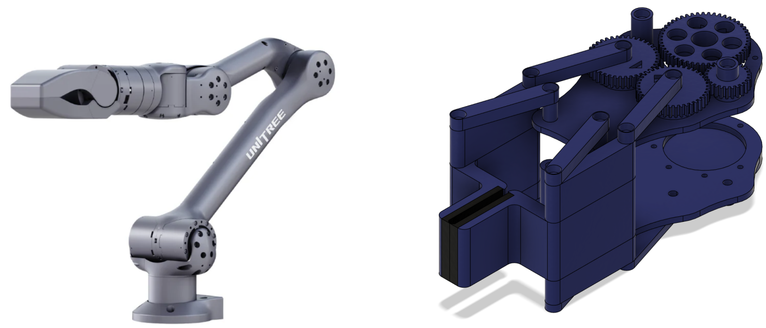


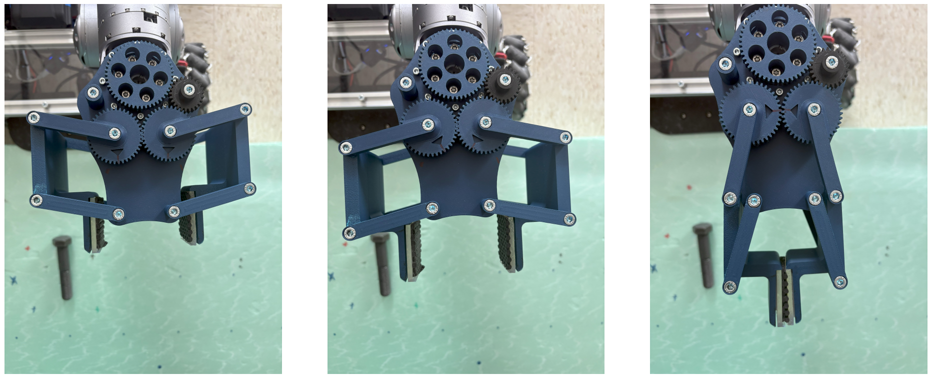
Fig. 3: Original Unitree Z1 Pro arm with end-effector on the left and new end-effector CAD design on the right. Blue material was printed in PLA and black in TPU.

3 Software

This section describes the software of our robot, which was mostly written in Python using the Robot Operating System 2 (ROS 2) framework [6]. A high-level software architecture can be seen in Figure 5. Instructions are given to the brain program. These instructions include what objects the robot needs to move, what table they are located at and what table those objects need to move to. The brain communicates with Nav2 to determine where the robot is in the environment map. Once the robot reaches the desired table the brain sends commands to the camera. Finally, once the camera has a location of the desired object on the table, it sends the coordinates to the manipulator which picks up and stores the object on the robot.

3.1 Navigation software

The robot uses two main software packages while navigating through testing arenas, SLAM Toolbox [5] and NAV2 [7]. SLAM Toolbox is a ROS 2 package that uses fused odometry sensors and LiDAR scans to map out an environment. The general publication of this software has been modified for our specific use case, first by including two 2D LiDARs for greater scan coverage, which require a separate transform, drivers, and topic. Along with this modification, the scan match parameters were modified to yield greater robustness during the mapping process. The second navigation software used is NAV2, a ROS 2 package that focuses on path planning through a pre-mapped area. This uses fused odometry from an onboard IMU unit, wheel encoders, and command velocities, along with scan matching to localize the robot within a map. Then, NAV2 creates a feedback loop where velocity commands are sent to the drive train, and the new position is localized until a final goal position is reached.



(a) End-Effector in Open Position

(b) End-Effector in motion of closing

(c) End-Effector in Closed Position

Fig. 4: Motion of end-effector from open to closed.

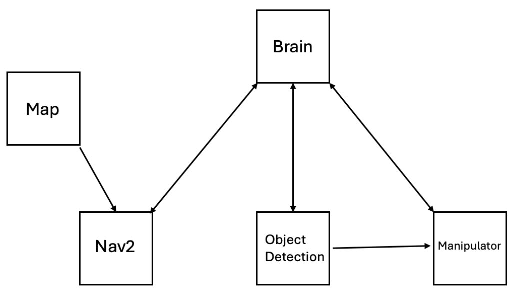


Fig. 5: A high-level software architecture the robot follows to complete desired tasks

3.2 Object detection software

The robot's object detection system leverages artificial intelligence, utilizing a trained YOLOv8 deep learning model[5] that processes images from an Intel RealSense D435i RGB-D camera. A Python script processes the camera feed and detects objects. For each detected object, the system extracts its 3D coordinates, assigns an object ID and label, and estimates its orientation angle. If the target object is in view of the camera, it will perform the proper transform calculations to determine the objects' coordinates from the manipulator base frame. The code then publishes its coordinates, orientation angle, and object type to a ROS 2 topic for the manipulator to use for collecting the object.

[5] https://yolov8.com/

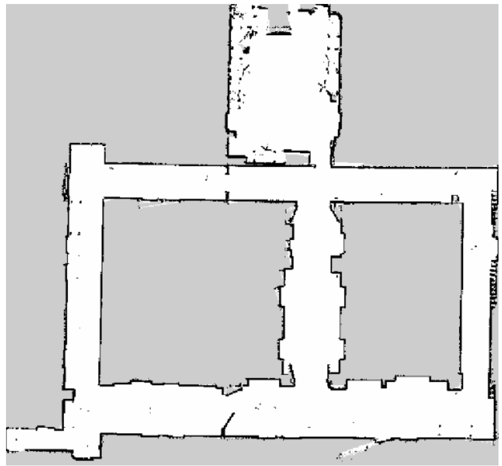


Fig. 6: Final map generated

3.3 Manipulator software

The manipulator program consists of a prebuilt Unitree program, which initializes and runs the arm, and a custom-built package for navigation and control. The Unitree components are primarily written in C++ but are designed to be Python-friendly, while the custom programming is entirely in Python and ROS 2, mainly using ROS 2 publishers and subscribers. The manipulator first turns on and connects via Ethernet and IP address, starting its software for computer control. The manipulator node is subscribed to a program from the camera, which sends it its goal coordinates. These coordinates then go through a program that checks if they are within reach. If not, the program publishes to the mobile base, telling it to move in a certain direction. If the coordinates are valid, then they are published to the primary navigation code for the manipulator. The manipulator starts by moving to a set upright position before approaching the target. Upon reaching its goal position, it then attempts to grab the object using the gripper. The object is then moved to one of four drop-off locations on the robot before the manipulator returns to its resting position and become ready for the next command.

4 Results

To evaluate the performance of our robot, we executed a series of tests under controlled conditions to test mapping, motion control, object detection, manipulation, and safety. This section presents some of these results.

4.1 Mapping Results

Mapping is the process of using various sensors, in our case LIDARs and odometry, to generate a model of the environment around the robot. Various adjustments on the default SLAM Toolbox parameters had to be made to generate an adequate map for the competition, which included adjusting wheel odometry and fine-tuning the scan matching parameters. Figure 6 showcases a map that was generated of our lab along with the hallway system on the ninth floor of our Engineering Sciences Building. This map was a total of 180 feet (55 meters) of travel on a smooth surface with various objects such as chairs and doors in the hallway.

4.2 Object Detection and Manipulation Results

For the manipulator to be able to pick up objects, it needs to have specific coordinates of where they are located as well as which object it is. This is done with object detection software. A predetermined model was used, created by team DIR [12]. In Figure 7, an array of competition objects is laid out for the camera to detect. As the figure shows, each object is uniquely identified by the camera correctly. After the detection, the coordinates of each object are published to the manipulator and used for picking the correct one. The object is detected correctly in the large majority of the cases with good lighting. However, the performance decreases with worse lighting. We are currently installing lights on the robot to guarantee a good system performance.

The picking process consists of our manipulator arm moving to coordinates that it received from the vision system and then pinching the object. After this is done, the arm moves on a predetermined path to one of the object trays located on the surface plate of the robot and places the object in the tray. The arm needs to be moved in a specific way to avoid collisions with the body of the robot. Figure 8 shows the process of picking an object from a table and placing it in an object tray. From our experience, the indicated object gets successfully picked around 85-90 percent of the time. Errors in picking occur with improper initialization of the robot.

5 Safety

For designing our robot, it was critical to consider broader constraints other than just the functional requirements of the robot. It was important for the engineers involved to remember the Engineering Code of Ethics which is states that the most important rule of practice is to "Hold paramount the safety, health, and welfare of the public." The team considered this with their design of the emergency shutdown circuit, wire sizing, and error-checking the code.

The emergency shutdown circuit consisted of an E-Stop that has power running through it to the actuators, motors, and the manipulator. If an error was to occur the E-stop can be pressed and all motion in the robot will cease. As

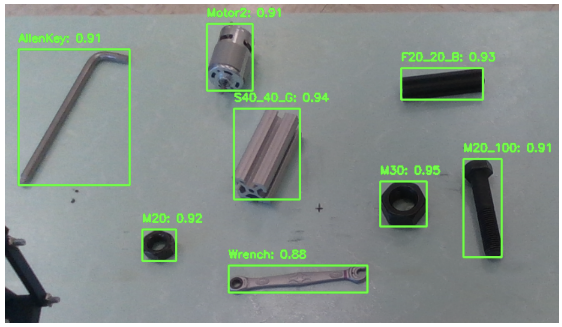


Fig. 7: Screenshot of the camera identifying objects

Fig. 8: Three images are shown, from left to right, picking an object, moving towards an object tray, and placing object in object tray.

required by the competition rule book, the E-stop is accessible from three sides of the robot, as seen in Figure 9. This ensures safety for all competitors and the robot itself.

As with any software, object detection is susceptible to error and can produce false results. A serious safety concern is the robot incorrectly detecting an entity that is not the object it is supposed to pick up, which has the potential to cause harm to people or the environment. Our robot features a filter to not publish any object coordinates that have a confidence rating under 80 percent. There is also error checking to ensure the object is within a reasonable range of the manipulator.

6 Innovative Technology

The progression of technology has allowed for many innovative ideas to be integrated into robotics. Using robotics in a factory setting enables cutting-edge technology to be used for safety and efficiency. When designing a robot to be used in a factory many things have to be considered such as safety, cost, and even maintenance. This robot was designed with all those factors in mind and provided innovative solutions to each aspect of design.

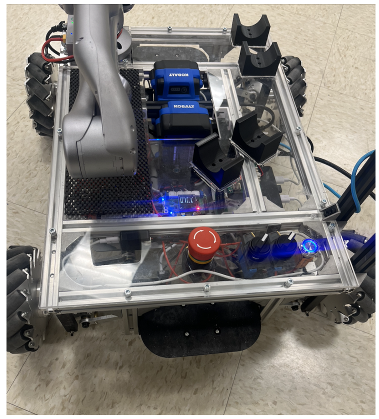


Fig. 9: Image of bright red emergency stop button

The integration of artificial intelligence (AI) into the robot has already enabled it to work at a pace that couldn't have been imagined just 10 years ago. The robot uses AI to detect objects for collection. Using AI for this process allows the objects to vary in size, orientation, and location and the robot will still be able to pick up and transport the object.

For a robot to work a battery is necessary to supply power for the period that is needed. The robot uses a unique approach to supplying power that not only allows for long battery life but also eliminates the downtime robots may see due to charging. Mounted in the center of the robot are two 24-volt drill batteries connected in parallel with the help of "ideal diodes", which are electronic circuits that work as diodes with very-small forward voltage drop. The ideal diodes are connected in series with the batteries and prevent one battery from charging the other. This circuit supplies sufficient power to all components of the robots with enough current for the processes. The batteries are exposed on the top of the robot (Figure 10) so they can be exchanged easily. This effectively eliminates the need to charge the robot. Additionally, the batteries can be replaced while the robot is still operational given the system the potential to change its own batteries in the future, getting rid of the need for human interaction.

7 Reusability of the system

The robot's modular frame built with extruded T-slot bars allows for rapid modifications and upgrades. This makes the robot adaptable to new tasks without extensive redesign. The robot currently has multiple USB 3.0 ports that are not in use. The plug-and-play nature of the camera and LiDARs ensures that expansion is available for evolving needs. On the software side, the use of ROS 2 provides a highly modular and reusable codebase. The navigation and object detection frameworks can easily be repurposed for different mobile robotic tasks.

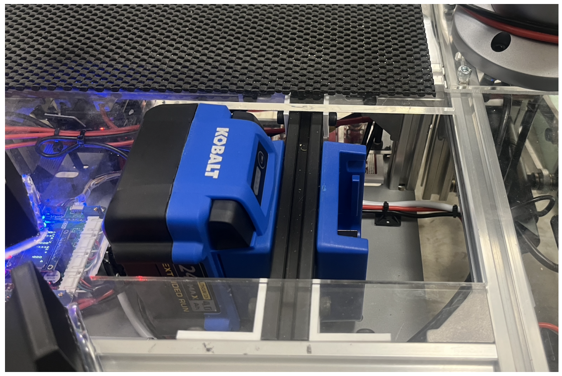


Fig. 10: Innovative design of the battery system allows for the robot to run on one battery while another is being replaced. Located on top center of the robot allows for quick replacement and minimal downtime.

8 Applicability and Relevance to Industry

The hot-swappable battery system has proven to be a useful design choice that allows continuous testing without having to stop and charge batteries. In an industrial setting, this would reduce downtime and improve efficiency. The system's compliance with industrial safety standards, including the emergency stop mechanism and fuse-protected electronics, ensures its viability in a real-world scenario. Overall, the system is directly applicable to automated material handling and manufacturing where autonomous robots are becoming more and more popular. This robot's ability to navigate tight spaces and precisely locate, grasp, and transport objects, provides proof that robotics will play an important role in the future of industrial automation.

9 Usage of components developed by other RoboCup@Work teams

When planning for this competition other teams papers and videos were analyzed to find an optimal approach for the task at hand. One example of this was the overhead camera mount was inspired by the b-it-bots@Work 2023 qualification video [6]. Upon first seeing the video the team determined that it would be optimal to have a static camera location to detect the objects.

In addition to previous qualification material, the MiRobot team, who competed in the RoboCup@Work 2024 competition, was consulted with questions about their robot, which is based on the same mobile base and manipulator, and the competition as a whole. The decisions followed because their input was the swapping of the suspension system and the lower speed motors to ensure no drift

[6] https://www.youtube.com/watch?v=n17P04lCFz8

while driving the robot with weight. Finally, the YOLO model Robocup@Work objects Computer Vision Project was used to define parts in the object detection program [12].

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