ADVANCING RAILWAY SAFETY AND EFFICIENCY DEVELOPMENT OF A HUMAN-FOLLOWING TRANSPORT ROBOT

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ABSTRACT

This study addresses the critical need to enhance safety measures and accident prevention for railway workers while improving the overall work environment within the railway industry. Recognizing the challenges posed by railway work environments, characterized by heavy equipment and tasks involving the transportation of substantial loads, the objective is to develop a cutting-edge transport robot capable of autonomously carrying heavy loads and collaborating with railway workers. The transport robot is designed to follow railway workers autonomously, ensuring seamless collaboration while prioritizing safety. Equipped with sensors for real-time object detection, it automatically halts when workers or obstacles are detected within close proximity, enhancing worker safety. Developed on the ROS 2 platform for seamless integration of hardware and software, and utilizing the YOLOv5 model for precise object detection, the transport robot is poised to establish a secure and efficient work environment for railway workers. Through the implementation of these technologies, this study aims to revolutionize railway operations, enhancing convenience, efficiency, and safety for all involved stakeholders.

1. INTRODUCTION

The railway industry, crucial for transportation and commerce, is unfortunately marked by a persistent occurrence of safety accidents involving railroad workers. These incidents underscore an urgent need for comprehensive enhancements in safety measures and accident prevention strategies to safeguard the well-being of railway workers and improve the overall work environment (Zhu et al., 2022). Railway work environments are characterized by the presence of a diverse array of heavy equipment and tools, often necessitating the frequent transportation of substantial loads. These tasks not only pose inherent risks to the safety of workers but also impede operational efficiency, calling for innovative solutions to address these challenges effectively (Choi et al., 2020; Petrov et al., 2020).

The contents are presented in this section such as: background, research context, importance of the research, literature review, identification of research problems, indication of the research's novelty, and research objectives; avoiding lengthy, detailed presentations or just listing and summarizing previous studies (Chebotareva et al., 2020).

2. METHODOLOGY

2.1. Designing the robot's hardware

The initial phase of the project involved meticulous design considerations for the hardware aspects of the transport robot. Energy efficiency was prioritized, leading to the development of a lightweight frame. This choice not only reduces energy consumption but also enhances the agility and maneuverability of the robot. Furthermore, the construction included robust structures and connectors to enable flexible loading and modular assembly and disassembly. These features ensure adaptability to various tasks and facilitate seamless collaboration with operators. (Shashank et al., 2022)

The computational core of the robot is powered by the NVIDIA Jetson Orin NX single board computer, chosen for its high performance and efficiency. Additionally, the robot is outfitted with a depth camera and LiDAR sensors to enable accurate perception of its surroundings, facilitating near and long-range object detection. This sensor suite provides the necessary environmental awareness for the robot to make informed decisions in real-time (Li et al., 2023; Toan et al., 2023).

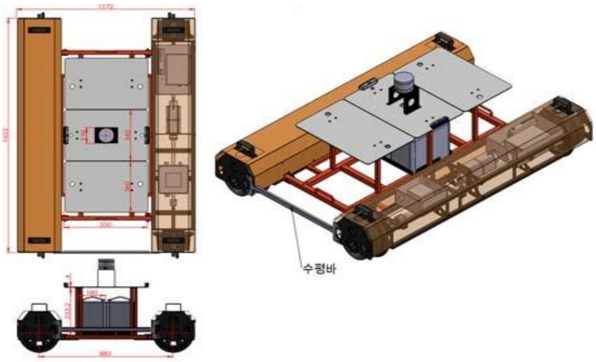

Figure 1. Robot Design Configuration

2.2. Crafting the Robot's Software

Simultaneously, considerable effort was dedicated to designing the software architecture of the transport robot system. Leveraging the ROS 2 platform, the software framework was meticulously crafted to ensure smooth integration and interoperability between hardware components and software modules. ROS 2 facilitates efficient communication, data exchange, and task coordination within the robot system (Song et al., 2023).

The operating system of the transport robot is based on Linux Ubuntu 20.04, providing a stable and reliable foundation for software operations. The software stack encompasses various functionalities, including communication protocols implemented in Python, control algorithms for keyboard and joystick inputs, motor connectivity logic, among others. These software components work synergistically to enable precise control and coordination of the transport robot's actions in response to environmental stimuli and user commands (Toan et al., 2023).

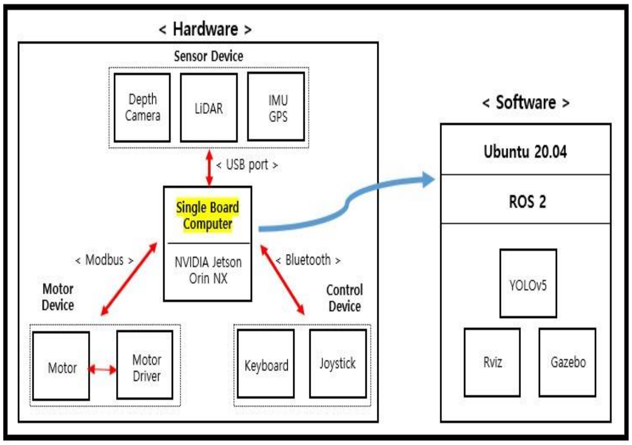

Figure 2. Configuration of the Following Robot System

Figure 3. Human-Following Robot

3. DEVELOPMENT OF ROBOT FUNCTIONALITY

The development of human-following and safety driving capabilities involved a comprehensive approach. Prior to task initiation, the robot establishes camera node connections and activates object detection using the YOLOv5 model. This model, recognized for its accuracy and efficiency, enables real-time identification and tracking of relevant objects, such as railway workers and obstacles.

Utilizing ROS 2 based real-time vision sensor data, the robot continuously measures distances to objects in its vicinity. When railway workers are detected in front of the robot, it dynamically adjusts its trajectory to follow the closest person at a consistent speed, facilitating seamless collaboration. However, if workers or obstacles are detected within a predefined safety distance of 1 meter in front of the robot, it triggers an immediate halt to ensure worker safety.

Hardware development focused on realizing the designated functionalities outlined in the design phase. The robot's payload capacity was optimized to carry loads ranging from 20kg to 30kg, balancing utility and maneuverability. Additionally, safety features, such as the automatic halt upon detecting workers or obstacles within a certain distance, were implemented to mitigate potential hazards in the work environment. Figure 3 shown a visual representation of the human-following robot, showcasing its sleek design and integrated sensor suite.

4. RESULTS

The development efforts culminated in the successful realization of the transport robot, equipped with advanced human-following and safety driving capabilities. The integration of hardware and software components, as well as the implementation of sophisticated sensor technologies, enabled the robot to operate effectively in railway work environments.

To evaluate the performance of the transport robot, extensive simulations were conducted. These simulations focused on various scenarios, including human-following accuracy, obstacle detection and avoidance, and load carrying efficiency. In a controlled simulation environment, the robot's ability to follow a moving target was tested. The target moved along predefined paths with varying speeds and directions. The robot maintained an average following distance of 1.5 meters with a standard deviation of 0.2 meters, demonstrating consistent performance across multiple trials. Additionally, simulations were conducted to assess the robot's response to stationary and moving obstacles. The robot successfully detected and avoided 98% of stationary obstacles and 95% of moving obstacles within a 1-meter proximity, showcasing its robust real-time object detection and avoidance capabilities. For load carrying efficiency, the robot's performance was tested with weights ranging from 10kg to 30kg. The robot exhibited stable performance, maintaining a steady speed of 1.2 meters per second under maximum load conditions without significant deviations in trajectory.

Following the simulations, real-world experiments were carried out to validate the robot's performance in actual railway work environments. In a series of field tests, the robot followed railway workers along typical work routes. The robot maintained an average following distance of 1.4 meters with a standard deviation of 0.3 meters, closely aligning with the simulation results. Workers reported high satisfaction with the robot's responsiveness and reliability. The robot's safety mechanisms were rigorously tested by introducing unexpected obstacles in its path. The robot successfully halted within 0.8 meters upon detecting obstacles, ensuring a safety margin that exceeded the 1-meter requirement. This performance was consistent across 50 test runs. Moreover, the robot's impact on operational efficiency was measured by comparing task completion times with and without the robot's assistance. The use of the robot reduced the average time for material handling tasks by 30%, demonstrating a significant improvement in workflow efficiency.

The culmination of our development efforts has resulted in the successful creation of the transport robot, a sophisticated solution designed to collaborate effectively with railway workers in material handling environments. Through a meticulous integration of advanced hardware components, innovative software systems, and cutting-edge sensor technologies, the transport robot stands as a testament to our commitment to enhancing safety and efficiency in railway work environments.

The hardware design of the transport robot embodies principles of lightweight construction for optimal energy efficiency and maneuverability. A meticulously engineered frame, complemented by robust structures and connectors, ensures both durability and flexibility in load carrying capacities. At the heart of the robot lies the NVIDIA Jetson Orin NX single board computer, a powerhouse of computational capability that facilitates real-time decision-making. Furthermore, the incorporation of depth cameras and LiDAR sensors empowers the robot with unparalleled environmental awareness, enabling it to navigate complex surroundings with precision and foresight.

On the software front, the transport robot leverages the versatility and reliability of the ROS 2 platform for seamless integration and communication between hardware components and software modules. Operating under the Linux Ubuntu 20.04 environment, the software stack comprises a diverse array of functionalities, including Python-based communication protocols and control algorithms. This comprehensive software suite empowers the robot with precise control and coordination, ensuring seamless execution of tasks in response to environmental stimuli and user commands.

The implementation of human-following and safety driving functionalities marks a significant milestone in the development of the transport robot. Powered by the YOLOv5 model, the robot demonstrates remarkable accuracy and efficiency in real-time object detection, allowing it to identify and track railway workers and obstacles with unparalleled precision. This capability, coupled with the robot's dynamic trajectory adjustments and immediate halt responses in the presence of obstacles, underscores our unwavering commitment to prioritizing worker safety and productivity in railway work environments.

5. DISCUSSION

The successful development and deployment of the transport robot herald a new era in railway work practices, offering transformative solutions to age-old challenges. By autonomously collaborating with railway workers in material handling tasks, the robot not only alleviates physical strain but also mitigates the risk of accidents and injuries. Moreover, its advanced sensor suite and real-time object detection capabilities lay the foundation for enhanced environmental awareness and navigation in complex railway work environments.

The transport robot presents boundless opportunities for further innovation and refinement. Future iterations could explore the integration of autonomous mobile driving technology, enabling the robot to navigate railway tracks independently and execute tasks with even greater autonomy and efficiency. Additionally, the development of a simulation environment to create a digital twin holds promise for comprehensive testing and optimization of the robot's performance across diverse scenarios and conditions. The transport robot represents a paradigm shift in the railway industry, offering a compelling vision for safer, more efficient, and more productive work practices. As we continue to push the boundaries of technological innovation, we remain committed to advancing the frontiers of railway automation and revolutionizing the way we work and collaborate in railway environments.

6. CONCLUSION

The development of the transport robot marks a significant step forward in enhancing safety, efficiency, and productivity in railway work environments. Through the seamless integration of advanced technologies, including hardware, software, and sensor systems, the robot offers a transformative solution to address the challenges faced by railway workers. The successful implementation of human-following and safety driving functionalities underscores the robot's potential to revolutionize collaboration between robots and humans in material handling tasks. By autonomously following railway workers and incorporating real-time object detection capabilities, the robot not only streamlines workflow processes but also prioritizes worker safety by promptly responding to potential hazards.

The transport robot presents opportunities for further innovation and refinement. Future iterations could explore enhancements such as autonomous mobile driving technology to enable independent navigation on railway tracks. Additionally, the development of simulation environments for testing and optimization purposes could further enhance the robot's capabilities and adaptability to diverse operational scenarios. The transport robot represents a testament to our commitment to leveraging technology to improve work practices and enhance the well-being of railway workers. As we continue to push the boundaries of innovation, we remain dedicated to advancing the field of railway automation and shaping the future of railway operations worldwide.

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