DEVELOPMENT OF A MOBILE PLATFORM WITH A MANIPULATOR ROBOT

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Abstract: Traditional manufacturing production lines are characterized by static and rigid configurations, resulting in significant idle time during reconfigurations for new products or processes. This inflexibility not only decreases productivity but also limits the ability to respond quickly to market demands. With the advent of Industry 4.0, mobile robotic units have leveraged the Internet of Things and Artificial Intelligence to significantly enhance their capabilities and application fields. By integrating sensors, actuators, and machine-to-machine communication, mobile manipulators have become essential components of modern smart industry. These systems combine the capabilities of a mobile platform with a robotic arm, making them versatile tools in production, science, military, construction, medical care, and business sectors. This paper introduces the development and implementation of the "CuRoK" mobile robot manipulator at the Dnipro University of Technology. The CuRoK features a robust hardware architecture, including a mobile platform and a multi-link manipulator arm with five degrees of motion. Critical components such as actuators, sensors, controllers, and human-machine interfaces are discussed in details. The paper addresses challenges encountered during the development process, such as mechanical vibrations and electrical interference, and presents solutions to mitigate these issues. Emphasis is placed on improving part machining quality, reducing tolerances, and enhancing electrical isolation. The successful deployment of CuRoK underscores the importance of integrating mobile manipulators in modern education and industry, highlighting their role in fostering skills essential for the next generation of engineers and technicians.

Key words: service robotics, mobile manipulation, modern manufacturing, Industry 4.0, education.

1. INTRODUCTION

Production lines in traditional manufacturing are static and rigid, which often leads to significant idle time during reconfiguration for new products or production process. This inflexibility not only decreases productivity but also limits the ability to

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react quickly to market needs. As part of Industry 4.0, mobile robotic units entered the era of Internet of Things and Artificial Intelligence, which significantly increased their capabilities and application fields. Using combination of sensors, actuators and machine-to-machine communication, mobile manipulators became essential part of modern smart industry [1].

Robot manipulator in traditional form [2], [3] consists of an articulated mechanical arm that is installed in a desired location and used for handling heavy or dangerous materials. They became the current manifestation of the third industrial revolution in automation, and they have been developing today to meet the dynamic demands of the industry. Modern requirement in intelligent human–machine collaboration pushed traditional manipulator robots further to mobile robot units or mobile manipulators.

Mobile manipulators are multipurpose robotic systems which combine the capabilities of a mobile platform and a robotic arm. Throughout last decades, mobile robots rapidly evolved from first mobile robot arm prototype MORO (1984, Frauenhofer IPA, Stuttgart) [4] to modern intelligent solutions,having been provided by world known organizations such as Boston Dynamics, KUKA, Fetch Robotics and Stanford [5]. They are actively used in various fields such as production, science, military, construction, medical care and business [6].

Therefore, modern education also needs to pay attention to studying and mastering the skills of working with mobile robots, which have already become an integral part of the production process. As a part of this idea, many educational facilities establish their own mobile robot projects [7] and participate in different robotics competitions [8] in order to promote robotics all over educational system and interest students and university stuff.

2. MOBILE MANIPULATOR "CUROK"

The hardware architecture of the vast majority of mobile manipulators consists of several blocks that can be divided by functionality [9]: actuators, sensors, controllers and human machine interface. Actuators consist of manipulator arm, which can perform different tasks, and mobile platform on which the manipulator is mounted. In order to provide safe and precise movement, robots require information about environment, which is provided from different types of sensors. Controllers are used to process sensor data and control actuators. The interaction with the human-operator is carried out through the human-machine interface.

On the basis of the Dnipro University of Technology Hardware Lab, a general-purpose mobile robot manipulator "CuRoK" was developed (Fig. 1).

The frame, made of aluminum profile, serves as a foundation for the mobile platform. With dimensions of 43x70x24 mm, the frame has the form of a parallelepiped and provides the construction with necessary rigidity, stability and reliability. The upper and bottom faces of the platform are secured with screws and are made of 2 mm steel sheets onto which the mobile robot's equipment is fixed.

Fig. 1. CuRoK general view

The next set of hardware is fixed and closed off from the surroundings on the lower platform, in the center of the frame (Fig. 2):

1. A 24-volt battery pack that consists of three electric car battery modules;
2. A Battery Management System that is dedicated to the oversight of a battery pack and maintains conditions for long-term uninterrupted operation of the autonomous power source;
3. An inverter to supply the power to the manipulator from the battery pack;
4. Twowheel hub motors;
5. An STM32-based motor-wheel control board;
6. An ESP32-based communication module.

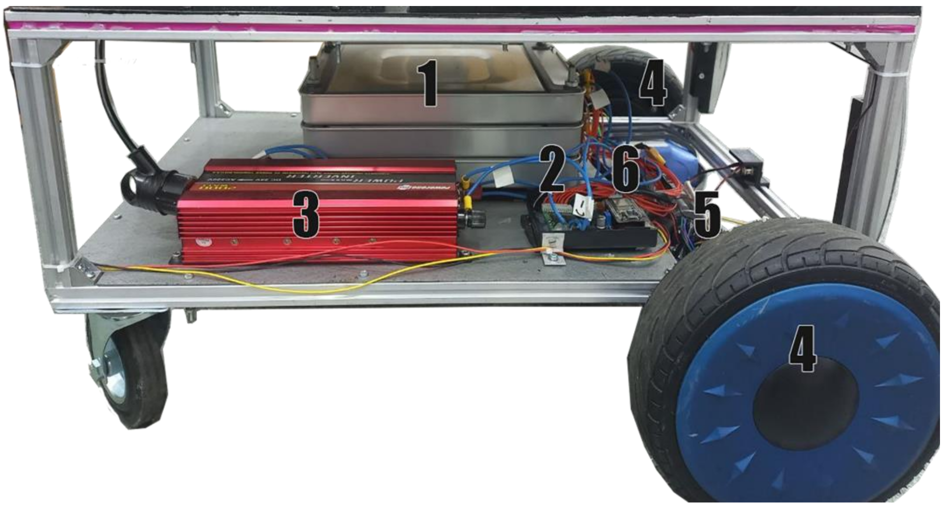

Fig. 2. Mobile platform structure

The main components of the manipulator are fixed on the upper platform, namely: executive, in the form of a manipulator arm, and control, in the form of a control unit. Robot manipulator (Fig. 3) is the multi-link mechanism that has five degrees of motion and all rotational joints, which provide flexibility and repeatability of movement [10]. Its end effector is agripper.

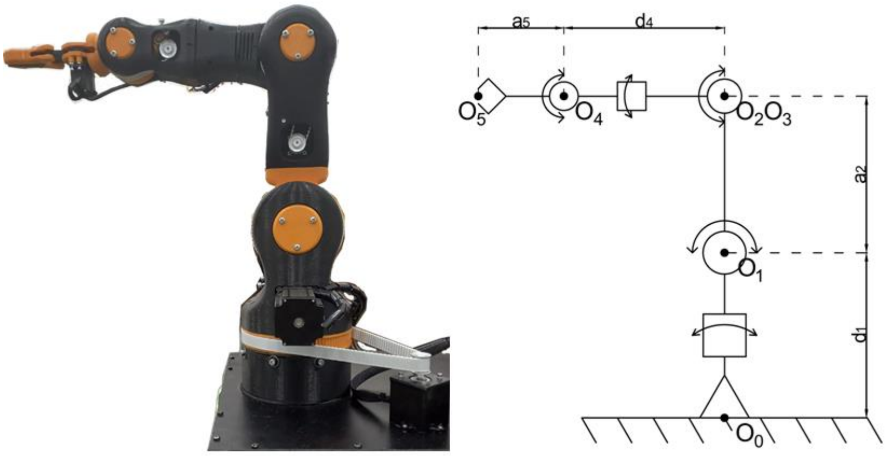

Fig. 3. a) general view; b) kinematic scheme

It consists of the following main nodes:
- supporting structures;
- drives (stepper motors);
- transmission mechanisms;
- executive mechanisms;
- capturer (capturing device).

The control unit is encasedand positioned adjacent to the manipulator. The following hardwareis situated inside(Fig. 4):

Fig. 4. Control unit

1. Stepper motor drivers, 6 pcs.;
2. Arduino Mega 2560 with RAMPS 1.4 expansion module;
3. Rectifier AC/DC 350 W, 24 V;
4. DC/DC converter for 12 V;
5. DC/DC converter for 6 V;
6. Cooling fan.

The diagram of electrical connections is shown in Fig. 5. The presence of separate inverter and rectifier is due to the need to maintain the ability to separate the mobile robot into two independent stands.

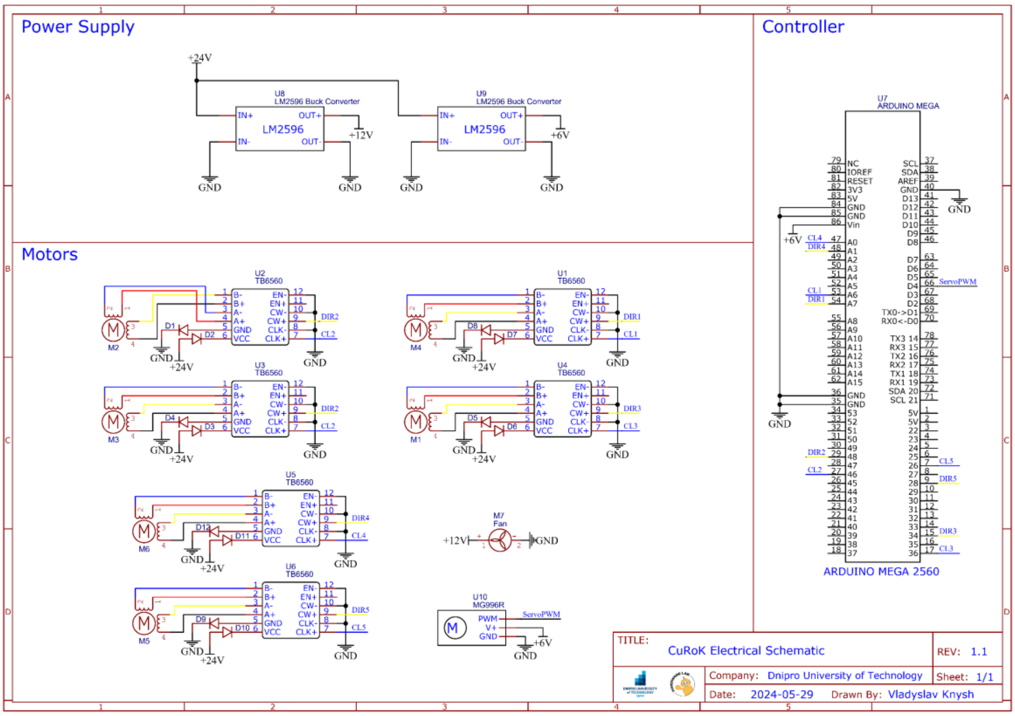

Fig. 5. Electrical Schematic

3. RESULTS AND DISCUSSION

The development of the CuRoK mobile robot manipulator at the Dnipro University of Technology Hardware Labprovided significant challenges. After the successful implementation of the system, it became possible to see the following key outcomes:

Mechanical design stability and ergonomics

The aluminum profile frame provides the necessary rigidity and reliability together with protection of inner components. Despite the robust design, challenges such as mechanical vibrations due to imperfections in the mechanical power transmission system and surface abrasives were encountered. Solutions included improving machining quality, reducing tolerances, and using dampers to minimize vibrations.

Another source of vibration is the use of a stepper motor with a significant discreteness of the rotation angle. In other words, the movement of manipulator was too fast, which is expressed in the form of vibrations, that damage joins of mobile manipulator. These mechanical vibrations were mitigated by switching motor drivers to micro-stepping mode and additional post-treatment of friction surfaces.

Electrical System and Control

The electrical system featured a 24-volt battery pack, controlled by Battery Management System (BMS), and an inverter for power supply. In order to maintain stable operation some changes in design was implemented, such as galvanic isolation of connection ports, use of separate power sources for each driver. Issues with electrical interference and back EMF from stepper motors were mitigated by redesigning the electrical circuit of motor drivers by including protection diodes.

Motion Control

Motor wheels used for mobile platform was originally designed for gyroscooter, which does require high manufacturing precision. The integration of vector control algorithms with speed feedback compensated for different wheel speeds, enhancing the overall stability and control of the mobile robot.

Discussion

The successful deployment of the CuRoK mobile robot manipulator highlights the critical role of mobile manipulators in modern education and industry. Several key insights emerged from the development process:

- Importance of Mechanical Precision: the mechanical design's precision directly impacts the robot's performance. Mitigating mechanical vibrations through better machining practices and using damping materials proved essential for stable operation.

- Electrical Isolation and Power Management: ensuring electrical isolation and proper power management is crucial to prevent interference and maintain system stability. The use of high-speed stepper motors and separate power sources for drivers were effective solutions.

- Educational Impact: The project provided valuable practical experience for students and highlighted the necessity of integrating mobile robotic systems into educational curricula. The practical skills gained are essential for preparing the next generation of engineers and technicians.

- Industrial Relevance: mobile manipulators like CuRoK are versatile tools for modern smart industries. Their ability to adapt to different tasks and environments makes them valuable assets in production, construction, medical care, and other fields.

Future Work

The development of CuRoK is important step forward for Hardware Lab team, but there are areas for further improvement:

• Enhancing the mechanical design to further reduce vibrations and improve precision.

• Integrating more advanced sensors and control algorithms to enhance the robot's autonomy and adaptability.

• Developing intuitive means of remote control of the robot.
• Chassis redesign for outdoor driving.
• Expanding the application fields of CuRoK to explore its capabilities in more diverse industrial and educational environments.

4. CONCLUSIONS

The development of the CuRoK mobile robot manipulator by the Dnipro University of Technology's Hardware Lab highlights the significant advancements in robotic technology and its applications in various fields. In the process of developing the CuRoK mobile robot manipulator, the Hardware Lab team faced a number of challenges and difficulties of various origins, both mechanical and electrical. A number of measures were taken to eliminate the identified problems, including: additional post-treatment of friction surfaces, the use of damping materials, switching drivers to micro-stepping mode, redesigning the electrical circuit of the manipulator control unit to ensure reliable and safe power supply to the modules, mandatory use of protective galvanic isolation at all times, as well as analysis and selection of the optimal wheel control algorithm. These measures ensured stable and precise operation of the manipulator. The project not only provided valuable theoretical and practical skills for the team but also emphasized the crucial role of mobile manipulators in modern education and industry. CuRoK's success underscores the necessity of integrating mobile robotic systems into educational curricula and industrial processes to foster innovation and meet dynamic market demands. This work serves as a model for future developments in mobile robotics, promoting versatility, efficiency, and collaboration in smart industry environments.

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