CURe-Mi mobile manipulator robot for contact-less COVID-19 patients serving missions

Ismail Rokhim, Nur Jamiludin Ramadhan, Zainun Najakh
Department of Manufacturing Automation and Mechatronics Engineering, Bandung Polytechnic for Manufacturing, Bandung, Indonesia

Article Info

Article history:

Received Nov 25, 2022
Revised Dec 27, 2022
Accepted Jan 16, 2023

Keywords:

COVID-19
CURe-Mi Robot
Health services robot
Mobile manipulator robot

ABSTRACT

Since March 2020, coronavirus disease (COVID-19) has become a major global concern. Even in an emergency, medical personnel should avoid contact with COVID-19 patients. Mobile manipulators are a non-contact alternative to medical personnel for performing healthcare tasks such as distributing supplies to COVID-19-quarantined patients. In this study, patients use an Android application to order mobile manipulator robots, which include the Collaborative Manipulator Robot UR5e and the autonomous mobile robot MiR200 (abbreviated and referred to as CURe-Mi). The HTTP protocol is used for communication between the Android application and the robot. The experiment was conducted in a small room with several tables and bottles used to simulate hospital rooms and medications. The delivery testing results show that all four items were delivered successfully. The results of the manipulator robot and mobile robot movement accuracy tests show that the average error is 0.213 and 4.51 cm, respectively. The Android application performance test demonstrates that the application successfully sends commands to the mobile manipulator robot within its maximum range of 1,800 cm. The CURe-Mi mobile manipulator robot has successfully assisted medical personnel in handling several contactless COVID-19 patients serving missions.

Corresponding Author:

Nur Jamiludin Ramadhan
Department of Manufacturing Automation and Mechatronics Engineering
Bandung Polytechnic for Manufacturing, Bandung, Indonesia
Email: nj_ramadhan@polman-bandung.ac.id

1. INTRODUCTION

Coronavirus disease (COVID-19) is a ribonucleic acid (RNA) virus with particle sizes ranging from 120 to 160 nm. The virus is highly contagious and has spread throughout China and over 190 other countries and territories. On March 12, 2020, the World Health Organization (WHO) declared COVID-19 a pandemic. Currently, human-to-human transmission of COVID-19 is the primary source of transmission, so the spread becomes more aggressive. COVID-19 is spread through droplets released by symptomatic patients when coughing or sneezing. According to recent research, over 3 million people worldwide have been infected with COVID-19, with a 6.9% chance of dying by April 27, 2020 [1]–[3]. When dealing with COVID-19 patients, who must avoid contact unless an emergency occurs, this is obviously a concern. Alternative methods of reducing patient contact include empowering robots to replace or assist medical personnel in providing services to COVID-19 quarantine patients. The routine task of delivering food, medicine, or other medical items that are routine and non-emergency services is one of the duties of medical personnel that can be replaced by robots [3]–[11].

Al-Issa and Trrad [4] utilized a robot in a prior study to leverage the Internet of things (IoT) and concentrate on the sterilization procedure. The mobile phone serves as the control mechanism for the robot, which navigates through various rooms to conduct sterilization procedures. This is achieved by regulating the quantity of water and sterilizer within the container through a pump, while the drying process is facilitated by controlling the fan. Previous studies have reported the development of teleoperated robots for various medical applications [5], [6]. Mobile robots with multiple functionalities have been designed and implemented to manage the COVID-19 outbreak within quarantine zones, thereby facilitating the delivery system. This aspect is of utmost importance as COVID-19 patients are highly susceptible to transmitting the disease [7]. The teleoperated robotic system [8] had been found to have various research applications such as fever detection, hand sanitizer distribution, space sterilization, and addressing medical queries and uncertainties related to COVID-19. The utilization of robots in this context serves to mitigate social transmission and minimize the incidence of severe cases [9]. The elimination of human intervention can potentially result in the preservation of the lives of medical personnel who have been impacted by the COVID-19 virus [10]. Yacoob *et al*. [11] endeavored to develop an economical teleoperated robotic arm capable of executing diverse functions to cater to patients undergoing COVID-19 quarantine.

Wang *et al*. [12] focused on the concept or implementation of a robot model for laboratories in serving COVID-19 patients' tasks. Most studies and research are done for laboratory testing and using laboratory-scale robots. The implementation of industrial specs mobile manipulator robot for serving COVID-19 is important to be studied in order to make sure that the concept is applicable for daily use in the hospital massively. There are several differences between robot model specs for laboratory purposes and industrial specs robots which have to be explored. This study aims to implement a manipulator robot as a tool for distributing medicine from medical personnel in serving COVID-19 quarantine patients without direct contact using industrial specs mobile manipulator robot, which is available in the market, so the system is ready to be applied in hospital in daily use. Patients will make orders via the Android application to the mobile manipulator robot. The mobile manipulator robot will move to the storage area and then take the patients' medicines based on the command sent by the patient. The mobile manipulator robot will send the medicine to the room where the patient is located.

2. METHOD

The first step in this investigation was to conduct literature reviews on the most recent mobile manipulator ideas. Traditional robot manipulators typically have a stationary base, which results in a restricted reachable workspace. The effective workspace can be significantly expanded by equipping a robot manipulator with a wheeled mobile platform. This provides the robotic system with a greater degree of mobility overall. A mobile manipulator robot is the name given to this particular configuration. Over the course of the past few years, research institutes have developed their very own mobile manipulators by building off of already existing mobile platforms and robotic arms on the market. The Cody robot developed at the Georgia Institute of Technology is made up of a Mecanum wheeled Segway platform and two arms manufactured by MEKA Robotics [13]. The primary purpose for which Cody was constructed was to research service robotics in the field of healthcare. Another example in this field is the Personal Assistant Robot, or POLAR, which was developed at Cornell University. It is comprised of a Barrett arm with 7 degrees of freedom that are mounted on a Segway Omni base [14]. The wheeled humanoid robot known as TOMM was developed at the Technical University of Munich (TU Munich). It is made up of a Mecanum wheeled mobile Platform and two UR5 robotic arms [15]. Other well-known examples in this field include the Care-O-bot 4 developed by the Fraunhofer IPA and the PR2 developed by Willow Garage. Mobile manipulators that are used in industrial applications work in environments that are more structured than the environments in which they are used in the professional and domestic service domains. However, in order for them to be suitable for use in industrial applications [16], they need to have a higher level of operational efficiency, for example, in terms of speed, accuracy, and robustness. KUKA's omniRob and Moiros [17], as well as ANNIE and LiSA from Fraunhofer IFF, which are all based on Mecanum wheeled platforms, are popular examples of mobile manipulators for use in industrial settings. The applications in [18]–[20] primarily utilized omiRob within the realm of intralogistics, where human-robot collaboration is frequently required.

As a result, the majority of robots used in services employ a comparable design. As can be seen in Figure 1, a mobile manipulator will typically include both a multi-link manipulator and a mobile platform in its construction. The functions of the mobile manipulator robots include taking medicine and moving these items from one location to another [21]–[23] with an unlimited amount of workspace area. The mobile manipulator robot that was utilized in this investigation was a combination of the Collaborative Manipulator Robot UR5e [24] and the Autonomous Mobile Robot MiR200 [25]; the combination will be abbreviated as CURe-Mi from here on out. The CURe-Mi mobile manipulator is working toward its goal of becoming a tool that can distribute medicine from medical staff to patients in the COVID-19 quarantine without the patients having to come into direct contact with the medical staff. In order to accomplish this goal, a manipulator robot is first attached to a mobile robot, and then an information system is integrated into the mobile robot in order to receive orders from patients. This allows the robot to carry out delivery tasks that are tailored to the requirements of each individual patient.

Figure 1. CURe-Mi mobile manipulator robot

2.1. Collaborative manipulator robot UR5e

This investigation made use of a collaborative robot of the Universal Robot (UR) type UR5e, which features six axes for manipulating objects. The UR5 robot can be programmed using a portable touchable device and its software interface called PolyScope, which supports a very simple textual programming language. This robot also supports data communication via ethernet with TCP/IP protocol so that it can be integrated with another system. This particular robot is equipped with a collaborative robotic arm that has been designed to imitate the range of motion of a human arm by having six joints and a high degree of adaptability. Because of its many desirable qualities, the UR5e has become the most widely used collaborative robot in the industry. The UR5e is a compact and lightweight robot that enables users to automate repetitive and potentially hazardous tasks. It can handle payloads of up to 11 pounds and has a reach of more than 33 inches. The UR5e, like all other Universal Robots, is designed to work safely and collaboratively alongside human workers, and it does so without the need for cumbersome or pricey safety guarding [24]. Because of this feature, the UR5e is suitable for COVID-19 patients who require assistance with tasks that require human-robot interaction but do not put the patients in danger.

2.2. Autonomous mobile robot MIR200

Mobile robots are robots that are able to move freely because they are equipped with a movement tool that allows them to change positions. The Mobile Industrial Robot 200 (MiR200) is the name of the mobile robot that was utilized for this study. The MiR200 is equipped with various accessories to accurately complete routine tasks and is capable of transporting goods weighing up to 200 kg. This robot is classified as an autonomous mobile robot (AMR), which is a robot with a working mechanism that does not require a special route to navigate but works dynamically in an environment [25]. This autonomous feature makes MiR200 suitable for COVID-19 patients serving tasks that will be operated in a dynamic environments area such as a hospital or other health facility where there is a lot of human activity.

2.3. Mobile manipulator robot CURe-Mi

The mobile manipulator robot will get the command from the COVID-19 patient through a smartphone with an Android application that is connected to the robot via a wireless local area network. The application is used for patients in every room to meet their daily medical needs. The general communication system can be seen in Figure 2.

Figure 3 is a flow diagram of how to work regarding this study. The figure shows that the robot will move regarding the input of commands given by the patient through an Android application on a smartphone. The robot moves from the initial position to the patient room. The mobile robot will continue to move until it reaches the desired position. The manipulator robot will move its arm to deliver the patient’s medicine according to the command. After completing the process of sending medicine, the robot will wait for new commands before returning to the initial position. If the mobile manipulator gets another command, the robot will repeat the cycle of delivering medicine. The robot will return to the initial position if there is no other command given by the patient. The sub-process of the system flow diagram uses the workflow of the MiR200 robot and the UR5e robot. The mechanism can be seen in Figure 4 and Figure 5. Figures 4(a) and 4(b) depict the UR5e Control's pick and place sub-system flow diagrams, respectively.

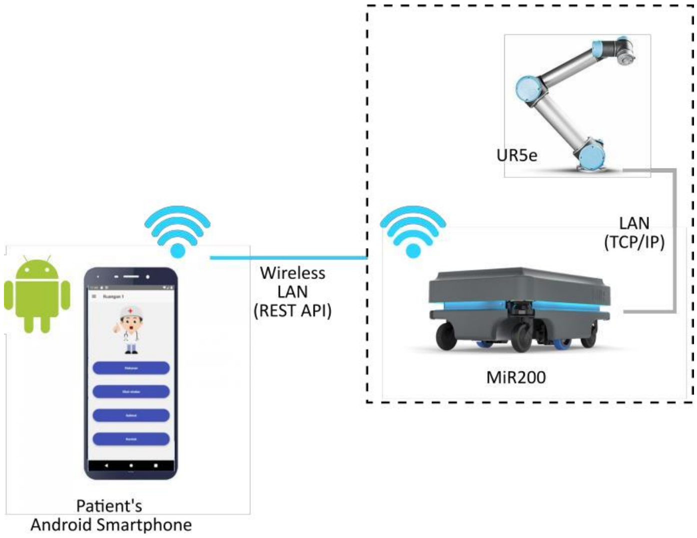


Figure 2. CURe-Mi communication system (source: personal collection)

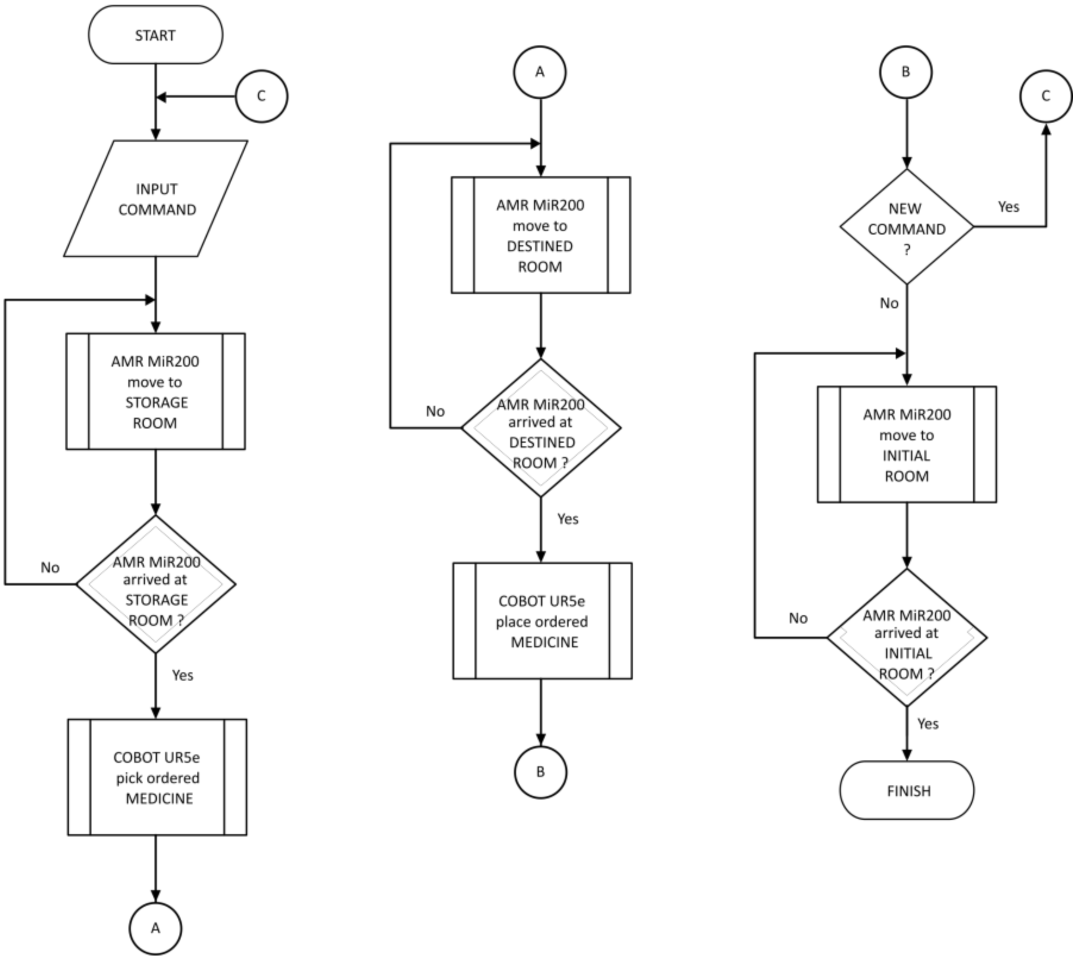


Figure 3. Integrated system flow diagram

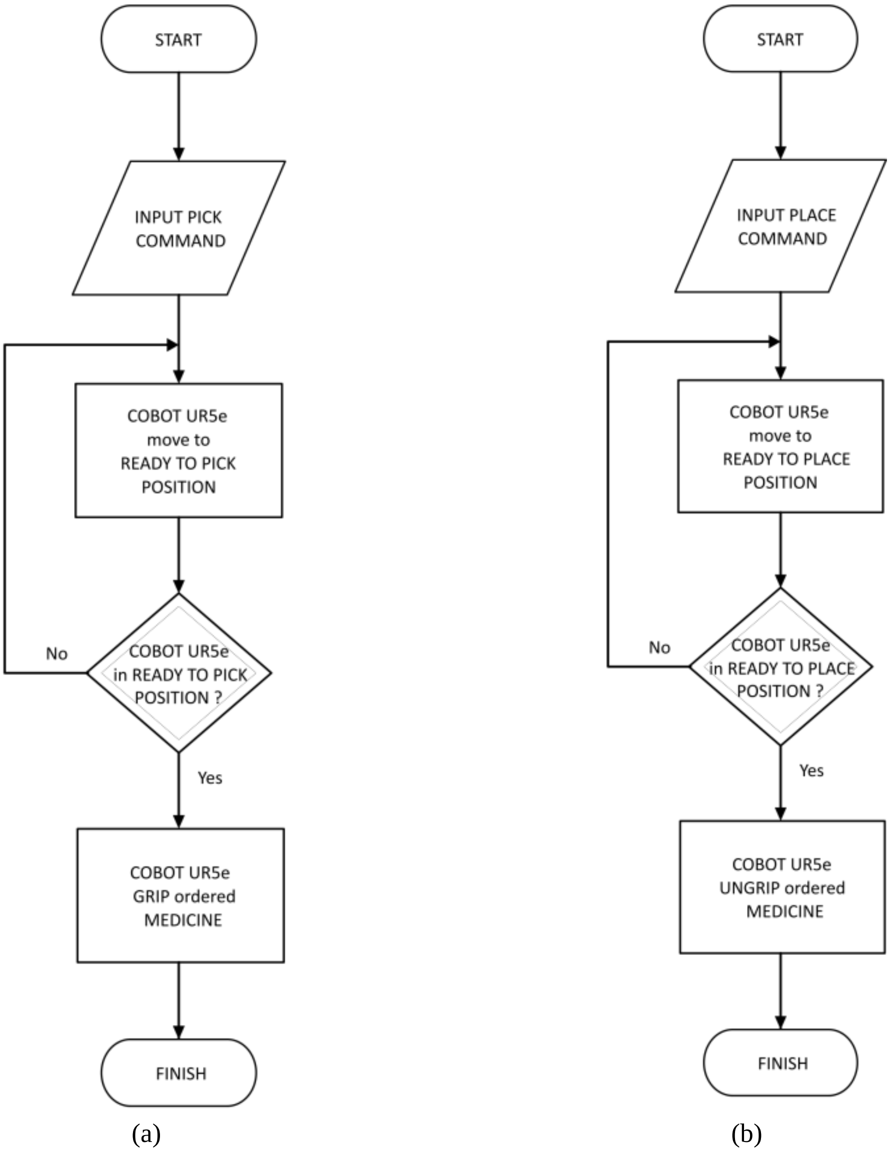


Figure 4. UR5e control for (a) pick and (b) place sub-system flow diagram

Figure 6 shows the mechanism for picking and placing medicine by the UR robot. The UR robot moves based on the given command input. The UR robot will move toward the item to be retrieved. After stopping the movement, the gripper will start ripping the medicine, and then it will be brought to the receiving position. Once in position, the gripper will release the item. The robot will return to its initial position after all processes have been completed.

The mechanism that controls the navigation system of the MiR200 robot is depicted in Figure 7. After receiving a command from an Android smartphone over a wireless local network, the MiR200 robot will move to the location specified by the command, at which point it will access the REST API contained within the MiR200. API stands for “Application Programming Interface,” and REST API is an implementation of API. REST, which stands for “Representational State Transfer,” is a method of communication in architecture that makes use of the HTTP protocol for the exchange of data. The REST API is made up of a few different parts, the most notable of which are the URL design, HTTP verbs, the HTTP response code, and the response format. After getting the command, the robot will execute global path planning to determine the path to go to the destined position. When the robot’s sensor detects an obstacle, both static and dynamic, the robot will find a solution using a local path planning algorithm to avoid the obstacle. The process will run until the robot successfully passes the obstacle. When finished running the process, the robot will move back to its destination. The robot will continue to run if there are no obstacles and if the robot has arrived at its destination, the robot will stop.

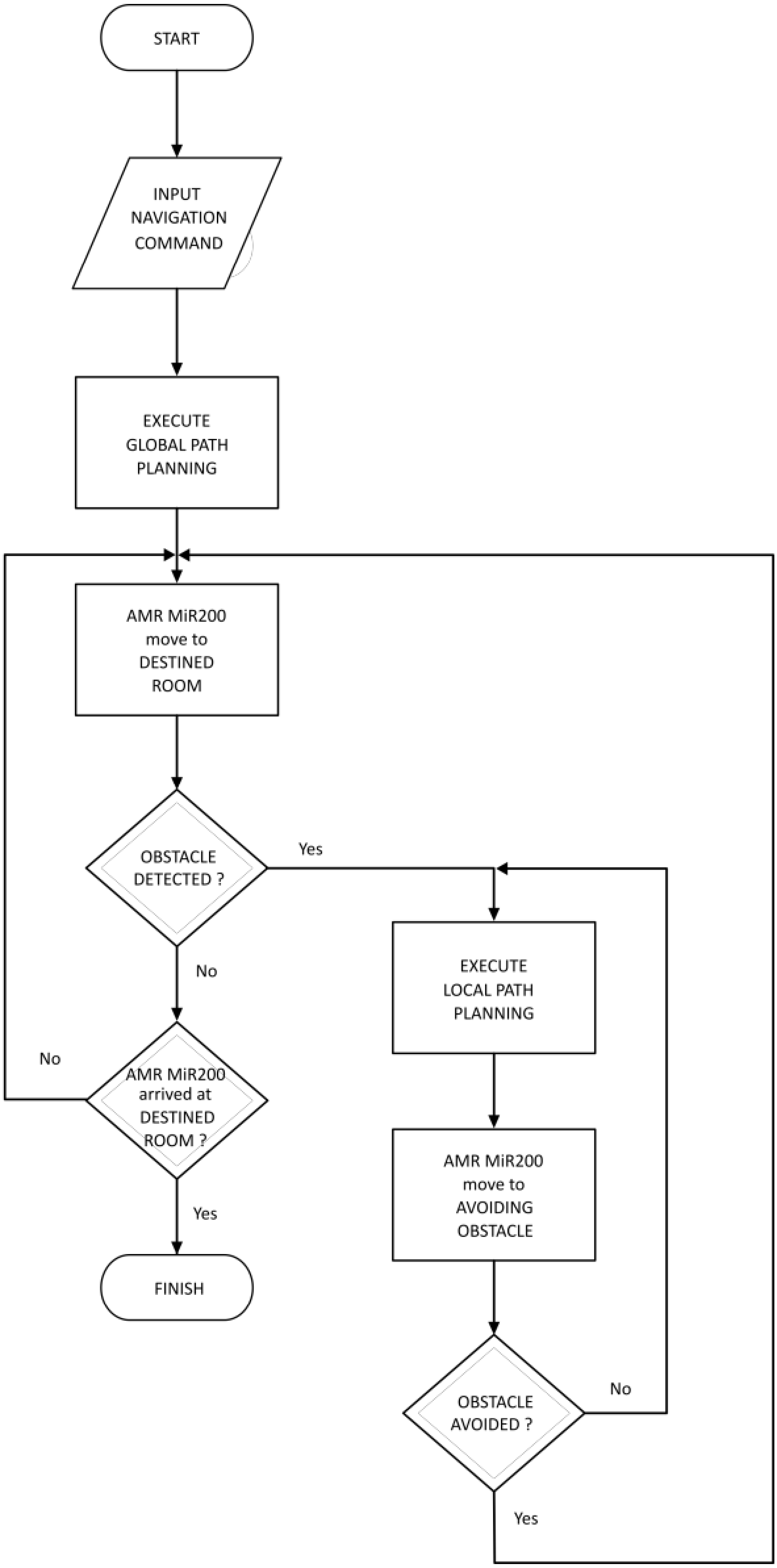


Figure 5. MiR200 control sub-system flow diagram

Figure 6. Laboratory room as health facility area simulation

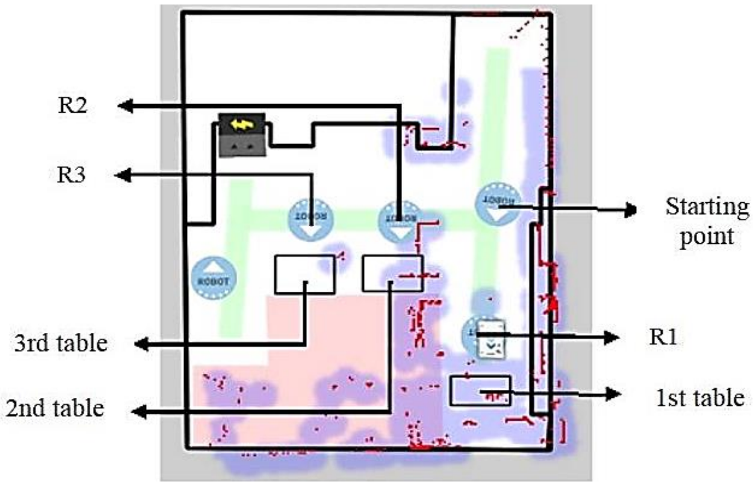


Figure 7. Working area map

3. RESULTS AND DISCUSSION

In this chapter, we discuss the result of the CURe-Mi mobile manipulator robot implementation as a health agent to serve COVID-19 patients. The location used in the test is not a hospital or health facility, but a simulation room located at the Department of Manufacturing Automation and Mechatronics Engineering in Bandung Manufacturing Polytechnic with an area of 7.5×9.6 m. The test location is then converted into a map by the MiR200 robot.

The map becomes a reference for the MiR200 robot in determining its presence and its work area. The map consists of six robot set point positions and three patient rooms, which are simulated by three tables. Robots set point positions. R1 is located in room 1 or simulated to be located near the 1st table 1, R2 is located in room 2 or simulated to be located near the 2nd table, and so R3 is located in room 3 or simulated to be located near the 3rd table. There are also set point positions used as references by the robot while in idle or standby condition: the charging position and the storage room, which are simulated by an initial starting position.

3.1. Mission success rate testing

Testing the robot system consists of two procedures, namely testing the success rate of the delivery mission and testing the accuracy of giving medicine. Delivery mission success rate testing is carried out using four types of medicine that are sent to each room with different sequences of destinations. This test aims to see the success of integration between applications with robots and success in application programming. This test shows that the program that has been made has been running well. From fifteen tests in the delivery of medicine, all conditions indicate that the robot successfully delivers medicine based on the orders given by the user through the application. The percentage generated in this test is 100%. This result is summarized in Table 1.

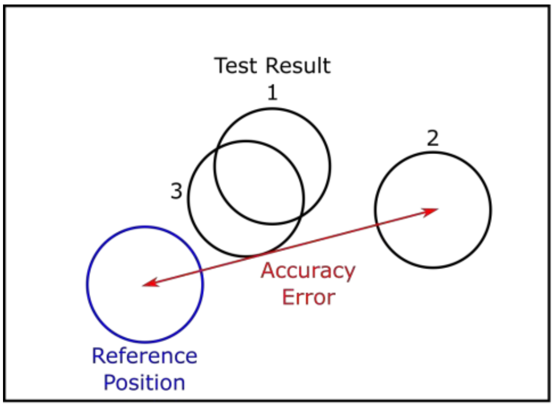
Table 1. Delivery mission success rate testing result

Test	Delivery Destination			Mission
No	Room 1	Room 2	Room 3	Status
1	Medicine 4	-	-	Succeed
2	Medicine 3	Medicine 1	-	Succeed
3	Medicine 3	-	Medicine 1	Succeed
4	Medicine 2	Medicine 2	-	Succeed
5	Medicine 2	Medicine 1	Medicine 1	Succeed
6	Medicine 2	-	Medicine 2	Succeed
7	Medicine 1	Medicine 3	-	Succeed
8	Medicine 1	Medicine 2	Medicine 1	Succeed
9	Medicine 1	Medicine 1	Medicine 2	Succeed
10	Medicine 1	-	Medicine 3	Succeed
11	-	Medicine 4	-	Succeed
12	-	Medicine 3	Medicine 1	Succeed
13	-	Medicine 2	Medicine 2	Succeed
14	-	Medicine 1	Medicine 3	Succeed
15	-	-	Medicine 4	Succeed
Success Rate				100 %

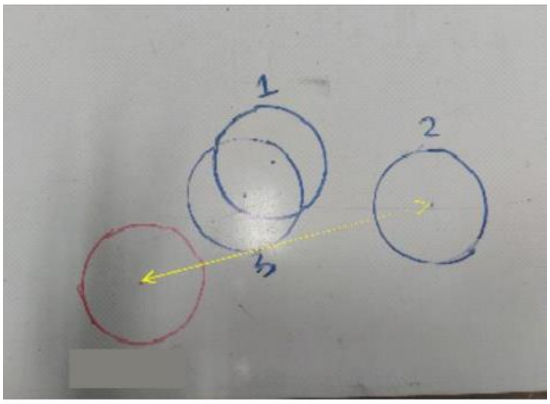
3.2. Robot accuracy testing

Robot accuracy tests are based on the distance between the center point of the object during the initial setting and the center point of the object at the time of testing. The distance used in giving commands is three meters from the robot. This test is divided into two parts, namely accuracy testing based on the movement of the robot manipulator and accuracy based on the overall movement of the robot.

Testing the accuracy of the manipulator robot movement takes the accuracy based on three types of robot manipulator movements. which consists of MoveJ, MoveL, and MoveP. This test is done by placing the object from the initial reference position to the object’s set point without moving the mobile robot. This set point is based on the initial setting of the robot manipulator in placing objects. The testing procedure is shown in Figure 8. Figures 8(a) and 8(b) depict an illustration and the actual result of the manipulator robot, respectively. The test results can be seen in Figure 9. The highest level of accuracy for object placement is found in the moveL movement type with an average error is 0.16 cm and the smallest accuracy level is found in the moveJ movement with an average error is 0.27 cm.



(a)



(b)

Figure 8. Manipulator robot accuracy testing procedure: (a) illustration and (b) real result

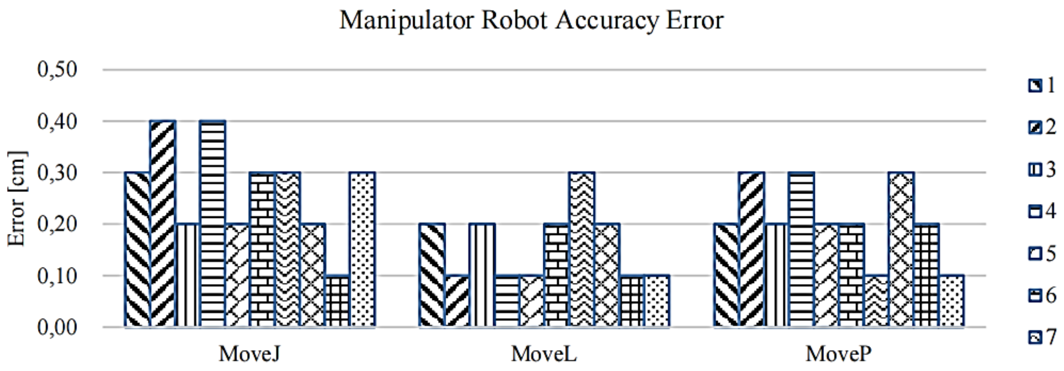
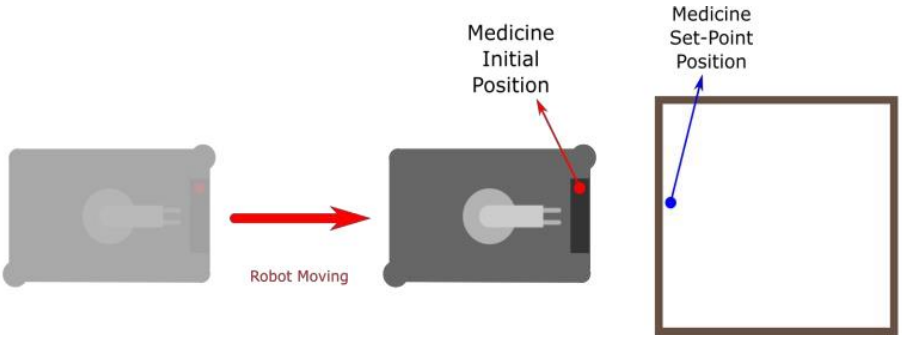


Figure 9. Manipulator robot accuracy testing result

The next test is testing the overall accuracy of the mobile manipulator robot. This test is based on the movement of the mobile manipulator robot to a destined room. The displacement of the robot's position is carried out by the mobile robot and the displacement of the object's position is carried out by the robot manipulator. The reference of measurements is robot's initial coordinate. The test procedure is shown in Figure 10. Figures 10(a) and 10(b) depict an illustration and the actual result of the overall CURe-Mi robot accuracy testing procedure. The test results can be seen in Figure 11.

The results of testing the accuracy of the placement of medicine as a whole mobile manipulator robot have different results. The initial position path to room 1 has an average of 6.45 cm, the initial position path to room 2 has an average of 2.17 cm, and the initial position path to room 3 has an average of 4.91 cm. The repeatability test results in the form of standard deviation values of 0.011 for x coordinates, 0.017 for y coordinates, and 0.024 for z coordinates indicate that the robot has a good repeatability value.



(a)

(b)

Figure 10. Overall CURe-Mi robot accuracy testing procedure (a) illustration and (b) real result

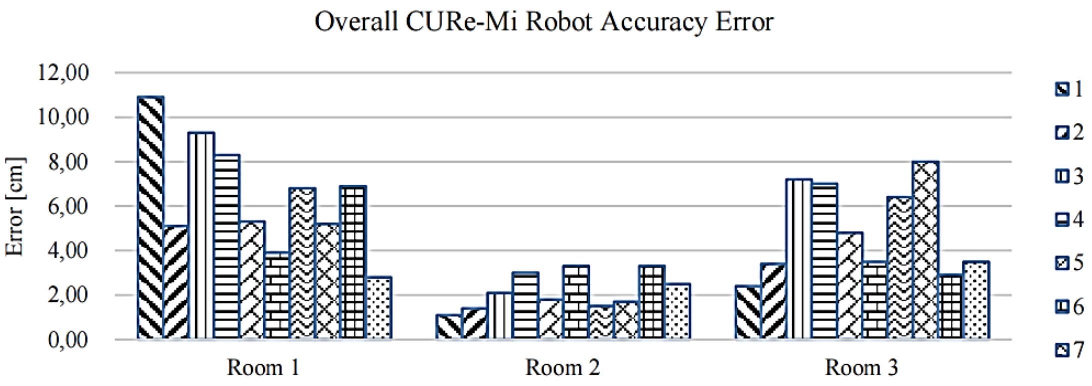


Figure 11. Overall CURe-Mi robot accuracy testing result

3.3. Information system performance testing

Information system performance will be carried out by measuring the delay response time of the robot before executing the command. This test is carried out by giving orders to the robot through the application for a certain distance from the smartphone to CURe-Mi mobile manipulator robot. The distance used in the test is 100 to 2,000 cm. The test results can be seen in Figure 12. The application performance test on the robot shows that the maximum distance required by the application to control the mobile manipulator reaches 1,800 cm. However, at a distance of 1,700 cm, the signal that connects the application with the robot is unstable, so the resulting response time is quite long up to 1.64 seconds.

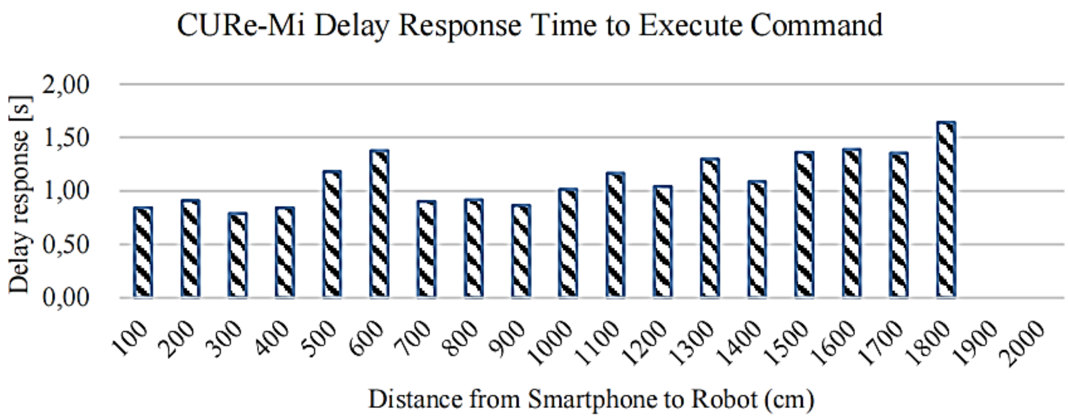


Figure 12. CURe-Mi delay response time testing result

4. CONCLUSION

The mobile manipulator CURe-Mi was developed to become a tool for distributing medicine from medical personnel to patients in COVID-19 quarantine without direct contact. The results of the research show that delivery of medicine by request from the smartphone Android application has a success rate of 100%. The highest level of accuracy of object placement using a robotic manipulator is found in the moveL movement with an average of 0.16 cm, and the smallest accuracy level is found in the moveJ movement with an average of 0.27 cm. The results of testing the accuracy of the placement of medicine as a whole robot using a mobile manipulator robot have different results. The initial position path to room 1 has an average of 6.45 cm, the initial position path to room 2 has an average of 2.17 cm, and the initial position path to room 3 has an average of 4.91 cm. The repeatability test results in the form of standard deviation values of 0.011 for x coordinates, 0.017 for y coordinates, and 0.024 for z coordinates indicate that the robot has a good repeatability value. In addition, the application performance test on the robot shows that the maximum distance required by the application to control the mobile manipulator reaches 1800 cm. However, at a distance of 1700 cm, the signal that connects the application with the robot is unstable, so the resulting response time is quite long, up to 1,682 seconds.

ACKNOWLEDGEMENTS

The study was conducted at the Robotic Laboratory, which is a part of the Department of Manufacturing Automation and Mechatronics Engineering at Bandung Polytechnic for Manufacturing. The author acknowledges the invaluable assistance provided by colleagues at Bandung Polytechnic for Manufacturing, namely Mr. Sarosas Castrena and Mr. Abdurrahman Harits, as well as senior lecturers Mr. Aris Budiarto and Mr. Yuliadi Erdani, without whom this paper would not have been feasible.

REFERENCES

[1] N. Chen *et al.*, "Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study," *The Lancet*, vol. 395, no. 10223, pp. 507–513, Feb. 2020, doi: 10.1016/S0140-6736(20)30211-7.

[2] Q. Ruan, K. Yang, W. Wang, L. Jiang, and J. Song, "Clinical predictors of mortality due to COVID-19 based on an analysis of data of 150 patients from Wuhan, China," *Intensive Care Medicine*, vol. 46, no. 5, pp. 846–848, May 2020, doi: 10.1007/s00134-020-05991-x.

[3] Z. Wu and J. M. McGoogan, "Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China," *JAMA*, vol. 323, no. 13, p. 1239, Apr. 2020, doi: 10.1001/jama.2020.2648.

[4] H. A. Al-Issa and I. Trrad, "Internet of things-based robot to take care of the Coronavirus patients and sterilize quarantine rooms," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 3, p. 1328, Jun. 2022, doi: 10.11591/ijeecs.v26.i3.pp1328-1337.

[5] S. Avgousti *et al.*, "Medical telerobotic systems: current status and future trends," *BioMedical Engineering OnLine*, vol. 15, no. 1, p. 96, Dec. 2016, doi: 10.1186/s12938-016-0217-7.

[6] Y. Wu, W. L. Chan, Y. Li, K. P. Tee, R. Yan, and D. K. Limbu, "Improving human-robot interactivity for tele-operated industrial and service robot applications," in *2015 IEEE 7th International Conference on Cybernetics and Intelligent Systems (CIS) and IEEE Conference on Robotics, Automation and Mechatronics (RAM)*, Jul. 2015, pp. 153–158. doi: 10.1109/ICCIS.2015.7274565.

[7] S. H. Alsamhi and B. Lee, "Blockchain-empowered multi-robot collaboration to fight COVID-19 and future pandemics," *IEEE Access*, vol. 9, pp. 44173–44197, 2021, doi: 10.1109/ACCESS.2020.3032450.

[8] M. Cardona, F. Cortez, A. Palacios, and K. Cerros, "Mobile robots application against Covid-19 pandemic," in *2020 IEEE ANDESCON*, Oct. 2020, pp. 1–5. doi: 10.1109/ANDESCON50619.2020.9272072.

[9] P. Manikandan, G. Ramesh, G. Likith, D. Sreekanth, and G. Durga Prasad, "Smart nursing robot for COVID-19 patients," in *2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, Mar. 2021, pp. 839–842. doi: 10.1109/ICACITE51222.2021.9404698.

[10] H. A. Hadi, "Line follower robot Arduino (using robot to control patient bed who was infected with Covid-19 virus)," in *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, Oct. 2020, pp. 1–3. doi: 10.1109/ISMSIT50672.2020.9254906.

[11] M. S. Z. Yaacob, J. Jalani, A. S. Sadun, and A. M. Z. A. Zulkarnain, "Development of a low-cost teleoperated and semi-autonomous robotic arm," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 27, no. 3, p. 1338, Sep. 2022, doi: 10.11591/ijeecs.v27.i3.pp1338-1346.

[12] S. Wang, K. Wang, R. Tang, J. Qiao, H. Liu, and Z.-G. Hou, "Design of a Low-Cost Miniature Robot to Assist the COVID-19 Nasopharyngeal Swab Sampling," *IEEE Transactions on Medical Robotics and Bionics*, vol. 3, no. 1, pp. 289–293, Feb. 2021, doi: 10.1109/TMRB.2020.3036461.

[13] Chih-Hung King, T. L. Chen, A. Jain, and C. C. Kemp, "Towards an assistive robot that autonomously performs bed baths for patient hygiene," in *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Oct. 2010, pp. 319–324. doi: 10.1109/IROS.2010.5649101.

[14] Y. Jiang, M. Lim, C. Zheng, and A. Saxena, "Learning to place new objects in a scene," *The International Journal of Robotics Research*, vol. 31, no. 9, pp. 1021–1043, Aug. 2012, doi: 10.1177/0278364912438781.

[15] E. Dean-Leon *et al.*, "TOMM: Tactile omnidirectional mobile manipulator," in *2017 IEEE International Conference on Robotics and Automation (ICRA)*, May 2017, pp. 2441–2447. doi: 10.1109/ICRA.2017.7989284.

[16] M. Hvilshøj, S. Bøgh, O. Skov Nielsen, and O. Madsen, "Autonomous industrial mobile manipulation (AIMM): past, present and future," *Industrial Robot: An International Journal*, vol. 39, no. 2, pp. 120–135, Mar. 2012, doi: 10.1108/01439911211201582.

[17] C. Sprunk, B. Lau, P. Pfaff, and W. Burgard, "An accurate and efficient navigation system for omnidirectional robots in industrial environments," *Autonomous Robots*, vol. 41, no. 2, pp. 473–493, Feb. 2017, doi: 10.1007/s10514-016-9557-1.

[18] D. Wahrmann, A.-C. Hildebrandt, C. Schuetz, R. Wittmann, and D. Rixen, "An autonomous and flexible robotic framework for logistics applications," *Journal of Intelligent & Robotic Systems*, vol. 93, no. 3–4, pp. 419–431, Mar. 2019, doi: 10.1007/s10846-017-0746-8.

[19] C. Wurll, T. Fritz, Y. Hermann, and D. Hollnaicher, "Production logistics with mobile robots," 2018.

[20] D. Pavlichenko, G. M. García, S. Koo, and S. Behnke, "KittingBot: A mobile manipulation robot for collaborative kitting in automotive logistics," 2019, pp. 849–864. doi: 10.1007/978-3-030-01370-7_66.

[21] M. Koseoglu, O. M. Celik, and O. Pektas, "Design of an autonomous mobile robot based on ROS," in *2017 International Artificial Intelligence and Data Processing Symposium (IDAP)*, Sep. 2017, pp. 1–5. doi: 10.1109/IDAP.2017.8090199.

[22] R. Humberto, B. Ilka, E. Octavio, H. Farid, and M. Héctor, "Optimal trajectory planning of a mobile manipulator for disinfection using multi-objective genetic algorithm," 2022, pp. 80–91. doi: 10.1007/978-3-030-90033-5_10.

[23] M. B. Alatise and G. P. Hancke, "A review on challenges of autonomous mobile robot and sensor fusion methods," *IEEE Access*, vol. 8, pp. 39830–39846, 2020, doi: 10.1109/ACCESS.2020.2975643.

[24] Universal Robots, *Universal robots e-series User manual UR5e original instructions (en)*. 2018. [Online]. Available: https://www.universal-robots.com/download/manuals-e-series/user/ur5e/58/user-manual-ur5e-e-seriessw-58-english-international-en/

[25] A. J. Moshayedi, G. Xu, L. Liao, and A. Kolahdooz, "Gentle survey on MIR industrial service robots: Review & design," *Journal of Modern Processes in Manufacturing and Production*, vol. 10, no. 1, pp. 31–50, 2021.

BIOGRAPHIES OF AUTHORS

Ismail Rokhim received his bachelor's degree in electronics engineering at Surabaya Polytechnic for Electronics in 1991. He received his master's degree in system control engineering at the Department of Electronics Engineering, Bandung Institute of Technology, in 2012. Currently, he is a senior lecturer and researcher focusing on robotics and system control technology. He can be contacted at ismail_r@polman-bandung.ac.id.

Nur Jamiludin Ramadhan received his bachelor's degree in mechatronics engineering at Bandung Polytechnic for Manufacturing in 2016. He received his master's degree in mechatronics engineering at the Department of Mechanical and Aerospace Engineering, Bandung Institute of Technology, in 2019. Currently, he is a lecturer and researcher who focuses on robotics technology and machine tools mechanisms. He has been a member of the Indonesian Society of Applied Science (ISAS) since 2021. He can be contacted at nj_ramadhan@polman-bandung.ac.id.

Zainun Najakh received his bachelor's degree in automation engineering at Bandung Polytechnic for Manufacturing in 2022. He can be contacted at znajakh@gmail.com.