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Development of a low-cost teleoperated and semi-autonomous robotic arm

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ABSTRACT

A safe human-robot physical interaction is required when the robot is used to help humans. This can be achieved by introducing a teleoperated robotic arm in which a human can teach the robot before performing tasks remotely. This paper develops and establishes a three-degree-of-freedom robotic arm and teaching pendant. In particular, a flexible robotic arm is operated in two different modes, namely, the teleoperated mode and the semi-autonomous mode. The teleoperated mode is a manual control using a teaching pendant, where the robot arm replicates various movements of the teaching pendant. On the contrary, the semi-autonomous mode allows the robot to execute a task from one point to another point repetitively after at least one training of the teaching pendant. The Arduino Uno board is employed as a microcontroller, and the integrated development environment (IDE) software is used to write and upload the computer code. A series of tests in which the robot performs different tasks is recorded to evaluate the accuracy and consistency of the semi-autonomous and teleoperated modes. The results show that the performance of the proposed low-cost teleoperated robotic arm is reliable and safe to perform various tasks based on the teaching pendant.

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1. INTRODUCTION

A teleoperated robot, also known as a telerobotic system, is the area of robotics that allows the control of semi-autonomous robots from a distance. For example, in a teleoperated robotic arm, the remote manipulator is controlled by sending position commands from the operator's site while receiving visual and other sensory feedback information. The remote manipulator is programmed to follow the operator's controls [1]. Local and remote systems are typically called the "master-slave system". Many researchers have used the master-slave control strategy in telerobotic applications. The application can be found in industry, such as the soldering process, pick and place, painting, screwing, and deburring [2], [3]. In 2018, a teleoperated robot system was improved and implemented through augmented reality (AR) to allow the operator to perform and program these manipulation tasks with better accuracy, dexterity, and visualization with minimal error [4]. Hence, a fixed and consistent trajectory industrial teleoperated robot is sufficient to perform the production line task. Note that the applications of the teleoperated robot are considered less in the production line compared in the military environment. This scenario may be because teleoperated robots are required to perform more critical and dangerous work in military sector. Examples of teleoperated applications in the military can be found in [5]–[7].

In 2020, healthcare operations in many countries were not prepared to serve COVID-19 patients [8]. This is the most critical disease that affects all countries around the world. The lack of staff in hospitals is mainly due to the staggering increase in COVID-19 cases. The provision of personal protective equipment (PPE) is insufficient to deal with the COVID-19 virus. Therefore, the teleoperated robot offers significant help to the healthcare center in the treatment of patients. The robot can be remotely controlled to diagnose COVID-19 patients. In a more advanced operation, the teleoperated robot can carry COVID-19 patients, allowing front-liners to step away (i.e., remotely assist the patients) for their safety. Moreover, multi-mobile robots have been developed to combat COVID-19 and future pandemics to work in the quarantine area to allow the delivery system. This could be critical because the disease can be easily spread by the COVID-19 patient [9]. Other applications of the telerobotic system include the detection of fever, the distribution of hand sanitizers, the sterilization of space, and the resolution of doubts and medical questions about the coronavirus [10]. The application of robots in this situation helps reduce social transmission and the number of severe cases [11]. Human intervention is not necessary, and this will prevent the lives of medical personnel affected by the COVID-19 virus [12].

Other scenarios in the medical sector show that there will be a possible shortage of medical personnel of approximately 500,000 in Germany by 2030 [13]. This is an example of a country that requires teleoperated and autonomous robot solutions to solve insufficient medical personnel supplies in the coming years. Other types of healthcare robot applications are based on the telepresence robot that can reach the isolated place in the hospital. This study was carried out by [14] that simulated the robot by controlling the system using the joystick command and the navigation command. Meanwhile, a study conducted by [15] showed that teleoperated robotic-assisted surgery and psychophysics-based safety operations resolve the lack of haptic sensation problems in telesurgery scenarios. Additionally, a teleoperation robot has been applied for remote dementia care in home environments. The teleoperated system allows caregivers to remotely help dementia patients by implementing the system with a dual-arm collaborative robot (Yu-Mi) and a wearable device to capture motion [16]. Furthermore, a teleoperated robot with virtal reality (VR) and AR technology requires a precise solution to the health problem. The surgeon could use VR to control the robotic arm during the operation and AR to map the patient's body to replace the X-ray or magnetic resonance imaging (MRI) [17].

Some of the most trending research focuses on telerobotic humanoid control with multiple degree-of-freedom (DOF). Due to flexible movement, humanoid robots play an important role in the daily human environment, such as in offices, homes, and hospitals [18]. Moreover, a humanoid robot was used as a teleoperated mini excavator to replace the traditional excavator, where the researcher developed a position-based impedance controller for excavator-type manipulators [19]. Other applications can be found in the fusion of laser scanner data to detect landmarks in the sewer pipe system [20]. Obviously, the teleoperated robot will benefit many sectors such as in military, healthcare, and manufacturing to increase productivity and provide a safe environment. Besides, the teleoperated robot also has the ability to become part of a massive rescue operation that can bring a thousand advantages to human life.

Many researchers have established and tested the development of teleoperated robots based on Arduino, program logic control (PLC), peripheral interface controller (PIC), and PS2 wireless control [21]–[26]. Their work can be used to study a new technique to apply a new teleoperated robotic arm. This research attempts to establish a low-cost teleoperated robotic arm to perform various tasks.

2. METHOD

Figure 1 shows the block diagram for the project development based on Arduino Uno. The power supply used in this project is 5 V from the output laptop port and the external 5 V power adapter. The controller used is Arduino Uno, which acts as an interface between hardware components and software. The input module in this system consists of switch 1 for the play and store button, potentiometer 1, potentiometer 2, potentiometer 3, potentiometer 4, and switch 2 for the pause button. Arduino Uno will control the motion of the servo motor (robot joint) using a potentiometer. Meanwhile, the output module of the system consists of a servomotor1 acting as a rotation (base) for the robot arm. The input signal of the potentiometer triggers the output of the system. The robot arm consists of three Tower Pro MG995 with 180º rotation and a G90 servomotor as a gripper that is connected to the input-output of the Arduino Uno controller (see Figure 2).

Analog input 0 (A0) is connected to the pin signal of the first 20K variable resistor (VR1). Meanwhile, A1 will be connected to the VR2 pin signal, and A2 will be connected to the VR3 pin signal. The A3 port will then be connected to the VR4 pin signal. The other two pins of the VR will be connected to the supply and the ground. The output port of the controller consists of four servo motors. Servomotor1 was used as a gripper for the robot arm and connected to the digital output pin 3 in Arduino Uno. Servomotor2 was used as a hand for a robot arm, and the pin signal was connected to the digital output pin 5. Digital output pin 10 was connected to the shoulder of the robot arm. Lastly, the rotating motor acts as the base of the robot arm, and the signal is connected to the digital output pin 11. The digital input 6 port is connected to a store/play switch and will be connected to a resistor. The resistor will reduce the amount of current flow to the switch. The store/play switch will record the steps made in manual operation to repeat it. Meanwhile, the digital output port 4 was connected to a pause switch to stop the whole system. The external adapter 5V was used to ensure that the amount of current and voltage was constantly supplied to smoothen the movement of the servo motor. Table 1 shows the number and function of each component to run the project.

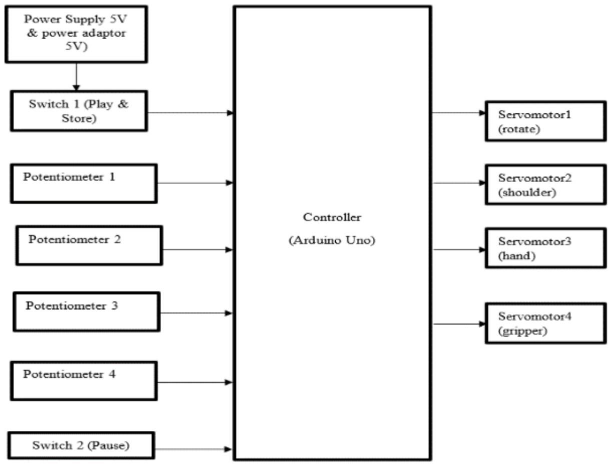


Figure 1. Project development based on Arduino Uno

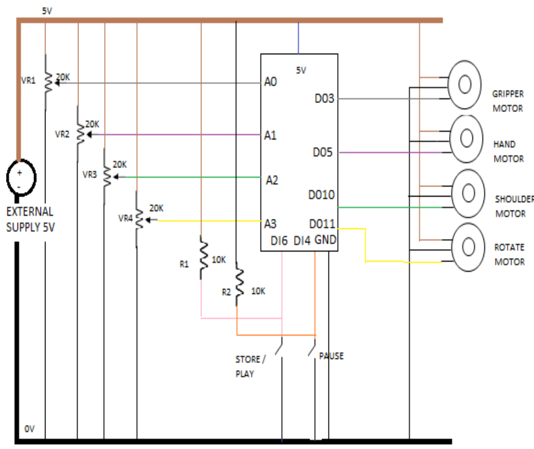


Figure 2. Circuit diagram

Table 1. List of hardware uses in the project

Components	Quantity	Description
Arduino Uno	1	The controller acts as the brain in the project.
Potentiometer 20K	4	The potentiometer is used as a joint to teach the pendent.
Tower Pro MG995 servomotor	3	Act as a joint for the robotic arm in rotation, hand, and shoulder.
G90 servomotor	1	Act as a gripper motor.
Resistor 10k	2	To decrease the voltage before introducing the switch.
Switch	2	Pause, play, and store.
5V power adapter	1	Act as an external DC power source to supply more current and voltage to stabilize the motors.
Wires	5 m	To make all the connection
Ice cream stick	-	As the body to teach pendant
3D printer ink	-	As the body of the robot arm

3. RESULTS AND DISCUSSION

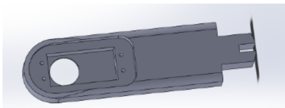
3.1. Solidworks

The development of the robotic arm is based on Solidworks, as depicted in Figure 3. More specifically, Figure 3(a) shows the base design of the robotic arm. The diameter of the base is 10 cm. The design was made in a cylindrical shape, which gives more stability and rigidity than a rectangular or square base. The height of this robotic arm was designed at 8.5 cm. At this height, the base is likely not easily slid down and can carry the weight of the other two joints. The screw hole is also attached to the base design, so it can be screwed up and completely mounted on the plywood. In the middle of the base, the servomotor mounting has been designed. Therefore, it will be easier to attach the servomotor to connect to the other part of the robotic arm. Figure 3(b) shows the design of the robotic arm shoulder that allows the interconnection between the base and the first limb. The waist dimension is 5 cm in height and 9 cm in diameter. The shoulder was designed with a screw hole to be mounted on the servomotor coupler. The distance between two holes is the same as the screw hole on the coupler. The upper part of the waist will connect to the first limb, which allows a rotating angle of 360 degrees. Figure 3(c) shows the hand design as the connection's first limb. The length of this limb is 16 cm. This limb was designed with a screw hole for the servomotor coupler at both ends of the limb. The rotating angle for this joint is 360 degrees. Figure 3(d) shows the gripper limb as the second limb of the robotic arm. It was designed with the servomotor and gripper mounted at the end of the limb. The length of this limb is 13.5 cm. The rotating angle for this limb is 360 degrees.

(a)

(b)

(c)



(d)

Figure 3. Development of a robotic arm using solidworks (a) base, (b) shoulder, (c) hand, and (d) gripper limb

3.2. Prototype of teaching pendant and robotic arm

Figure 4 shows the prototype of the teaching pendant using an ice cream stick. The prototype consists of three axes, each joint connected to a potentiometer for the actuator. The gripper of the teaching pendant is connected to a potentiometer. Meanwhile, Figure 5 shows the prototype robotic arm based on the Solidworks design. The robot arm consists of three axes and a gripper. The robotic arm actuator used a servomotor, and the robotic arm body was developed using 3D printing. All actuators can rotate up to 180°, and the gripper can grip and ungrip.

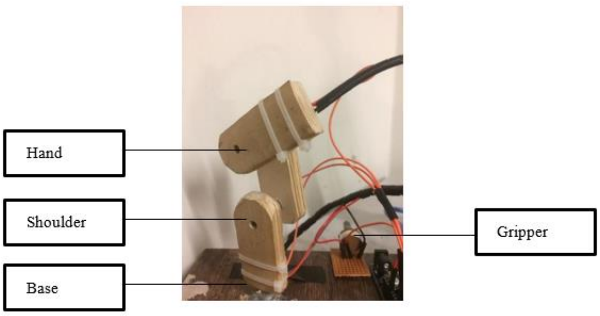


Figure 4. Prototype of teach-pendent

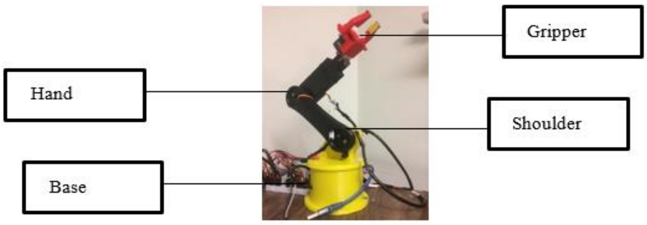


Figure 5. Prototype of the robotic arm

3.3. Teleoperated performance for painting, drawing, and writing

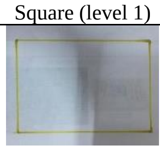
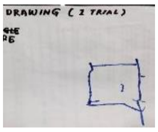
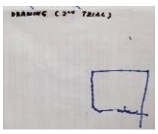
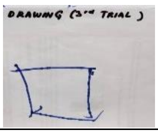
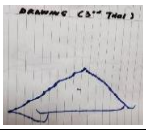
Table 2 summarizes the results of the painting test using two types of brushes, namely, a large brush and a small brush. During this test, the teleoperated mode is used. The main objective of this test is to analyze the performance of the robot arm to precisely paint the square area. The results show that using a big brush is much easier for the robot arm to handle and is more precise. The robot arm can fully color the square nicely using a large brush. This is because a big brush has a larger surface than a small brush. Thus, the robot arm can easily paint without involving much movement. Meanwhile, the robot cannot paint neatly compared to a large brush when using a small brush. The robot arm needs extra movement when using a small brush to paint the whole square. Thus, the accuracy decreased due to the smaller surface of the brush. It can be concluded that, when using the teleoperated mode, the angle of the motor and the accuracy are important. Table 3 shows the results of the drawing test. This test aims to analyze the performance of the robot arm when using the teleoperated mode for the drawing task. Note that, in the drawing task, there were edges and lines. The results show that the robot arm can draw the square and triangle satisfactorily as required, although the square has four edges. Similarly, the robot arm successfully draws two slopes and a single line for the triangle shape.

Figure 6 shows the results of the writing task. Figure 6(a) is a reference word that the robot should follow. Figure 6(b) was the first trial, Figure 6(c) was the second trial, and finally, Figure 6(d) was the third trial. The robot was tested to write the word 'natasha'. The word 'natasha' was clearly written by the robot arm. This test was proven to show that the robot arm is flexible to move at an adjustable angle to draw the alphabet, although the alphabet consists of different shapes. This robot arm has limitations in flexibility, accuracy, and precision. This is due to the limitation of the number of joints that can only reach a certain angle in a trajectory motion. Hence, the robot arm joints can be added to permit more flexibility for the robot arm. The teaching pendant also plays an important role in affecting the flexibility of the robotic arm. The teaching pendant must be designed according to the application of the robotic arm.

Table 2. Accuracy in painting

Type of brush	Big brush (level 1)	Small brush (level 2)
Demand		
1st trial		
2nd trial		
3rd trial		

Table 3. Accuracy in drawing

Shape	Square (level 1)	Triangle (level 2)
Demand		
1st trial		
2nd trial		
3rd trial		

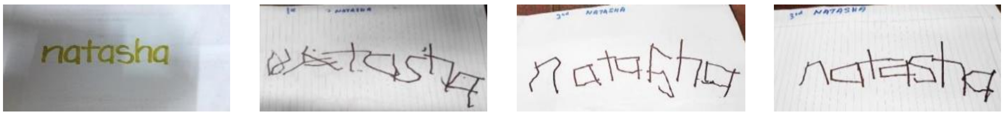


Figure 6. Accuracy in writing (a) reference, (b) first trial, (c) second trial, and (d) third trial

3.4. Semi-autonomous performance for pick-and-place

The robot must be able to repeat as much as possible during picking up the object and placing it on the conveyor. Figure 7 shows the flow process in which the robot arm picks up the object in the storage and places it on a conveyor. The conveyor has an ultrasonic sensor to detect the object placed on the conveyor, and the conveyor will begin to move once the object is detected. This process resembles an industrial production line. The robot arm will place the material on the conveyor, and the operator will start assembling the part. The robot arm can pick up 18 objects and place them on the conveyor without failure for one minute. Meanwhile, for two minutes run, the robot arm can pick 35 objects and place them on the conveyor seven times fail. Lastly, when the robot arm runs for three minutes repeatedly, only 50 objects can be picked and placed on the conveyor, and 15 times fail. The reason is that when the robot runs continuously, some wiring problems affect the robot's movement. The wires should be neatly and permanently connected. However, jumper wires are used for all connections during the test run to ease troubleshooting.

Table 4 shows the results of the success and failure rate of the pick-and-place application. Although the robot arm has some problems, the success rate is more than 70% and the failure rate is about 23%. For a one-minute trial, the success rate is 100%; meanwhile, in two minutes, the success rate is 83% and the rate of success in three minutes is 77%.

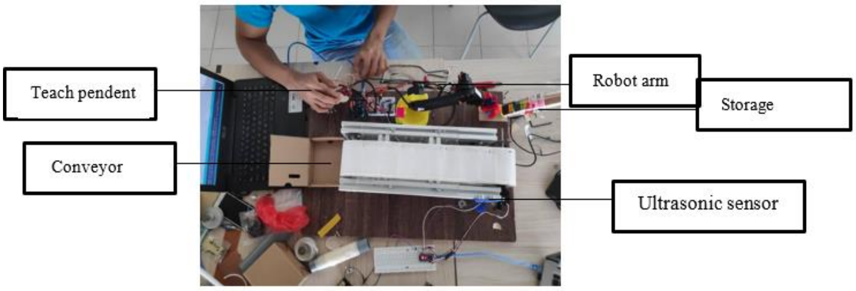


Figure 7. The flow of the pick-and-place process

Table 4. Success and failure rate of the pick-and-place application

Duration	One minute (%)	Two minutes	Three minutes
Success	18 times (100%)	35 times (83%)	50 times (77%)
Failure	0 times (0%)	7 times (17%)	15 times (23%)

3.5. Motor performance of angle rotation, voltage, and current

Table 5 shows the maximum and minimum rotation angles. This experiment was carried out to observe the rotation angle (in degrees) of the servomotor and the potentiometer. According to the Tower Pro MG995 servomotor specification, the maximum rotation angle is 180º, and for the potentiometer, it is 300º. Thus, the results show that servomotor1, servomotor2, and servomotor3 cannot reach the required maximum angle (300 degrees). This is because current and voltage are supplied and divided for four servomotors. The potentiometer has some percentage tolerance that causes the signal to be not 100% accurate. Therefore, the signal that is sent to the motor will have some reduction. Another reason for the unreachable angle rotation of the servomotor is that some mechanical losses may affect the ability of the motor to rotate at an exact angle (i.e., the friction of the mechanical gear and shaft of the servomotor).

Table 6 shows the current and voltage readings from the potentiometer and the servomotor to observe changes. Current and voltage measurements are made at each component's positive pole. From the measurement, there are not many changes on the potentiometer. The value of voltage and current are stable. In the servomotor, there are some current changes at the positive pole of the supply, as shown in Table 7. The current starts to increase as the servomotor moves at some angle. The bigger the rotational angle, the higher the current reading. More current is needed to bring the motor to maximum rotation. The voltage reading is stable.

Table 5. Maximum and minimum angle of rotation

Motor	Potentiometer angle (degree)	Servomotor angle (degree)
Servomotor 1 (rotate)	300	178
Servomotor 2 (shoulder)	300	179
Servomotor 3 (hand)	300	177
Servomotor 4 (gripper)	300	180

Table 6. Reading of current and voltage on the potentiometer

Potentiometer	Starting voltage (V)	Finishing voltage (V)	Starting current (mA)	Finishing current (mA)
1 (Base)	4.93	4.92	0.21m	0.21m
2 (Shoulder)	4.93	4.84	0.21m	0.21m
3 (Hand)	4.90	4.85	0.21m	0.21m
4 (Gripper)	4.90	4.89	0.21m	0.21m

Table 7. Reading of current and voltage in the servomotor

Servomotor	Starting voltage (V)	Finishing voltage (V)	Starting current (mA)	Finishing current (mA)
1 (Base)	4.97	4.95	12.2	39.6
2 (Shoulder)	4.97	4.97	12.2	39.6
3 (Hand)	4.97	4.96	12.2	39.6
4 (Gripper)	4.37	4.82	2.03	2.85

3.6. Gripper performance

Table 8 shows the gripper performance where the mini servomotor is employed. The square of plastic Lego block is used for the gripping test. The voltage obtained is 4.37 V when gripping and 4.82 V when ungripping. For measuring current, the obtained data are 2.03 mA for gripping and 2.85 mA for ungripping. The current increased as the Lego block gripped. This is because the servomotor needs more current to hold the load. The firmer the gripper holds the Lego block, the more current is produced.

Table 8. Performance of the gripper

Servomotor	Starting voltage (gripping)	Finishing voltage (ungripping)	Starting current (gripping)	Finishing current (ungripping)
Gripper	4.37 V	4.82 V	2.03 mA	2.85 mA

4. CONCLUSION

The main objective of this project is to develop a low-cost semi-autonomous robotic arm that allows a teleoperated controller. The Arduino Uno is utilized as a controller for operating the teleoperated robotic arm. The teaching pendant robot based on ice cream sticks is used to perform the teleoperated controller mode, and the robotic arm is used to execute a semi-autonomous controller mode. The proposed teleoperated and semi-autonomous robotic arm performs different tasks successfully. The technique reduces time consumption because the teleoperated mode allows us to reprogram a new trajectory after at least one training by teaching pendant before the robotic arm performing different tasks. However, there are recommendations for further studies, such as improving the design of the robotic arm. Different types of robotic arm motion can be added to improve flexibility, such as translational motion. The robotic arm can be more flexible when more area can be reached. The robotic arm also entirely depends on the teaching pendant. The teaching pendant can also be enhanced to improve the accuracy and precision of the robotic arm.

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REFERENCES

[1] 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.

[2] 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.

[3] Q. Meng, H. Wang, P. Li, L. Wang, and Z. He, "Dexterous underwater robot hand: HEU hand II," in *2006 International Conference on Mechatronics and Automation*, Jun. 2006, pp. 1477–1482, doi: 10.1109/ICMA.2006.257847.

[4] F. Brizzi, L. Peppoloni, A. Graziano, E. Di Stefano, C. A. Avizzano, and E. Ruffaldi, "Effects of augmented reality on the performance of teleoperated industrial assembly tasks in a robotic embodiment," *IEEE Transactions on Human-Machine Systems*, vol. 48, no. 2, pp. 197–206, Apr. 2018, doi: 10.1109/THMS.2017.2782490.

[5] K. Nonami, N. Shimoi, Q. J. Huang, D. Komizo, and H. Uchida, "Development of teleoperated six-legged walking robot for mine detection and mapping of mine field," in *Proceedings. 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2000) (Cat. No.00CH37113)*, 2000, vol. 1, pp. 775–779, doi: 10.1109/IROS.2000.894698.

[6] P. D. Healy and B. E. Bishop, "Sea-dragon: an amphibious robot for operation in the littorals," in *2009 41st Southeastern Symposium on System Theory*, Mar. 2009, pp. 266–270, doi: 10.1109/SSST.2009.4806802.

[7] C. Meagher, D. Hooper, C. Cirullo, J. Neff, and J.-C. S. Chieh, "Adaptive Beamforming for tele-operated unmanned ground vehicles," in *MILCOM 2013-2013 IEEE Military Communications Conference*, Nov. 2013, pp. 1161–1165, doi: 10.1109/MILCOM.2013.199.

[8] "Telerobotics: A 'smart' remedy for productivity during COVID-19." https://roboticsandautomationnews.com/2020/11/19/telerobotics-a-smart-remedy-for-productivity-during-COVID-19/38324/ (accessed Jun. 15, 2021).

[9] 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.

[10] 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.

[11] P. Manikandan, G. Ramesh, G. Likith, D. Sreekanth, and G. D. 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.

[12] 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.

[13] A. S. Sayed, H. H. Ammar, and R. Shalaby, "Centralized Multi-agent mobile robots SLAM and navigation for COVID-19 Field hospitals," in *2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES)*, Oct. 2020, pp. 444–449, doi: 10.1109/NILES50944.2020.9257919.

[14] K. Borvorntanajanya, P. Thiuthipsakul, S. Chalongwongse, C. Moonjaita, and J. Suthakorn, "Development of differential suspension wheeled system for telepresence robot in rural hospital area," in *2016 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Dec. 2016, pp. 1046–1051, doi: 10.1109/ROBIO.2016.7866463.

[15] X. Yin, S. Guo, N. Xiao, T. Tamiya, H. Hirata, and H. Ishihara, "Safety Operation consciousness realization of a MR Fluids-based novel haptic interface for teleoperated catheter minimally invasive neurosurgery," *IEEE/ASME Transactions on Mechatronics*, vol. 21, no. 2, pp. 1043–1054, Apr. 2016, doi: 10.1109/TMECH.2015.2489219.

[16] H. Lv, G. Yang, H. Zhou, X. Huang, H. Yang, and Z. Pang, "Teleoperation of Collaborative robot for remote dementia care in home environments," *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 8, no. May, pp. 1–10, 2020, doi: 10.1109/JTEHM.2020.3002384.

[17] G. Conrad, "Teleoperated robots: the industrial future using AR and VR." https://blog.robotiq.com/teleoperated-robots-the-industrial-future-using-ar-and-vr (accessed Jun. 15, 2021).

[18] W. Zhang, Q. Huang, P. Du, J. Li, and K. Li, "Compliance control of a humanoid arm based on force feedback," in *2005 IEEE International Conference on Information Acquisition*, 2005, no. 1, pp. 528–531, doi: 10.1109/ICIA.2005.1635145.

[19] S. E. Salcudean, S. Tafazoli, P. D. Lawrence, and I. Chau, "Impedance control of a teleoperated mini excavator," in *1997 8th International Conference on Advanced Robotics. Proceedings. ICAR'97*, pp. 19–25, doi: 10.1109/ICAR.1997.620156.

[20] A. Ahrary, A. Nassiraei, and A. M. Ishikawa, "A study of an autonomous mobile robot for a sewer inspection system," *Artif Life Robotics*, Jan. 2007, vol. 11, pp. 23–27, https://doi.org/10.1007/s10015-006-0392-x.

[21] S. Verma, "Hand gestures remote controlled robotic arm," *Advance in Electronic and Electric Engineering.*, vol. 3, no. 5, pp. 601–606, 2013.

[22] S. Bularka, R. Szabo, M. Otesteanu, and M. Babaita, "Robotic Arm control with hand movement gestures," in *2018 41st International Conference on Telecommunications and Signal Processing (TSP)*, Jul. 2018, pp. 1–5, doi: 10.1109/TSP.2018.8441341.

[23] Y. K. Chao, Y. F. Zhou, and Y. L. Xu, "Mobile robotic control system based on master-slave teleoperate mechanical arm," in *2013 25th Chinese Control and Decision Conference (CCDC)*, May 2013, pp. 3195–3198, doi: 10.1109/CCDC.2013.6561496.

[24] S. S. Dheeban, D. V Harish, A. H. Vignesh, and M. Prasanna, "Arduino controlled gesture robot," in *2018 IEEE 4th International Symposium in Robotics and Manufacturing Automation (ROMA)*, Dec. 2018, pp. 1–6, doi: 10.1109/ROMA46407.2018.8986730.

[25] Z. M. Ripin, T. B. Soon, A. B. Abdullah, and Z. Samad, "Development of a low-cost modular pole climbing robot," in *2000 TENCON Proceedings. Intelligent Systems and Technologies for the New Millennium (Cat. No.00CH37119)*, 2000, vol. 1, pp. 196–200, doi: 10.1109/TENCON.2000.893569.

[26] R. K. Megalingam *et al.*, "Design, implementation and analysis of a low cost drawing bot for educational purpose," *International Journal of Pure and Applied Mathematics*, vol. 118, no. 16, pp. 213–230, 2018.

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