Design and development of a low-cost pole climbing robot using Arduino Mega

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Abstract. Nowadays, climbing robots are widely used in industrial and hazardous environments for inspection purposes. On the other hand, the Pole climbing robot can help workers fix maintenance, power transmission, etc. This article aims to design and fabricate an autonomous pole climbing robot, which can climb upward/downward a pole. The robot has two grippers at the top and bottom of the robot body, climbing along a pole by alternating release/grip mechanism. The robot body and robot grippers are fabricated using a rapid prototyping machine using PLA material. The prototype of the robot is tested on a pole of diameter 110 cm. The average time taken for the robot to climb 40 cm on a straight pole is 18.18 s and 17.21 s for upward and downward motion, respectively.

1. Introduction
The article discusses an autonomous pole-climbing robotic that can climb-up on a pole. The pole's diameter is set to be between 110~120 cm. An autonomous mobile robot is a mobile robot that can work with the aid of itself through programming written in the microcontroller to function in some predefined tasks. The microcontroller used in this work is Arduino. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software [1]. This project aims to design and fabricate a fully autonomous pole climbing robot that can climb a pole without human interaction.

There have been many attempts in the literature to build robots that can climb vertical structures for various purposes, such as cleaning, maintenance, and inspection of high rise building [2], surveillance [3], pylon maintenance [4], coconut harvesting [5], and so on. Examples of such robots are LizBot for autonomous surveillance, which can climb on the walls and tall structures [3], and RISE climbing robots [6], which can climb straight structures made of soft and non-metallic materials. Other types of climbing robots can be found in [7-19].

This paper describes the design, fabrication, and testing of a pole climbing robot. The materials used to fabricate the robot are essential because the robot's weight will affect the robot's stability. Besides, this project helps us understand the concept and features of various motor types, such as servo motor and others. Each motor has its concept of conversion of electrical energy into mechanical energy. The climbing robot can climb poles to access power transmission lines, telephone lines, and lamps. Climbing poles can be dangerous for the technicians and municipal workers and needs the
expertise to avoid injuries or loss of lives. Besides that, it can also help firefighters rescue humans in a dangerous building by climbing the poles.

2. Methodology
In this work, Arduino Mega is used due to its stability and functionality of the microcontroller. The servo motor is the main component of the gripping mechanism. Besides, a servo motor will be used as the main joint for the pole climbing robot's body. Three servo motors are attached to the body of the robot and act as the main joint. The robot can change its direction of movement, either upward or downward motion. Two IR sensors are attached at the top and bottom of the robot to detect an obstacle and initiate upward or downward motion. Moreover, a pushbutton switch is used to start the program of the Pole Climbing Robot.

The robot's body and gripper are designed using SolidWorks 2019 and 3D printed with an Ender-3 – 3D Rapid Prototyping Machine. The main material for the robot body is Polylactic Acid (PLA) filament. 3D printed body and gripper are chosen instead of aluminum and wood body is due to dimension factor where printed components have more accurate dimension. Also, PLA is a light material, and it can ensure the robot cling to the pole. On top of that, modification can be easily carried out with the aid design software such as SolidWorks 2019.

2.1. Circuit design
Figure 1 shows the circuit connection for Pole Climbing Robot. Arduino Mega 2560 R3 is used as the microcontroller for the robot. It functions to receive signals from the sensors and interpret them before sending the servo motor signals as a response. Also, there are two IR sensors attached to the top and bottom of the robot, respectively. According to program coding, the IR sensors' connection as the pins that receive and transmit signals on the Arduino is mapped by the coding.

All the servo motors have rated voltage of 4.8 V and 6 V as each of the rated voltage has different stall torques, respectively. However, servo motors can be connected to more than 8 V, and in this work, the servo motors are connected to two lithium-ion batteries with an approximate voltage of 7 V. A voltage greater than 7 V cannot be used as it might burn the servo motors. The signal pins of all the servo motors are connected according to the program coding to ensure the robot's smooth movement.
Up LED and Down LED are connected according to program coding. It will light up according to the motion of the robot, either upward or downward motion. Two lithium-ion batteries are used as the power source of Arduino. While all the $V_{cc}$ of sensors, positive pins of LEDs are connected to 5V pin of Arduino for power supply.

2.2. Robot behavior
The robot operating system is demonstrated in Figure 2 below with the block diagram showing the robot process's mechanism flow in work. Initially, the system will start by setting the robot at the initial position. Once the pushbutton switch is initiated, the robot will start with an upward motion. Else, it will remain at its initial position. Up LED will light up to indicate that the robot is in an upward motion. After every cycle of the robot's upward motion, the top IR sensor will continuously read whether the obstacle is detected or not above the robot.

![Figure 2. Circuit design of the proposed climbing robot](image)

If there is no obstacle detected, the robot's upward motion will continue till an obstacle is detected above. If there is an obstacle detected above the robot, the system will switch the motion of the robot
to downward motion. After every cycle of downward motion, the bottom IR sensor will continuously read whether an obstacle is detected below the robot. If there is no obstacle detected, the robot's downward motion will continue till an obstacle is detected below the robot. If there is an obstacle detected, the robot will stop at that position.

Besides, to achieve smooth upward and downward motion, two functions have been created: Upward Motion and Downward Motion. In Upward Motion, Up LED will light up once Upward Motion is initialized. The Servo motor in the top gripping mechanism will be unclamped by writing a specific angle to the servo motor. Next, three servo motors will rotate at a specific angle to stretch the robot's body upward by writing a specific angle to each servo motor in each joint. The Servo motor in the top gripping mechanism will clamp by writing a specific angle to the servo motor.

Next, the servo motor in the bottom gripping mechanism will be unclamped by writing a specific angle to the servo motor. Three servo motors in each joint of the body of the robot will return to their original position. Thus, the bottom gripping mechanism will be brought upward and clamped after the movement. While in Downward Motion, Down LED will light up, and Up LED will be turned off once Downward Motion is initialized. The Servo motor in the bottom gripping mechanism will be unclamped by writing a specific angle to the servo motor.

The Servo motor in the bottom gripping mechanism will clamp by writing a specific angle to the servo motor. Next, the servo motor in the top gripping mechanism will be unclamped by writing a specific angle to the servo motor. Three servo motors in each joint of the body of the robot will return to their original position. Thus, the top gripping mechanism will be brought down and clamped after the movement.

The whole program will stop once the reset button in Arduino is pressed. The robot will move to its original position once the reset button is pressed, and it will continue to move after the push button switch is pressed.

2.3. Robot design
SOLIDWORKS 2019 is used to sketch and design the robot mechanical part in this work. The robot comprises several parts, which are the gripping mechanism and the body. Where the main motors used are servo motors. Figure 3 below shows the robot in its initialized position.

![Figure 3. Mechanical Design of Pole Climbing Robot.](image)

The top servo motor holder (Figure 4) is designed to hold the top gripper's servo motor in place. Also, it acts as a joint between the body and gripping mechanism of the pole climbing robot. The
bottom servo motor holder (Figure 5) is designed to hold the bottom gripper’s servo motor in place. Also, it acts as a joint between the body and gripping mechanism of the Pole Climbing Robot.

The design of the gripper for the bottom and top parts of the robot is identical. As the servo motor rotates, the gripper will follow the servo motor's motion and grab the pole.

The design of gripper support for the bottom and top parts of the robot is identical. Gripper Support functions to ensure the gripping mechanism works well by ensuring more surface area of the pole surfaces are covered and held by the gripper.

The Body of the Robot is designed to hold two servo motors in place. The servo motors act as the robot joints, which enable the robot to move upward or downward. The body will bend according to the rotation of servo motors in it.

3. Results and Discussion

3.1. Prototype

Figure 6 and Figure 7 below show the prototype of the pole climbing robot in initialized position. The robot is able to hinge well, with the top and bottom gripper functioning well. Once the pushbutton switch is pressed, an Up LED will light up, and the robot will move upward. While the Down LED will remain off.

Once the Top IR sensor detects an obstacle, the robot will shift to downward motion. While the Up LED will turn off, and the Down LED will light up to indicate downward movement. Once the bottom IR sensor detects an obstacle, the robot will stop its motion. While the Down LED will turn off, and the Up LED will light up. Then, it will wait for the pushbutton switch to be pressed to start an upward movement.

3.2. Speed

The data was measured using a stopwatch and a measuring tape. From Table 1 and Table 2, the average distance of upward motion and downward motion is identical. This is due to the stability of the design of the robot. The robot's upward and downward extension is stable, resulting in the same distance moving upward and downward. Simultaneously, there is a slight difference in the time taken for the robot's upward motion and downward motion.
The average time taken for downward motion is slightly faster than upward motion, with a difference of 0.97 s. The reason may be that the time taken for the robot's downward extension is faster as the motion is not against gravity. It may also be due to insufficient torque of servo motors in the body and causes servo motor rotation changes to be slightly faster.

Table 1. Time taken for the climbing robot to climb-up 40 cm.

| Attempt | Time (s) |
|---------|---------|
| 1       | 18.01   |
| 2       | 18.30   |
| 3       | 18.22   |
| 4       | 18.18   |
| 5       | 18.07   |
| 6       | 18.15   |
| 7       | 17.46   |
| 8       | 18.16   |
| 9       | 18.45   |
| 10      | 18.37   |
| Average | 18.18   |

Table 2. Time taken for the climbing robot to climb-down 40 cm.

| Attempt | Time (s) |
|---------|---------|
| 1       | 17.45   |
| 2       | 17.10   |
| 3       | 17.08   |
| 4       | 17.30   |
| 5       | 16.55   |
| 6       | 17.21   |
| 7       | 16.53   |
| 8       | 18.00   |
| 9       | 17.25   |
| 10      | 17.23   |
| Average | 17.21   |

3.3 Power consumption

Table 3 and Table 4 are the potential differences and the current flowing through the top gripper and bottom gripper servo motors while in clamping. The measurements were taken using a multimeter to get an accurate result.

As shown in Table 3 & Table 4, the average voltage of servo motors for top and bottom grippers is identical as they were connected in parallel. In contrast, there is a difference in the servo motors'
average current in the top and bottom gripper. The power consumption of the servo motor for the bottom gripper is higher than the bottom gripper. This is because the bottom gripper required greater torque to hinge the robot in position than the top gripper. This may also be due to the center of gravity of the robot at the bottom end of the robot; hence, more power is required to hinge the robot in the bottom gripper.

| Attempt | Voltage (V) | Current (A) |
|---------|-------------|-------------|
| 1       | 7.34        | 0.416       |
| 2       | 7.35        | 0.371       |
| 3       | 7.34        | 0.390       |
| 4       | 7.34        | 0.416       |
| 5       | 7.35        | 0.371       |
| 6       | 7.34        | 0.392       |
| 7       | 7.34        | 0.390       |
| 8       | 7.34        | 0.416       |
| 9       | 7.35        | 0.371       |
| 10      | 7.34        | 0.390       |
| Average | 7.34        | 0.392       |

Table 4. Current and voltage of the bottom gripper during gripping.

| Attempt | Voltage (V) | Current (A) |
|---------|-------------|-------------|
| 1       | 7.34        | 0.558       |
| 2       | 7.35        | 0.605       |
| 3       | 7.34        | 0.587       |
| 4       | 7.34        | 0.558       |
| 5       | 7.35        | 0.605       |
| 6       | 7.34        | 0.583       |
| 7       | 7.34        | 0.587       |
| 8       | 7.34        | 0.558       |
| 9       | 7.35        | 0.605       |
| 10      | 7.34        | 0.587       |
| Average | 7.34        | 0.583       |

4. Conclusion

In conclusion, the aim to design a simple pole climbing robot that can climb a pole with a diameter of 110 cm has been successfully fabricated. The fabricated robot has been tested on a pole to climb 40 cm upward and downward motions; the time is taken, averaging at 18.18 s and 17.21 s, respectively.

Even though the work has been carried out successfully, there is still an area for improvement. One of them is the gripping mechanism. The gripping mechanism applied in the current prototype is a bit unstable and unable to hinge on the pole properly while on upward or downward movement. Hence, a study has been made, and a gripping mechanism wheel-based has been decided as the best gripping mechanism. The robot from the figure below required specific and precise calculations.

Nevertheless, the robot's force towards the pole is strong enough and enables to make sure that the robot would not slip easily. Besides, a better material of robot can be chosen as the main material. Aluminum can be used to substitute PLA 3D printed material as it is light and durable.

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