MJSAT

Malaysian Journal of Science
and
Advanced Technology

journal homepage: https://mjsat.com.my/

Designing an Autonomous Mobile Robot based on Rocker-Bogie Concept for Terrain Purposes

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KEYWORDS

Autonomous Mobile Robots
Microcontroller
Terrains
Rocker-Bogie

ARTICLE HISTORY

Received 9 February 2024
Received in revised form
17 February 2024
Accepted 3 March 2024
Available online 9 March 2024

ABSTRACT

Currently, extensive research has been done on improving self-controlling mobile robots. This robot is called autonomous mobile robots (AMRs) and it was designed for various applications like moving around in places such as libraries, restaurants, and healthcare. This paper focuses on designing a six-wheeled mobile robot using Fusion 360 software, based on Rocker-Bogie structure. The main idea from the Rocker-Bogie concept is that it does not use springs or separate stub axles for each wheel, allowing the robot's body to overcome obstacles like rocks, ditches, and sand. The actuator of the DC motor for each wheel was used to study the robot's stability and its movement. Meanwhile, the movement of the robot was controlled by implementing a user graphical interface (GUI) using Blynk software. There are four main directions for the movement of the robot: moving forward, backward, and turning left and right position. Importantly, the Rocker-Bogie can be a starting point for developing an independent mobile robot that can navigate different terrains like sand, grass, and roads. This capability comes by using various sensors that help the robot navigate its surroundings effectively.

1. INTRODUCTION

Nowadays, the innovation in industrial robotics has become popular, which is the robot able to do multiple tasks and repetitive jobs in precise and accurate ways including autonomous mobile robots (AMRs) [1]. This robot can navigate and explore its environment without human intervention. Most AMRs consist of wheels and platforms equipped with sensors like cameras, radar, ultrasonic, and LIDAR. These sensors allow them to alert and detect their environment's condition to create a map and path-planning of their environment and destination. The applications of AMRs also can be used for a variety of tasks, such as transporting goods, delivering food, and providing customer service [2].

One of the robotic technologies widely used is the military sector. The innovation of robots, especially AMR, is in high demand which can be used as a helper for a variety of jobs such as surveillance, bomb disposal, and logistics [3]. Furthermore, by using the robot, it can protect the people, especially soldiers from the harm of landmines [4]. The war's countries can replace humans with robots to detect the landmines and improve the efficiency and effectiveness in their job [5]. The advantages by implementation of AMRs in the military include it can operate in dangerous and hazardous places that are too risky for humans. Other than that, the robot also can operate for long periods without needing to rest or refuel. Finally, AMRs also can be used to collect data that would be difficult or impossible for humans to obtain [6].

However, there are some challenges associated with the AMRs in the military. Firstly, most AMRs are expensive to develop and purchase, because of size and its technology [6].

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https://doi.org/10.56532/mjsat.v4i2.263
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Secondly, AMRs can be difficult to control in complex and unpredictable environments. Another reason for creating the AMR was because of the collapse which led to severe loss of human life due to inadequate facilities in rescue operation. For example, Chennai, has faced huge permanent loss of belongings and caused life from heavy downpour [7]. This heavy downpour turned to flood, grounding the road surface uneven since debris, soil, and trees along their path, damaging the road and building structure. The robot must be able to traverse rough terrains and uneven surfaces.

To overcome such situations, a robot implemented with the Rocker-Bogie mechanism could be used. Early study, the Rocker-Bogie mechanism is primarily used for space exploration and is designed to traverse rough and challenging terrain on other planets or moons [8]. The mechanism of Rocker-Bogie consists of a series of six wheels, and the four middle wheels arranged in pairs on a pivot bar. This pivot bar is connected to the chassis of the mobile robot. The outer wheels are fixed, and the inner wheels can move up and down independently [9]. This concept allows the rover to maintain traction on uneven terrain, so each wheel can adjust to the contours of the surface without disturbing the overall stability of the mobile robot [10]. The rocker-bogie mechanism helps to ensure that the rover can navigate obstacles that are larger than its wheels. When the front wheels encounter an obstacle, the pivot bar tilts upward, which lifts the rear wheels off the ground and allows the rover to pass over the obstacle without getting stuck [11]. It is worth noting that AMRs and rocker-bogie mechanisms have different purposes and are used in different environments. The comparison between the two is entirely appropriate as shown in Table 1.

Table 1 Differences between autonomous mobile robots (AMRs) and rocker-bogie mechanisms [12].

Criteria	**Autonomous Mobile Robots (AMRs)**	**Rocker-Bogie Mechanism**
Definition	A self-navigating robot. It can move freely around a given environment and path.	A robot which has a suspension system. It is commonly used in rovers and designed to traverse the rough terrain or uneven surface.
Navigation	It can navigate and remote control using various technologies such as lidar, sensors, and cameras.	It is typically used in a controlled environment, like space exploration.
Mobility	Most robots have wheels and can move in any direction within a given environment and various surroundings.	Has a specific design that allows for reliable and robust suspension to traverse in challenging terrains.
Application	Used in various industries include logistics, healthcare, hospitality, and manufacturing.	Used in space exploration, such as NASA's Mars rovers but expand to narrow space.

In the previous research study, the Grizzly from Clearpath Robotics is an AMR engineered for outdoor applications. It features a suspension system that incorporates articulated bogie axles, offering exceptional mobility and stability when traversing rugged terrain [13]. The Grizzly has the capacity to transport payloads up to 400 kg and a maximum speed of 8 km/h. Another AMR using the Rocker-Bogie mechanism is the ANYmal robot. It was developed by ANYbotica, which the company has specifically designed for deployment in both industrial and outdoor settings. The ANYmal has four independently controlled legs equipped with specially designed suspension components, facilitating dependable and agile movement across challenging landscapes [14]. Consequently, the ANYmal is proficient in carrying payloads up to 10 kg and can achieve a maximum speed of 1.5 m/s.

This paper focuses on designing the autonomous mobile robot based on the Rocker-Bogie system that can move on its own and direction based on GUI. The robot has a unique wheel that helps to move on the different types of terrains that can be used for the classification of uncertainty terrains. The purpose of this robot also is to be used as a rescue equipment during emergencies like big floods, then it is able to do the tasks that humans usually do. The six-wheeled tires are considered for movement either in rough or smooth surfaces depending on the conditions of sensors by controlling IoT application. A software called Blynk software is used to control the robot movement in different directions like forward, backward, left, and right. One of the advantages of the wheel system for this robot is to make sure the robot's weight is spread out evenly on all its wheels.

2. METHODOLOGY

In the methodology, there are two main parts that are considered in designing and controlling the movement of the autonomous mobile robot (AMR): - mechanical part and electrical part. The mechanical part consists of the chassis, wheels, and suspension. Meanwhile, the electrical part of the robot system includes the motors, controllers, and sensors. However, in this paper, it will focus on designing and fabricating the mobile robot based on the Rocker-Bogie system. Figure 1 is a flow in representation of the AMR Rocker-Bogie process. It shows all the stages of the project, starting from the initial research until the final implementation of the prototype.

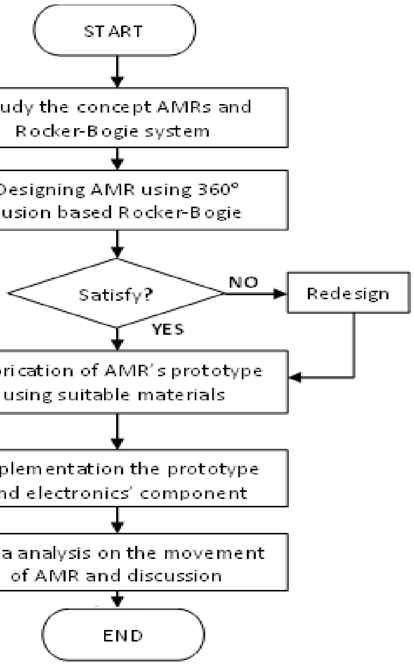


Fig.1. Process flow of designing and fabrication of autonomous mobile robot (AMR)

2.1 Concept of Rocker-Bogie System

In developing a mobile robot utilizing the Rocker-Bogie mechanism, the initial step involves comprehensively studying the fundamental principles of its mechanism. The Rocker-Bogie mechanism is a crucial system emphasis in Mars rovers to navigate challenging landscapes while upholding stability. This mechanism is NASA's preferred choice for space vehicles and rovers due to its effectiveness [15]. It has a pair of arms, each equipped with a wheel, and these arms are interconnected through a movable joint.

The term "rocker" refers to the rocking motion demonstrated by the links positioned on both sides of the suspension system [16]. These rockers play a main role in balancing for bogies, as they are interconnected with each other and the vehicle chassis through a modified differential. Meanwhile, the term "bogie" is associated with the interconnected links, each featuring a drive wheel affixed at its ends. Bogies are utilized to move in the tracks of military tanks as well as to distribute the weight over the terrain. Additionally, bogies were frequently used on the trailers of semi-trucks, as these trucks often needed to carry significantly heavier loads during that period.

In line with the objective of studying the overall vehicle's centre of gravity, when a rocker ascends, the other rocker will descend. The chassis assumes a critical function in upholding the mean pitch angle of both rockers and permitting their movement in response to the prevailing conditions [17]. In general, the calculation for the Rocker-Bogie mechanism is divided by two approaches: - rocker link and bogie link calculation using Pythagoras theorem. The calculations are made to ensure the stability of climbing obstacles, which is the position of one pair of wheels at a time must be raised [18]. The obstacles assumed are the height and length 150 mm and 400 mm respectively. Figure 2 shows the Rocker-Bogie mechanism, and the calculations are made from the triangle of ABC and ADE. Both shapes have the angles of 90o. The constraints between link AE and link EC are equal, same for link AB and link BC. Finally, equation (1) and equation (2) are used to calculate the possible dimension for link AC and link AE.

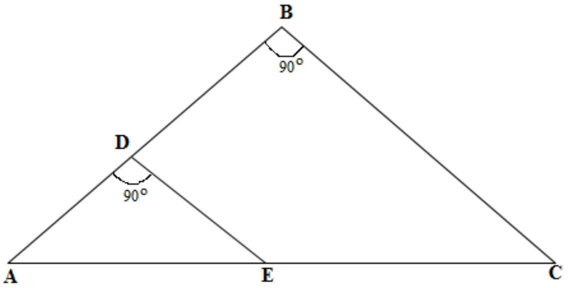


Fig.2. Two triangular ADE and ABC for calculating the Rocker-Bogie mechanism.

From the calculation, it will be considered as an input parameter to design the AMR system based on the triangle of ABC and ADE.

From the triangle of ABC, the dimension of AC as follow: -

$$AC^2 = AB^2 + BC^2 \qquad (1)$$

where $AB = BC = 200$ mm

$$AC^2 = 200^2 + 200^2$$

$$AC = 282.84 \text{ mm}$$

Same for the link of AE.

$$AE^2 = AD^2 + DE^2 \qquad (2)$$

where $AD = DE = 100$ mm

$$AE^2 = 100^2 + 100^2$$

$$AE = 141.42 \text{ mm}$$

Then finally, the recommended measurement size for the Rocker-Bogie mechanism as shown in Figure 3.

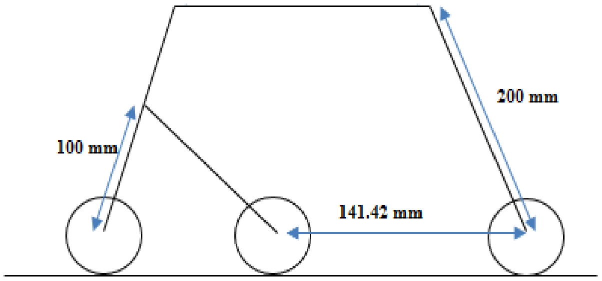


Fig.3. The dimension of AMR based on the Rocker-Bogie mechanism.

In this work, equation (3) can be used for calculating the required wheel torque.

$$T = Fr \qquad (3)$$

where F is the force required to move the rover, and r is the radius of the wheel. The required torque is 2.5 kg x 9.81 kg/ms^{-2} x 19 mm = 0.47 N. m. Meanwhile, equation (4) can be used for calculating the minimum ground clearance of the rover.

$$H = 2r\,(\sin\alpha + \cos\alpha + b) \qquad (4)$$

where H is the minimum ground clearance, r is the radius of the wheel, α is the angle of the rocker-bogie mechanism and b is the distance between the rocker pivot and the wheel. The minimum ground clearance can be 7.65 m.

All equations can be used to design the various aspects of the Rocker-Bogie system, such as the size of wheels, the distance between the wheels and body, and the angle of between the Rocker-Bogie mechanism. In the previous study, it is also found that the Rocker-Bogie system reduces the motion by half compared to other suspension because each of the bogie's six wheels has an independent mechanism for motion [19]. The motor on these wheels does hit the ground with the external terrains during its operation. Therefore, the two front and two back wheels have individual steering systems which allow the mobile robot to turn in its own place without needing any space [20].

2.2 Designing the Autonomous Mobile Robot using Fusion 360 Software

Basically, the idea and concept of AMR based on the Rocker-Bogie system was designed using Fusion 360 software. This software was developed by Autodesk to use in 3D design, computer aided manufacturing (CAM). Fusion 360 not only focused on designing, but it can be used for analysis especially finite element analysis as well as structural analysis [21]. In general, the mobile robot was divided by two main parts: (a) main body and (b) link for both rocker and bogie system. The connection between both links and differential bars allows them to move independently of each other. It gives the AMR Rocker-Bogie system good maneuverability, even in tight spaces.

Figure 4 to Figure 6 show the steps or processes of designing the AMR using Fusion 360. The measurement and dimension for each part of the robot are based on the general size of AMR and suitable for the outdoor environment. The robot can fit all mechanisms of the robot needed including the tire and location of actuators. For example, the main body part was built up using a PVC pipe with 35-mm diameter. Figure 4 illustrates the connection between four-PVC pipes and the elbow joint of the PVC pipe for the main body of the robot.

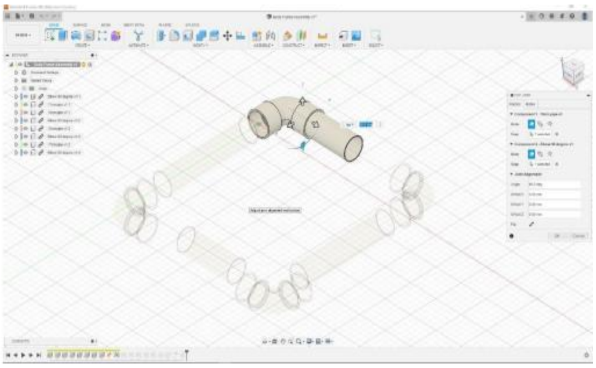


Fig. 4. The connection of 4-pipes and elbow joint

Furthermore, Figure 5 shows the design of the robot's tires according to 60-mm diameter size. For further visuals of the link Rocker and Bogie, the PVC pipes were drawn and designed clearly as shown in Figure 6. Through designing on the software, it can be seen clearly on planning to do the joining and proper type of fasteners.

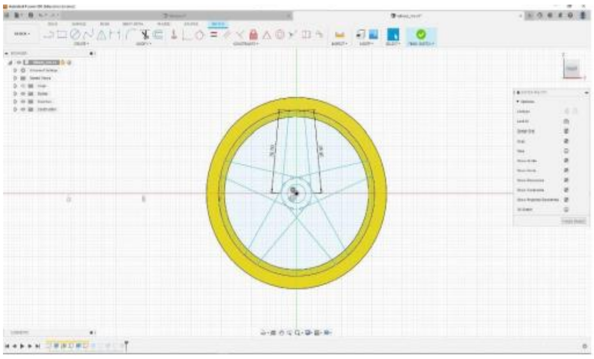


Fig. 5. Designing a tire with 60-mm diameters

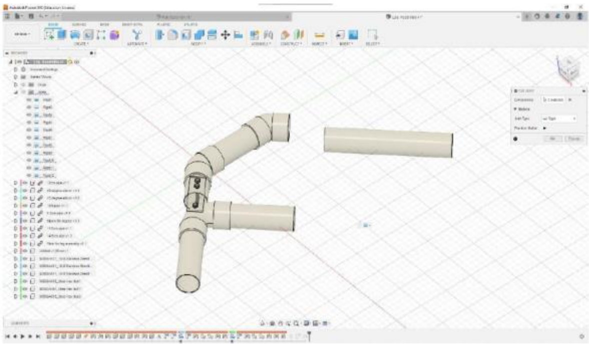


Fig. 6. The connection between two links of Rocker and Bogie system

Finally, the main body of the robot and link of Rocker and Bogie are assembled as shown in Figure 7. The AMR has six-wheeled tires, and the DC motor was attached for each link. The electric component and sensor also were placed together with the robot.

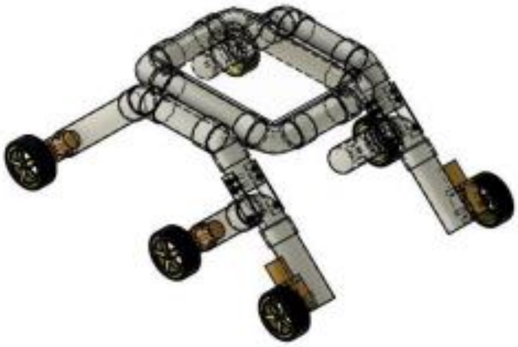


Fig.7. The AMR based Rocker-Bogie system

2.3 Fabrication the Prototype of AMR

Once the process of designing has finished, the next stage is to fabricate a prototype based on the dimensions that were calculated. The fabrication process of every part includes a main body, two links of rocker and bogie. The process of fabricating the prototype for the autonomous mobile robot can be divided into the following process steps: -

i) Preparing and gathering the materials. In this step, after creating the autonomous mobile robot (AMR) model using Fusion 360, the common materials including PVC pipe, acrylic sheets, screws, nuts, and bolts will be chosen to fabricate it.
ii) Cutting the materials to the proper and accurate size. The materials have been gathered, they need to be cut to the correct dimension and size.
iii) Drilling the holes for mobile robot. The holes need to be drilled in the PVC pipe and acrylic sheet to allow for attachment of the various components of the mobile robot. This involves screwing and bolting all the components together.
iv) Assembling the mobile robot. This step involves the assembly of two links of rocker and bogie with the main body by screwing and bolting all the parts.
v) Placing the tires on the mobile robot. The six tires have been attached with the six DC motors on the robot. The location of the tire will be placed on the end for both rocker and bogie's link.
vi) Analysing the movement of mobile robot. Once the robot has been assembled, it is important to test in order to make sure that it is functional well. This step involves moving the mobile robot through its range of motion and controlling the movement by using Android's application.

The summary of all steps in fabricating the prototype can be illustrated in Figure 8. By following the step outlined above, it can create an autonomous mobile robot that is functional and capable of performing a variety of tasks such as being able to move in different terrains like grass, smooth surface, as well as rough surface.

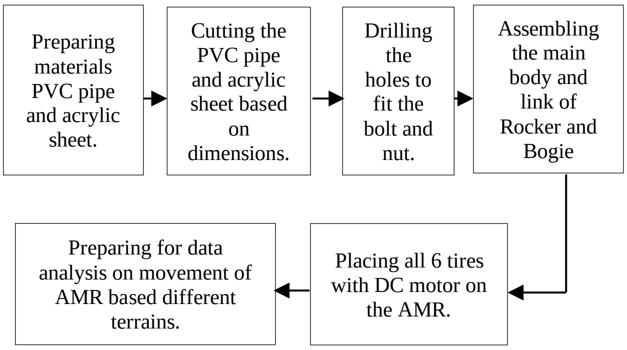


Fig. 8. The steps of fabrication of prototype of AMR

Table 2 shows the details of dimensions of the prototype for the robot. Meanwhile, Figure 9 shows the prototype that had been assembled with PVC pipe.

Table 2. Details of the prototype of AMR

Criteria	Details information
Size	355 mm (W) x 460 mm (L) x 228 (H)
Number of tires	6 tires (3 wheels on each side)
Movement	Turn right and left, forward and backward movement
Weight	2.5 Kg
Actuator	DC motor
Power	9 -12 V
Controller	Arduino 32 ESP

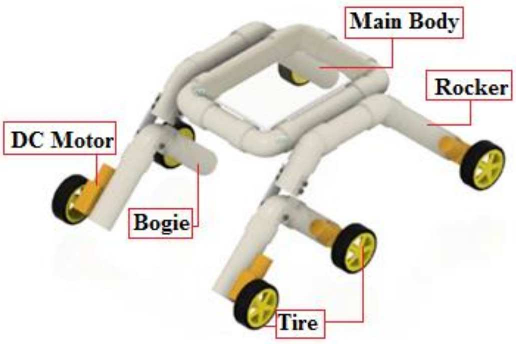


Fig. 9. The prototype of autonomous mobile robot (AMR)

2.4 Implementation the Prototype with Electronics Component

Finally, testing the performance of the autonomous mobile robot (AMR) based on the Rocker-Bogie mechanism via implementing the prototype and electronics component. By testing the AMR on different types of surfaces, it can gain insights into its capabilities and limitations. For example, it can see how the AMR can handle the rough terrain, travel on smooth surfaces as well as how it responds to the obstacles. This information will be valuable in improving the design of the AMR and making it more robust and versatile.

In the circuit installation, the electric circuit was firstly tested by using Proteus software as illustrated in Figure 10. In this work, the Blynk apps also was introduced for allowing users to control the AMR manually or automatically. Overall, the implementation and fabrication process of AMR were successful, where the AMR is a promising technology with the potential to be used for a variety of applications such as for outdoor environments.

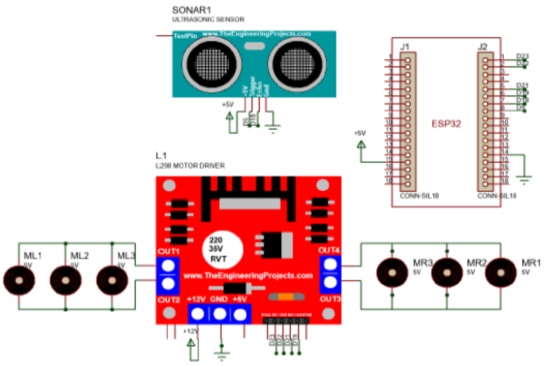


Fig. 10. The connection of electronics component (sensor, motors, motor drive and ESP32)

In the AMR based on the Rocker-Bogie system, the HC-SR04 ultrasonic sensor was used to detect obstacles in front of the robot. The sensor detects the obstacles through ultrasonic waves [22]. By using the sensor, it allows the robot to avoid collisions and to navigate safely around its environment. This sensor is also a popular choice for robotics projects because it is affordable, easy to use, and has a good range of detection. The range of limitation of the HC-SR04 is up to 400 cm, and it can detect small objects like 2 cm in diameter.

Once the electric circuit has been completed, the circuit will proceed through a testing phase to verify its adherence to the programmed algorithm in the project plan. Subsequently, the complete algorithm will undergo testing to assess its compatibility with the provided input. Successful validation of the algorithm against its intended plan enables progression to the implementation phase for both circuit and software components. During the process of testing the code, the software operates in tandem to ensure comprehensive validation of the code's functionality before it can be successfully uploaded to the Arduino ESP 32. Finally, the Blynk software has been implemented via a smartphone to enable the robot's control, whether in automated or manual modes. A graphical user interface (GUI) embedded within the smartphone facilitates the robot's manipulation, allowing it to perform forward, backward, left, and right motions.

3. RESULTS

To understand the operation based on the efficiency of the autonomous mobile robot (AMR), a series of tests were conducted to analyze its performance across various surface types. These tests were carried out in pursuit of comprehending and determining the extent to which the project's overall objectives were realized. The experimentation is diverse surface conditions, including rough, smooth, and uneven grass surfaces. In order to ensure the precision in the results, the AMR tests were conducted three times over the same total distance.

There are two methods that were approached in handling and controlling the movement of AMR: - manual and automated mode. For manual control, a human operator directly manipulates the AMR's movement. In this method, the graphical user interface (GUI) on a smartphone was used in order to provide real-time commands for the robot's motion, direction, and speed. On the other hand, automated control relies on the pre-programmed algorithms and sensors to guide the AMR's action. The ultrasonic sensor was used to navigate and respond to its surroundings. This mode eliminates the need for real -time human invention during routine tasks.

The data was gathered through experimentation aimed at evaluating the performance of the mechanism under varying surface conditions with two control modes, either in manual or automated. To ensure precision in the findings, a standardized demonstration involving a 3-meter distance was conducted on each surface, with time measurements recorded and the process repeated three times to ensure accuracy. The recorder data for each surface type, namely rough, smooth, and grass, are presented in Table 3 through Table 4 in both modes.

Table 3. Study the Performance of Rocker-Bogie Mechanism on Manual Control in Three Different Surfaces

Type of terrains	Time (seconds)			Average (seconds)
	1st reading	2nd reading	3rd reading	
Rough surface –road	7.18	7.03	7.45	7.22
Smooth surface – Cemented floor	6.23	6.27	6.45	6.37
Uneven surface – grass/scattered	21.15	22.09	24.60	22.61

Table 4. Study the Performance of Rocker-Bogie Mechanism on Automated Control in Three Different Surfaces

Type of terrains	Time (seconds)			Average (seconds)
	1st reading	2nd reading	3rd reading	
Rough surface –road	22.67	25.44	28.01	25.37
Smooth surface – Cemented floor	20.34	20.96	22.70	21.33
Uneven surface – grass/scattered	68.2	68.15	70.00	68.78

Based on the data in Table 4 and Table 5, it is shown that across all three types of surfaces, the AMR exhibits quicker movement on a cemented floor or on surfaces that are smooth and slippery. This enhanced performance in shorter time spans could be attributed to the reduced need for significant forces when the AMR moves forward and backward on these smooth and slippery surfaces. In contrast, when navigating roadways or rough terrains, the AMR takes a slightly longer duration compared to the smooth and slippery surfaces. This discrepancy in time could be attributed to the surface conditions, wherein the AMR encounters more resistance and requires additional effort to move along the road surfaces. Notably, among the three surface conditions, the grassy surface stands out as it necessitates the longest duration in seconds for the AMR to achieve movement.

From observations made during the demonstration, it was noted that the dimensions of the tires play a significant role in influencing the performance of the Rocker-Bogie mechanism on grassy surfaces. This is particularly pronounced because the grassy terrain is characterized by its rough and uneven nature. As a result of these surface conditions, coupled with the specific size and dimensions of the tires, the AMR needs to exert more force to navigate across the grassy surface.

Figure 11 presents the comparison between manual and autonomous control modes. The graph illustrates that automatic modes exhibit a duration that is twice as long as manual modes. The increase in time taken for performance in contrast to manual control can be ascribed to the instability in connection and the state of the autonomous control system such as weak Wi-Fi signal. In such a situation, the remote's autonomous control system might struggle to maintain a consistent and reliable connection to the control centre, leading to delays in commands and responses.

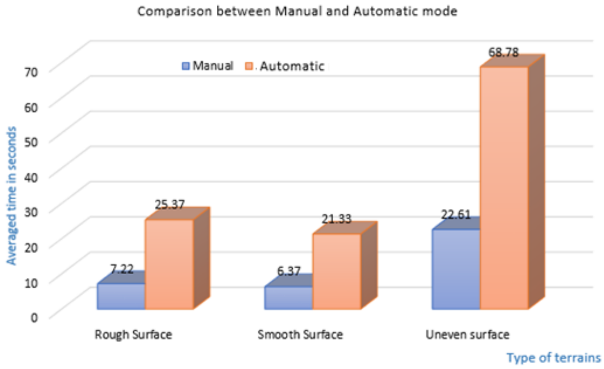
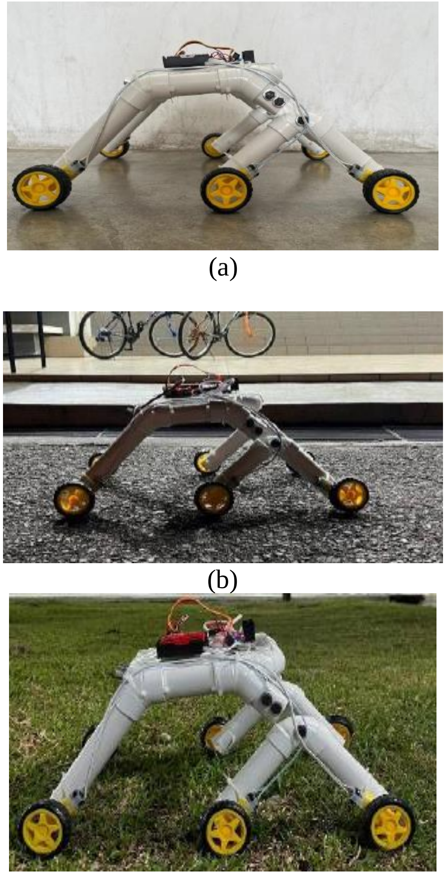


Fig. 11. The comparison between manual and automatic mode

According to the practical testing conducted on the Rocker-Bogie system, it was determined that the performance is acceptable. The outcomes of tests conducted on the different obstacles and surfaces are depicted in Figures 12 (a) to Figure 12 (d). For climbing the staircases, the robot capability to surmount obstacles and maneuver across uneven terrains.



(a)

(b)

(c)

(d)

Fig. 12. The movement of AMR's robot in terrain condition: (a) smooth surface (b) rough surface (c) uneven surface (d) during climbing the stairs.

4. CONCLUSION

In conclusion, the work's demonstration and innovation have successfully fulfilled the main objectives. The findings show that the AMR utilizing the Rocker-Bogie mechanism has achieved the desired performance, which is the data collected that reveals that the AMR can perform well in the various surfaces. Moreover, differences in the time it took were noticed on the three surfaces. These variances might be due to the conditions of the surface, suggesting that more obstacles lead to the AMR moving slower. To attain the precise and accurate results, an increased number of experiments is necessary to validate its performance, consequently affecting its mobility. Comparing the performance between manual and automated control modes, the autonomous mode takes much more time for the robot to start moving compared to the manual mode. This takes a longer time to finish the 3-meter track on different surfaces. For future research, the AMR will work better if the tires for six wheels need to be wider and larger. When the tires are bigger, the Rocker-Bogie system performs better on the different surfaces, especially outdoors. Another suggestion in the next study is to improve the performance of the robot by implementing the high spec of DC motor, add on the webcam like spy webcam and apply the industry sensor.

ACKNOWLEDGEMENT

This research was funded by a grant from Ministry of Higher Education of Malaysia (FRGS Grant FRGS/1/2022/TK10/UITM/03/11) and many thanks to Final Year of Mechanical Engineering, Universiti Teknologi Mara as well as Universiti Teknologi MARA Cawangan Pulau Pinang Kampus Permatang Pauh.

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