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Initial Design of Automated Latex Cup Robot Collector on Rough Terrain

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ABSTRACT

Despite the growing demand in rubber products, the world rubber production has declined in recent years. In this paper, a prototype of an automated latex cups collecting robot is constructed to assist the workers in the latex collection process. This robot is constructed on a mobile platform with a rear-wheel drive, double wishbone suspension, Ackermann's steer transmission, motor-driven Four Degree of Freedom (DoF) manipulator arm and a latex storage tank. Ultrasonic sensors and camera are employed to locate the position of rubber trees and latex cups. The developed prototype robot has undergone the functional test to verify the control system, in which the robot can collecting the latex cup located at the height of 105 cm and 160 cm. In the mobility test, the robot can overcome obstacles of 15 mm height. While in the static test, the platform and the robotic arm can withstand the stress in the range of 107 N/m2. In the balance test, the topple angle is more than 40°, guaranteeing the stability of the robot platform. Those results showed that the prototype design is feasible to perform basic tasks automatically in the unstructured terrain of rubber plantation.

Keywords: Latex cups collector robot; 4 Degree of freedom robotic arm; automated robot; rear wheels drive robot; control system

INTRODUCTION

Industry 4.0 revolution is the major developing direction of technologies. It introduces the development of robotics, automations, and the Internet of things (Martin et al. 2021). As the compared to manpower, the robots are more effective in prolonged operating period, when the stable power source is provided. Since the total daily working period of humans is limited since humans can become exhausted. Also, robots are obtaining better accuracy on the condition of the working environment with the help of sensors that are having higher reliability. Control systems are needed to dedicate the task to the robots and hence robots can perform the operation to settle human's specific demands. Embedded system is the most common type of control system that has been always applied to complete a specific task.

The applications of robots in agriculture, office and industries are growing in assisting humans to overcome many tasks and demands (Javaid et al. 2021). In this paper, a robot is presented in providing service in the agriculture sector for latex cup collection, which is inspired from the high demands of the rubbers in Malaysia. However, the rubber production in Malaysia is declining due to the reduction in available workforce, primarily caused by the potential health risk for this job such as Ocular diseases (Gopal et al. 2021) and musculoskeletal disorders (Meksawi, Tangtrakulwanich and Chongsuvivatwong, 2012), which further made worse due to the low market price of rubber (Kang, 2021), leading to the reduction in rubber production. To address this issue, robots can be introduced in rubber tapping, improving the working efficiency while adapting the trends in autonomous machines (Nuanmeesri and Poomhiran 2020).

Liquid latex are the essential materials for the gloves and other latex products which are in high demand in market instead of hardened lump form latex. Hence, the latex cup collector robot can contribute to solve this issue to increase productivity and reduce workload. Also, there is one invention on the latex harvesting process (Kang et al. 2021) but its design is not favorable to unstructured environments. Thus, a modified version of latex cup collection robot is designed and developed in this paper in hopes to increase the robustness and the reliability to perform the latex harvesting process in rubber plantation.

For agricultural robots, the three common locomotion methods are legs, track and wheels. For leg locomotion, it is advantageous to be used in the agriculture field due to its flexible movement towards the high occlusion of obstacles (Fue et al. 2020). However, as the slope increases, the robot platform can suddenly fluctuate to achieve balance (Zhang et al. 2019). Whilst track locomotion can travel on soft terrains such as mud or sandy surfaces (Bruzzone and Quaglia 2012). However, this locomotion method is not speed and energy efficient (Bruzzone and Quaglia 2012). Furthermore, the large vibrations due to the motor rotation may lead to the spoilage of the liquid onboard (Wickramanayake 2020). For robots in agricultural applications such as latex cup collections, it is challenging to operate in ill-defined and unpredictable events (Bechar and Vigneault 2016). Hence, the leg and track locomotion methods are not suitable for robots transporting liquid products, such as the robot used in this project.

For robots adopting wheel locomotion, speed performance is the key advantage to be considered in agricultural robots. Hence, most agricultural robots employing wheels as the locomotion method (Oliveira et al. 2021). However, wheeled robots could be strongly affected by unstructured terrain (Oliveira et al. 2021). Various researchers proposed several methods to address the issue of unstructured terrain, such as separating the rear wheels and front wheels by two independent moving axles that could be turned vertically when confronted with obstacles (Nakajima, 2011), or by using a six-wheel transformable mobile robot which can transform link and wheels to encounter different types of terrain (Kim, Jeon, and Yang 2017). Furthermore, one of the important aspects of the agricultural robot's ability to overcome unstructured environments is the suspension system (Pastor et al. 2018). It is mostly used for wheeled robots due to their constant contact with the ground. Thus, with the help of external mechanisms such as steering and suspension, wheel robots can perform greatly at low cost, high speed, and low power consumption which is adopted in the robot presented in this paper.

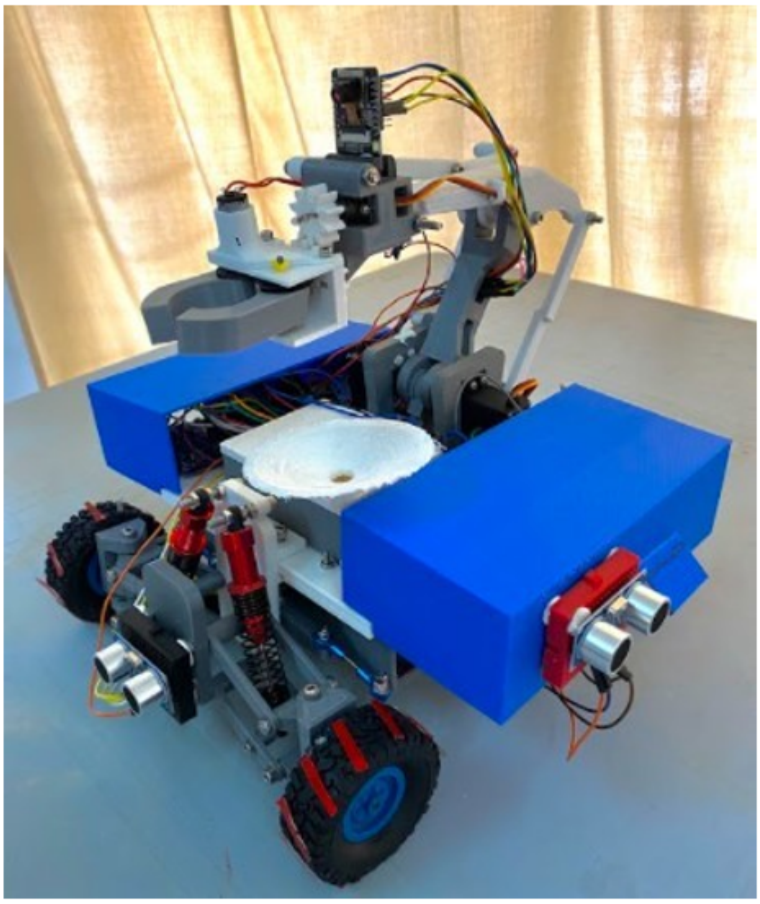

FIGURE 1. Prototype of Latex cup collector robot.

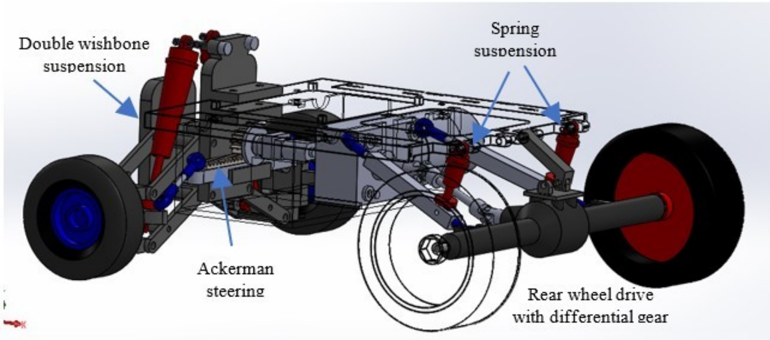

FIGURE 2. Locomotion Design.

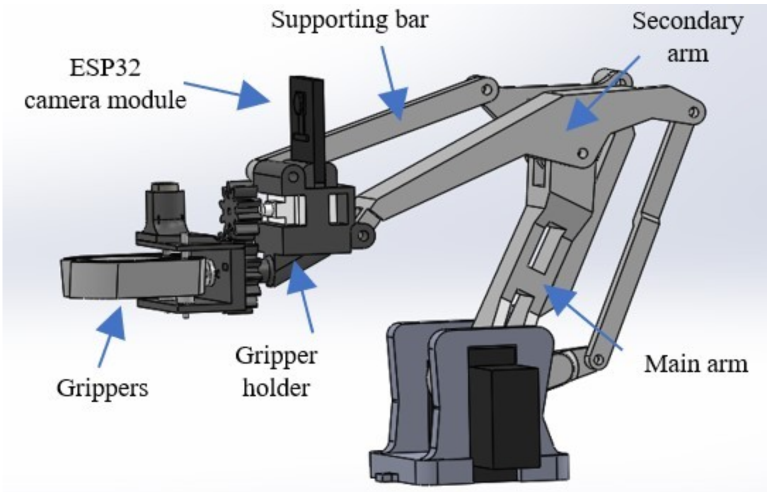

FIGURE 3. Manipulator Design.

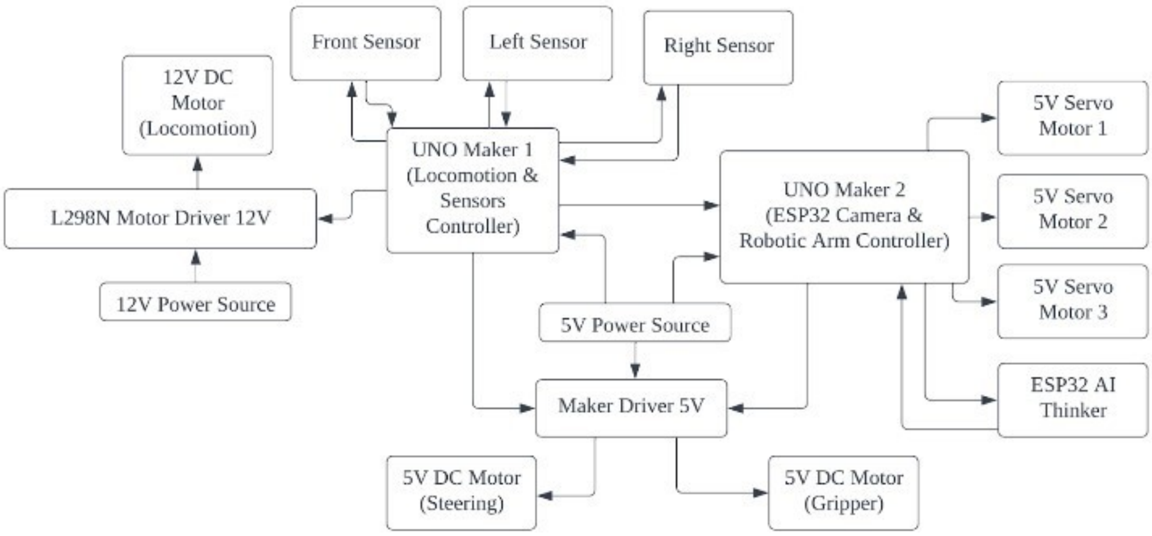

FIGURE 4. Block Diagram of the Robot Controller.

METHODOLOGY

In this section, the latex cup collector robot is presented in detail. The robot prototype is shown in Figure 1. The constructions of the robot are divided into two subsections which are the mechanical design and the controller design.

MECHANICAL DESIGN

The latex cups robot collector is designed using a 3D modeling software called Solidworks After that, the designed parts are fabricated by 3D printer with Polylactic acid (PLA) plastics as the base material. This robot consists of a locomotion subsystem, manipulator subsystem, a latex tank, and a platform.

In the locomotion subsystem, it consists of 4 wheels and the transmission used is rear wheel drive with differential gear which is driven by using a 12V DC motor. Rear wheel drive ensures stable and straight transmission while differential gear provides good traction with minimum wheel wear. So, this will ease the robot transmission in the rubber plantation. Besides, Ackerman steering is designed for front wheels. Different turning wheels radii of this mechanism provides greater steered angle and ensures the robot to turn with a shorter path and save time. Double wishbone is chosen for the front suspension while spring is for rear suspension as they ensure big vertical movement of wheels, making the robot able to cross obstacles with less platform tilting. Figure 2 shows the locomotion design in Solidworks. These designs provide a good condition for the robot to travel on unstructured terrain.

For the manipulator subsystem, it is a 4 Degree of Freedom (DoF) robotic arm. The first DoF is to move the main arm forward and backward, then the second DoF is to move the secondary arm up and down. The third DoF ensures the open and close of the gripper and fourth DoF is for the gripper rotation. This robotic arm is designed to grab the latex cups at different heights. As shown in the figure 3, a supporting bar is designed to let the gripper stay parallel to the platform so that it can grab the latex cups tighter and steadier. This design also reduces the use of one extra motor to control the movement at that point. Next, a ESP32 AI thinker is placed on top of the gripper holder to determine the height of the latex cup before the robotic arm executes its action.

The latex tank is designed to be rectangular in size and is placed on the robot platform. To transfer the latex from the cups to the tank, a funnel is designed to give a big allowance for the pouring latex to transfer into the tank without spilling out. Besides, two boards are placed horizontally at the side of the platform to store electronic stuff such as chips, wires, and batteries. Covers are built for these two boards to protect them from water and any sort of damage.

CONTROLLER DESIGN

Figure 4 shows the block diagram of the control system. The controller of the latex cup collector robot consists of two main parts, which are the locomotion and robotic arm. These two parts are controlled by two different chips. The directions of the arrows in Figure 4 indicate the connection between the blocks and components and also the direction of the transmitting of signals or instructions. The UNO Maker 1 Chip controls the activation of three ultrasonic sensors (front, left, and right sensors) and receives the signals from these sensors. The rotation of the two rear wheels is controlled by the UNO Maker 1 and the L298N motor driver, which drives the 12 V DC motor. Besides that, the steering action is also controlled by the UNO Maker 1 Chip, which steers the two front wheels by controlling the Maker Driver to drive the 5V DC Motor. Then, the UNO Maker 1 Chip sends instructions to the UNO Maker 2 Chip to transmit the trigger signals to activate the robotic arm and ESP32 camera when the conditions are fulfilled.

EXPERIMENT EQUIPMENT

The decision-making process is managed by the UNO Maker 2 Chip, which also controls how the ESP32 AI Thinker is activated and receives data from it. The UNO Maker 2 Chip also manages three servo motors that determine the length of robotic arms. Lastly, this chip also manages the Maker Driver, which drives the 5 V DC motor, to control the Gripper's condition.

Figure 5 illustrates the test module for the robot that collects latex cups. The locations of the rubber trees are shown by the black squares with number labels. The moving direction of the robot is indicated by the blue arrows, while the walls are represented by the green rectangle blocks. Ultrasonic sensors are employed in determining the location of the rubber trees (Zhmud et al. 2018). During the front row check, the front and left sensors are activated by the robot. When the left sensor detects the presence of rubber trees, the robot will move to the front of the rubber trees to collect the latex cup. This process is repeated until arriving at a wall that blocks the robot. This condition will trigger the robot, causing it to move to the next row, turning off the left sensor and turning on the right sensor for next row checking. The cycle of collecting the latex cup is then repeated as shown in Figure 5.

RESULTS AND DISCUSSION

This section presents the experimental testing results of this latex cup collector robot prototype. Functional, mobility, static and balancing tests are carried out to test the performance of the robot for latex cup collecting working cycle and the mechanical stability of the prototype robot.

FUNCTIONAL TEST

The functional test is divided into two parts. In the first functional test, the robot needs to perform navigating, sensing, and manipulating on its own. Figure 6 shows the working cycle of the prototype in collecting the latex cup for one rubber tree. A plastic bottle is located on the left of the robot to emulate a rubber tree. The distance between the prototype and tree is set at 600 mm to provide enough spacing for the prototype robot to turn towards the tree. It takes 105 seconds to complete a working cycle, and most of the time is spent on navigating and travelling.

Whilst in the second functional test, the testing on the working of the robotic arm is carried out. To test the ability of the robotic arm to reach the target at different heights, two latex cups located on different bottles, positioned at the height of 105 cm and 160 cm from the floor are used. Each bottle is adhered with a QR code to store the height information of the latex cup. The ESP32 AI thinker is employed to scan the QR code, determining the height, before controlling the movement of the robotic arm to reach the target. From the video snapshots shown in Figure 7, the robotic arm performs the tasks perfectly.

MOBILITY TEST

This robot is designed to encounter unstructured terrain in the rubber plantation. As mentioned above, both the front and rear wheels are equipped with suspension systems. To test for its mobility, two blocks (both with 15 mm height) act as barriers and are located at the left and right sides for the prototype to travel across. Figure 8 shows the video snapshot of the case. From Figure 8, a slight tilt is observed on the prototype. This is due to the speed of the robot being slow, leading to less impact to compress the spring. However, the prototype has sufficient power to overcome the obstacle and barrier.

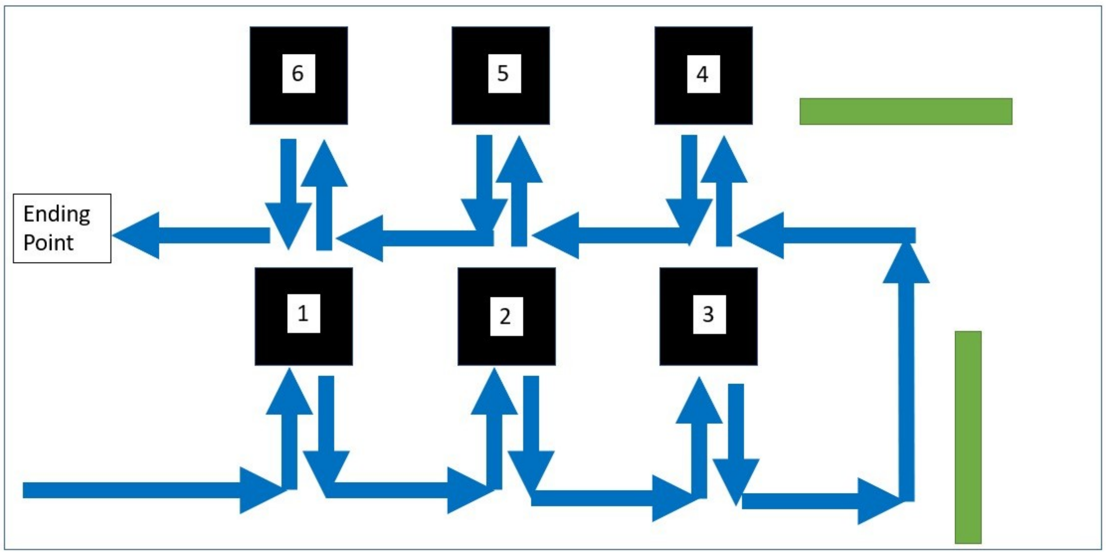

FIGURE 5. Pathing Order and Moving Mechanism.

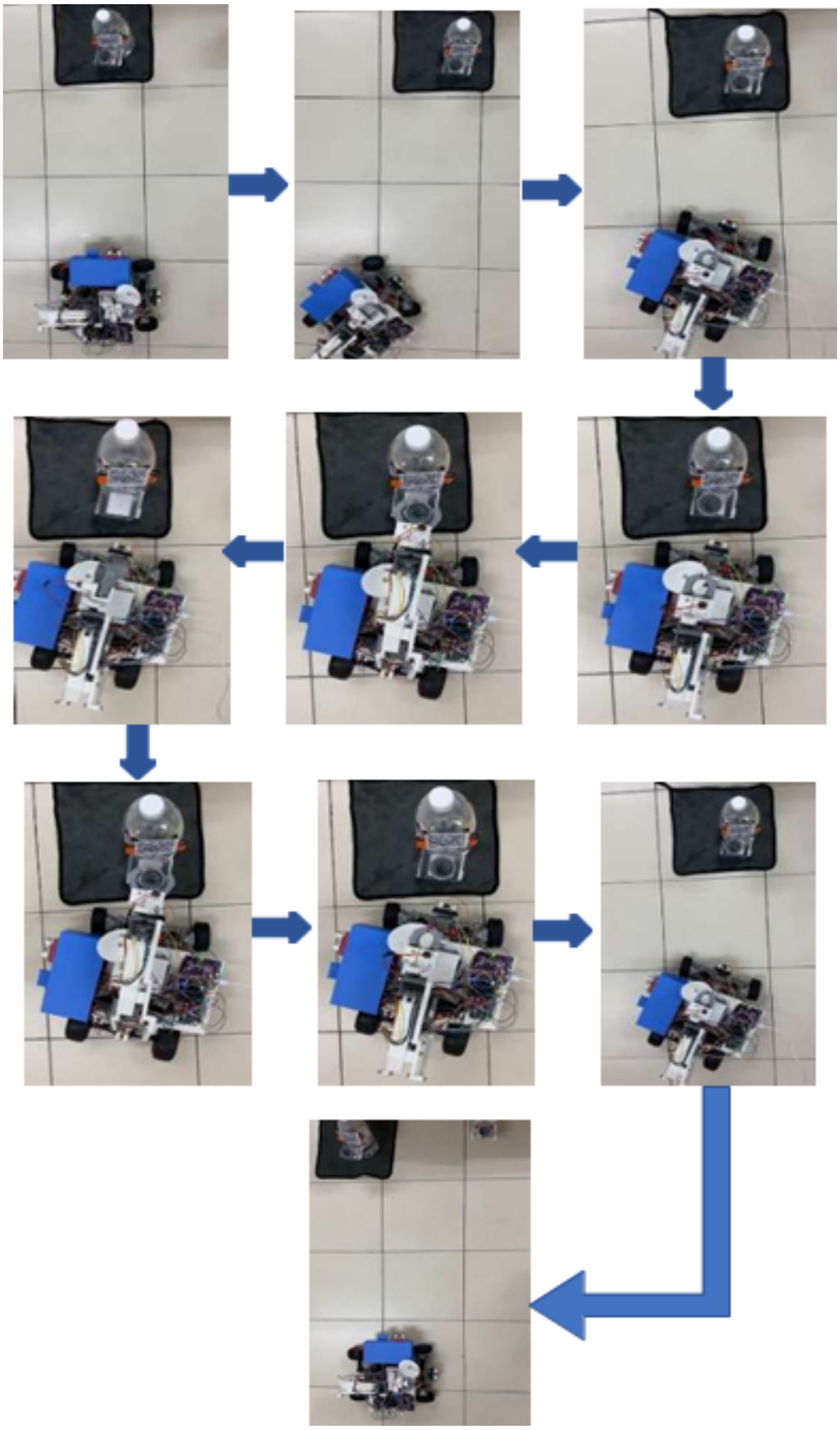

FIGURE 6. One Working Cycle of the Prototype in Latex Cup Collection.

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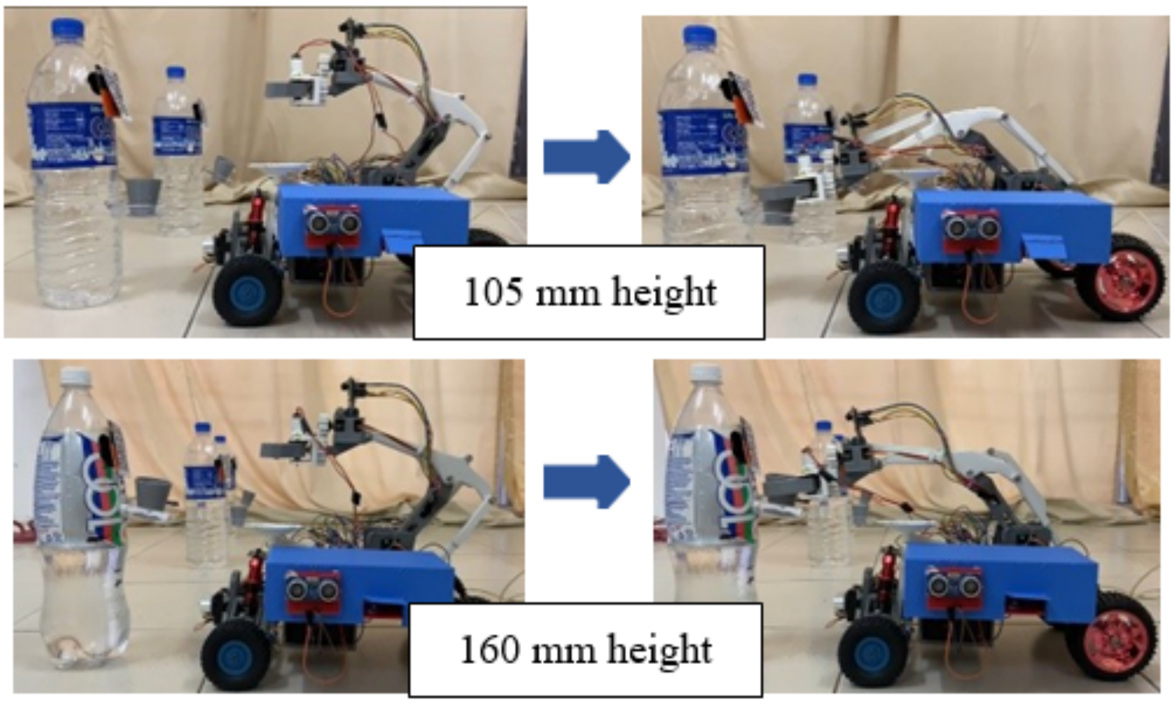

FIGURE 7. Testing the Robotic Arm with Different Height.

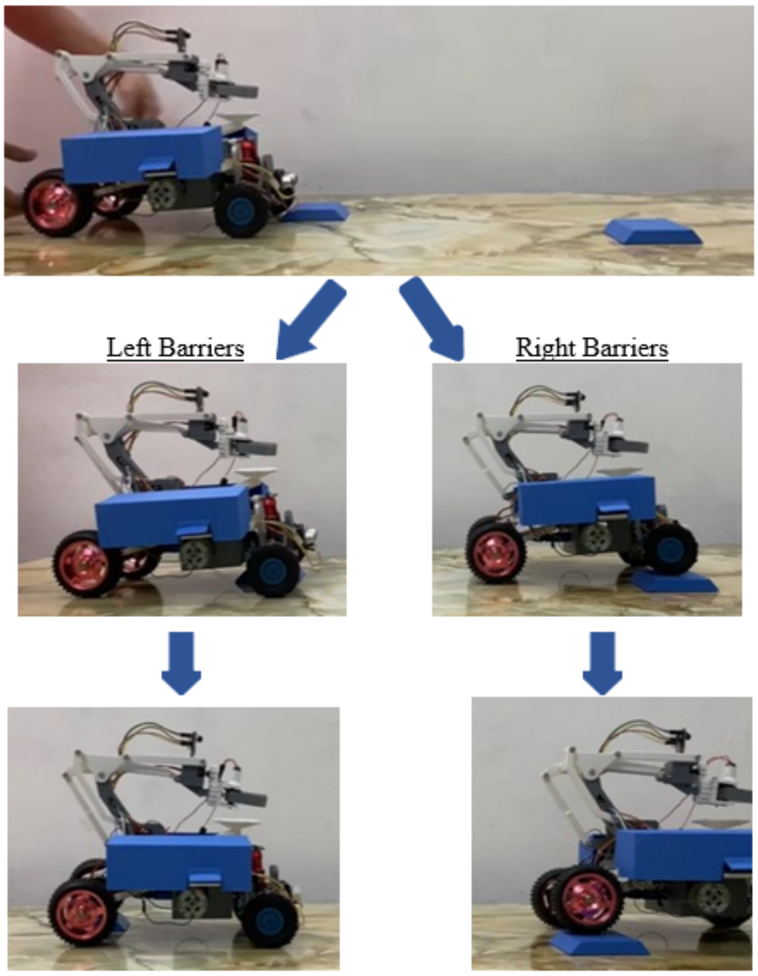

FIGURE 8. Testing the Robotic Arm with Different Height.

TABLE 1. Maximum Stress, Displacement, and Strain.

	Maximum Stress (N/m2)	Maximum Displacement (mm)	Maximum Strain (N)
Robot Platform	2.589×10^{7}	1.494×10^{-1}	3.551×10^{-4}
Robotic Arm	8.676×10^{7}	1.868×10^{-1}	1.683×10^{-4}

TABLE 2. Calculated and Experimental Topple Angle.

	Front	Rear	Left	Right
Calculation	52.08°	52.35°	52.3°	52.04°
Experimental	43° - 47°	41° - 45°	46° - 50°	47° - 52°
Error (%)	15.71	21.74	8.96	6.20

STATIC TEST

From the perspective of design, robot platform and robotic arm are the two parts that experiences larger loads and forces. However, from the Table 1, we observed that both parts mentioned will not be broken as the maximum stress experienced is not beyond the yield strength of the Polylactic acid (PLA) plastics, which is 7.00×10^{7} N/m^2.

BALANCE TEST

The terrain in rubber plantation is unstructured, the balancing of this robot is also one of the prior factors to be verified. So, topple angle of all four sides of the robot are calculated and the actual topple angles are determined. From Table 2, we can observe that the actual values are lower than the calculated values. However, these values also prove that this robot will not topple in the rubber plantation.

CONCLUSION

In this paper, we design a latex cup collector robot that can detect the existence of the rubber trees, then moves to the front of the tree and performs the collecting operation. Also, this robot can grip the latex cup with different vertical positions due to its 4 DoF robotic arm. Besides, by the design of the suspension system, this robot can also travel on unstructured terrain without big platform fluctuation. Lastly, this robot is mechanical stable as it passed the static and balance test. Useful information would be provided from the outcome of this paper for future works. For the future recommendations, RWD should be replaced by better transmission to improve the path navigation as RWD takes more steps, longer time and larger space for robot turning. Besides, a new alternative power source can be considered as power limitation will affect the performance of the control system. Lastly, one additional DoF can be designed for the robotic arm so that the robot does not need to have complex path planning but letting the robotic arm do most of the task.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Basu, A., Ghosh, S. K.. & Sarkar, S. 2016. Autonomous Navigation and 2D mapping using sonar. 2016 5th International Conference on Wireless Networks and Embedded Systems (WECON). DOI:https://doi.org/10.1109/wecon.2016.7993421.

Bechar, A. & Vigneault, C. 2016. Agricultural robots for field operations: Concepts and components. *Biosystems Engineering* 149: 94-111. DOI:https://doi.org/10.1016/j.biosystemseng.2016.06.014.

Bruzzone, L. & Quaglia, G. 2012. Review article: locomotion systems for ground mobile robots in unstructured environments. *Mechanical Sciences* 3(2):49-62.

Fue, K., Porter, W., Barnes, E. & Rains, G. 2020. An extensive review of mobile agricultural robotics for field operations: focus on cotton harvesting. *AgriEngineering*, 2(1):150-174.

Gopal, B., Isaac, I., Shankar, A., Banna KM, H. & Rajendran, N. 2021. Prevalence and risk factors of ocular diseases and injuries among rubber tappers in a rural area in Kanya Kumari. *Paripex Indian Journal of Research* pp.69-71.

Kang, S. J. 2021. Design and development of a controller for latex cups collector robot [Bachelor's thesis, Universiti Tunku Abdul Rahman]. Universiti Tunku Abdul Rahman.

Kang, S., Wong, C., Lim, C. & Tan, Y. 2021. Design and development of an automated robot for collecting latex cups in rubber plantation. IOP Conference Series: Earth and Environmental Science, 945(1), p.012015.

Javaid, M., Haleem, A., Singh, R. & Suman, R. 2021. Substantial capabilities of robotics in enhancing industry 4.0 implementation. *Cognitive Robotics* 1:58-75.

Kim, I., Jeon, W. & Yang, H. 2017. Design of a transformable mobile robot for enhancing mobility. *International Journal of Advanced Robotic Systems* 14(1): 172988141668713.

Lee, S. Y., Yeoh, K. S. & Soetedjo, A. 2008. Developing a blind robot: Study on 2D mapping. In: 2008 IEEE Conference on Innovative Technologies in Intelligent Systems and Industrial Applications. DOI: 10.1109/CITISIA.2008.4607326.

Mardiyanto, R., Anggoro, J. & Budiman, F. 2022. 2D map creator for robot navigation by utilizing Kinect and rotary encoder. In: 2015 International Seminar on Intelligent Technology and Its Applications (ISITIA).

Martins, R., Mak, P., Chan, C., Yin, J., Zhu, Y., Chen, Y., Lu, Y., Law, M. & Sin, S. 2021. Bird's-eye view of analog and mixed-signal chips for the 21st century. *International Journal of Circuit Theory and Applications* 49(3):746-761. DOI:https://doi. org/10.1002/cta.2958.

Meksawi, S., Tangtrakulwanich, B. & Chongsuvivatwong, V. 2012. Musculoskeletal problems and ergonomic risk assessment in rubber tappers: A community-based study in southern Thailand. *International Journal of Industrial Ergonomics* 42(1):129-135.

Nakajima, S. 2011. RT-Mover: a rough terrain mobile robot with a simple leg–wheel hybrid mechanism. *The International Journal of Robotics Research* 30(13): 1609-1626.

Nuanmeesri, S. & Poomhiran, L. 2020. Improving rubber cup lump production process efficiency using iot for smart farmers in Thailand. *International Journal of Control and Automation* 13(2):1738-1746.

Oliveira, L., Moreira, A. & Silva, M. 2021. Advances in Agriculture Robotics: A State-of-the-Art Review and Challenges Ahead. *Robotics* 10(2):52.

Pastor, R., Vysocky, A., Siroky, P., Konecny, Z. & Karnik, L. 2018. Use of different simulation methods for design of experimental rover. *MM Sci. J.* 12(2018):2616-2620.

Wickramanayake, P. 2022. Hybrid locomotion for agricultural robotic platform. Master's dissertation, Massey University. Massey University.

Zhang, F., Wang, Y., Teng, S., Zheng, L., Wang, J. & Chen, Z. 2019. Development of agricultural bionic four-legged robot: Effect of head movement adjustment on the stability of goats. *International Journal of Agricultural and Biological Engineering* 12(4):10-15.

Zhmud, V. A., Kondratiev, N. O., Kuznetsov, K. A., Trubin, V. G. & Dimitrov, L. V. 2018. Application of ultrasonic sensor for measuring distances in robotics. *Journal of Physics: Conference Series* 1015, 032189. DOI:https://doi.org/10.1088/1742-6596/1015/3/032189.