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Study on Mechanical Structure Design for Plug-and-play Wheel Mobile Robot

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Abstract: *In the field of wheel mobile robots, researchers focused on learning and developing new algorithms to improve robot capabilities. But the lack of the actual hardware along with expensive costs has limited the study to only simulation. Furthermore, the result from simulation alone cannot conclude the robot's actual performance in real-time. A plug-and-play robot structure is designed and tested for its function. In addition to that, finite element simulation is used to analyze stress and displacement for avoiding the change in the mobile robot shape which affects wheel kinematics or deforms to fracture the body that makes the mobile robot inoperative. The goal of the design is to enable mobile robots to have different types of wheels and still function flawlessly. The simulation of the mobile robot body's mechanical strength can guarantee a certain final result. The plug-and-play wheel mobile robot is a platform for researchers to test software or algorithms to obtain real-world results from four different types of robots by using only one reconfigurable mobile robot platform. It can be reconfigured into 4 types such as differential drive with castor, three-wheel Omnidirectional drive, Omnidirectional drive with four Mecanum wheels, and Omnidirectional drive with four Omni wheels. The structure was made with acrylic and aluminum profiles. This design and the finite element simulation are done on Solidworks software. The average reconfiguration time from one wheel robot type to another is 16min and 11s. The movement result shows that the forward, backward, left, right, and rotation works well, and robots can go at full speed without failure. By comparing the price of this plug-and-play mobile robot to the cost of purchasing 4 separate mobile robots to perform the same task with the same performance but with a little extra time to change its wheel, it is anticipated to save about 70%.*

Keywords: Wheel Mobile Robot, Plug and Play, Structure Design, Omni-directional Drive, Mechanical Design

1. INTRODUCTION

Wheel mobile robots are robots that can move from one place to another place by using wheels. Wheel mobile robots are very popular because they are appropriate for typical applications with relatively low mechanical complexity and energy consumption. Nowadays, wheel mobile robots are used in numerous applications such as medical services, operation support, laboratory analyses, cleaning applications, applications in agriculture, and especially, systems at research institutions aimed at learning and developing new Algorithms. Most mobile robots are constructed with rigid structures that prevent any of the robot components from being changed. It is limited to performing one application only. An idea to create a reconfigurable structure has been applied to overcome this limitation of mobile robots. Plug-and-play mobile robots are mobile robots that can be used in a variety of applications by changing their structure. A plug-and-play standard for robotics would catalyze dramatic growth by transforming the structure of the industry from vertical integration (one-company integration) to horizontal integration (multi-company integration) [1].

To improve the capabilities of wheel mobile robots, researchers focused on learning and developing new algorithms that allow robots to perform specific tasks. Since the simulation result is proven to be insufficient for the research conclusion, algorithms must be tested on various types of robots in real-time. There are four common types of mobile robots such as differential drive with castor, three-wheel Omnidirectional drive, Omnidirectional drive with four Mecanum wheels, and Omnidirectional drive with four Omni wheels. The researcher needs to buy 4 separate wheels mobile robots to experiment on 4 different types. Instead of buying those 4 robots, they can just change the wheels on the reconfigurable wheel mobile robot. It will save a lot of money. A plug-and-play mobile robot that can change its structure to four different types of mobile robots is proposed to solve this problem. The free-to-change electronic part such as microcontrollers, sensors, and actuators with easy plug-and-play input and output ports will give a robot absolute freedom of usage.

The Leo Rover Developer Kit is produced to serve those

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purposes. In the construction kit, the small Leo Rover mobile robot bares all, from A to Z. The Leo Rover Developer Kit allows you to assemble essential components of the robot. With an internal Raspberry Pi, a powerful controller, and ROS-based software, it is ready to begin programming. However, it is so expensive that it is not affordable for researchers and students.

A low-cost mobile robot for engineering education had been developed by [2] at Instituto Superior Tecnico to use this low-cost mobile robot as a platform for complementing university laboratories. This robot uses motors from electrical screwdrivers, a normal laptop as a processing unit, low-cost webcam as a sensor. All these components of a robot are enough to have the feature that allows the student to learn and prepare for local robotics competitions for as low as the cost of 200 Euro [2].

Another robot had been developed at the University of Manchester for swarm robotic research studies. The robots are operated using a user-friendly interface, Arduino with relative ease [3]. The limitation of its application is just to be used in swarm robotics and the fixed microprocessor which makes this robot not able to serve as a general laboratory research platform. These two previous academic research robots are lack plug-and-play features and reconfigurable.

A reconfigure mobile robot name AZIMUT-2 is a four-steered wheeled mobile robot that allowed us to create an innovative omnidirectional non-holonomic robot. The novelty of this wheel concept resides in the non-conventional positioning of the steering axis and the wheel axis. This robot used a special design implementation of the wheel mechanism to overcome a hyper motorization issue inherent to the geometrical properties of the wheel [4].

The purpose of this study is to design, simulate, and test a plug-and-play wheel mobile robot that can be reconfigured into four different types of wheel mobile robots. Additionally, a finite element analysis will be used to visualize the deformation area and determine where to place the support that needs to be strengthened. By realizing the plug-and-play concept, our newly created mobile robot will have a fully customizable mechanical and electrical system. This means that this plug-and-play mobile robot can work as a developer kit, like The Leo Rover, or it can be used as a research mobile robot to learn about swarm robotics or to have an Omnidirectional drive, comparable to AZIMUT-2.

In general, papers will have sections for the introduction, methodology, results and conclusions; however, authors may exercise some flexibility in organizing the content of their papers.

The paper should be formatted with 1.78 cm margins on the left and right, 2.49 cm at the bottom and 3.00 cm at the top. Standard letter size (8.5” x 11”) will be used. The introduction should give a brief background of the study, describe relevant developments in the literature to date, and describe the objectives and scope of the study.

2. METHODOLOGY

2.1 Mobile robot concept

There are three types of mobile robot structures such as flexible structure, rigid structure, and reconfigurable structure. Flexible structure robots can rotate the part of the structure that connects both wheels of one side of the robot independently from the rest of the robot but the main problem with robots made with this kind of structure is the payload. Mobile robots with rigid structures are the type of robots that have a better relationship between load capacity and their weight, but they cannot be plug-and-play [5]. The reconfigurable structure allows the user to rearrange the physical components which suit our robot concept.

Three types of wheels are usually used in mobile robots such as the conventional wheel, the Omni wheel, and the mecanum wheel. The special thing about the Omni wheel is that it can move in any direction and exhibits low resistance when they move. Mecanum Wheel is also a type of Omni wheel that rollers are attached at a 45° angle around the circumference of another bigger wheel. Those three-wheel types are used in different arrangements in a mobile robot and those differences classify the types of wheel mobile robots.

The typical Mecanum-wheel-based vehicle has two wheels on each side of the frame and is square or rectangular. A vehicle may go in any direction using four wheels instead of a traditional steering system. Based on its unique wheels, the robot can move forward, backward, as well as sideways, and turn instantly. When navigating a confined space, like a factory floor, this is especially useful. In the case of our study to design a plug-and-play wheel mobile robot that can be reconfigured between four different types such as differential drive with castor, three-wheel Omnidirectional drive, Omnidirectional drive with four Mecanum wheels, and Omnidirectional drive with four Omni wheels.

The differential drive with castor is usually seen on the tri-cycle vehicle. A differential is necessary when the wheels cannot slip to avoid mechanical destruction. The omnidirectional drive can move at any time in any direction along the ground plane (x, y) regardless of the orientation of the robot around its vertical axis. This level of maneuverability requires omnidirectional wheels which presents manufacturing challenges. Four spherical wheels are used in the second omnidirectional wheel design, each powered by a different motor. On various research robots, the omnidirectional layout shown has been employed to great effect. The robot can move along any track in the plane by adjusting the relative speeds and direction of rotation of its four wheels, and even more amazingly, it can rotate concurrently around its vertical axis.

The plug-and-play wheel mobile robot should have a specific shape that can mount those kinds of wheels and wheel arrangements. Plug-and-play or modularity allows us to combine modules quite easily and gives us an almost endless variety of structure modifications afterward [6]. In our case, our plug-and-play mobile wheel robot should have the combination of differential drive with castor type, three-wheel Omnidirectional drive type, Omnidirectional drive with four Mecanum wheels type, and Omnidirectional drive with four Omni wheels type which is shown in Fig. 1 respectively.

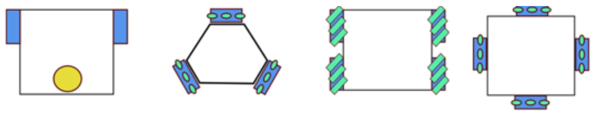

Fig. 1. Concept mobile robot wheel arrangement

2.2 Material selection

Material selection is a phase in the design of any physical object. The major objective of material selection in the context of product design is to minimize costs while achieving product performance goals. The goal of the mobile robot design is to be reconfigurable. To achieve an idea of reconfigurable, the frame structure should be easy to drill and strong but a little bit flexible. Moreover, the type of material used for the structure will determine the durability and reliability of the robot. Costs, performance, safety, risk, aesthetics, and environmental impact are the criteria to consider while selecting material for the robot's structure. The material selections are also influenced by the structure design and the environment [7]. Acrylic is a transparent plastic material with outstanding strength, stiffness, and optical clarity as shown in Table 1. Acrylic sheet is easy to fabricate, bond well with adhesives and solvents, and is easy to thermoform. It has superior weathering properties compared to many other transparent plastics. Also, acrylic has been used to produce mobile robot frames and has good feedback. Of all this proof, the mobile robot frame is decided to be made of acrylic.

Table 1 Acrylic properties

Properties	Quantity	Units
Tensile strength	42-76	MPa
Yield point	65	MPa
Density	1.2	kg/dm^3
Modulus of elasticity E	3300	MPa
Hardness	410	MPa

Aluminum Alloy 6063-T5 also known as Aluminum profiles are usually for structural purposes. In robotics, aluminum is the most popular material to design and make prototypes because of its fair price, ease of assembly, or disassembly and it can endure situations whether it is in water, a hot environment, or where the force is being pressured on due to its strong tensile strength, low density and its high number of hardness as shown in Table 2. We chose an aluminum profile for the motor module holder where the force is gathering. The connections that we usually use are the Angle bracket and L bracket. The choice of size of the aluminum profile is 20mm, 30mm, 40mm, and 40mm light. In our case, an aluminum profile was used to hold the motor module. It would be best if the aluminum profile is small then the aluminum profile with 20mm is the best choice.

Table 2 Extruded profile properties

Properties	Quantity	Units
Tensile strength	245	MPa
Yield point	195	MPa
Density	2.7	kg/dm^3
Modulus of elasticity E	70000	MPa
Modulus of rigidity	25000	MPa
Hardness	75	HB

2.3 Solidworks 3D design

Difficulty in reconfigurable robot research is mainly about new mechanisms and reconfigurable technique [8]. The mechanism is considered the bone of the robot system, which decided the basic characters and reconfigurable ability of the robot system [9].To have a plug-and-play feature, this robot structure must divide into three parts such as body, motor module, and electrical part. The body has the option of being made of acrylic which can be easily drilled for installing components from the motor module and electrical part. Motor modules consist of the acrylic motor holder, aluminum extruder motor holder, motor, motor driver, and wheels.

Since this robot structure is made from acrylic and the robot is desired to run smoothly that benefits the result of algorithms testing, a suspension system would need to be considered. The vertical suspension system that has been used in the past is not suitable for plug-and-play mobile because of its fixed and not flexible joint with the wheel [10]. An idea of dividing the mobile robot into two parts and using a shaft to make it move freely from each other. It is suitable for plug-and-play features, and it is simpler to produce. The use of this shaft is needed only for four-wheel types of robots but for three-wheel types and 2 wheels and caster wheel types already create three contact points on the ground.

There is ten-part that had been designed in Solidworks software such as a body, aluminum extruder motor holder, acrylic motor holder, motor, normal wheel, caster wheel, Mecanum wheel with a dimension of 150 mm, Omni wheel with a dimension of 130 mm, pipe, and pipe holder. The Platform is classified into three big assemblies such as body part, motor module, and electronic part. These three assemblies use removable joints that are easily put and removed, which is so-called plug-and-play. All these parts are easily purchased locally.

In this design detail, we focused on the mechanical part and motor module because the electrical parts will be used differently in accordance with the preference of the user in research. It can be reconfigured into 4 types such as differential drive with castor as shown in Fig. 2, three-wheel Omnidirectional drive (Fig. 3), in Fig. 4 shown Omnidirectional drive with four Mecanum wheels, and Omnidirectional drive with four Omni wheels shown in Fig. 5.

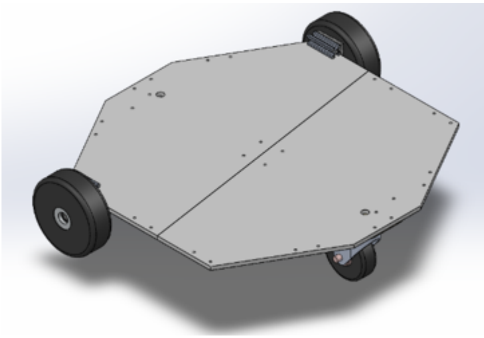

Fig. 2. Differential drive with castor type

The differential drive with the castor mobile robot (Fig. 2) is a type of mobile robot that use two wheels at the back and use the castor wheel as support. It is driven by the two back wheels which power by the motor. This type of robot can rotate or change direction by differing the speed of the two back wheels. Path-planning research frequently uses robots of this kind.

The three-wheel omnidirectional type mobile robot (Fig. 3) uses three Omni wheels at a 120-degree angle to move in any direction. Moving this kind of mobile around a small area is simple. The previous two types both have three wheels and thus three points of contact with the ground, eliminating the requirement for a suspension system.

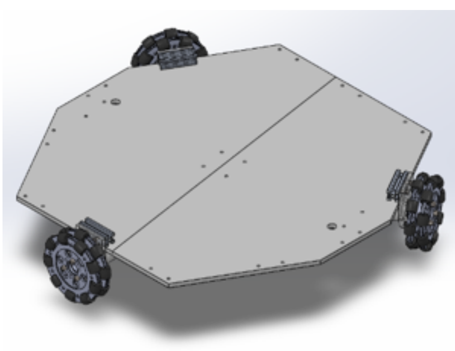

Fig. 3. Three wheels omnidirectional type

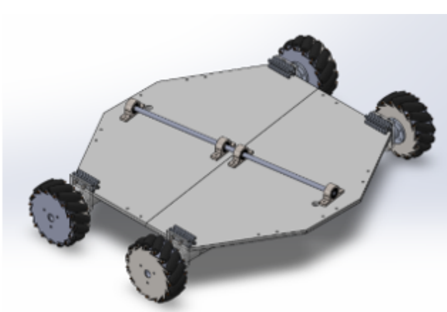

Fig. 4. Four mecanum wheels type

The four mecanum wheel type mobile robot (Fig. 4) is made of four mecanum wheels arranged in a rectangular shape. Since this robot uses a four-wheel, it needs suspension to support the robot while facing a small obstacle. It is the most popular type for industrial use on the flat floor.

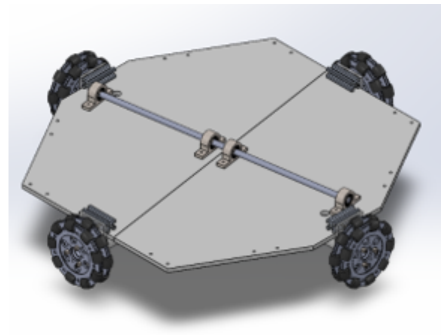

Fig. 5. Four omni wheels type

The four Omni wheel types (Fig. 5), consisting of four independent omnidirectional wheels, are capable of three degrees of freedom motion and have an extra degree of freedom. The rotation movement is ideal for this kind of robot.

2.4 Finite element analysis

As mentioned in the material selection section we chose acrylic as the main frame of the wheel mobile robot. To validate enough strength of the structure, we use finite element analysis to visualize the area which would have the most deformation and find the maximum stress.

The simulation is being done by Solidworks simulation software. This simulation worked on 3 models, the Omni 3 Wheels Model, Omni 4 Wheels Model, and 4 Wheels Mecanum since we perform only the half parts of the body frame, the 4 Wheel Mecanum Model and Differential Drive Model have the same boundary condition. The boundary conditions are fixed on where the wheels of each model are located and apply force on the middle of the body frame as 200N.

As the results of the 3 Omni model, the maximum working stress for 200N applies force is 1.93E+07 N/m^2 with a safety factor of 2.5. When modeling 4 Omni's maximum working stress for the same payload is 2.44E+07 N/m^2 with a safety factor of 2 as shown in Fig. 6 and for maximum displacement is only 6mm which is shown in Fig.7. For the last model, the 4 mecanum models, the maximum working stress is 6.73E+06 N/m^2 with a safety factor of 7.3. The problem faced here is the 4 Omni models have the maximum stress compared to other models and have a safety factor of only 2 which is shown in Fig. 8. So, we decide to add support to the model, and as result, we can improve maximum stress to only 6.73E+06 N/m^2 (Shown in Fig. 9) and reduce model displacement from 6.8mm to only 0.8 mm (Shown in Fig. 10) with a safety factor of 3.5 (Shown in Fig. 11). Since the support is made from aluminum whose weight is so small compared to the robot body that has a small effect on the wheel's kinematics. According to this, we decide to add support to the design. Below is the result visualized from the software:

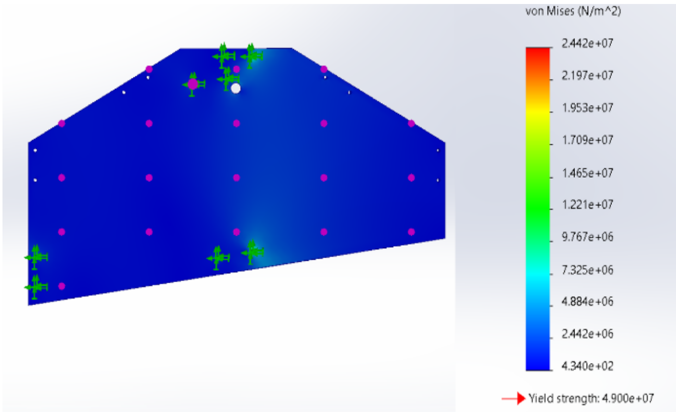

Fig. 6. Stress result of model 4 Omni

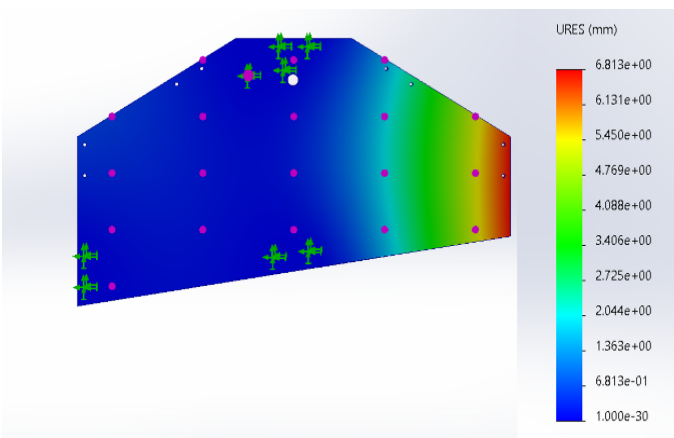

Fig. 7. Displacement result of model 4 Omni

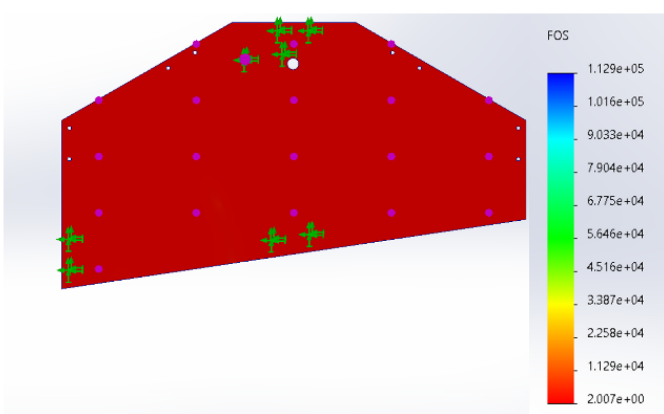

Fig. 8. Safety factor result of model 4 Omni

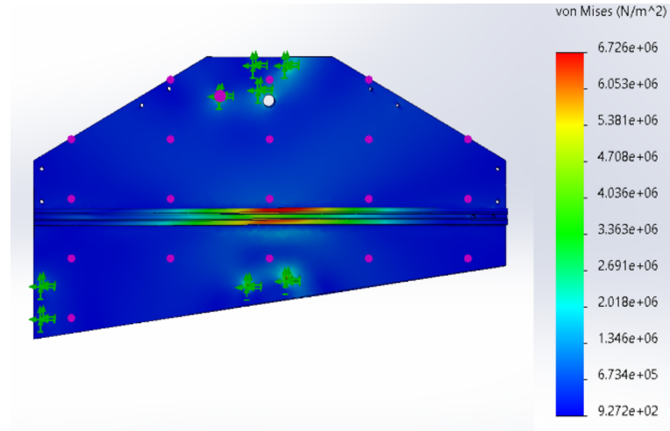

Fig. 9. Stress result of model 4 Omni with support

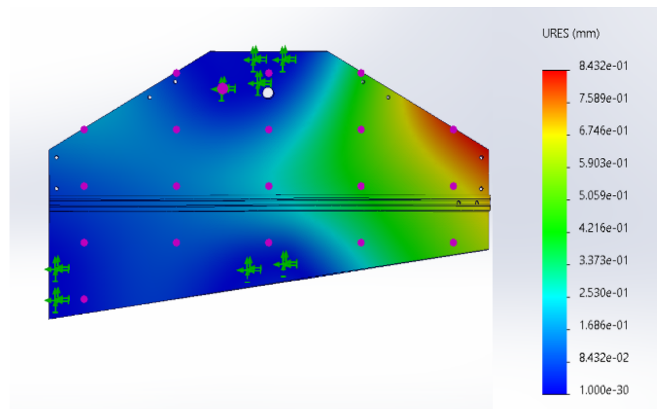

Fig. 10. Displacement result of model 4 Omni with support

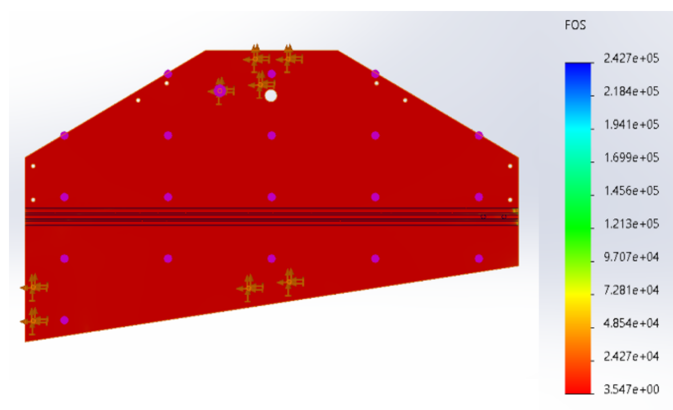

Fig. 11. Safety factor result of model 4 Omni with support

2.5 Wheel mobile robot prototyping

We can divide the material into two categories mechanic, and electronic. The mechanic is including the acrylic body, motor holder, wheel, and connection which spend around 371 USD. The electronic is counted from Arduino Due, battery, motor, motor driver, buck converters, wire, and other connectors which cost 285 USD. The total amount of material that has been purchased to build this robot is 656 USD as shown in Table 3.

Table 3 List of material

Component	Price
Acrylic 60cm x 60cm (2 psc)	50$
Aluminum Profile 2020 1m (2 psc)	10$
Normal Wheel (2 psc)	6$
Caster Wheel (1 psc)	3$
Mecanum Wheel (4 psc)	152$
Omni Wheel (4 psc)	140$
Bearing Seat (4 psc)	5$
Shaft (1 psc)	1$
Hexagon Head M5 (40 psc)	2$
Slider 5mm (12 psc)	2$
Arduino Due (2 psc)	80$
Battery Lipo 3 Cells (1 psc)	30$
DC Motor (4 psc)	132$
Motor Driver (4 psc)	24$
Wire 200 Degree 1m (24 psc)	16$
Nylon M3 (40 psc)	3$
Total	**656$**

After finishing the purchase, the process of making the robot is going smoothly. The acrylic sheet needs to be cut into the body frame and motor holder by HELIX Acrylic Cutter. The aluminum profile is cut into 12 pieces of 8mm and 2 pieces of 560mm to use as the support that is being placed according to the result simulation of Abaqus finite element analysis. The next step is to assemble other parts of the robot such as the motor module, electronics, and wheels.

Fig. 12 shows the robot assembly as a differential drive with castor types, as the three-wheel omnidirectional drive mobile robot in Fig. 13, four mecanum wheels mobile robot in Fig. 14, and four Omni wheel type in Fig. 15.

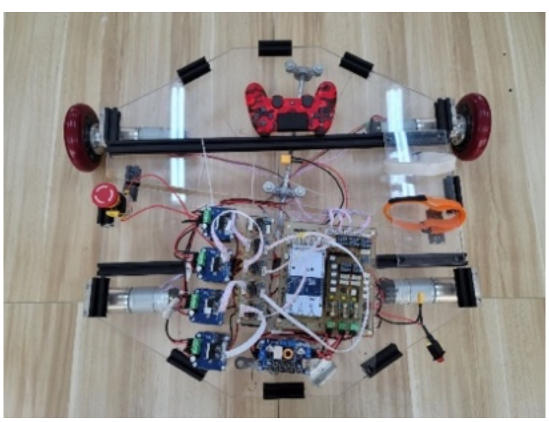

Fig. 12. Differential drive with castor mobile robot

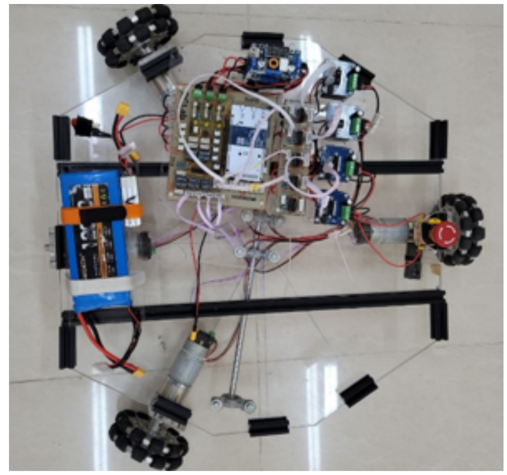

Fig. 13. Three-wheel omnidirectional drive mobile robot

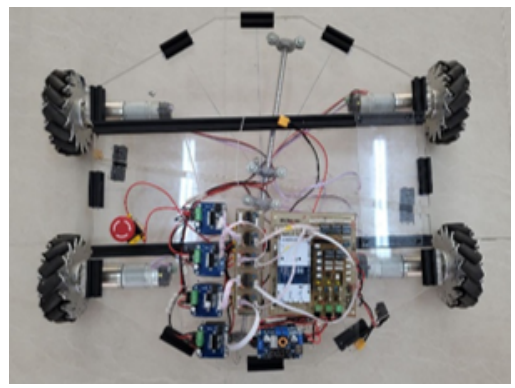

Fig. 14. Four mecanum wheels mobile robot

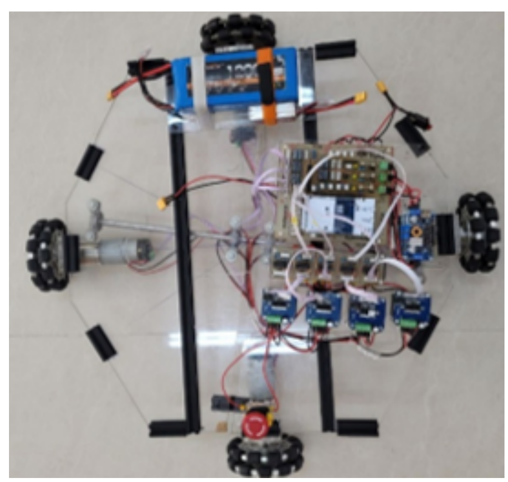

Fig. 15. Four Omni wheels mobile robot

3. RESULTS AND DISCUSSION

3.1 Robot movement and deformation

To perform robot testing, electronic devices have been used to perform this task. The four motors are driven by four IBT-2 motor drive which is powered by a 24V battery. The PCB board is designed to organize and connect electronic devices. Buck converters are used to convert 12V batteries to 3.3V and 5V for supplying PCB board. We use two Arduino Due, one for control motors and one for communicating with the joystick. We use PlayStation 4 controller as a joystick to control the robot's movement.

We use the 2 models of robot for movement testing such as omnidirectional drive with 4 Omni wheels difficult to control but also work without failure too. The last testing movement is rotation which works well with both models as shown in Fig. 16 with the Mecanum model and Fig. 17 with the Omni model. During the testing time and reconfiguring of the robot, there is no sign of deformation that can notable.

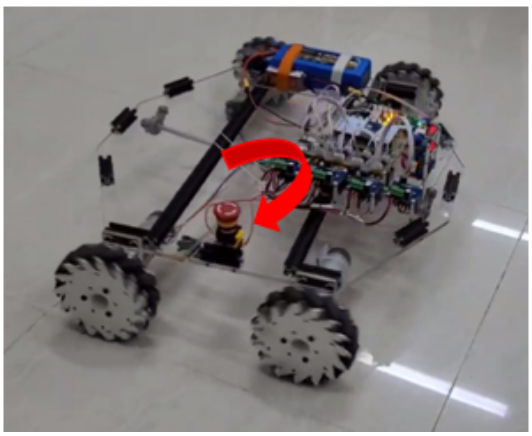

Fig. 16. Mecanum model testing rotation movement

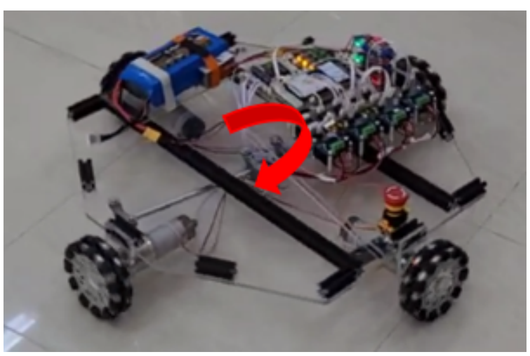

Fig. 17. Omni model testing rotation movement

3.2 Plug and play feature and reconfiguration time

The plug-and-play feature is feasible using the main material like acrylic and aluminum extruder. The plug-and-play feature works well from the first assembly to testing. The configuration times are tested from bare base to 2 normal wheels, 3 Omni wheels, 4 Omni wheels, 4 mecanum wheels, and from each model to another model as shown in Table 4. The testing is done by 5 times and recorded in seconds. Recnfigurations that take the most time are from the 2 to 4 wheels model. The minimum reconfiguration time is 14 min, and the maximum time is 19 min in this testing. The average reconfiguration time from one model to another is 16 min and 11s.

3.3 Cost comparison

The cost comparison with other robots is a must thing to do. It is proof that this plug-and-play wheel mobile robot is worth producing. Several mobile robots serve as research applications and are available in the market. Leo Rover Developer Kit (5371 USD), LIMO Open-source Mobile Robot (2335 USD), Development Platform (3095), Rover Robotics 4WD Rover Zero (4249 USD), all of those robots are commercial research mobile robot platforms available in the market. By comparing to the plug-and-play mobile robot, we can see that our robot is very affordable even if we double the price of our robot to 1300 USD including the labor cost, marketing cost, and profit.

The plug-and-play mobile robot can serve in 4 models of robot. Here, we will do a comparison in the case of the purchase of 4 small mobile robots to do the same job as our robot to see if the price is higher or lower. The differential model can find in the market for around 808 USD, the 3 Omni model is 600 USD, the 4 Omni model is around 650 USD and the 4 mecanum wheels is around 750 to 800 USD.

Table 4 Reconfiguration time

Reconfiguration Form	Average Time
Bare base to 2 Normal Wheels	16m20s
Bare base to 3 Omni Wheels	14m20s
Bare base to 4 Omni Wheels	15m16s
Bare base to 4 Mecanum Wheels	18m08s
2 Normal Wheels to 3 Omni Wheels	15m28s
2 Normal Wheels to 4 Omni Wheels	15m31s
2 Normal Wheels to 4 Mecanum Wheels	15m30s
3 Omni Wheels to 2 Normal Wheels	14m3s
3 Omni Wheels to 4 Omni Wheels	17m1s
3 Omni Wheels to 4 Mecanum Wheels	17m6s
4 Omni Wheels to 2 Normal Wheels	19m33s
4 Omni Wheels to 3 Omni Wheels	16m24s
4 Omni Wheels to 4 Mecanum Wheels	16m20s
4 Mecanum Wheels to 2 Normal Wheels	18m10s
4 Mecanum Wheels to 2 Normal Wheels	15m9s
4 Mecanum Wheels to 2 Normal Wheels	14m20s

4. CONCLUSIONS

In this project, the development of a structure for a plug-and-play wheels mobile robot is designed, simulated, and tested. The plug-and-play wheel mobile robot is a platform for researchers to test software or algorithms to obtain real-world results from four different types of robots by using only one reconfigurable mobile robot. The shape of the structure is a combination of mobile robots such as differential drive with castor, three-wheel Omnidirectional drive, Omnidirectional drive with four Mecanum wheels, and Omnidirectional drive with four Omni wheels. This mobile robot intends to reconfigure into those types of mobile robots. The structure was made with acrylic and aluminum profiles, creating a reconfigurable structure. The robot will be used in well-structured engineered environments, on flat surfaces, such as office buildings. The robot's dimension is 600mm x 600mm with a weight of 10 kg.

After building the mechanical structure, the flexibility of acrylic is a little too much which requires placing a support on it. The finite element simulation to visualize the deformation of the structure to decide where to place support was proposed. The ABAQUS software is used to simulate 3 models of the mobile robot such as differential drive with castor, three-wheel Omnidirectional drive, and Omnidirectional drive with four Omni wheels with applying loads of 200N. After finding out the critical deformation place, the aluminum profile is placed as the support. The testing with robot movement with 2 models of omnidirectional drive with four Mecanum wheels, and omnidirectional drive with four Omni wheels since they have four wheels in contact with the ground which causes the most friction. The rotation around itself is the most critical moment. After testing those two models in the critical moment, we can assure that the mobile robot works perfectly with its support.

To improve the capabilities of mobile robots, the next step should focus on electronic plug-and-play. Electronic plug-and-play will allow researchers to change and use any type of microcontroller and other electronic devices for this robot simply like the mechanical plug-and-play concept.

REFERENCES

[1] Magnus. (2010). *Plug-and-Play Robotics.* Swedish Defend Research Agency.

[2] Carlos Cardeira, J. S. (2005). A Low Cost Mobile Robot for Engineering Education. *IEEE*, 2162-2167.

[3] F. Arvin, J. E. (2017). Mona: an Affordable Mobile Robot for Swarm Robotic Application. *UK-RAS Conference on 'Robotics and Autonomous Systems'* (pp. 49-52). Manchester: Manchester Research Explorer.

[4] Michel Lauria, I. N. (2006). Design and Control of a Four Steered Wheeled Mobile Robot. *IEEE*, 4020.

[5] Rodrigues, J. (2017). *Development of a structure for a mobile robot.* Coimbra.

[6] Potapchuk, V. K. (2014). A Low-Cost Mobile Robot for Education. *Springer International Publishing Switzerland*, 182-190.

[7] Razak, A. (2016). Mobile robot structure design, modeling and simulation for confined space application. *IEEE International Symposium on Robotics and Manufacturing Automation (ROMA).*

[8] Zou Dan, W. T. (2004). Modularization of Miniature Tracked Reconnaissance Robot. *Proceeding of the 2004 IEEE International Conference on Robotics and Biomimetics*, (pp. 456-460). Shenyang.

[9] Mark Yim, D. G. (2000). Poly Bot: a Modular Reconfigurable Robot. *Proceedings of the 2000 IEEE International Conference on Robotics and Automation*, (pp. 514-520). San Francisco.

[10] Jun Qian, B. Z. (2017). The Design and Development of an Omni-Directional Mobile Robot Oriented to an Intelligent Manufacturing System. *Sensors*.