Omni-directional Movement on the MRT PURVI Ship Robot

Ryan Satria Wijaya[1*], Aldi Kaputra[1], Naufal Abdurrahman Prasetyo[1], Hendawan Soebhakti[1], Senanjung Prayoga[1], Anugerah Wibisana[1], Rifqi Amalya Fatekha[1], Eko Rudiawan Jamzuri[1], and Mochamad Ari Bagus Nugroho[2]

[1]Politeknik Negeri Batam, Batam, Indonesia

[2]Politeknik Elektronika Negeri Surabaya, Surabaya, Indonesia

[*]Email: ryan@polibatam.ac.id

***Abstract*— Ship transportation is the primary mode of trade and transportation at sea in the maritime industry. Initially, humans employed ships as a method of pursuing and capturing fish or animals in aquatic environments. As the ship era progresses, it actively engages in all aspects pertaining to ships. Presently, the ship is propelled by its engine, which is a significant improvement over its initial reliance on wood or oars. In addition to engines, propellers are employed to transform the rotational motion of the engine into propulsive force in the marine environment. Propellers are also present on aircraft, serving the same purpose but positioned at various locations in the air. A thruster is a hybrid device that combines an engine and a propeller. This sort of thruster is specifically designed for use on tiny boats or prototypes, for the purpose of simulating, exhibiting, or participating in contests. ESC is a component that facilitates the alteration of the input value to the intended velocity. In addition to their primary function of fulfilling food requirements, ships are presently employed in diverse capacities, including military vessels, tourist vessels, submarines, passenger ships, and more.**

Keywords: ***Propeller, Ship Omni-movement, Thruster***

I. INTRODUCTION

MOTION refers to the displacement of an object from its starting location to its final location. Within the realm of motion, two fundamental components exist: direction and distance. Direction refers to the trajectory that an object will follow, whereas distance quantifies the displacement of the object from its starting point to its ending point. Ships will experience a variety of movements, including linear, curved, and circular motions.

A thruster is a ship component that facilitates the propulsion and movement of the ship. The thrust force produced by the thruster enables an object to change its position in accordance with its intended destination. The utilization of the law of action and reaction, which is Newton's third law, constitutes a functional principle. When the thruster exerts a rearward force, the object will propel forward. The thruster comprises various components, including a brushless motor and propeller [1]. The thruster utilized is a 1200 thruster, accompanied by a corresponding electronic speed controller (ESC).

The ship robot is an unmanned prototype vessel designed for conducting movement simulations, displays, and even participating in similar competitions. Ship robots can be propelled either through remote control or by operating autonomously. The ship robot has been doing research under the team's supervision for over a year. Implement researched ship robot characteristics, including vision for object detection, ship motion for enhanced mobility, automatic water shooters, and automatic ball shooters. The ship robot is named PURVI MRT Ship Robot.

This article will examine the locomotion of the PURVI MRT autonomous marine robot. The method of propulsion utilized by this robotic vessel, which methodology is employed, any object utilized to propel this robotic vessel. The form of the actuator position on the ship robot.

II. METHOD

After conducting research by analyzing and comprehending literature on the locomotion, constituents, and rotational mechanisms employed in maritime robots. In order to enable omnidirectional movement of the ship robot, it is equipped with a thruster, electronic speed controller (ESC), and remote control. A thruster is a propulsion device that facilitates the smooth movement of a ship robot. The ESC is a tool that governs the speed and regulates the rotational direction of the thruster. A remote control is employed to assist the ship robot in managing its locomotion.

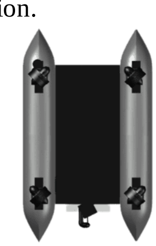

Fig. 1. Thruster position design on the Ship Robot

Figure 1 displays the arrangement of 4 thrusters and their respective locations on the ship. The utilization of four thrusters enhances the ease and stability of the ship robot's mobility. A thruster is a propulsion device powered by a motor that is mounted on the thruster itself. In addition to the thruster, the ship's robot is equipped with an Arduino, an ESC, and a remote control to facilitate its movement. Esc serves as a pulse width modulation (PWM) converter for converting RPM, a speed controller, and a means to control the direction of thrust generated by the thruster. Control the Arduino by providing PWM value from a remote device. The Arduino receives input from the remote control through code and then proceeds to execute the ESC command.

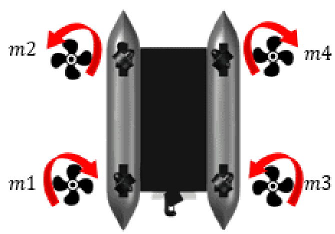

Fig. 2. Propeller design used on each thruster

The propellers employed are CW (Clockwise) for motors m1 and m4, and CCW (Counterclockwise) for motors m2 and m3. The rotation direction is also aligned with the propeller's application, as depicted in Figure 2. The thruster and propeller's shape, as depicted in Figure 2, enables the achievement of omnidirectional motion [2], [3], [6], [9], [10]. The orientation of the thruster can be described as an X shape, with a tilted angle of 45 degrees.

The ship robot needs the motor on the thruster to rotate in order to generate thrust and enable movement. Regarding forward movement, the thruster motor rotates in accordance with PWM input received from the remote control, and its rotation is determined by the specific type of propeller employed. Figure 2 depicts the utilization of two propellers, necessitating the motor to rotate in accordance with the propeller's configuration, thereby generating forward propulsion.

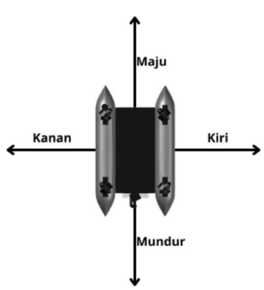

Fig. 3. The Ship Robot can be seen from the bottom and the direction of the Ship Robot is clear

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{1} \\ \mathbf{0} & \mathbf{1} \end{matrix} \tag{1}$$

note:

$m1$ = Motor 1 on Thruster 1
$m2$ = Motor 2 on Thruster 2
$m3$ = Motor 3 on Thruster 3
$m4$ = Motor 4 on Thruster 4
1 = Motor moves according to the shape of the propeller
-1 = Motor moves in the opposite direction of the propeller
0 = Motor does not move or is not active

Figure 3 is a view of the ship robot from the bottom and the direction [4] contained in the figure is the movement of the ship robot direction. These directions can be used as a benchmark for ship movement. In order to determine the rotation of the motor and the direction of rotation of the propeller that supports the movement of the ship robot according to the direction, you can use Equation 1.

A. Ship Robot Movement

1) Go Forward

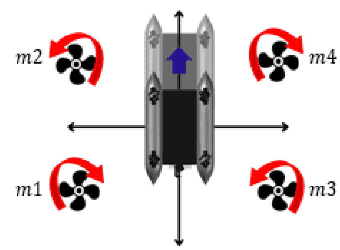

Fig. 4. Forward Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{1} & \mathbf{1} \\ \mathbf{1} & \mathbf{1} \end{matrix} \tag{2}$$

As shown in Figure 4 and also the logic in Equation 2, the ship robot can move forward. The condition of the motor on the thruster [5] all moves and rotates according to the shape of the propeller used. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote [7] control and is processed by the program on Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

2) Back Off

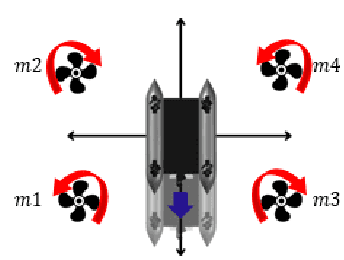

Fig. 5. Backwards Robotic Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{-1} \\ \mathbf{-1} & \mathbf{-1} \end{matrix} \tag{3}$$

As shown in Figure 5 and also the logic in Equation 3, the ship robot can move backwards. The condition of the motor on the thruster moves all and rotates opposite to the shape of the propeller [8] that is used. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

3) *Right*

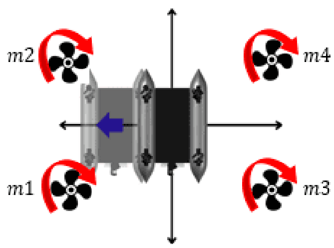

Fig. 6. Right Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{1} \\ \mathbf{1} & \mathbf{-1} \end{matrix} \tag{4}$$

As shown in Figure 6 and also the logic in Equation 4, the ship robot can move to the right. The condition of the motor on the thruster moves all and the propeller rotation on m1 and m4 corresponds to the shape of the propeller used, while the propeller rotation on m2 and m3 is opposite from the shape of the propeller used. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

4) *Left*

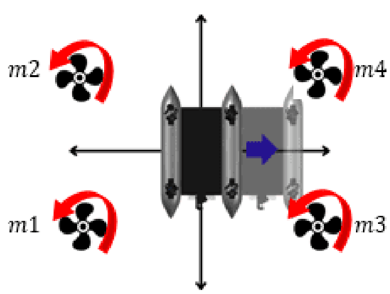

Fig. 7. Left Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{1} & \mathbf{-1} \\ \mathbf{-1} & \mathbf{1} \end{matrix} \tag{5}$$

As shown in Figure 7 and also the logic in Equation 5, the ship robot can move to the left. The condition of the motor on the thruster moves all and the propeller rotation on m2 and m3 corresponds to the shape of the propeller used, while the propeller rotation on m1 and m4 is opposite from the shape of the propeller used. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

5) *Forward Right*

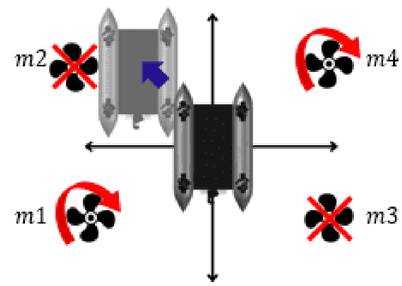

Fig. 8. Ship Robot Movement Forward Right

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{matrix} \tag{6}$$

As shown in Figure 8 and also the logic in Equation 6, the ship robot can move forward with an additional direction to the right. The condition of the 2 motors on the 2 thrusters moves and rotates according to the shape of the propeller used, namely the m1 and m4 motors. Motor m2 and m3 because they are not used, they are not activated. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

6) *Forward Left*

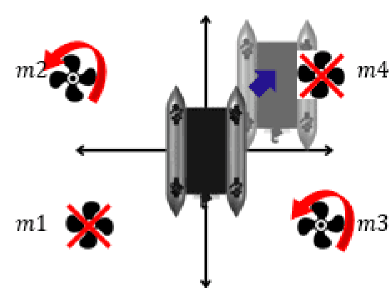

Fig. 9. Left Forward Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{matrix} \tag{7}$$

As shown in Figure 9 and also the logic in Equation 7, the ship robot can move forward with an additional direction to the left. The condition of the 2 motors on the 2 thrusters moves and rotates according to the shape of the propeller used, namely the m2 and m3 motors. Motors m1 and m4 because they are not used, they are not activated. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

7) Backward Right

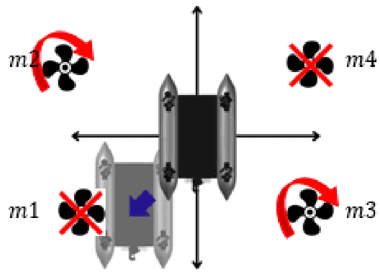

Fig. 10. Right Reverse Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} \end{matrix} \tag{8}$$

As shown in Figure 10 and also the logic in Equation 8, the ship robot can move backwards with an additional direction to the right. The condition of the 2 motors on the 2 thrusters moves and rotates opposite to the shape of the propeller used, namely the m2 and m3 motors. Motors m1 and m4 because they are not used, they are not activated. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

8) Backward Left

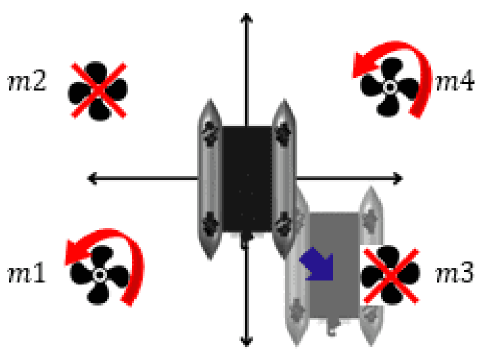

Fig. 11. Left Backward Robot Ship Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{0} & \mathbf{-1} \\ \mathbf{-1} & \mathbf{0} \end{matrix} \tag{9}$$

As shown in Figure 11 and also the logic in Equation 9, the ship robot can move backwards with an additional direction to the left. The condition of the 2 motors on the 2 thrusters moves and rotates opposite to the shape of the propeller used, namely the m1 and m4 motors. Motor m2 and m3 because they are not used, they are not activated. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

9) Spin Forward Right

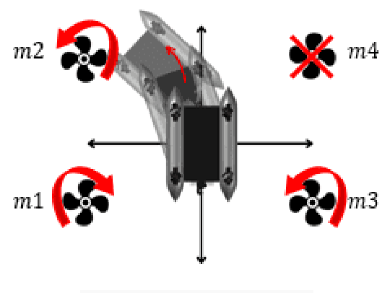

Fig. 12. Movement of the Ship Robot Rotating Forward Right

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{1} & \mathbf{0} \\ \mathbf{1} & \mathbf{1} \end{matrix} \tag{10}$$

As shown in Figure 12 and also the logic in Equation 10, the ship robot can rotate forward to the right. The condition of the 3 motors on the 3 thrusters moves and rotates according to the shape of the propeller used. Under these conditions, the ship will move forward, so that the [10], [11] movements can rotate forward to the right, then the 4 or m4 motor does not move or is not active. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

10) Spin Forward Left

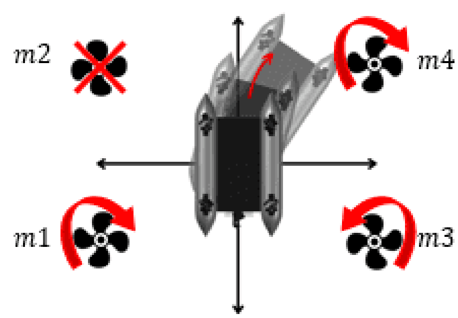

Fig. 13. Movement of the Left Forward Rotating Ship Robot

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{1} \end{matrix} \tag{11}$$

As shown in Figure 13 and also the logic in Equation 11, the ship robot can rotate forward and left. The condition of the 3 motors on the 3 thrusters moves and rotates according to the shape of the propeller used. Under these conditions, the ship will move forward, so that the movement can rotate forward to the left, then the motor 2 or m2 does not move or is not active. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

11) Spin Backward Right

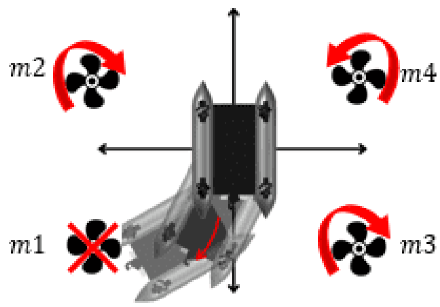

Fig. 14. Right Rotating Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{-1} \\ \mathbf{0} & \mathbf{-1} \end{matrix} \tag{12}$$

As shown in Figure 14 and also the logic in Equation 12, the ship robot can rotate backwards right. The condition of the 3 motors on the 3 thrusters moves and rotates opposite to the shape of the propeller used. Under these conditions, the ship will move backwards, so that the movement can rotate backwards to the right, then motor 1 or m1 does not move or is not active. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

12) Spin Backward Left

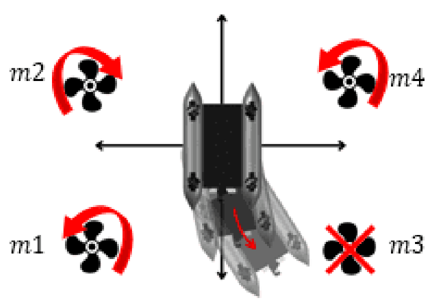

Fig. 15. Left Rotating Ship Robot Movement

$$\begin{matrix} \boldsymbol{m2} & \boldsymbol{m4} \\ \boldsymbol{m1} & \boldsymbol{m3} \end{matrix} = \begin{matrix} \mathbf{-1} & \mathbf{-1} \\ \mathbf{-1} & \mathbf{0} \end{matrix} \tag{13}$$

As shown in Figure 15 and also the logic in Equation 13, the ship robot can rotate backwards left. The condition of the 3 motors on the 3 thrusters moves and rotates opposite to the shape of the propeller used. Under these conditions, the ship will move backwards, so that the movement can rotate backwards to the left, then the 3 or m3 motor does not move or is not active. The speed of each rotation on the thruster is the same. The speed comes from the value given by the remote control and is processed by the program on the Arduino and continued by esc to order the motor on the thruster to rotate according to the remote.

B. Flowchart

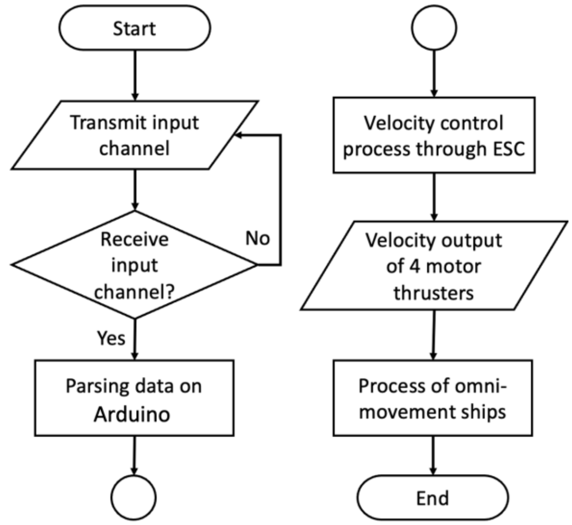

Fig. 16. Ship Robot Movement Flowchart

The process in Figure 16 starts from the input from the channel on the remote. Then it is processed to Arduino to be programmed using the value on the remote as the speed for the thruster. Before being forwarded to the thruster, the output speed value will be processed again in the ESC and also adjusts the direction of the propeller rotation on the thruster. The propeller on the thruster rotates and generates thrust from the propeller.

III. Results and Discussion

After testing all movements on the ship's robot, the thruster can function properly and produce appropriate movements. By using 4 thrusters and forming a thruster position in a cross position it makes it easier for the ship robot to move in all directions.

A. Go Forward

Fig. 17. Results of Forward Ship Robot Movement

Figure 17 experimental results of the movement of the ship robot forward. The speed used is not so fast that it produces a stable and calm movement. The ship robot moves forward with a distance of 6 meters in 5 seconds.

$$v = \frac{s}{t} = \frac{6}{5} = 1.2\ {}^{m}/_{s} \tag{14}$$

By using Equation 14, it is possible to calculate the speed traveled by the ship. The distance is symbolized by the letter s and the distance is 6 meters. While the time is symbolized by the letter t and the time is 5 seconds. The distance is divided by the time, so the result is a speed of 1.2 m⁄s.

B. Back Off

Fig. 18. Result of Backward Robot Movement

Figure 18 experimental results of the movement of the robot ship backwards. The speed used is not so fast that it produces a stable and calm movement. The ship robot moves backwards with a distance of 1.5 meters in 1 second.

$$v = \frac{s}{t} = \frac{1.5}{1} = 1.5\ {}^{m}/_{s} \qquad (15)$$

By using Equation 15, it is possible to calculate the speed traveled by the ship. The distance is symbolized by the letter s and the distance is 1.5 meters. While time is symbolized by the letter t and the time is 1 second. The distance is divided by the time, so the result is a speed of 1.5 m⁄s.

C. Right

Fig. 19. Result of Right Ship Robot Movement

Figure 19 experimental results of the movement of the ship robot to the right. The speed used is not so fast that it produces a stable and calm movement. Because it moves to the left side, the speed obtained will decrease with the motion of the ship's hull. The ship robot moves to the right with a distance of 3 meters in 4 seconds.

$$v = \frac{s}{t} = \frac{1.5}{1} = 1.5\ {}^{m}/_{s} \qquad (16)$$

By using Equation 16, it is possible to calculate the speed traveled by the ship. The distance is symbolized by the letter s and the distance is 3 meters. While time is symbolized by the letter t and the time is 1 second. The distance is divided by the time, so the result is a speed of 0.75 m⁄s.

D. Left

Fig. 20. Left Ship Robot Movement Results

Figure 20 experimental results of the movement of the ship robot to the left. The speed used is not so fast that it produces a stable and calm movement. Because it moves to the left side, the speed obtained will decrease with the motion of the ship's hull. The ship robot moves to the left with a distance of 3 meters in 4 seconds.

$$v = \frac{s}{t} = \frac{1.5}{1} = 1.5\ {}^{m}/_{s} \qquad (17)$$

By using Equation 17, it is possible to calculate the speed traveled by the ship. The distance is symbolized by the letter s and the distance is 3 meters. While time is symbolized by the letter t and the time is 1 second. The distance is divided by the time, so the result is a speed of 0.75 m⁄s.

E. Forward Right

Fig. 21. Result of Ship Robot Movement Forward Right

Figure 21 experimental results of the movement of the ship robot to the northeast. In this experiment only 2 thrusters are lit with the same propeller. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

F. Forward Left

Fig. 22. Results of Left Forward Ship Robot Movement

Figure 22 experimental results of the movement of the ship robot to the southeast. In this experiment only 2 thrusters are lit with the same propeller. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

G. Backward Right

Fig. 23. Result of Right Reverse Ship Robot Movement

Figure 23 experimental results of the movement of the ship robot to the southwest. In this experiment only 2 thrusters are lit with the same propeller. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

H. Backward Left

Fig. 24. Left Backward Robot Movement Results

Figure 24 experimental results of the movement of the ship robot to the northwest. In this experiment only 2 thrusters are lit with the same propeller. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

I. Spin Forward Right

Fig. 25. Result of Ship Robot Movement Rotating Forward Right

Figure 25 experimental results of the movement of the ship robot maneuvering forward right or turning forward right. In this experiment only turned off 1 thruster. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

J. Spin Forward Left

Fig. 26. Result of Left Forward Rotating Ship Robot Movement

Figure 26 experimental results of the movement of the ship robot maneuvering forward left or turning forward left. In this experiment only turned off 1 thruster. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

K. Spin Backward Right

Fig. 27. Result of Right Rotating Ship Robot Movement

Figure 27 experimental results of the movement of the ship robot maneuvering backwards right or turning right backwards. In this experiment only turned off 1 thruster. The speed used is not so fast that it produces a stable and calm movement. Movement like this gets a big enough obstacle, because the hull on a large ship.

L. Spin Backward Left

Figure 28 displays the experimental findings of the ship robot's movement while maneuvering in a backward left direction or turning left while moving backwards. Only one thruster was deactivated in this experiment. The velocity employed is insufficient to generate a steady and tranquil motion. The movement of a large ship encounters significant obstacles due to its hull

Fig. 28. Result of Left Rotating Ship Robot Movement

TABLE I
EXPERIMENTAL RESULTS OF FORWARD SHIP ROBOT MOVEMENT
GO FORWARD

Test	X (m)	Y (m)	Time (s)	Velocity (m/s)
1	0.5	4.5	7.87	0.58
2	0.2	5	8.58	0.58
3	1	4.3	6.92	0.64
4	0.3	5	8.04	0.62
5	0.1	5	9.01	0.56

TABLE II
EXPERIMENTAL RESULTS OF BACK OFF SHIP ROBOT MOVEMENT
BACK OFF

Test	X (m)	Y (m)	Time (s)	Velocity (m/s)
1	1	3	5.72	0.55
2	1.5	4	8.52	0.50
3	0.5	3.5	6.83	0.52
4	0.1	5	10.98	0.46
5	0.1	5	9.63	0.52

Based on the trials conducted in Table I and Table II, perform tests on both forward and backward motions. There are five iterations of each movement. Out of the two movements, they continue to encounter mistakes in their execution. As a consequence, the ship's robot failed to meet its ultimate defecation goal. In order to achieve the desired goal of both forward and backward movement, the X axis has no significance.

IV. CONCLUSION

Utilizing this technique, the ship robot is capable of maneuvering in any direction. The thruster configuration is arranged in a cross shape, similar to that of a four-wheel omnidirectional robot. However, a minor inaccuracy still happened during the relocation. This approach is effective in regions devoid of waves, currents, and other factors that could potentially destabilize the ship's motion.

REFERENCES

[1] Gong, J., Ding, J., & Wang, L. (2021). Propeller-duct interaction on the wake dynamics of a ducted propeller. *Physics of Fluids*, *33*(7). https://doi.org/10.1063/5.0056383

[2] Hijikata, M., Miyagusuku, R., & Ozaki, K. (2022). Wheel Arrangement of Four Omni Wheel Mobile Robot for Compactness. *Applied Sciences (Switzerland)*, *12*(12). https://doi.org/10.3390/app12125798

[3] Ikeda, K., Ei, S. I., Nagayama, M., Okamoto, M., & Tomoeda, A. (2019). Reduced model of a reaction-diffusion system for the collective motion of camphor boats. *Physical Review E*, *99*(6). https://doi.org/10.1103/PhysRevE.99.062208

[4] Azizi, M. R., Rastegarpanah, A., & Stolkin, R. (2021). Motion planning and control of an omnidirectional mobile robot in dynamic environments. *Robotics*, *10*(1). https://doi.org/10.3390/robotics10010048

[5] Laidani, A., Bouhamida, M., Benghanem, M., Sammut, K., & Clement, B. (2019). A Low-Cost Test Bench for Underwater Thruster Identification. *IFAC-PapersOnLine*, *52*(21). https://doi.org/10.1016/j.ifacol.2019.12.316

[6] Lukmana, M. A., Hidayatur-Rohman, Q. A., Fahrudin, F., & Saputra, N. (2021). SIMULASI NUMERIK KENDALI KAPAL CEPAT TAK BERAWAK DUA PROPELLER TANPA RUDDER. *Jurnal Poli-Teknologi*, *20*(2). https://doi.org/10.32722/pt.v20i2.3624

[7] Makhataeva, Z., & Varol, H. A. (2020). Augmented reality for robotics: A review. In *Robotics* (Vol. 9, Issue 2). https://doi.org/10.3390/ROBOTICS9020021

[8] Posa, A., Broglia, R., & Felli, M. (2022). Acoustic signature of a propeller operating upstream of a hydrofoil. *Physics of Fluids*, *34*(6). https://doi.org/10.1063/5.0096030

[9] Rijalusalam, D. U., & Iswanto, I. (2021). Implementation kinematics modeling and odometry of four omni wheel mobile robot on the trajectory planning and motion control based microcontroller. *Journal of Robotics and Control (JRC)*, *2*(5), 448–455. https://doi.org/10.18196/jrc.25121

[10] Subur, J. (2019). Pengaturan Kecepatan Motor Penggerak Propeller Pada Kapal Menggunakan Metode Pid Kontrol. *Prosiding Seminakel*, *04*(02).