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Unmanned Hovercraft for Firefighting Based on IoT

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Abstract

A hovercraft is a vehicle that utilizes air pressure inside the skirt to produce an air cushion to support the entire load. It carries a ship that runs on an air cushion. Hovercrafts use propeller or fan rotation to move the hovercraft. However, there are many developments problem in hovercraft in terms of usability due to the emergence of hovercraft designs. Therefore, in this study, we propose a hovercraft as a fire extinguisher on a ship in the middle of the sea. The hovercraft frame is created using 3D printing with dimensions of 37 cm long, 30 cm wide, and 17 cm high. The hovercraft design uses a smartphone application as a remote control, which is developed using MIT App Inventor and ESP32 as a microcontroller. This hovercraft is controlled at a distance without any obstacles at 42 meters and with wall obstacles at 12 meters. The addition of DC water pump components and nozzles are used as fire extinguishers and 2 (two) servos to regulate the direction of watering, and the furthest range of watering points is at 2 meters 10 cm. The power source usage of the battery time reaches 50 minutes with active hovercraft movement. The selection of low power consumption components and lightweight 3D print materials makes this hovercraft effective in working with only a 12-volt battery and can operate for almost 2 hours.

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1. Introduction

On this earth, there are several waters that challenge technology to make humans easily reach them. Hovercraft, or often referred to as air-cushion vehicles, were created as a solution to the limitations of conventional transportation that relies on surface conditions. Before the creation of hovercraft, water transportation modes such as ships and boats could only operate efficiently in fairly deep and calm waters. Meanwhile, land vehicles such as cars and trucks cannot traverse muddy surfaces, swamps, or shallow waters. This condition creates a need for vehicles that are able to move across various types of surfaces — such as water, mud, sand, or hard land — without being disturbed by uneven terrain or directly bordering water and land. Hovercraft were created to answer these needs. By utilizing air cushions produced by high-pressure fans, hovercraft are able to "float" above the surface, so they can move from water to land without obstacles. Hovercraft is a vehicle that utilizes air pressure in the skirt to produce an air cushion that is used to support all the loads it carries, or in other words a ship that runs on an air cushion. Hovercraft uses propeller or fan rotation to fill the air in the cushion and move the hovercraft[1]. Air cushions are made by filling air through flexible bulkheads to the bottom of the ship, which can be a buoy, with this the internal air pressure of the buoy is higher than the outside air pressure, creating lift. The thrust that comes from the propeller like on an airplane is used to move the plane. The lift of this ship operates on a wide cross-section, resulting in little ground pressure being created[2]. Resulting in this vehicle being able to drive on land, in the air, or while carrying a fairly heavy load. With the principle of air cushions, the hovercraft body does not touch land or water, so the hovercraft can drive on land and in water. Because there is no direct contact between the hovercraft and the water or land surface, the hovercraft can travel fast, hovercraft are usually used to transport SAR teams to places that cannot be reached by land vehicles, such as swamps or muddy ground, as well as for guard vehicles on the coast[3], [4]. Generally, the hovercraft that is commonly used still uses a ship's crew to control the ship, so it still requires humans to jump in directly when driving the hovercraft. Therefore, in certain circumstances, an unmanned hovercraft is needed that can be controlled remotely[5]. In addition, the shape of the hovercraft model can be adjusted according to specific needs and requirements. Hovercraft have advantages in mobility on various types of surfaces, including water and land, which makes them an attractive choice to be used as a firefighting ship in the middle of the sea without a crew by reaching areas that cannot be extinguished by humans directly[6].

In previous research on hovercraft, namely Development of a Working Hovercraft Model, S.H. this study discussed the design process and manufacture of hovercraft prototypes only on a small scale which were tested on various surfaces such as water, grass, cement, and tiles[7]. The next study entitled Optimization of Integrated Type Hovercraft Lift Force with Changes in Axial Fan Configuration, but only focused on one type of axial fan without comparing it with other types of fans[8]. In addition, there is a study entitled Numerical Investigation of Lift Force Increase in a Hovercraft by Changing the Geometrical Parameters of Flow Transfer Part and Air Channel, This study uses CFD simulation to analyze the effect of geometric changes in the air duct on the pressure distribution and lift force of the hovercraft, but does not consider the dynamics of the load when the hovercraft is moving. In another study titled Creating an Autonomous Hovercraft for Bathymetric Surveying in Extremely Shallow Water (<1 m), developed an autonomous hovercraft for bathymetric mapping in shallow water using sonar and an automatic navigation system, the navigation accuracy is affected by external factors such as wind and current, causing deviations from the desired path[9]. The next study on hovercraft titled Experimental Investigations of Underwater and Airborne Noises Produced by a Large Hovercraft in [10] measured the airborne and underwater noise produced by a large hovercraft in the Ural River estuary to assess its impact on wildlife, This study focuses more on long-term analysis of the impact of noise on animal behavior.

From several studies before, they does not use an adjustable Electronic Speed Controller (ESC) module to change the direction of motor rotation, so the hovercraft cannot go backwards, so it is become point negative and none of them use 3D printing material as the main material. Therefore, in this study, the hovercraft design uses 3D printing material as a study that provides an alternative contribution to the use of cheap, easy-to-use and save materials of unmanned ships. The main mission of this research given to this hovercraft is to extinguish fires in dangerous areas. With the ability to control movement using a remote from a distance, the hovercraft in this study was able to move forward and backward, reaching fire locations that could potentially endanger humans.

2. Research Methodology

The research method in this study uses the research and development (R&D) method. consists of several stages starting from the design block diagram, compiling a hovercraft programming flowchart, engineering design, hardware design, hovercraft hardware assembly, and hovercraft testing. The following are the main stages in making this unmanned hovercraft for firefighting:

2.1. Block Diagram

Smartphones are chosen because of their ease of use in terms of function and economy. It is used as control equipment for hovercraft movements control and for remote fire extinguishing command. The block diagram system in this research can be shown in Figure.1. To make it easier to understand and organize, the block diagram is clustered including input, process and output, the observable flow to read is from left to right on this hovercraft block diagram.

This system is not equipped with smart fire or flame sensors, meaning that the extinguishing process is carried out visually by the pilot. In addition to maneuver commands such as turning left, turning right, forward and backward, this hovercraft is also equipped with equipment that can suck up water to then be sprayed onto the fire point.

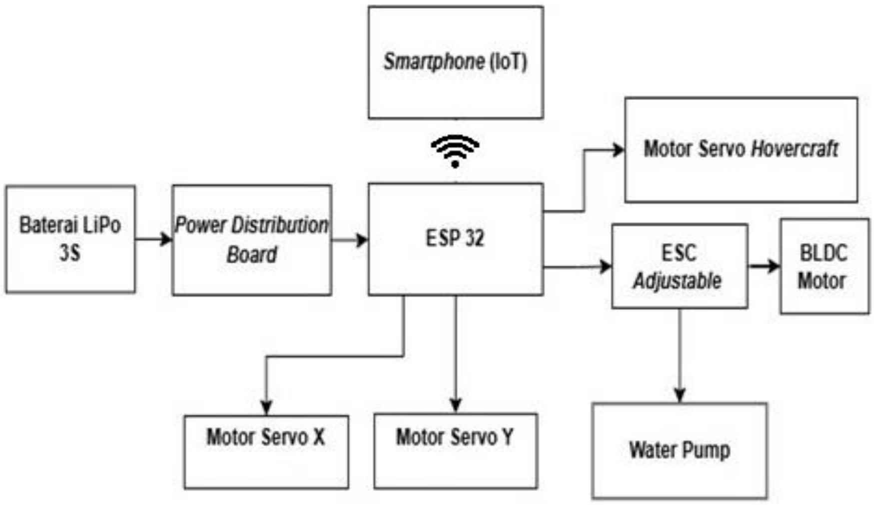


Figure 1. Block Diagram

Explanation and function of the block diagram as shown in Figure1, it is include Smartphone (IoT) as a connecting medium between ESP32 and Hovercraft Controller Software. ESP32 becomes the control system or brain of the working system of this tool circuit. 3S LiPo Battery functions as an energy source for this tool circuit. Power Distribution Board (PDB) as a device that has been designed with several outputs to be used as a distribution of 12V and 5V electricity to the components assembled in this tool. This Adjustable Electronic Speed Controller (ESC) is an output that is useful for regulating the speed and direction of rotation of the Brushless DC (BLDC) Motor so that the hovercraft can move forward and backward [11], [12]. The BLDC motor in this circuit functions to produce the hovercraft's thrust so that the hovercraft can move forward and backward. The hovercraft Servo Motor is used to turn the BLDC Motor so that the hovercraft can turn. The X Servo Motor is used to adjust the direction of the water spray to the right or left[12]. The Y Servo Motor also functions to adjust the direction of the water spray with the direction of the spray up or down. The DC Water Pump functions to move water from the bottom side and spray it upwards for watering. Servo is an output used to control the direction of the rudder so that the hovercraft can turn and control the direction of the watering range [13], [14].

2.2. Hardware design

The hardware design can be seen in Figure 2 below, while a detailed explanation of the equipment or components can be seen in Table 1. The numbering of the components also shows the process direction on this hovercraft, from the initial input to the final output of the system.

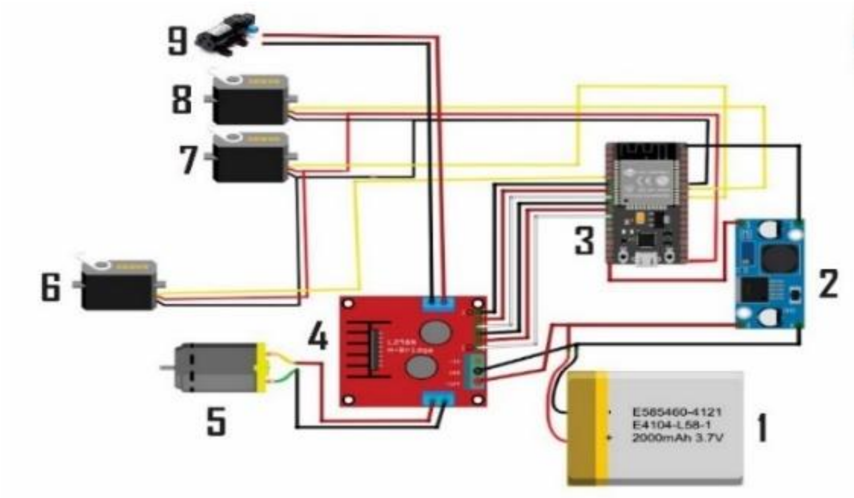


Figure 2. Hardware Design

Table. 1 Component description

No	Description
1	Battery LiPo 3S
2	Converter DC 6-35V
3	ESP32
4	ESC Adjustable
5	Brushless Motor
6	Servo controls the direction of motion
7	Servo X Flush
8	Servo Y Flush
9	Water Pump DC

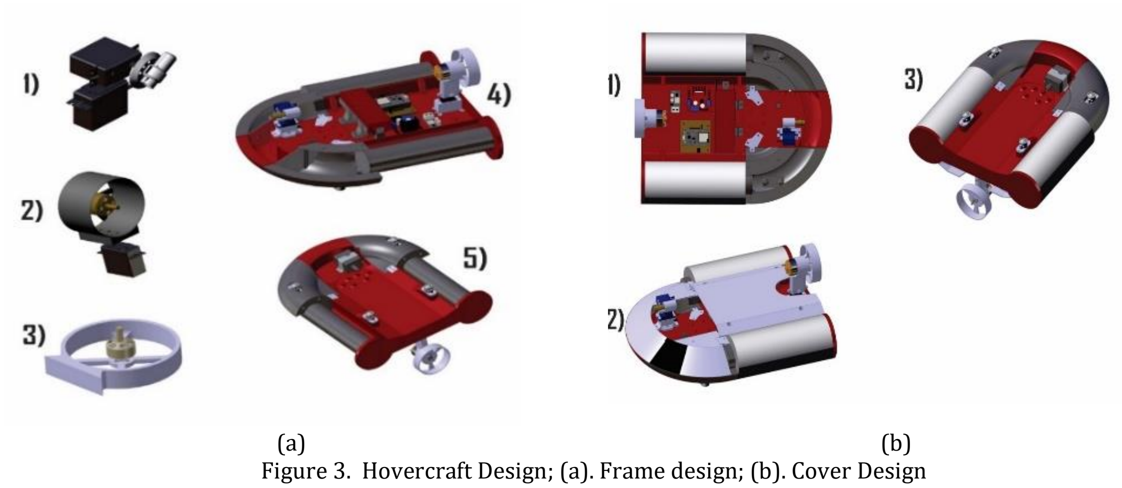
The workflow of the hovercraft begins with a smartphone giving a command. The command includes Turn Right then the hovercraft Servo will turn to the right 45° which causes the hovercraft to turn to the right, if not then there is another command namely Turn Left then the hovercraft Servo will turn to the left 45° which causes the hovercraft to turn to the left, for the Forward command then the BLDC Motor turns on clockwise so that the hovercraft will move forward, and the Backward command then the BLDC Motor turns on in the opposite direction so that the hovercraft will move backward[15]. If all commands are not executed, then an error occurs.

The workflow of watering the hovercraft begins with a smartphone giving a command. The command includes Water ON then the Water Pump will turn on if not then there is another command namely Water OFF then the Water Pump will turn off, for the Up command it is useful for moving the Servo Y upwards which results in the direction of the watering upwards, and the Down command is useful for moving the Servo Y downwards which results in the direction of the watering downwards, the Right command is useful for moving the Servo X to the right which results in the direction of the watering to the right, while the Left command is useful for moving the Servo X to the left which functions to cause the direction of the watering to the left. If all commands are not executed, then an error occurs.

2.3. Hovercraft design

Water Spray is a fire extinguishing system that sprays water in the form of mist or fine droplets, or spray distributed to a certain area. This system works automatically or is controlled remotely to handle fires manually. Figure 3(a) explains the design of the hovercraft frame with a water spray design like figure number 1 with 2 servos that can direct the spray to the right or left and up or down, figures number 2 and 3 are the design of the jet movement part driven by a DC motor that functions as a hovercraft driver so that it can move forward or backward in numbers 4 and 5 are the design images of the upper and lower hovercraft frame or frame.

Figure 3(b) is a picture of a hovercraft model after assembling the hovercraft components. Picture number 1 without a case or cover with the placement of components according to the picture, pictures number 2 and 3 are hovercraft that have been covered with a case. This hovercraft has dimensions of 35 cm long, 12 cm wide, and 8 cm high.



(a) (b)

Figure 3. Hovercraft Design; (a). Frame design; (b). Cover Design

Figure 4. MIT App Inventor

2.4. MIT App Inventor

In the design of an IoT-based unmanned hovercraft, an application is needed to control the hovercraft. MIT App Inventor is a web-based platform that allows users to create mobile applications visually by dragging and dropping code blocks, without having to write complex programming code. This application was chosen because of its ease of programming.

MIT App Inventor is an application that will be used to create this hovercraft control application. Figure 4 above is the home page of MIT App Inventor. This application works directly in the browser, no special software installation required (only requires a Google account).

Here are the Steps to Create an application using MIT App Inventor :

a. Design View (Designer View)
   Drag and drop UI components such as: Button, Label, Textbox, Image, etc.
b. Logic Program (Blocks View)
   Use blocks such as: when Button1. Do…
c. Test the Application Live
   Use the MIT AI2 Companion application on Android to connect your phone via QR Code.
d. Build the Application
   Download the APK file to install on Android.

There are 2 General Methods of MIT App Inventor Connection to ESP32. The first is Bluetooth, the second is using Wi-Fi. In this study, the connection used is Wi-Fi (HTTP/Web Server) use web components on MIT App Inventor. Send a request to the ESP32 through command as follows:

http://192.168.4.1/motor/on
http://192.168.4.1/waterpump/off

ESP32 microcontroller is used in this research which has advanced wireless connectivity capabilities, such as Wi-Fi and Bluetooth. ESP32 has a Dual-Core Processor, providing high performance for more complex applications, and Wireless Connectivity Supports Wi-Fi and Bluetooth, suitable for IoT (Internet of Things) applications. Power Consumption ESP32 is designed for low power consumption, ideal for applications that require energy efficiency and Easy Programming Can be programmed using a platform such as Arduino IDE to create programs that will be applied to the ESP32 microcontroller. Figure 5 above shows the appearance of the Arduino IDE coding software.

Figure 5. Arduino IDE Software

2.4. How to test

2.4.1. Component Testing

The components tested include Servo, BLDC Motor, Water Pump, and battery. This test is used to determine whether the components are working properly or not before the tool is assembled according to the tool designer's design.

2.4.2. Overall Testing

The hovercraft test was carried out in various aspects, namely:

a. Testing the hovercraft controller software created using Android Studio.
b. Testing the direction of the water spray.

2.4.3. Planning Test

The hovercraft test will be tested in the training pool, because there are no waves, and the water does not flow. The test carried out is to test how far the spray distance is and how far this hovercraft can be controlled using the ESP32 microcontroller with the hope that the hovercraft can function as a fire extinguishing tool for ships in the middle of the sea, as well as testing the duration of battery life when used for this hovercraft. Later the results of this test will be included in the test results table.

3. Results and Discussions

3.1. LiPo Battery Endurance Test Result

The 2200mAh 11.1V 30C 3S Lipo Battery Pack is a LiPo battery which contains 3 battery cells connected in series to produce a battery voltage of 11.1V with a capacity of 2200mAh. According to Table 2, the components that are turned on refer to the battery duration endurance capability. From the results showing the battery duration from 100% to 0% experienced a significant decrease when the components were turned on together, but the battery did not experience a voltage drop which was marked by a decrease in the performance of the hovercraft components. The Hovercraft control distance test with obstacles and open area are presented in Table 3 and Table 4.

Table 2. Data on the Results of the 3S LiPo Battery Endurance Test

No.	Category	Description	Time
1	All components are on Active	Hovercraft movement with the pump always on	50 minutes
2	The DC pump is always on and other components are not always on	Active hovercraft movement with the pump always on	1 hour 1 minute
3	The DC pump is not always on, and other components are always on	Active hovercraft movement with the pump not always on	1 hour 38 minutes
4	All components are not always on.	Passive hovercraft movement with the pump not always on.	1 hour 53 minutes

Figure 6. Hovercraft control distance test and spray

Table 3. Data on the Results of the Hovercraft Control Distance Test with Obstacles/ Non-Line of Sight (NLOS)

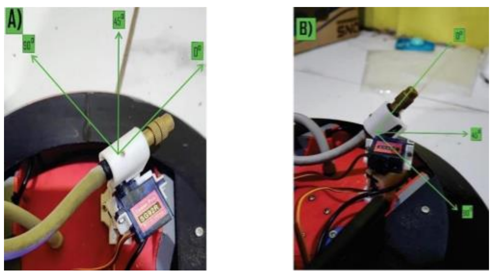
No.	Distance	Diskripsi	Response
1	1 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✓
2	3 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✓
3	6 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✓
4	9 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✓
5	12 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✓
6	13 meter	Facing the Obstacles/Non-Line of Sight (NLOS)	✕

Table 4. Hovercraft Control Distance Test Results Data with open area / Line of sight (LOS)

No.	Distance	Diskripsi	Response
1	5 meter	Open area / Line of sight (LOS)	✓
2	9 meter	Open area / Line of sight (LOS)	✓
3	15 meter	Open area / Line of sight (LOS)	✓
4	20 meter	Open area / Line of sight (LOS)	✓
5	25 meter	Open area / Line of sight (LOS)	✓
6	30 meter	Open area / Line of sight (LOS)	✓
7	33 meter	Open area / Line of sight (LOS)	✓
8	38 meter	Open area / Line of sight (LOS)	✓
9	42 meter	Open area / Line of sight (LOS)	✓
10	43 meter	Open area / Line of sight (LOS)	✕

3.2. Hovercraft Control Distance Data with Remote Software Result

Maximum hovercraft control distance testing by running the hovercraft until the hovercraft cannot respond to remote software commands. Figure 6 is a photo taken during the hovercraft control distance test and tests the ability to spray the water. Testing the distance and direction of the Hovercraft water spray by turning and raising and lowering the servo water spray direction according to the angle to be tested and then measuring the distance of the spray results. In Figure 7 explains the direction of the spray with an angle, with Figure 7(a) explaining the angle of the servo Y (horizontal) water spray direction to the right and left while Figure 7(b) explains the direction of the servo X (vertical) water spray angle up and down.



(a) for-Servo Y (Vertical) (b) Servo (Horizontal)
Figure 7. Flush Direction Based on Angle;

Table 5. Results of Water Spray Distance and Direction Tests

No	Servo Command Angle X (°)	Servo Command Angle Y (°)	Spray Distance
1	0°	0°	1 m 40 cm
2	0°	30°	1 m 73 cm
3	0°	45°	2 m
4	30°	0°	1 m 43 cm
5	30°	30°	1 m 72 cm
6	30°	45°	2 m 7 cm
7	45°	0°	1 m 46 cm
8	45°	30°	1 m 76 cm
9	45°	45°	2 m 10 cm

10	60°	0°	1 m 45 cm
11	60°	30°	1 m 71 cm
12	60°	45°	2 m 4 cm
13	90°	0°	1 m 45 cm
14	90°	30°	1 m 73 cm
15	90°	45°	2 m 2 cm

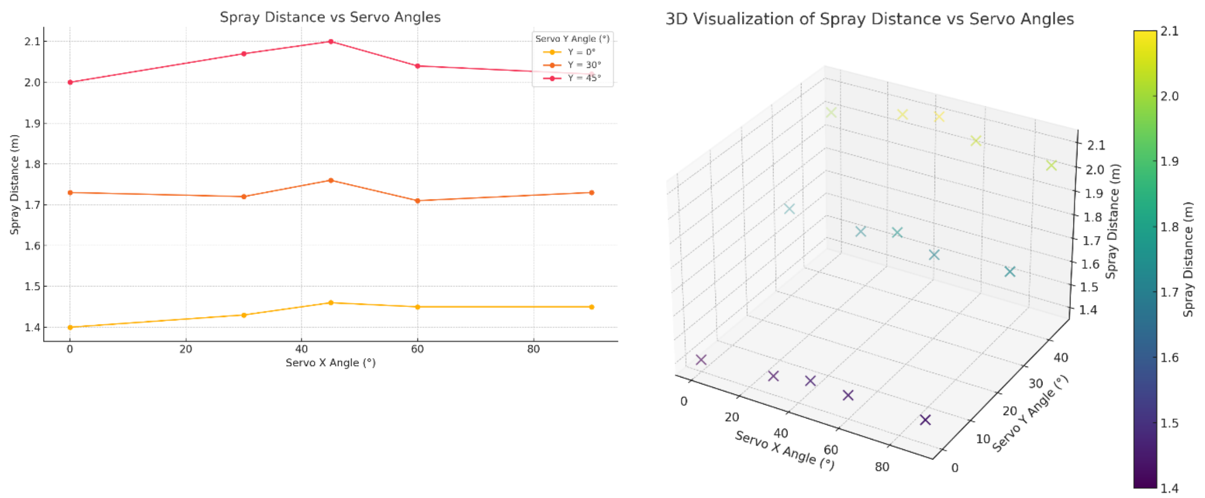


Figure 8. Visualization of the ability of servo to spray

Figure 8 describes the ability of servo to spray water. Here are the Explanation: X-axis: X Servo Angle (horizontal tilt). Y-axis: Y Servo Angle (vertical tilt). Z-axis (dot color and position): Spray distance in meters. The color indicates the intensity of the spray distance (the brighter/greener → the farther the distance). Additional Analysis: The highest point is at a combination of around X = 45°–60°, Y = 45°, which means the maximum angle on the vertical axis (Y) produces the furthest spray. The optimal combination of horizontal and vertical tilts produces maximum spray performance.

3.3. Discussions

The advantages of this hovercraft can be shown from the battery endurance test. The selection of components which have very low power consumption can make the ship's operational time for 1 hour 53 minutes or almost 2 hours as shown in Table 5. The selection of a low watt DC pump motor also helps the operational effectiveness of the system. Based on several previous studies, the use of an Electronic Speed Controller (ESC) module that can be adjusted to change the direction of motor rotation has not been implemented. As a result, the hovercraft developed in those studies were unable to move backward, which is one of the design weaknesses. ESC regulates power consumption according to the motor's needs, thereby increasing energy efficiency and extending the operating time of the device. The ESC is the main component on this unmanned hovercraft. Smooth and precise motor speed control, according to the signal from the controller using a remote control as an automatic forward and reverse control system. This ESC can reverse the direction of motor rotation (forward and reverse), so that the vehicle can move forward and backward easily – also as an important feature for moving in confined spaces.

Hovercraft in this study, although superior because it can traverse various terrains (water, mud, land), this unmanned ship has quite significant weaknesses in missions that require position precision, such as watering or certain points in swampy areas or puddles.

a. No Direct Contact with the Surface
This hovercraft floats above the surface using an air cushion. Because there are no wheels or propellers attached to the ground or water to hold its position, this vehicle, however, has the disadvantage of not having an anchor point or grip on the surface. So it is easily pushed by water currents, wind, or small slopes.

b. Vulnerable to Being Carried Away by Currents
In waters or wetlands with flow, the water current will push the hovercraft in the direction of the flow, even though the push is small.

c. Because hovercraft is light and has minimal friction, a small push can cause a significant shift in position, especially when the vehicle is stationary.

d. Difficulty Locking Position (Position Holding)

Unlike drones or ships with GPS lock systems or lateral thrusters, hovercraft cannot lock positions precisely. When watering is needed at a certain point, the hovercraft can drift or move, causing the water to be off target. This worsens the efficiency of water and the effectiveness of the spraying mission. Further research requires streaming cameras or intelligent fire sensors, so that extinguishing is location-oriented with movement settings to maintain the position and stability of the unmanned ship.

e. Fine Maneuvers Are Difficult
Hovercraft tends to have slower and less precise maneuvering control than vehicles with wheels or water propellers, especially in narrow spaces or with specific direction requirements.

4. Conclusion

The conclusion based on the results of the research and testing; the design of this unmanned hovercraft ship was successfully developed as a fire extinguishing tool for ships in the middle of the sea. The hovercraft has a design with dimensions of 37 cm × 30 cm × 17 cm, using a 3D printed frame and white foam to ensure its stability in the water. The control system is based on a smartphone application created with MIT App Inventor and connected via Wi-Fi using ESP32. All components, including the BLDC motor, DC water pump, and servo motor, function properly. This hovercraft ship has a control range of up to 42 meters in open space and 12 meters with obstacles and is capable of operating for 1 hour 53 minutes. Hovercraft in this study, although superior because it can traverse various terrains (water, mud, land), this unmanned ship has quite significant weaknesses in missions that require position precision, such as watering or certain points in swampy areas or puddles. Further research requires streaming cameras or intelligent fire sensors, so that extinguishing is location-oriented with movement settings to maintain the position and stability of the unmanned ship.

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