Journal of Engineering and Technology

ISSN 2180-3811 eISSN 2289-814X https://jet.utem.edu.my/jet/index

DESIGN AND DEVELOPMENT OF HOVERCRAFT AMPHIBIOUS ROBOT LOCOMOTION FOR UNMANNED MISSIONS

M. S. M. Yusof [1], M. Rafeeq*[2] and S. F. Toha[2]

[1] Department of Electrical Engineering, Intel Sdn Bhd, Penang, Malaysia.

[2] Department of Mechatronics Engineering, Faculty of Engineering, International Islamic University, Malaysia.

*corresponding: rafeeqatpace@gmail.com

Article history:
Received Date: 1 June 2023
Revised Date: 24 August 2023
Accepted Date: 7 November 2023

Keywords: Hovercraft, Amphibious Robot, Locomotion, Unmanned

Abstract— Unmanned aerial vehicles have been popular for unmanned missions like monitoring, data collection, and rescue operation. These wide varieties of applications in military, search and rescue, and civil areas require the unmanned vehicle to traverse multiple environments such as land, water, and air. However, Unmanned vehicle maneuvering in these dynamic and unstructured environments increases the complexity of the design and development of Unmanned vehicles. Thus, there is a requirement to design simpler models, lower control capability, and prototype development with lower hardware requirements. The study aims to design and develop an amphibious vehicle integrating hovercraft capability that allows the system to traverse in a different environment with a lower transformation mechanism and simpler control design. The Hovercraft amphibious robot is designed using Solidworks, and a prototype is developed. For the evolved design and the functionality of the developed system is evaluated. The hovercraft was lifted and was propelled by the thrust system. It was able to carry craft weight 1.34 kg and hovered with an air cushion of 0.5 inch. The developed system with an IoT system plugin will serve in the data collection, sample collection, and monitoring of disaster-prone water bodies and amphibious reconnaissance missions.

I. Introduction

In the past two decades, research and development in the domain of UAVs have had tremendous growth. A variety of UAVs are applied in environmental monitoring [1], structural health monitoring [2], and in developing micro aerial vehicles[3], [4], [5]. However, the standalone UAV can traverse in a single environment. The real-world applications involve the vehicle having multiple environment traverse functionality. The water-borne and land environment manoeuvring is addressed by amphibious locomotion [6]. The challenge is to have a simpler integrated mechanism with a lower control design. The commonly used existing control techniques for hovercraft like LQR control [7] ,PID control [8] and improved genetic algorithm control design [9] can be applied to a controller to achieve manoeuvring in all these environments with a developed system.

An amphibious vehicle is simply a vehicle that is a means of transport, viable on land and on (or under) water. Amphibious vehicles include amphibious bicycles, ATVs, cars, buses, trucks, military vehicles, and Hovercraft. Cooperative intelligence research studies cooperative robots, including their design, physical body, and controlling behaviours. It is defined as the collective behaviour of decentralized, self-organized systems, natural or artificial [10] .

Prieto, Navarro, Plaza & Polo [11], and Yorihisa Yamamoto et al. [12] had been designed a hovercraft robot based on LEGO Mindstorm. These researchers used NXT controllers to develop their robots. However, this type of controller is relatively expensive. Many researchers have developed autonomous Hovercraft using various control methods such as Linear Quadratic Regulator (LQR), proportional Integrated Derivative (PID) Controller, Fuzzy Logic Controller, Pole Placement Controller, and many other control methods available to achieve their targets. Some of these control methods are quite complex, particularly for students in terms of implementation.

Since the focus of this study is to develop and design a hovercraft robot for the locomotion that involves both air-borne and water-borne using an unmanned vehicle is achieved using hovercrafts. The integrated Hovercraft with amphibious features is designed and developed to fulfil the contemporary complex environment traversing requirement. However, these require the complex design of multiple mechanisms, and each mechanism serves and is specialized for a single environment, increasing the complexity of design, control, hardware, and computing requirement. Thus, using an affordable microcontroller and a not too complex control method is more practical. In this study, the use of Arduino microcontroller will be considered because of its affordability factor, reliability, and it is open source-based programming. The use of the R.F. control method will be considered for the control method.

The paper is organized with section one detailing the current research on hover amphibious robots, and section 2 highlights the conceptual design and development of Hovercraft. In section 3, we discuss the development and evaluation of the design of the Hovercraft amphibious robot. Finally, the conclusions are drawn and discussed in last section.

II. Design Methodology

Carlos Camoesus [13] studied the hovercraft floats on the ground surface by lift fan. The cushion makes it frictionless. Figure 1. shows design Assembly view of the hovercraft that is superior to boat over water because it has less drag and requires less horsepower to push it. The principle of operation of hovercraft is when air is blown into the skirt through a hole by the blower, as shown in Figure 1. The skirt inflates, and the increasing air pressure acts on the base of the hull, pushing up (lifting) the unit. Small holes in the skirt prevent it from bursting and provide the necessary cushion of air. A little effort on the Hovercraft propels it toward the push.

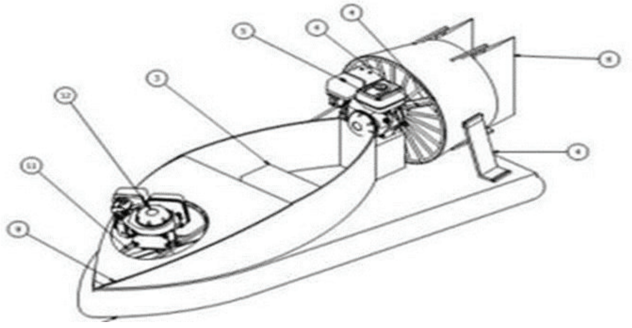


Figure 1: Assembly view of the Hovercraft [13]

The vehicle has two engines; the rear and the front. A stator fan is attached to the front or lifts the engine, which directs air into the skirt to provide the air pressure needed to lift the craft. The propeller attached to the rear or thrust engine develops the thrust needed to propel the craft. The propeller is enclosed by the thrust duct, making it possible to direct the air. The duct is bell-shaped, increasing the velocity of air escaping it. The polyester skirt is PVC coated, giving it more strength to sustain the air pressure. It is made airtight. The hull is a platform that sustains the entire weight of the craft. A hole is made in the hull through which air enters the skirt. Hovercraft is like a boat, but it has a unique part that differentiates it from a boat, the hull. Hull is the lowest part that supports when not moving on the ground. This lowest part is designed to glide on a solid surface and reduce friction when Hovercraft is on a water surface.

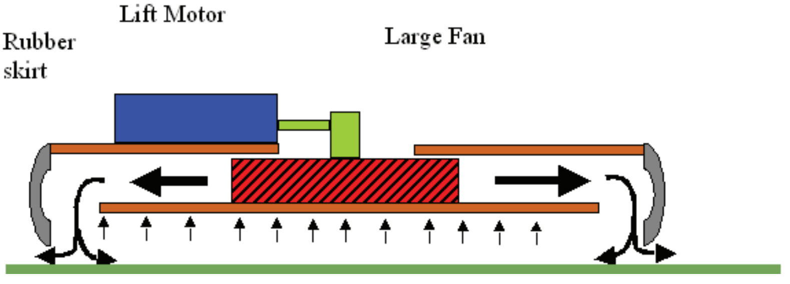


Figure 2: Hovercraft Skirt and Air Flow [14]

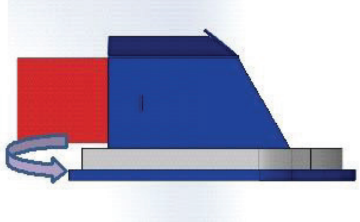
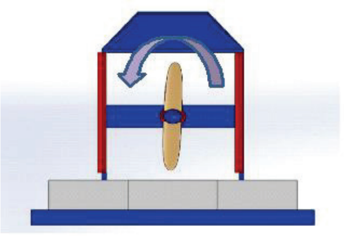
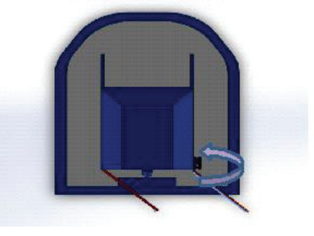
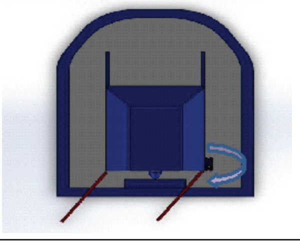
Thrust is the force that will oppose drag; it is a force that induces movement on the hovercraft skirt and is a device that lets the air cushion be maintained. The retaining air mass before and after should be calculated when designing the skirt.

Solidworks is used for the mechanical design of vehicles. We are using an Arduino controller to send and receive commands. The vehicle is tested to find specific problems and limitations regarding the mechanical design; friction force with the ground was challenging, so we needed to use a material with the lowest friction with the ground. At the end of the methodology, we have designed a hovercraft that can be controlled using a simple controller by using the R.F. module.

A. Conceptual Design

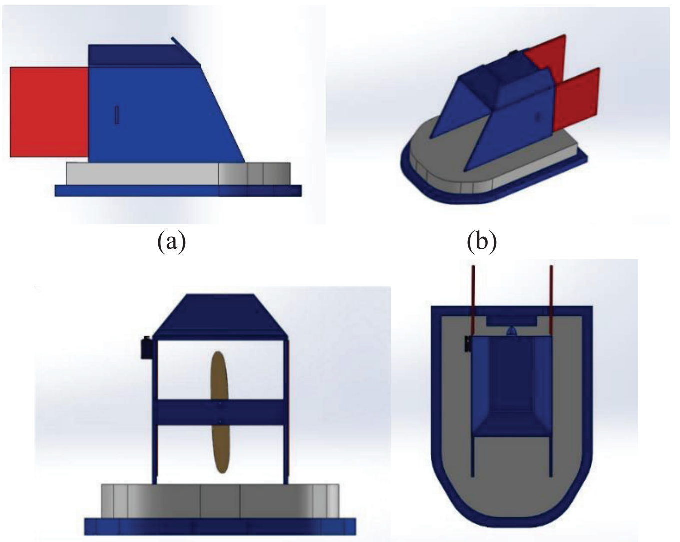
Solidworks is used to design the Hovercraft amphibious robot. Table 1. shows the configuration of a hovercraft amphibious robot elaborating different operations. After the design is completed, the design validation tool is used to do the simulation on the designated part. The simulation allows users to see the strength of their design and to ensure the design can function properly. By using simulation, the users can check Finite Element Analysis (FEA) of their design.

Table 1: Configuration of Hovercraft Amphibious Robot

Operation	Design	Function
Lift up		The motor will rotate the propeller, and then the air will blow into the skirt. So, the skirt will expand.
Motor movement		When the motor rotates anti clockwise, it will produce speed and thrust through the propeller. So, it will give some force and speed toward Hovercraft.
Right motion		When the servo turns 180 degrees, the wings will follow the rotation. The movement of the wing affect the motion of Hovercraft.
Left motion		When the servo turns 0 degree, the wings will follow the rotation. The movement of the wing affect the motion of Hovercraft.

B. Hovercraft Amphibious Robot Concept

HOV POD and general Hovercraft serve as the primary reference for Hovercraft amphibious robot development. The basic idea is to pump, by whatever means, a large and continuous amount of air under a craft to achieve lift. To effectively use this air, some form of a retention system is employed to help control this air; this mechanism is known as the skirt. The hovercraft amphibious robot is designed.



(a) (b) (c) (d)

Figure 3: a) Proposed design b) front view c) side view d) top view of Hovercraft Amphibious Robot

using Solid work design software because it is easy to use and construct the project design.

C. Frame Design

Figure 3 are the conceptual frame designs of Hovercraft, which uses Solidwork as the main software for the design. While the Hovercraft is moving forward with desired speed controlled by the Arduino coding, the servo is responsible for turning the Hovercraft. The coding sets the servo on how many degrees the robot will turn. In this project, we used a micro servo instead of digital servo because the analog micro servo can perform the turning degree until 180 degrees while the digital servo could only turn 90 degrees in the coding.

III. System Development and Testing

A. Materials

After selecting the suitable component and design, the real design was constructed, as shown in the previous part. Many suitable criteria have been tested and the materials of the main body's materials were designed with lightweight materials such as impraboard, foamboard, and heavy-duty plastic sheet for skirting that can easily lift the body of the Hovercraft as shown in Figure 4 and Table 2.

Table 2: Material for hovercraft components

Material	Component
Aluminum	Hull base
Polyethylene	Lift Duct
Foamboard	Skirt
Acrylic	Fan Assembly
Acrylic	Motor mount
	Arduino nano
PVC	Bullet propellor
	Micro servo

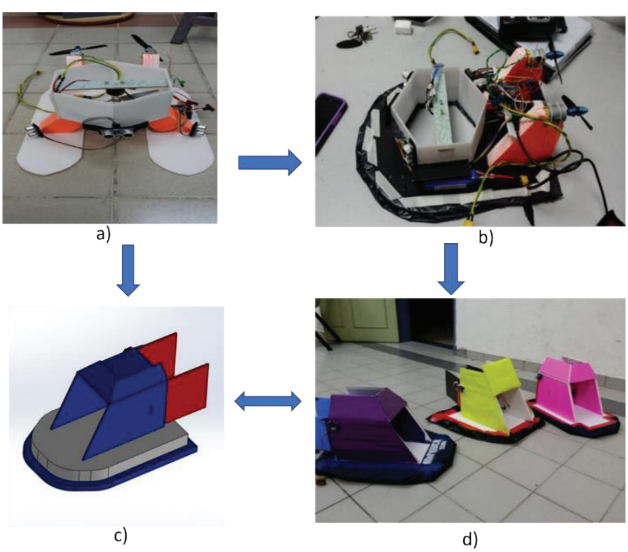


Figure 4: Evolution of design a) initial design b) second design c) final design

B. Evaluation of Hovercraft Performance

For designing the Hovercraft, we have tested many designs due to several factors to improve. the performance, such as speed and the force to lift. Back to the hovercraft system on how it works after several tests, the Hovercraft operated by forcing air inside the skirt under the body. The air pressure inside the skirt is supported by the brushless motor using the propeller.

Table 3: Hovercraft Vehicle Specification

Component	Units
Hull length	0.44 m
Hull width	0.22 m
Hull weight	0.67 Kg
Surface area of skirt	0.0968m
Propeller cover	0.15kg
Motor weight	0.5 kg
Total craft weight	1.31 kg
Lift force	107.91 N

While the air pressure increases, the body will push off the ground, reducing friction between the skirt and the ground. Here is the calculation of the force needed to support the weight (W) as in equation (1):

$$F_{cu} = W = P_{cu}A_c \quad (1)$$

where:
P_{cu} = cushion pressure
A_c = effective cushion area

The other one is the power needed to lift a hovercraft is shown in Equation (2):

$$P_a = h_a l_{cu} D_c \left({}^{W}/_{A_c}\right)^{3/2} \left({}^{2}/_{d}\right)^{1/2} \quad (2)$$

where:
h_a = lift up height
l_{cu} = cushion perimeter
d = density of air
D_c = discharge coefficient (it varies from 0.5-1.0 depending on wall design but assume it is equal to 0.611 for a skirt with a straight wall)

IV. Conclusion

UAVs are utilized in variety of applications that involve capturing of information, monitoring the environment and as carriers of payload and stocks to destination. However, the UAVs can maneuver only in the air medium restricting their usage in single environment. Applications that involve complex operations like reconnaissance, search and rescue operation and monitoring disaster area requires the unmanned vehicle to traverse in multiple media. the unmanned vehicle achieves multimedia locomotion by having separate mechanism to specialized for a particular medium. However, to traverse from one media to another requires transformation or adjustment of mechanism to adapt to different environment making the system complex intern creating complex control design. Hence there is requirement of simple mechanism with lower control design. The designed amphibious hovercraft achieves multiple environment locomotion in land, water, and air media. The design using Solidworks encompasses simple design, with hardware having lesser computing allowing for lower control techniques to be implemented. It is anticipated that the prototype developed will create appropriate lift and propulsion to be utilized for applications that involves disaster arena and search and rescue operations.

V. Acknowledgement

This work was supported by Collaborative Research Grant IIUM, UPSI, UPNM, UMP titled “Sophibian: An Amphibious Robot Upscaling for Multi-Scheme Maneuvering Environments”, Grant number of the research grant is “C-RIGS22-011-0017”.

VI. References

[1] N. K. U. Prakash *et al.*, “Design, development and analysis of air mycoflora using fixed wing unmanned aerial vehicle (UAV),” *J. Appl. Sci. Eng.*, vol. 17, no. 1, pp. 1–8, 2014.

[2] S. Sankarasrinivasan, E. Balasubramanian, K. Karthik, U. Chandrasekar, and R. Gupta, “Health monitoring of civil structures with integrated UAV and image processing system,”

Procedia Comput. Sci., vol. 54, pp. 508–515, 2015.

[3] L.-J. Yang, B. Esakki, U. Chandrasekhar, K.-C. Hung, and C.-M. Cheng, "Practical flapping mechanisms for 20 cm-span micro air vehicles," *Int. J. Micro Air Veh.*, vol. 7, no. 2, pp. 181–202, 2015.

[4] U. Chandrasekhar, L.-J. Yang, B. Esakki, S. Suryanarayanan, and S. Salunkhe, "Rapid prototyping of flapping mechanisms for monoplane and biplane ornithopter configurations," *Int. J. Mod. Manuf. Technol*, vol. 9, pp. 18–22, 2017.

[5] C. Udayagiri, M. Kulkarni, B. Esakki, S. Pakiriswamy, L.-J. Yang, and others, "Experimental studies on 3D printed parts for rapid prototyping of micro aerial vehicles," *J. Appl. Sci. Eng.*, vol. 19, no. 1, pp. 17–22, 2016.

[6] M. Rafeeq, S. F. Toha, S. Ahmad, and M. A. Razib, "Locomotion Strategies for Amphibious Robots-A Review," *IEEE Access*, vol. 9, pp. 26323–26342, 2021.

[7] H. Mansoor, S. Habib, and others, "Genetic algorithm based LQR control of hovercraft," in *2016 International Conference on Intelligent Systems Engineering (ICISE)*, 2016, pp. 335–339.

[8] B. R. Yenugula and M. Zia-ur-Rahman, "Stability control structure of hovercraft prototype utilising PID controller," *Bull. Electr. Eng. Informatics*, vol. 6, no. 4, pp. 348–350, 2017.

[9] H. K. Tran, H. H. Son, P. Van Duc, T. T. Trang, and H.-N. Nguyen, "Improved genetic algorithm tuning controller design for autonomous hovercraft," *Processes*, vol. 8, no. 1, p. 66, 2020.

[10] H. Asama, "Design of an autonomous and distributed robot system: ACTRESS," in *Proc. of IEEE RSJ Int. Conf. Intelligent Robots and Systems*, 1989, pp. 283–290.

[11] S. S. Prieto, T. A. Navarro, M. G. Plaza, and O. R. Polo, "A monoball robot based on LEGO Mindstorms [focus on education]," *IEEE Control Syst. Mag.*, vol. 32, no. 2, pp. 71–83, 2012.

[12] Y. Yamamoto, "Nxtway-gs model-based design," *Rep. Cybernet Syst. CO., LTD*, 2009.

[13] C. Camoesas, "Hovercraft Design," portugal. https://www.ovarcraft.com/prod01.htm

[14] M. I. A. A. Koko, "Design of a Typical Multi-Role Vehicle Using Quad-Rotor Theory," Sudan University of Science and Technology, 2014.