LINEAR FORWARD AND BACKWORD LOCOMOTION FOR AMPHIBIOUS VEHICLE WITH ROCKER BOGIE MECHANISM

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ABSTRACT

Amphibious vehicles, capable of operating on both land and water, are essential for applications such as search and rescue, environmental monitoring, and military operations. This study investigates the linear forward and backward locomotion of an amphibious vehicle using advanced simulation tools. A detailed 3D model from SolidWorks was integrated into MATLAB's Simulink and Simscape to simulate and analyze the vehicle's motion dynamics. The simulation results demonstrated efficient and stable linear locomotion, with effective control mechanisms ensuring smooth and controlled movement where the peak motor current of 1.8 A during start-up was reduced to a steady-state current of 0.8 A, and power dissipation decreased from 0.25 W to 0.1 W, indicating significant energy efficiency. These findings validate the robustness of the design and highlight areas for potential optimization. Future work will focus on further refining the vehicle's design and conducting real-world testing to validate and enhance its performance.

Keywords: *Amphibious vehicle, Simulink, Simscape, Linear Locomotion Simulation*

1.0 INTRODUCTION

Amphibious vehicles that function both for land and water have received considerable attention because of their diverse and multifaceted uses in fields including search and rescue, environment protection, and even in the military. As with many other automobile classes, an effective solution means the search for suitable propulsion technologies that can improve vehicle mobility in various environments. This paper concerns with the straight forward and backward motion of amphibious vehicles examining the design approaches and efficiencies through simulation in MATLAB Simulink and Simscape.

Technological development has enhanced the invention of amphibious vehicles even though the idea is not new in the society. A lot of early for amphibious vehicles was built for military uses, including the DUKW used in world war II. Recent amphibious cars, on the other hand, are built for civil and commercial tasks as well as military operations. These vehicles operate on various terrains and water, have to include complex motility systems that can switch between land and water modes [1]

The first major consideration when considering the design of amphibious vehicles is that the auto must be equally good on land and water. In AGV, on-land effects that the vehicle has to consider include traction, friction and surface roughness. In water it has to deal with issues of buoyancy, drag forces and propulsion. It is thus clear that the incorporation of these very divergent needs into a single vehicle design requires a systems approach; this calls for usage of elements from mechanical engineering, fluid dynamics and control engineering [2]. To this end, this paper seeks to address these challenges by highlighting on the linear motion mechanisms for efficient navigation in the two terrains.

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1.1 Linear Locomotion

Linear motion defines how a car can move in one direction or the other in a straight path forward or backward. Specifically, challenges in designing efficient linear motion of amphibious vehicles are next discussed starting with the fact that such vehicles are intended to be used both on the land and in water. On ground there are parameters like traction, the degree of friction, and roughness of the ground etc, have to be taken into account. And within water context there are such primary forces as buoyancy, drag and propulsive forces. Several works have been undertaken to analyze improved methods of forward movement for amphibious robots, such as the vibration system and the biomimetic system [3-4].

Another solution to improve the linear mobility is in using helical drives motors that can be efficient in soft and unconsolidated grinds. For instance, the MAARCO rover with helical drives designed to move across various Arctic terrains shows the viability of the concept of the application of this technology in amphibious operations [3]. Furthermore, ad hoc flexibilities inspired by amphibian movements add up to general purpose and efficacy. Such designs often entail the use of slender and splayed cores that are much better suited to the task of maneuvering in constrained spaces [4].

With respect to the development and analysis of these locomotion mechanisms, MATLAB's Simulink and Simscape products serve as fundamental simulation enables. The technologies mentioned allow making the realistic and accurate simulation of vehicle and environment, and thus verify and improve various locomotion approaches before physical realization. In this approach many considerations can be made and it runs with much efficiency is saving time as well as cost [5]. As the evaluation of the proposed model takes into account many variables, the flexibility of the application allows for the examination of different scenarios that may happen during an unmanned flight to maximize the odds of success.

1.2 Amphibious Vehicle Model

It must be pointed out that the design and the modeling of the amphibious vehicles involve combination of features that should be efficient in both terrains. This covers structural requirements for the car in question as well as the power source and the operating controls. Sophisticated simulation such as MATLAB Simulink and Simscape are employed to model and simulate the performance of such cars. For instance, the researchers can import the Stereolithography files in the format of 3D models from the tools like SolidWorks in Simulink to mimic and repair the complex movement system of the car under different contexts [5][6].

Amphibious vehicles can be defined as the vehicles that have a capability to move on both on land and in the water and such vehicles have both wheels or tracks for the terrains and propellers or water jets for the water surface. There must be a smooth transition from these modes of locomotion for the system to run efficiently. For example, the Gibbs Quadski, which is an ATV, can from land to water mode and vice versa within few seconds; it folds the wheels and uses jet power [6]. This capability is important for applications where the tuning is needed to be fast and adaptive.

In addition, forces and stresses acting upon the amphibious vehicle differ and therefore the structure of the amphibious vehicle must also be designed to handle the difference environments. On land it is necessarily to have powerful under-carriage to propel the vehicle over rough terrains while in water, the vehicle has to be buoyant and streamlined to reduce drag. There is therefore the need to reach a balance in utilizing materials and construction techniques. Aluminium and other composite sources including fibre glass are favoured light weight and corrosion resistant materials. Besides, the combination of improved control systems contributes to accurate control and stability when operated in both terrains thereby increasing the efficiency of the functioning vehicle.

2.0 METHODOLOGY

In the methodology section, the approach used in simulating and analyzing the linear forward motion of an amphibious vehicle is described systematically. This necessitates the use of modern modelling methods and simulation assessment procedures to assess the viability of the vehicle during both on land and water voyages. The main focus is to develop the simulation model which would be realized on the vehicle and its interaction with surroundings. The structure of the amphibious vehicle is modeled in 3D and then exported to MATLAB Simulink and Simscape for the modeling and simulation of dynamic systems. The layout of the simulation can be setup in terms of the electric vehicle's direct kinematics and dynamics together with the slope terrain and water depth for both land and submersion modes.

The simulation process implies the initiation of several sequences to assess the linear mobility of the vehicle. Quantitative performance indicators or rate of speed, acceleration

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and specific energy consumption are used in order to evaluate the efficiency of the design. Higher level control strategies include model predictive control and adaptive control are used to improve the vehicle stability and response. Simulation and performance analysis is done with an aim to evaluate various parameters like tractive effort, adhesion, stability and fuel efficiency. The simulation and analysis in the paper are iterative to permit improvements to the vehicle model to improve the output of the design that is needed to operate on both land and water.

The most promising results of recent studies are connected with the problem of determining performance of amphibious vehicles. For instance, Dhana et al. (2023) used CFD simulation analysis to assess the resistance performance of an amphibious vehicle with caterpillars and discovered that using of caterpillars causes the resistance value to be increased by 40% at the design speed of the amphibious vehicle [7]. Also, Karaseva et al. (2023) investigated effects of the hydrodynamical interference of rotary-screw propulsion units in amphibious vehicles with the focus on the requirements for the improvement of their design to improve functionality in different conditions [8].

2.1 Design of Amphibious Vehicle

The configuration of the amphibious vehicle employed in this study is developed from the known concept that employs both the rocker bogie together with the wheel-paddle system. It is in this configuration that the company is provided with flexibility for operation both on land and water. Nevertheless, the concern of this paper is strictly bound to the simulation and evaluation of the linear translation of the vehicle on solid ground: mainly in the up and backward direction. The rocker bogie mechanism increases traverse capability on irregular surfaces by offering some flexibility of the frame in relation to the main vehicle structure to ensure stability during movements. The unified wheel-paddle mechanism allows easy switching between environments, without the need for any other switching mechanism. All wheels contain radial paddles for propulsion equal to or better than a remora fish and allow the vehicle to swim and traverse the seabed without additional propulsion devices.

It makes the structure of a vehicle free from complex parts, and the car remains capable of moving over various terrains. Thus, for the land locomotion, the rocker bogie, in particular, makes an attempt to preserve traction and stability on irregular ground. The exclusion of lateral motions facilitates easier control dynamics since it reduces the number of variables to the study of the basic movements of the vehicle. The SolidWorks model of the amphibious vehicle is exported to MATLAB Simulink for simulation of the linear motion in the model. The simulation offers possibilities to study response of the vehicle to various terrestrial conditions when the system can be tested in practice only through the modeling. The following Figure 1 is the SolidWorks design of the amphibious vehicle, on which the simulation is based.

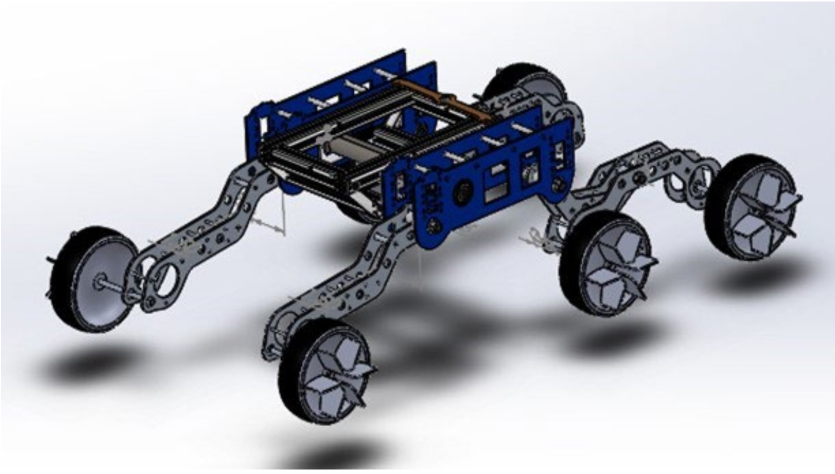

Figure 1: SolidWorks model of the rocker bogie amphibious vehicle.

Six-wheel paddle arrangement has been adopted to maintain the stability of the robot, as well as, the maneuverability as well as the propulsion characteristics of the amphibious robot. Six wheels help distribute the robot's weight evenly and also help the robot move with ease on inclined floors and flat surfaces. They are both driven at inception, allowing flexibility and decentralization; if one wheel malfunctions, the others are sufficient for mobility. This design also helps to locate the center of mass of the robot lower to the ground thus minimizing chances of falling over. The distance between two wheels is designed in such a way that it optimally utilize the space and at the same time is capable of performing its function adequately. Adequate separation of components facilitates the functioning of the rocker-bogie suspension wherein the robot can adjust to irregular surfaces and force distribution. For water propulsion, the poles do not come in contact with each other affording the paddle continuous rotatiön, and also reducing drag. This design also minimizes waves in water hence increasing efficiency in terms of propelling. In conclusion, the six-wheel positioning as well as the intervals aim at achieving stability, flexibility and conversion between the land and aquatic scenery.

2.2 Simulink and Simscape

MATLAB Simulink and Simscape software were employed to simulate straight mobility of the amphibious vehicle. It started by creating the vehicle model on SolidWorks 2021 as a preparation process to the simulation. To enable link between them the Simscape Multibody Link plugin was downloaded and installed in the solid works environment. This plugin allows the user to export the CAD design as an XML tab along with STEP files concerning the different sections of assembly of the vehicle.

The next step was to export the CAD design of the circuit and then imported the XML file created into MATLAB Simulink through the smimport function. In this step it was necessary to download and install the required Simulink and Simscape toolboxes in MATLAB to have the compatibility. The smimport function rebuilds the XML file into a Simscape Multibody model that can be simulated within the Simulink model.

The simulation flow required putting together the amphibious vehicle model in SolidWorks 2021 which also involved downloading the Simscape Multibody Link plugin add-in export the CAD design in form of an XML file together with STEP files for all the assemblies of the vehicle. Then for compatibility, Simulink and Simscape were added into MATLAB. The XML file created was exported and imported into MATLAB Simulink using the smimport function which converted the design into a Simscape Multibody model. To determine the characteristics of the vehicle as regards its linear motion whereby it moves forward and backward on land, simulation parameters in Simulink were set for evaluation. This was facilitated by a removal of excess frills hence allowed for documentation of the stabilities and traction of the vehicle during simulation.

In Simulink environment, the vehicle maneuver in forward and backward motion was simulated and the result was observed. The performance was then examined, where results which included the stability and traction were determined. MATLAB code used to demonstrate the use of the smimport function and the import of the vehicle model into Simulink is depicted in Figure 2 below.

```
Command Window
>> ver
-----------------------------------------------------------------------------------------------------
MATLAB Version: 24.1.0.2603908 (R2024a) Update 3
MATLAB License Number: 41162524
Operating System: Microsoft Windows 11 Home Single Language Version 10.0 (Build 22000)
Java Version: Java 1.8.0_202-b08 with Oracle Corporation Java HotSpot(TM) 64-Bit Server VM mixed
-----------------------------------------------------------------------------------------------------
MATLAB                                                Version 24.1        (R2024a)
Simulink                                              Version 24.1        (R2024a)
Simscape                                              Version 24.1        (R2024a)
Simscape Multibody                                    Version 24.1        (R2024a)
Simscape Multibody Link                               Version 24.1        (R2024a)
Statistics and Machine Learning Toolbox               Version 24.1        (R2024a)
>> smimport('sophibian.xml')
```

Figure 2: MATLAB code for importing the vehicle model into Simulink.

Several similar papers have proved the applicability of applying Simulink for modeling complicated vehicle structures. For instance, Wang et al. (2023) used Simulink for modeling and simulation of dynamic response of an amphibious vehicle with the interest of evaluating the response of the control mechanisms in various terrains.phibious vehicle, focusing on the integration of control systems to enhance performance in diverse environments [9]. Furthermore, Chen et al. (2023) used Simulink to apply the aspect to the energy issue of amphibious vehicles and described how Simulink is capable of simulating different operation modes and control approaches. This simulation framework presents a solid structure to evaluate the linear mobility of the amphibious vehicle [10]. The study shows how the integration between both SolidWorks and MATLAB is highly useful in achieving the objective of the study, because of how well it can prove the capability of the vehicle under terrestrial circumstances with particular attention to its dynamic characteristics and virtue.

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3.0 RESULTS AND DISCUSSION

The simulation of the amphibious vehicle's linear movement was achieved through MATLAB Simulink and Simscape. By linking the data from the SolidWorks model to Simulink, the dynamics behind the physical movement of the forward and backward motion of the vehicle were analyzed in depth. Simulation setup can be demonstrated as shown in the Figure 3 below which depicts the mechanics explorer used in the simulation.

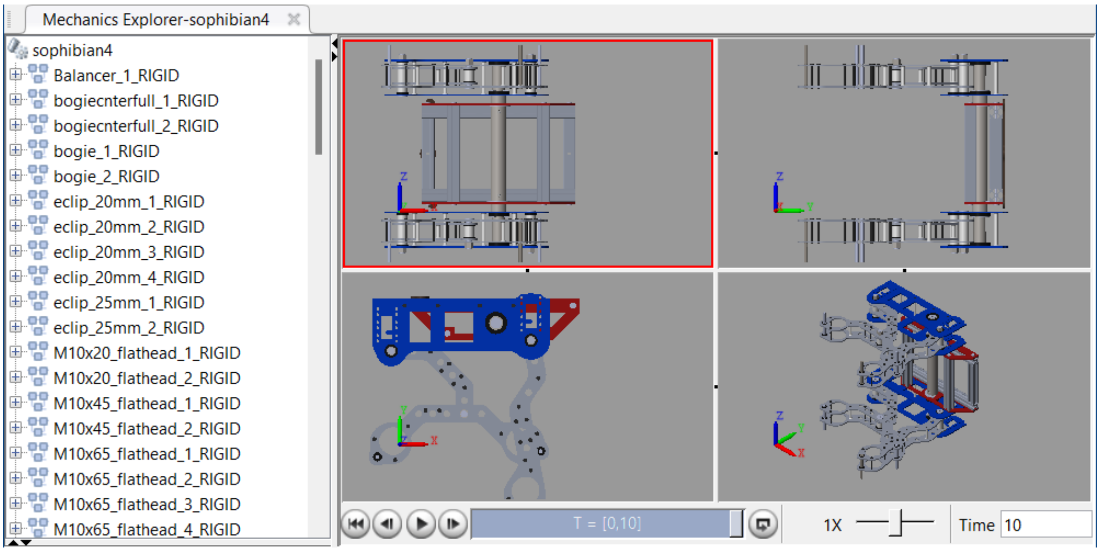

Figure 3: Diagram of the simulation setup.

Motion of the vehicle was managed by the help of DC motor that was operated by PWM voltage supply and an H-Bridge driver circuit that operated to manage the tires of the vehicle. The H-Bridge motor driver is set in such a way that it would enable the control of each tire separately to make the linear movement of the vehicle possible. Figure 4 shows the circuit diagram that was used in the simulation.

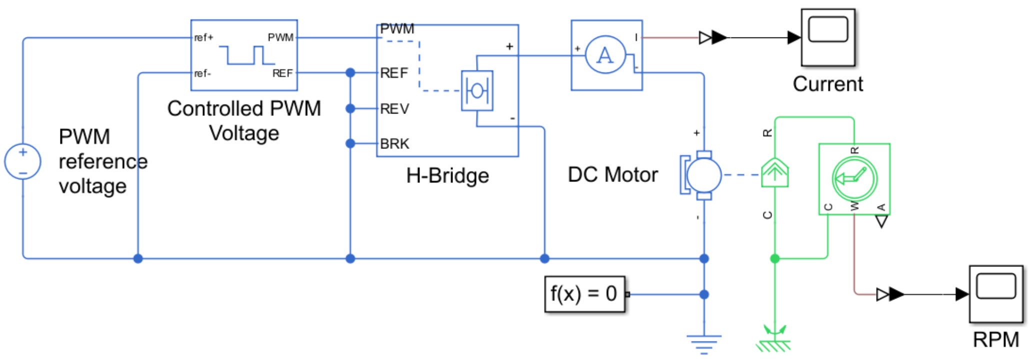

Figure 4: H-Bridge driver and DC Motor circuit configuration.

The implementation of DC motors and H-bridge circuits for the simulation of the locomotion of an amphibious vehicle has basis on several researches highlighting similar applications of motors and circuits for robotic systems. For example, Wang et al. (2012) presented efficiency of DC motors within amphibious robotic platforms because of the intrinsic size and capability to incorporate with the control mechanisms [11]. Similar to above discussion, for self-propelled bipedal and quadrupedal wheeled robot, mobility and stability, DC motors with H-bridge circuits are used smartly by Premkumar and Manoharan, (2017), to have backward as well as forward control of motor direction important for amphibian robots and to have precise control during the transition between different terrains [12]. In addition, the H-bridge circuit with full direction control and speed modulation according to Luo and Ge (2005) is irreplaceable for emulating real-life operation of the amphibious vehicle [13]. Altogether, these results provide rationale for utilizing a DC motor and H-bridge configuration in the simulation based on the extant amphibious robotics literature.

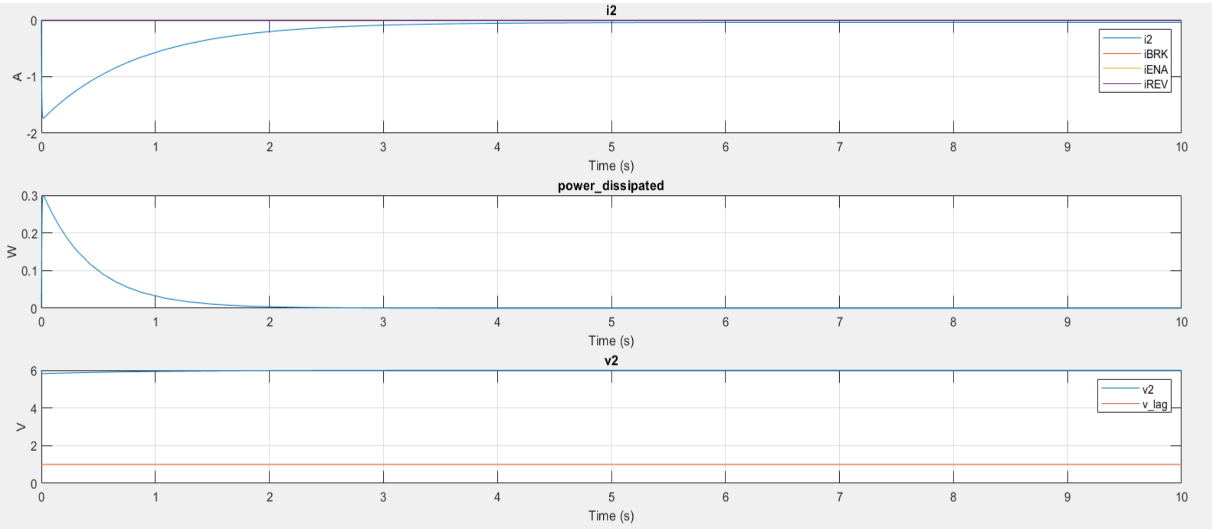

Figure 5: Combined graphs of current signals, power dissipated, and voltage signals.

Based on Figure 5, the simulation results provide enhanced information on the motor's work and the H-Bridge driver under PWM control. Current signals (i2, iBRK, iENA, and iREV) represent the behaviour of various currents in the H-Bridge driver circuit and the motor. The first graph in Figure 5 indicate the current changes with time across the motor and H-Bridge components which clearly illustrates the dynamic characteristics of the system. The current through the motor is referred as i2 which initially is around 0 A and increases quickly and reaches to approximately 1.8 A within the first second. This peak is attributed to the inrush current required to overcome the motor statics and to bring the motor to an accelerated rate. With this stabilization of the motor, the current reduces gradually but it is more gradual and at t = 4s it has gently settled at a current of about 0.8 A. This steady-state value represents the present current, which is needed to sustain the revolution and withstand load to show that the motor is now in its optimum condition. Thus, the braking current, iBRK, is also limited to 0A all along the time simulation, pointing to the nonoccurrence of active braking. Equally, the enable current, iENA, begins when the system powers up and hovers just over 1 A, constantly for forward movement. On this aspect, a significant difference can still be observed as the reverse current, iREV, remain very small as 0 A proving that it is not operating in reverse.

Furthermore, the power dissipation curve illustrated in the Figure 5 includes energy losses that are associated with resistive heating and switching. At the beginning of the startup phase, at t = 0, the dissipated power clearly reaches a maximum of about 0.25 W, as with the current peak shown in the first graph. The peak hence arises due to resistive losses ($P = I^2R$) when the motor starts operating. At t = 2 seconds there is a massive decrease in power dissipation to an average of 0.12W as the motor machining interval progresses towards steady state. For t > 4s, the power dissipation is again fairly constant and is around 100mW proving that steady state efficiency of the system is satisfactory. A reduction from 0.25W at starting to 0.1W in the steady condition, which is approximately 60 % reduction, shows that the energy efficiency increases as the motor gets in steady state.

The voltage signals v2 and v_lag are clearly shown in the last graph of Figure 5 as additional confirmation of the control dynamics of the system. The second voltage which is the applied voltage, v2, at the start is zero at t = 0 and rises significantly at a higher rate and comes close to 5.5 V at t = 3 s. This stabilization is synonymous with the motor attaining its no-load speed and the PWM supply a continuous unchanging duty cycle to deliver the necessary power. In contrast, the lagging voltage v_lag begins about 2V as the symbol for the inductive opposition of the first current variation. Using the software, the value of v_lag reduces gradually from 10V unto being almost equal to 0 V by the 5th second. This decrease shows us that the inductive effects are temporary and reduce as soon a motor is under normal cycling operation, for optimal functionality.

4.0 CONCLUSION

The MATLAB Simulink and Simscape models for the simulation of the amphibious vehicle have been successfully established, analyzing in detail the linear movement of the vehicle in both forward and backward positions. When we introduced the SolidWorks model into Simulink, it proved possible to consider the dynamics of the vehicle and evaluate its performance in terms of movement more comprehensively. In addition, the simulation results show that PWM-controlled H-Bridge driver is able to control motor acceleration and steady-state efficiently. From the design, the peak motor current of 1.8 A during start-up is lowered down to a steady state current of 0.8 A, thus proving the system's efficiency in managing inrush current and maintaining proper performance. The power dissipation reduces tremendously from 0.25 W at start up to 0.1 W when running, making it an energy efficient system. Moreover, the stabilization of the applied voltage at 5.5 V, and the decrease of the lagging voltage from 2 V to almost zero for the present prototype means that the system is capable of defeating initial inductive effects and provide steady readings. These quantitative trends confirm the optimized design and energy efficient operating mode of the motor and the H-Bridge driver in this simulation.

Therefore, these affirm that the chosen simulation model is stable and the used design is suitable for linear motion. The information gains from this research offer a good starting point for further fine-tuning and practical application. The successful simulation therefore proves that great results can be achieved if the latest simulation models are adopted to improve the performance of amphibious vehicles. Future work will be directed towards enhancements of the vehicle model and controls using the outcomes of the simulation. Desk research will be used to confirm conclusions, as well as to handle functional concerns that may emerge in the context of real-life applications. The future evolution of amphibious vehicle technologies indicates new discoveries in their use in different sectors including search and rescue, environmental management among others.

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