Design and Development of an Autonomous Underwater Vehicle (AUV): For Rip Current Data Collection and Shallow Water Explorations

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Abstract *- Autonomous Underwater Vehicle is an emerging trend in the modern maritime scenario. Though there are various developed designs, researchers are keen on developing more maneuverable, stable and endurance structures with improved capabilities. Based on utilization, AUVs can be divided into two major categories; Deep-water operated and shallow-water operated. The purpose of the AUV designed and developed in our study is two-fold; this can be utilized for rip current data collection and shallow water exploration operations. However, the project is planned under two phases and this paper only describes the design and constructional aspects of the vessel with improved stability, maneuverability and lighting capability. On achievement of the full design, it will enable precise rip current data collection and conduct shallow-water exploration operations in both sea and freshwater streams with an online video streaming facility. In the present context, such operations are undertaken in presence of a diver and our new design eliminates the need of a diver.*

***Keywords* -** Autonomous Underwater Vehicles (AUV), maneuverability, stability, endurance, rip current data collection, shallow water explorations

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) and "Remotely Operated Underwater vehicles (ROV)" are two different kinds of unmanned underwater robotic applications. Generally, ROV is operated from the surface, through a wired connection and restricted its maneuverability. However, AUV is a bit different from ROV and when it assigns a task, it collects data and come back to the original position with high maneuverability and using narrow complex pathways (Blidberg, 2001). In addition, the underwater research community is focused on manufacturing materials, adopting new technologies, fixing with advanced sensors, utilization of Computational Fluid Dynamics (CFD) simulations, and advanced batteries to produce very reliable AUV in this juncture (Aras, et al., 2009).

AUV is an emerging research field that maintains an economy of effort during large-scale and long-term underwater data collection without risking human divers. A significant amount of theoretical, experimental, and CFD simulation has been carried out in the field of AUV over the last few decades, especially in the area of underwater and hydrography (Kim, et al., 2015). AUV is comprised of three major components such as propulsion system, controlled system, and navigation system. Present-day context, it is revealed that many universities are researching AUV to optimize existing capabilities of control systems and endurance.

Once reviewing earlier studies, a technical team of the Department of Marine Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University designed an AUV with limited capabilities for Rip current data collection and shallow water explorations. The complete project is undertaken under two phases; (1) design and develop an AUV with adequate maneuvering and lighting capability, and (2) develop an advanced control system to collect Rip current data and deploy it for shallow water exploration missions (Engle & MacMahon, 2002). Accordingly, this paper describes phase 1 of the AUV project; firstly, it describes the basic design of KDU AUV (version 1) and then it explains the detailed records of trials and performances of AUV.

II. DESIGN AND DEVELOPMENT

At the start of the project, the requirement of rip current data collection and robust shallow water exploration is identified and then the capabilities of AUV are defined. The pressure rise with the depth of the sea and the upsurge of strong external force is the major factors taken into consideration in designing the AUV structure. Accordingly, based on the findings of previous studies and a thorough analysis of material strengths to build the AUV hull is chosen, which is characterized to withstand high pressures, strong corrosion-resistant and light in weight. The AUV construction project is undertaken under three stages; (1) design and development of mechanical structure, (2) the basic control system for maneuvering and lighting, and (3) GRP (Glass Reinforced Plastics) structure. Initial drawings of AUV were made using Solid Works software, and principle dimensions are determined with stability calculations and trial and error. Then, decided to design a remote operating system to navigate the AUV to achieve the expected shallow-water exploration. In addition, the maximum submerged depth was decided to have 1m for AUV KDU (version 1).

A. Hull

The AUV KDU (version 1) is comprised of a 22 cm diameter PVC pipe as the middle part of the spherical body and GRP nobs are fitted with either side of the PVC pipe to minimize water resistance during forward movement and to get the standard shape of the AUV (Alvarez, et al., 2009). Further, components of the hull are easily detachable and maintainable. The PVC hull and anticorrosive marine paints applied on the hull provides complete hull protection against corrosion. Watertight integrity and dryness inside the hull are of paramount importance in AUV operation, which is achieved by simple mechanical fastenings.

Figure 1. Construction of AUV hull by PVC pipe

B. Hull Resistance

Conventionally, the total hull resistance is comprised of friction, waveform and wave resistance components. The friction resistance is mainly depends upon the wetted surface area, speed and length of the vessel, and density of the operating fluid. Since AUV (Version I) is a partially submerged vessel, the residuary resistance contribute to the total resistance of the vessel, as it is applied for a displacement hull vessel. Considering above aspects, the hull of the AUV was designed and built in such a way to minimize friction, experiencing minimal hull resistance.

C. Propulsion

A three-baled propeller is fitted with an electrically driven motor to propel the vessel. The propulsion mechanism is positioned in a way to minimize noise interference with other electronic components and propeller-to-hull interactions. Therefore, avoids unwanted impacts on the hydrodynamics of AUV. With this propulsion system, the speed of the vessel can be varied by a wireless remote controller, overriding the function of a conventional AUV and optimizing its capabilities in rough sea conditions. Figure 2 and Figure 3 depicts the preliminary stages of construction of AUV.

Figure 2. Preliminary stages of construction of AUV

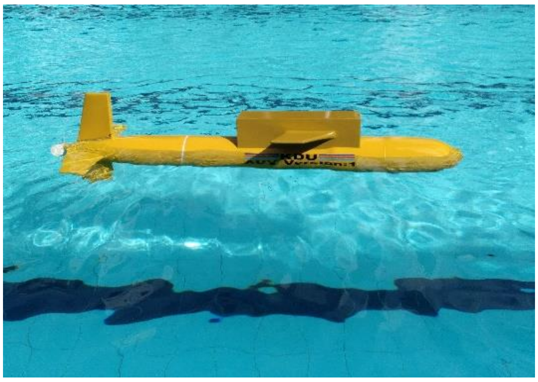

Figure 3. Developing of the propulsion system and testing at KDU Swimming Pool

D. Stability and Submerging

The AUV used for the rip data collection and shallow water exploration should be able to dive deep in order to change the submerged depth. Such capability can be achieved with ballasting or thrusters. However, AUV KDU (version 1) is designed and developed to partially submerge on the water surface as the main objective of this development phase of the project is to improve the maneuverability of the vessel. Accordingly the volume of the vessel remains constant, which provides space to install equipment for rip current data acquisition system and further improvements which enhances diving capabilities and maneuverability. Though KDU version 1 does not use ballasting or thruster utilization in this operation to dive a consistent weight of 50 maintains a fixed draft from the beginning of the operation and enough to meet the focused requirement. Figure 4 depicts the efforts taken by the designing team to determine the actual drafting condition after theoretical calculations, pertaining to maintenance of above stated draft.

Further, the vessel is designed with four static hull stabilizers at the amidship of the hull and the tail of the vessel, which adds extra stability to the vessel achieving neutrally equilibrium condition even in extreme wave conditions. The constructed vessel was tested at sea and KDU swimming pool under varying wave conditions to ensure safe operations in both sea and freshwater conditions.

Figure 4. Preliminary stability testing at KDU lake.

E. Rudders

The improved maneuverability is one of the main concerns in the development of KDU AUV (version 1). With identified loopholes in previous designs, KDU AUV (version 1) is designed with two GRP-made spade type rudders, which are capable to generate adequate lift to maneuver the vessel even against strong wave conditions. Further, improved response to the command is another cause of improved maneuverability of our design. These rudders are operated with linear actuators and capable of changing its course as per the given command by the rudder control system. However, the fixed planes provide stability to the vessel.

Figure 5: Rudder testing at hydrodynamics laboratory, KDU

F. Powering

AUV is powered by 12V sealed batteries. There are three major sections to be powered by batteries such as propulsion, control system, and high-intensity light.

Therefore, the batteries are parallel connected and current flow between batteries is avoided using protective devices. More importantly, components and essential equipment are selected to draw minimum power to enhance endurance in order to complete the focus mission comfortably.

G. Lighting

KDU AUV (version 1) is equipped with 12V waterproof light to provide illumination required for shallow-water exploration (Leathermen & Leatherman, 2017). For the version I, we have used a basic light considering the cost-benefit and it is installed at the forward underwater surface of the vessel with a fixed mounting.

Figure 6. Illumination device

III. RESULTS AND DISCUSSION

As discussed in the previous section, the objective of phase I of the KDU AUV (version 1) development project is to design and develop the vessel with improved maneuverability and lighting capability to conduct shallow exploration missions. The capability of rip current data collection and online video streaming facility for shallow water explorations will be added during the second phase of the development project. Accordingly, our model's maneuverability and illumination capability were tested at sea and lake under various lighting conditions.

A. Testing at sea

The model was tested for its performance at the Colombo harbour in day and night light. During testing, predefined performance parameters of the model were tested with the assistance of a diver. During testing, the model has operated at various locations of the harbour with different wave conditions. Subsequently, the following average data was recorded;

Table 1. Performance data during testing at sea in the daylight

Performance parameter	Performance
Depth	Surface submerged
Average Speed	2.0 Knots
Turning circle radius	3.0 m
Speed drop during turning	Negligible
Illumination	
Up to 5 m	Clearly visible
5 -8 m	Clearly visible
8 - 10 m	Clearly visible
10-12 m	Visible
Endurance	5 hours
Max. remote operation	50 meters

Table 2. Performance data during testing at sea under the night light

Performance parameter	Performance
Depth	Surface submerged
Average Speed	2.2 Knots
Turning circle radius	3.0 m
Speed drop during turning	Negligible
Illumination	
Up to 5 m	Clearly visible
5 -8 m	Visible
8 - 10 m	Visible. But objects are unidentifiable
10-12 m	Not visible
Endurance	5 hours
Max. remote operation	50 meters

B. Testing in the lake

The performance of the model in freshwater is tested at the KDU lake and the following data are recorded.

Table 3. Performance data during testing at the lake in the daylight

Performance parameter	Performance
Depth	Surface submerged
Average Speed	2.4 Knots
Turning circle radius	3.0 m
Speed drop during turning	Negligible
Illumination	
Up to 5 m	Clearly visible
5 -8 m	Clearly visible
8 - 10 m	Visible
10-12 m	Objects are unidentifiable
Endurance	5 hours
Max. remote operation	50 meters

Table 4. Performance data during testing at the lake in the nightlight

Performance parameter	Performance
Depth	Surface submerged
Average Speed	2.5 Knots
Turning circle radius	3.0 m
Speed drop during turning	Negligible
Illumination	
Up to 5 m	Clearly visible
5 -8 m	Clearly visible
8 - 10 m	Objects are unidentifiable
10-12 m	Not visible
Endurance	5 hours
Max. remote operation	50 meters

The recorded data reveals that the developed model is capable to provide adequate lighting for the video recording during shallow-water exploration. Further, it's maneuverable enough to conduct such operations with minimized water currents.

IV. CONCLUSION

AUV is an emerging trend in underwater research. AUVs are utilized for numerous ocean-based applications, thus the need for AUVs with improved capabilities is demanding. The model designed and developed during this study is the successful outcome of the first phase of the AUV project which is intended to use for rip current data collection and shallow-water exploration. The developed model is a redesign of the existing AUV model with new modifications to improve identified loopholes. The PVC hull structure of the model eliminates corrosion damages experienced when using steel AUVs, and further, powerful maneuvering capability eliminates drag due to water current which is a common issue in AUVs. More importantly, sea trial results have proven it's fitness in terms of stability and maneuvering to utilize for rip current data collection, which will be developed through equipping an improved control mechanism. Further, test results have proven the best results of its illumination capability in order to utilize for shallow water explorations and thus, our model will be further developed by introducing a modern online video streaming facility during next development stage.

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