Biologically inspired autonomous underwater vehicle (AUV) for structural inspection and survey in coastal regions

Santhosh Ravichandran and Prabhu Rajagopal

Center for Non-Destructive Evaluation and Department of Mechanical Engineering, IIT Madras, Chennai 600036, T.N., India

Presenting author's contact: +91-9003009375 and santhosh11dec@gmail.com

Abstract

Coastal and littoral assets need to be inspected for structural faults periodically, but this process is affected by difficult wave conditions close to the shore line. Typically manual inspection using boats is challenging closer to the shore where the draft is lesser. Automated robotic inspection using conventional propulsion techniques is also difficult as the power and manoeuvrability required to operate against rough wave action can be considerable. However, marine organisms are able to navigate and swim through such conditions and here we aim to learn from such natural mechanisms to improve the performance of robotic underwater vehicles for inspection and survey. This paper describes research on the development of a biologically inspired autonomous underwater vehicle for operation in near-shore marine locations. The design incorporates biomimetic biologically inspired propeller together with conventional rotary thrusters. Key parameters such as propulsive efficiency, cost of transport, manoeuvrability and the overall performance of the design are studied.Further development and suitability of such designs for on-field observatory missions is also discussed.

Keywords: Autonomous Underwater Vehicle (AUV), bio-inspired biomimetic design

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I. INTRODUCTION

The expansion of the oil and gas industry has led to the need for regular and reliable inspection operations at offshore structures. Manual inspections of such structures are often challenging,can put operators at risk and also yield unreliable results. This situation has led to the involvement of remotely operated underwater inspection vehicles to inspect such structures. With the advancements in technology, these vehicles are alsoavailable in autonomous mode to facilitate periodic unmanned inspections. They still encounter problems related to stability, manoeuvrability and efficiency in a harsh ocean environment with strong waves along with other perturbations. These problems have resulted in the research on biological designs to understand the mechanisms by which marine organisms overcome such problems. Biological organisms produce thrust in a much more efficient manner than conventional rotary propellers [1] motivating researchers to mimic marine organisms for the propulsion of their robots. Addressing these issues, in this paper, a novel hybrid design of a bio-inspired underwater vehicle which uses both a biomimetic propulsion system and conventional rotary propellers is proposed.

In this paper, the design and development of this design will be discussed along with its suitability for offshore inspections. Some key parameters such as propulsive efficiency, cost of transport, manoeuvrability will be also discussed in detail to understand and appreciate the advantages of this design.

II. VEHICLE REQUIREMENTS

Underwater observation class vehicles should be capable of operating in conditions of strong waves, cold temperatures and high hydrostatic pressures at greater depths. Moreover, Autonomous Underwater Vehicles (AUVs) should be capable of operating with longer range which requires the vehicle to be more efficient with its on-board power source. With such a requirement, the vehicle should have efficient propulsive mechanisms to achieve longer range with its on-board batteries and in most cases, autonomous underwater vehicles have to travel straight line navigation routes to reach the mission site with lesser requirements in manoeuvrability. On the mission site however, the vehicle has to be more manoeuvrable to execute the mission operations effectively. The size of the vehicle should be such that it is easier for deployment manually without the need for sophisticated and expensive mechanisms. With such a consideration, the size should be limited to the dimensions 0.5m x 0.5m x 0.5m and should not exceed seven kilograms in weight. The vehicle is also required to be autonomous, for which the vehicle should have the necessary sensory systems on-board such as inertial measurement unit, camera (for visual localisation) and depth measurement systems. The vehicle should be able to swim with a velocity of about 1 m/s during long distance navigations. The depth rating of the vehicle should be about 100 mas an initial target for development and proof of concept, but the depth rating can be further increased till 300m with added cost as most of the offshore structures are built at this depth [2]. The design of the vehicle has been made to satisfy the aforementioned requirements and it is explained in the following section.

III. VEHICLE DESIGN

With the requirements mentioned in the previous section, a hybrid design with a biomimetic caudal fin propulsion system in the rear of the vehicle and two conventional rotary thrusters as pectoral appendages is used. The design has been illustrated in Fig. 1.

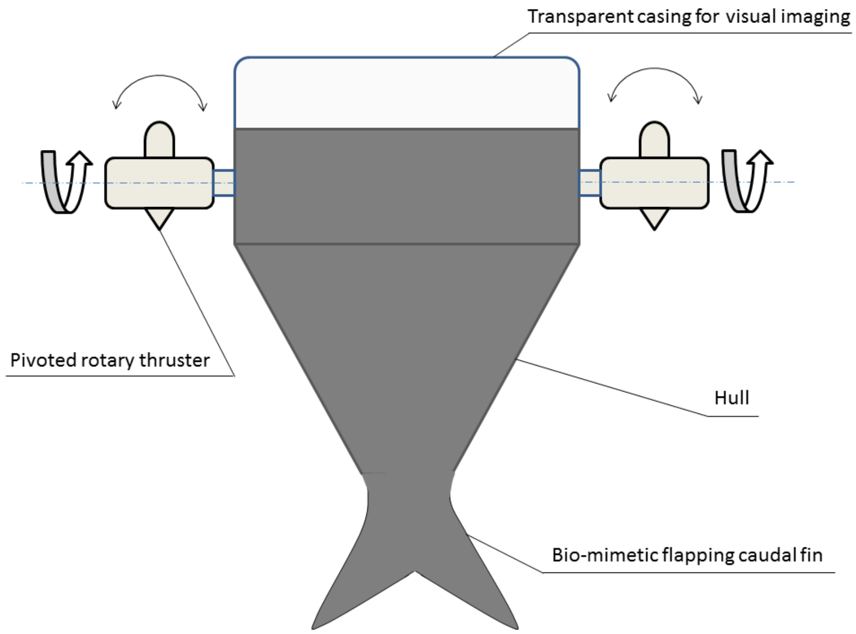

Fig. 1 Illustration of the hybrid underwater vehicle design showing the key components of the system

The design consists of three key components - hull, pivoted rotary thrusters and bio-mimetic caudal fin (see Fig. 1). The hull is shaped like a fish to reduce hydrodynamic drag and also such that it satisfies the dynamic requirements. The bio-mimetic flapping caudal fin is horizontal to reduce oscillations of the hull during operation. The rotary thrusters are pivoted and can be actuated to rotate and produce thrust in the required direction.

IV. PERFORMANCE ANALYSIS

The key parameters involved in the performance analysis of this design are cost of transport, propulsive efficiency and manoeuvrability. Cost of transport (COT) of underwater vehicles is the measure of the amount of energy required to transport a unit mass of the vehicle through unit distance[3]. It can be calculated in the vehicle by operating the vehicle through a particular distance without external perturbations to find the energy consumed and using the following equation,

$$COT = \frac{E}{md} \text{ (J/m/kg)} \tag{1}$$

where$E$ is the energy consumed by the vehicle for propulsion in Joules through a particular distance d (in meters),and m is the mass of the vehicle in kg. The cost of transport of this design propelled by the bio-mimetic caudal fin is estimated to be about 3 J/m/kg which is lower than other conventional rotary propelled designs which has a COT of about 10 J/m/kg, whereas dolphins have a COT in the range of about 1.1-4 J/m/kg [4].

Propulsive efficiency of underwater vehicles is defined as the ratio of the mean rate of work derived from the thrust produced to the amount of energy expended for the production of the thrust[5]. It is given by the following equation,

$$\eta = \frac{FU}{P} \quad (2)$$

Where F is the average thrust force, U is the forward velocity of the vehicle and P is the power input for propulsion. Propulsive efficiency of this design is not measured yet, but it is estimated to be better than other conventional rotary propellers which have a propulsive efficiency of about 40% [1]. The design is highly manoeuvrable with capability to move towards any desired direction by orienting the rotary thrusters in the required direction, so the design has six degrees of freedom with the help of its rotary thruster modules.

V. SUITABILITY FOR NDT OPERATIONS

With the high manoeuvrability of this design, it is found to be suitable for conducting non-destructive vision based observation operations with this vehicle. The vehicle will be capable of conducting such inspections autonomously once the location to be inspected is pre-programmed into the system. The vehicle uses vision based localisation with the combination of inertial measurement units to successfully navigate autonomously. With the help of the powerful rotary thrusters and its capability to orient in the required direction, supports the vehicle's ability to resist ocean waves and other flow perturbations in harsh environments. The relatively lower cost of transport allows the vehicle to be operated for a longer range, thereby extending its capabilities. As a result, this vehicle can be used in applications ranging from normal vision based observation operations to more sophisticated ultrasonic inspections on offshore structures and pipelines with the help of additional modules.

VI. CONCLUSION

A novel hybrid bio-inspired underwater vehicle design has been proposed for the structural inspection and survey in coastal regions. Key features of such a design with both rotary thrusters and bio-mimetic caudal fins have been discussed. The hybrid design is also found to be more efficient and manoeuvrable than other conventional underwater vehicle designs in the market. The suitability of such hybrid designs in non-destructive evaluations of coastal and littoral assets has been studied and it is found that such designs are well suited for those purposes.

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