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A synergetic approach to the conceptual design of Autonomous Underwater Vehicle

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HIGHLIGHTS

- The complete design of AUV embraces synergetic combination of mechanical, electrical, electronic and control systems.
- It has a hydrodynamic design and modular construction.
- The vehicle is also fitted with a series of sensors interfaced with the microcontroller.
- An obstacle avoidance system using SONAR is also implemented.
- Suitable communication is provided within the AUV and with the shore station.

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ABSTRACT

Coastal areas are among the most vulnerable of all regions to global climate change. Projected impacts from global warming include rising sea levels, intensification of tropical cyclones, larger storm surges, increasing sea-surface temperatures, rising sea levels and larger storm surges caused by climate change, etc. These potential hazards threaten human life and property. So, it becomes unavoidable to understand the Ocean systems. Continuous time series observation is essential and development of innovative Autonomous Underwater Vehicle (AUV) with suite of sensors would be very necessary. In order to address these ocean related problems, this paper introduces a new approach to the design of such interdisciplinary systems that are functionally complex in structure.

1. Introduction

Due to the interdisciplinary nature and real-time operation related requirements of AUV, its design is a difficult and complex task [1–3]. The main complexity in the design of intelligent robotic systems is to provide the system with the necessary abilities to sense environmental changes and to adapt itself by means of intelligent decision making while autonomously achieving a task which is proposed by H. Yavuz [3].

Sensory system and related issues are addressed by the researchers in this field [4–9].

An integrated approach to the conceptual design and development of an intelligent autonomous mobile robot, providing solutions to some typical design problems is proposed by H. Yavuz [10].

Yoerger and Slotine [11] proposed sliding mode controller for trajectory control of underwater vehicles neglecting the cross coupling terms.

Healey and Lienard [12] used multi variable sliding mode control for diving, steering and speed control of underwater vehicles with decoupled design. A new control scheme for robust trajectory control based on direct estimation of system dynamics is proposed for underwater vehicles by Prasanth Kumar [13].

For conceptual design of an underwater vehicle, Ross [14] and Smith [15] proposed the use of composite materials. The buckling and failure characteristics of moderately thick-walled filament-wound carbon–epoxy composite cylinders under external hydrostatic pressure were investigated by Chul-Jin Moon [16] through

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Nomenclature

Greek symbols

γ	Specific weight (g/cm^3)
σ_b	Strength limit (N/mm^2)
ϵ	Modulus of elasticity (kN/mm^2)
σ_a	Fatigue strength (N/mm^2)

List of symbols

G	Centre of gravity
B	Centre of buoyancy
Ma	Mach number
l	Length of AUV (m)
D	Diameter of AUV (m)
C_d	Co-efficient of drag
C_l	Co-efficient of lift
F_L	Lift force (N)
F_D	Drag force (N)
X, Y, Z	Cartesian co-ordinates
C	Absolute velocity (m/s)
w	Relative velocity (m/s)
s	Spacing between the blades (m)
Z	Number of blades
u	Peripheral velocity (m/s)
C_{x1}	Inlet flow velocity (m/s)
C_u	Inlet velocity (m/s)
C_s	Outlet velocity (m/s)
C_{x2}	Outlet flow velocity (m/s)
ρ	Density of fluid (kg/m^3)
ρ_w	Density of water (kg/m^3)
ρ_a	Density of air (kg/m^3)
g	Acceleration due to gravity (m/s^2)
h_w	Head of water (m)
h_a	Head of air (m)
V_o	Upstream velocity (m/s)
A	Area under consideration (m^2)

finite element analysis and testing for underwater vehicle applications.

The design and implementation of ISiMI, including its positioning system in the OEB, are presented, a series of test results in the OEB and discussions of the results were presented by Bong-Huan Jun [17], with comparisons of the simulation and experimental outputs.

Autonomous Underwater Vehicles are applied to complete different missions under different working conditions [18,19].

The problems and general solutions for unmanned underwater vehicles' power supplies, the mechanisms and structures of tether power system, characteristics of several batteries, the characterization of potential environmental energy, and energy conversion for unmanned underwater vehicles have been represented by Xiaoming Wang [20].

Navigation of REMO I Robot is performed by the capability of its parallel structure to modify its geometric structure (thruster and front ring) and to displace by itself was proposed by Roque Saltaren Pazmiñoa [21].

In this present work, the Autonomous Underwater Vehicle (AUV) is designed for efficient, high-speed, reliable operation in shallow water. The complete design of AUV embraces synergetic combination of mechanical, electrical, electronic and control systems.

It is 1.2 m long and has a mass of 48 kg. It has a hydrodynamic design and modular construction. Side-mounted thrusters are used to drive and differentially turn, and vertically mounted thrusters are used to dive and pitch. The vehicle has slight (approx. 2%) positive buoyancy, and is held at depth by the vertical thrusters (accomplished by air compressor).

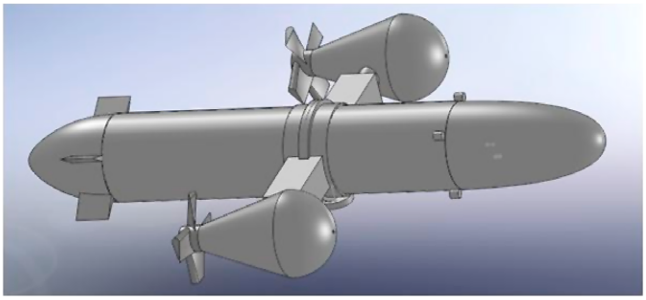

Fig. 1. 3D view of the proposed AUV.

The vehicle is also fitted with a series of sensors interfaced with the microcontroller ATmega 8. These sensors are used for monitoring underwater conditions and alert before the hazards starts to intensify. The sensors used are pressure sensor, temperature sensor, sound sensor (hydrophones), depth sensor and camera.

In order to provide safety to the AUV, an obstacle avoidance system using SONAR is also implemented. Suitable communication is provided within the AUV and with the shore station. Thus the multi-featured AUV is able to replace the deep sea divers and can autonomously operate under the sea and investigate the beneath conditions.

The proposed approach is a systematic conceptual design method that ensures the overall system's integrity and efficiency, as well as high system performance and synergy. These contributions to understanding such systems should not only improve the designers' view of the design problem, but also allow novel design concepts with potentially better configurations.

2. Mechanical design of AUV

2.1. Different motion mechanisms of AUV (manoeuvrability)

The different motions of the AUV are steering, pitching and linear motion. As depicted in the 3D modelling of AUV shown in Fig. 1, the linear motion is achieved by placing two thrusters (propellers) at the starboard (right) and the port side (left) when viewed from the stern side. Turning of the AUV is achieved by switching one thruster ON and the other OFF i.e. to turn left, switch the left thruster ON and the right thruster OFF thereby turning it to left and the same method can be applied to right turning also. The axes (X, Y & Z) definition is depicted in the Orthographic views as shown in Fig. 2. Upward and downward motion and the position of AUV in space could be varied by means of buoyancy force. Magnus Effect has been successively employed in the propulsion of AUV by means of electric power. According to Bernoulli's principle, pressure on the high velocity side (upper half portion) will be lower than the pressure on the lower velocity side (lower half portion). A pressure force acts in the upward direction and obviously a lift force is exerted on the cylinder. The magnitude of the transverse force i.e. lift may be changed by altering either the speed of rotation or the stream velocity.

2.2. Stability of the vehicle

The main body of the AUV is 812.8 mm in length and 203.2 mm in diameter made of PVC as shown in Fig. 2. The pipe serves as the watertight electronics compartment, the buoyancy volume, and the framework for mounting the thrusters. The body is selected as