Design of Affordable Semi-Autonomous Underwater Vehicle Platform using Robot Operating System (ROS) for Marine Robotics Research

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*Abstract*—In the maritime world, operations are divided into two categories: inspection, and action. this paper discusses the development of a hybrid underwater vehicle (HUWV) that combines the features of autonomous under-water vehicles (AUV) and remotely operated vehicles (ROV). this can be configured with multiple sensors beside cameras that use visual-simultaneous localization and mapping (V-SLAM) Technology and maneuvered by an intuitive platform. The vehicle is designed for use across several sectors, including underwater research, environmental assessment. When running the vehicle in autonomous mode, all missions are operated using artificial intelligence (AI) control, taking feedback from available sensors on board. Additionally, the vehicle runs Robot Operating System (ROS), enabling the vehicle to be piloted and tested using software-in-loop modelling with Gazebo& rviz based on UUV Simulator.

Keywords—component, formatting, style, styling, insert (key words)

# Introduction

Underwater robotic vehicles play a major role in the environmental, commercial, military, and emergency operations. Underwater robotic vehicles can be divided into two groups: manually operated, and autonomous, both with their different applications [1]. In recent development, Robot Operating System (ROS) [2] expanded rapidly through community support to include software libraries, simulation platforms, and compatible hardware components to facilitate robotics development. However, the wide-reaching base of available ROS and similar software, in addition to the difficulties of developing underwater-compliant robotic systems, means that the barrier of entry into marine robotics needs reduced. This paper aims to propose a method that combine the advantages of the manual and autonomous vehicles with a low overhead, while applying the open-source ROS framework. This hybrid vehicle should be able to produce maps of maritime life underwater and analyze their ecological status using use visual-simultaneous localization and mapping (V-SLAM) technology [3], and other object detection technologies. The project also includes designing an integrated underwater vehicle simulation platform through which we can test command and control systems in various marine environments such as high currents and polluted environments to avoid the problems that the submarine may encounter in the working environment, and this feature is needed by everyone who works in the field of autonomous vehicles. On the commercial level, the hybrid underwater vehicle (HUWV) will be able to conduct survey patrols of the depths of water. The vehicle qualifies it to carry out industrial operations using the automatic or autonomous command system.

## Related work

Creating an underwater robotics research platform involves significant overhead, works exist that aim to reverse engineer existing vehicles to support open-source software [4] [5] [6]. Additionally, some systems achieve autonomy but rely on expensive commercial platforms [7]. Open-source platforms are scarce and out-of-date or have incomplete instructions [8] [9]. Other open-source platforms are targeting low-cost without considering additional devices payload for underwater robotics research [10] [11] [12]. Manual-control only platforms offer additional examples of the mechanical and electrical design of underwater robotics [13].

## Contributions

We contribute full design plans for a locally manufactured marine robotics research platform, excluding thrusters. The design uses readily available materials and manufacturing processes (wood routers, laser-cutters, metal work). Also included are the electrical system diagrams includes, and software tools used. In focus we contribute the following:

* Mechanical system with body plans, insulation procedures, insight into design considerations; CAD drawings, assembly instructions, bill of materials and comparisons with commercial-off-the-shelf (COTs) items.
* Electrical system components, power circuit schematics, inter-system communication and tether.
* Software setup, ROS software libraries, documentation of hardware-software considerations.
* Documentation of helpful websites.

The open-source documentation and files live *ad infinitum* at

<https://github.com/Walid-Rovo/Semi-AUV>

# System Design

While designing the HUWV the main aim was to reach an underwater robotics research platform. The design is separated into three disciplines: mechanical, electrical, software. The mechanical design facilitated interlocking acetal sheets, and acrylic tubing for insulation. The electrical system consists of the power circuit, and the data circuit shown in Figure XX. Power is supplied via the tether with optional batteries on-board for verifying vehicle dynamics and software independent of the tether. The software is based on a collection of open-source libraries under the ROS framework with access to software-in-loop simulations in Gazebo.

## Hardware

The system is designed from the ground-up for ease of manufacturing and modularity for research. The system considers local alternatives to importing systems from companies like BlueROV to reduce cost and decrease financial barrier of entry. Various make-decisions were made such as with manufacturing the main electronics insulated enclosure from acrylic tubing and metal flanges made at a metal workshop.

## Sensors and computing

The sensors and computing hardware is consisted of incorporates ZED 2K stereographic camera, 3 IP Cameras that provide clear vision for sides, bottom and front of the vehicle. In addition to an anti-vibration IMU sensor that locates the orientation of the vehicle, as well as Blue Robotics BAR03 pressure sensor which provides precise identification for the depth of the vehicle.

The system is connected to Nvidia Jetson Nano which has been selected for its AI processing capabilities.

# Autonomy & Control Software

The control system of the HUWV is ROS based, where the system consists of a set of “Nodes”. Each node represents a single process that can then communicate with other nodes. Nodes are a convenient method to develop software for each subsystem in the vehicle.

As shown in figure, different ROS nodes communicate together and integrate data to perform the desired mode of operation. In the HUWV case, feedback data received from ZED camera, and other cameras installed on vehicle, in addition to IMU sensors, set the intelligent action of the vehicle, this action is directed to the PIXHAWK controller that provides order to thrusters to perform the maneuvering decision. The challenge is in the smoothness of data transmission between different ROS nodes, and how the GPU would act upon pre-set intelligent algorithms.

## V-SLAM Technology

The SLAM can be defined as follows: given the robot’s controls U, the observations of the world Z determine the map of the environment M, and the robot’s pose X.

And in the probabilistic world as every element exhibits some errors, it can be expressed as:

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It can also be represented as a flow diagram as in Figure ‎0 Flow diagram of a typical SLAM algorithm.Figure ‎0.

Another important aspect of SLAM is that filters ought to be used since the robot is always operating under the assumption of being inside a distribution of errors. Kalman filters are used here as the error distribution can be Gaussian, particularly the Extended Kalman Filter as underwater robotics often experience non-linear motion models.

Upon the general idea of SLAM technology, ZED 2K Stereoscopic Camera convert the visual data into laser-based chart. Which is identified by its relative node in the ROS system.

## PID auto-levelling

The aim of this function is to keep the vehicle vertically and horizontally stable as much as possible by using the Blue Robotics pressure sensor to calculate the depth & orientation of the vehicle, which gives the pilot an advantage when doing several in the ROV mode - tasks on the same depth by changing the desired depth on the graphical user interface (GUI) input box. Using the pressure Equation(2). pressure can be easily converted to depth where P denotes pressure, denotes density, g denotes gravity's acceleration, and h denotes depth.

*P= ρ\*g\*h* 2

For the orientation of the vehicle, the IMU provides clear data for the ROS system to identify the HAUV status underwater, this is maintained within the IMU-ROS node using the PID control method that provides stable and smooth control upon the desired sampling rate. The following flowchart declares the mode of operation of the IMU-ROS node.

## Object detection and identification

Object recognition is one of the features that, if implemented properly, will greatly enhance the technology of a HUWV in the field of work. This is due to the many applications in which it can be used to replace human divers, whether for protection or to save time.

## Software In-loop simulation

In the process of designing control systems, a simulation model may be a very useful method. On a simulation model, the control system can be tested, which is both much cheaper and easier than if the control system could only be tested in the actual process. For a simulation model, the system's stability is easily checked since the disruptions and atmosphere can easily be modified. In such a method, the key challenge is to make the simulation model as real as possible. There are several components that lead to the final force working out of the water on the vehicle. and when creating a simulation model, the most important ones should certainly be considered [14].

The goal is to develop the foundations of ROV&AUV simulation platform. Two primary elements, a simulator, and a control system, will consist of the platform. Dynamic ROV simulations will be provided by the simulator, including versions of the various sensors.

The control system will be the ROV control program which will contain: an estimator, a path planner, a guidance system, and a controller. The aim is that, when the software is used on the real vehicle, the simulation platform will provide a framework for evaluating control software without significant modifications necessary. [15] The following figure shows a block diagram for the software system design.

Without manually testing the vehicle in service, the platform can be used for testing applications for vehicle operations and missions. It will be tested on a with simulated sensor performance during the production of the control system. The program will be checked with the individual ROV in the loop when the production is completed. Based on thruster inputs and environmental parameters, the simulation platform must be able to replicate ROV motions. This requires a practical calculation of the hydrodynamic forces acting on the ROV, as well as a realistic estimate of the thrust forces for each propeller for a given number of revolutions per minute (RPM).

The appropriate components for the simulation of ROV systems, including sensor models with all possible add-ons such as sonar and Doppler velocity logs (DVL), an estimator, a route planner, a guidance system, and a controller, must be used in the control system section of the simulation platform. The platform is designed to be module oriented, where a particular role is performed by each module. Modules communicate with each other and, if needed, one module can be replaced with another module of the same kind. If a user needs to try a new controller algorithm, a realistic example of this is that they should substitute the controller module with their controller module on the simulation board, where the new algorithm is applied.

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