2004 8th International Conference on
Control, Automation, Robotics and Vision
Kunming, China, 6-9th December 2004

Design and Development of an Autonomous Underwater Vehicle Test-Bed (USM-AUV I)

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Abstract

In this paper, the development of an underwater robotic vehicle is described. The description includes the mechanical and controller design, and the sensor integration. The vehicle has been designed to have a dimension 1.0 m long, 0.7 m wide and with a mass of 30 kg. The USM-AUV I was designed mainly for testing conventional and advanced control algorithms. The vehicle directional control was performed by two thrusters in the horizontal plane while depth control by two thrusters in the vertical plane. There are several sensors which are used as feedback elements for the vehicle control system of vehicle. The AUV is also equipped with camera for monitoring purposes. This pan-tilt-zoom camera mounted in the upper enclosure, serves to assist in the close up viewing of objects without moving the whole vehicle. For beginning, this research is limited to a depth between 0-50 meters.

1. Introduction

Autonomous Underwater Vehicles (AUVs) are submersibles with the ability to operate and carry out missions without manual inputs, tethers or remote control. They appeal to the community in that they are able to operate using their own power supply, make decision according to the input from the onboard sensors and provide data storage capabilities. This is the main difference between AUV and Remotely Operated Vehicle (ROV). The ROV needs a tether connection or an "umbilical cord", and human operator in a base platform to control and monitor its mission [1, 2]. AUVs have various potential applications and great advantages over ROVs in terms of operational cost and safety[3]. ROV design requires the integration of various supporting technologies and proper optimization procedures. A low-cost AUV for multiple applications is aimed in our research. Nevertheless, this aim depends a lot on the types of application targeted.

2. Vehicle Description

2.1 Introduction

The USM-AUVI test-bed is designed and developed to act as a test bed platform for a variety of research in underwater technologies especially involving small-scale and low-cost underwater robots. Based on the important design criteria for the NEROV vehicle [3], the design criteria used for USM-AUVI were that the vehicle should be:

- *inexpensive with low cost material for vehicle body*
- *controllable in 6 Degree of Mobility (DOM)*
- *neutral buoyant*
- *designed for maximum depth of 50 meters*
- *flexible modular platform*
- *suited with typical on-board sensors*
- *used in underwater robotic research e.g. control and intelligent, embedded control system, "smart" sensor and actuators, monitoring and surveillance*

The USM-AUVI pressure hull has been designed based on the ORCA [4] body structure. It has a mass of 30 kg without accessories payload with the dimension of 1 m long and about 0.7 m wide (*see fig.1*). Due to the design criterion which requires the underwater robot to be built in good modular platform, the USM-AUVI hull was designed to be a flexible modular platform.

Different to the ORCA, our USM-AUVI only has a single dry compartment. This compartment contains an electronic on board system, batteries pack for power source and vision system for the monitoring purposes. The sensor modules with water resist enclosures are mounted outside the compartment. In addition to these, a lighting system is mounted on both sides of the bow section for better visual input to the controller system.

0-7803-8653-1/04/$20.00

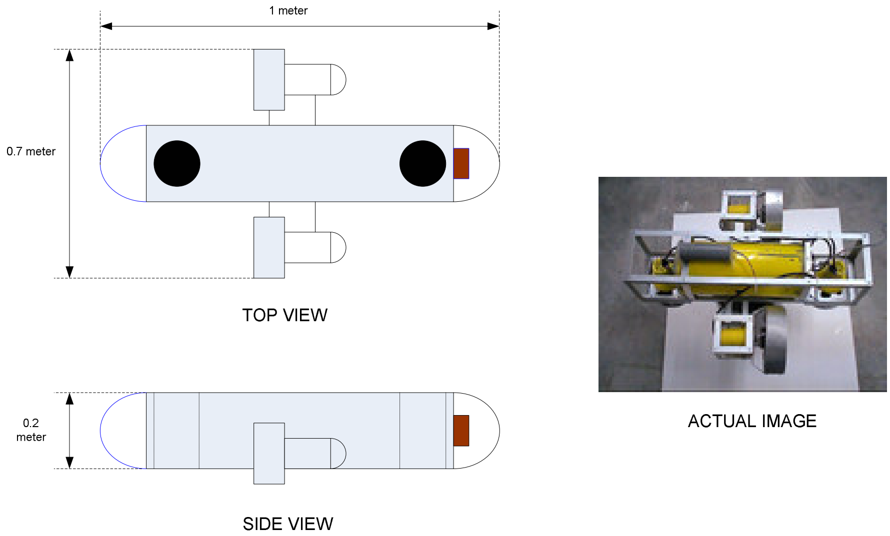

Fig.1. Mechanical drawing and the actual image of the USM-AUV

2.2 Propulsion Systems

The USM-AUVI test-bed uses two thruster motors in horizontal plane for turning and heading propulsion (*see fig.1*). These motor with propeller blades are mounted on the left and the right rear half of the vehicle. By turning these two motor reverse and forward, the vehicle can move forward, back, left and right. A few simple turning combination between motor A and motor B will produce the resultant of the vehicle motion in different directions. In the vertical plane, there are also mounted two thruster motors for depth propulsion. Similar to the thruster motors in horizontal plane, by controlling the motion of the two motors will be produced different movement in z-axis.

2.3 Sensor Suite

The AUV master controller will receive feedbacks from the on-board sensors for decision making or reaching a desired response to the input command. As an example, our USM-AUVI controls its depth with feedback from a sonar module and a depth pressure sensor. The heading control is handled by using compass module as the input sensor for relative direction. Our robust digital compass provides a low cost and direct interface providing effective direction sensor that is perfect for many applications. For the tilt and rotation measurement, a Memsic 2125 Accelerometer is utilized. The Memsic 2125 is a low cost, dual-axis thermal accelerometer capable of measuring dynamic acceleration (vibration) and static acceleration (gravity) with a range of ± 2 g. This enables proper stabilization requirement to be fulfilled.

2.5 Power System

The USM-AUVI used a battery pack which contains four batteries of 12 Volts for powering all the electrical equipment and the thrusters. These batteries are used to supply 5V and 12V power lines to the sensors. Two pair of batteries for powering the thrusters, whiles another two pair of batteries for electronic includes vision system. The onboard power supply is required to enable the vehicle to operate in autonomous mode. The battery pack is placed at the center of the dry compartment to ensure the vehicle stability.

2.6 Control System Design

Currently, from the literature [5, 6 and 7], it is proven that the sliding mode control theory is the best control theory for design the control system of an AUV. In [8], the sliding mode control system has been described detail. Sliding mode is categorized as a variable structure control system which has excellent stability, robustness, and disturbance rejection characteristics. Sliding mode control is a robust technique, or one that provides high performance through widely varied operating conditions, used for compensating nonlinear systems as well as for systems whose parameters vary in a predictable way with speed [9]. Various advanced underwater robot control system have been proposed in the literature, such as sliding control [10], learning control [11] and adaptive control [12]. For the initial stage, the study about controllers design has been focused on the low level controllers design. The low level controller design is limited to three control parameters i.e., depth, speed and vehicle heading. These parameters receive a command from the mission planner and react to the environment for reaching the desired goal. Additionally, simple line-of-sight (LOS) guidance rules are used to maintain path tracking by looking ahead to planned waypoints.

A variable structure control (VSC) is a nonlinear feedback control that has a discontinuity on one or more manifolds in the state space. The central feature of VSC is sliding motion [13]. This occurs when the system state repeatedly crosses and immediately re-crosses a switching manifold, because all motion is directed inwards (i.e. towards the manifold). In the sliding mode the motion of the system is effectively constrained to lie within a certain subspace of the full state space, and thus it becomes completely insensitive (invariant) with respect to perturbations or parameter variations which are normal with respect to the surface where the sliding occurs. Specifically, given a linear system, written in the form:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ y \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{21} & A_{22} & B_2 \\ C_1 & C_2 & D \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ u \end{bmatrix}$$

(1)

where rank(B_2) = rank(B), during sliding the state is constrained to lie in the subspace defined by $S_x=S_1x_1+S_2x_2=0$, thus the dynamics become:

$$\dot{x}_1 = (A_{11} + A_{12}S_2^{-1}S_1)x_1$$

(2)

with manifold $\sigma = S_x = 0$ which is completely independent by A_{21}, A_{22}, *and* B_2, and therefore from any uncertainty / perturbation on these matrices. From a “modern robust control” viewpoint, one can say that, when the VSC block is active the transfer function from *w to z* (let us call it FVSC(s)) approaches 0, so the uncertainty attached between z and w “sees” a zero transfer function, and therefore it cannot affect the controlled system, no matter how “large” this uncertainty is, provided it is bounded. It should be noted that the complete invariance happens as long as the feedback mechanism is able to drive the state to the same surface no matter the values of A_{21}, A_{22}, and B_2. In other words, the feedback must be completely independent of these 3 matrices. We will point out later that unfortunately this behaviors (which requires high gain nonlinearity), cannot be obtained in the whole state space but only in a certain region surrounding the surface, moreover the greater the uncertainty on A_{21}, A_{22}, and B_2 is, the smaller the region. Eventually, it should be noted that direct linearization will come out with a linear model in the form (1), where A_{11} A_{12} corresponds to the kinematics and A_{21} A_{22} B_2 corresponds to the dynamics, hence from a physical standpoint, VSC is structured to be robust especially against uncertainty on vehicle dynamics.

3. Experimental Results

3.1 Vehicle testing.

The lab experiments have shown that the vehicle has neutral buoyancy, fulfilling the design criteria (without an additional accessories/payload). After successfully testing the buoyancy capability, the vehicle was tested in the maneuvering test. The stability in x-y-z axis is the important factor when trying to maneuver this vehicle in the maneuvering test procedure. Overall test will be conducted on the USM-AUVI test-bed as in *fig.2*.

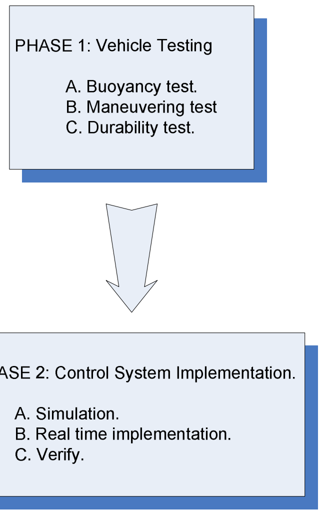

Fig.2. Testing procedures for the USM-AUV I

3.2 Controller Simulation

Let consider the heading control system using Unmanned Free-Swimming Submersible Vehicle [14]. We apply the PID controller to regulate the heading command and get the desired heading output. The simulation results as show as in fig.3. Fig.3a shows the open loop step response for the vehicle dynamics. From the figure, we can determine what were needed to be improved. By applying the conventional PID control approach, fig.3b-3d were acquired, as a closed loop response for the heading control requirement.

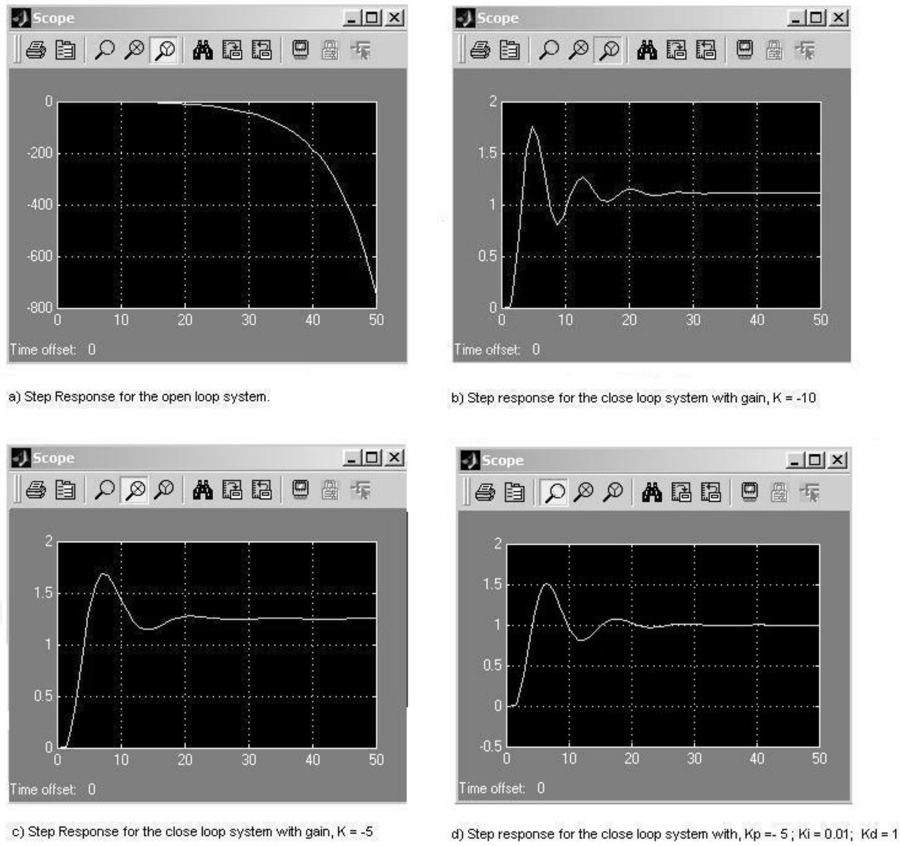

Fig.3. Simulation results for heading control system

4. Conclusion

The USM-AUV I test-bed has been developed as a research tool for conducting research in the underwater robotics applications. Our research aim is to develop a programmable underwater robotic vehicles system which can execute a variety of tasks which include visual inspection of man-made structures and seafloor mapping. A modular hardware and software allowed the researchers to tinker around with the test-bed while testing a new invention. For future efforts, we will consider the cost and other important parameters like thruster capability, robustness of the control system and power consumption.

Acknowledgement

The authors would like to thank Yayasan FELDA for the research grant, and also to Universiti Sains Malaysia (USM – URRG Group).

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