A VERY LOW COST AUTONOMOUS UNDERSEA VEHICLE USING COMMON MATERIALS AND COMPONENTS

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Abstract

Autonomous Undersea Vehicles are usually very cost-intensive either in terms of capital expenditure and/or time expenditure. Commercial organizations usually have more capital, while educational institutions have more time in the form of students and internal craftspeople and technicians.

Many existing vehicles are one-of-a-kind or may have at most several siblings. Additionally most existing vehicles require substantial support equipment and are designed to be deployed from relatively large surface craft.

This paper describes a small, low-cost, easily manufactured vehicle, which is supported by a laptop computer and deployed from a small inflatable boat. The entire system fits in a single piece of checked (airline) baggage. While not equal in all ways to the performance of much larger and more expensive AUVs, this low-cost vehicle permits usage in high-risk environments where rapid deployment is desirable. In the event a vehicle is lost, a replacement is easily re-deployed. Missions such as situation assessment and asset tracking may be initiated without lengthy preparation.

A simple internal architecture facilitates the integration of desired transducers and other sensor systems.

Construction techniques are simple and easily reproduced. An emphasis is made on the use of easily obtained, off-the-shelf components and materials with a straightforward software integration.

Prototype Low Cost AUV

The system is analyzed from a cost perspective. Various improvements in each vehicle subsystem and their projected incremental cost and functional value are discussed in relation to additional mission capabilities.

The possibility of deployment from an aircraft is discussed.

Introduction

The utility of underwater video in assessing sub-surface situations is long established. Information relating to scientific, industrial, military, or safety concerns can be rapidly gathered and assessed through onsite video reconnaissance. Traditionally, video is generated by a camera mounted in an ROV. However, it may take hours or more typically a number of days before an ROV is on station with its associated support ship. While newer smaller ROVs are easier to deploy, observation targets are often beyond their operational capabilities. Additionally, weather and other environmental factors may hinder or preclude the use of ROVs.

Since 1983, the author has been convinced that there is a need for a low cost or perhaps expendable camera carrying AUV, which can be rapidly deployed from a small boat or an aircraft. The mission of this system being to take video of a pre-programmed seafloor geography or seaspace and then to transmit this video back to some appropriate terminal at sea, in the air (or space), or at a terrestrial location.

While there are various rumors and realities of high-speed data transmission through water using various optical or electromagnetic means, the author is unaware of any affordable systems at present. If traditional acoustic means are used, it might take many weeks to send an hour of video.

Objective

The author and associates have had significant experience with terrestrial and satellite RF, video, telemetry, acoustic nav, GPS and the usual associated software and controller skills. On the other hand, experience with AUVs has previously been limited to reading. The author believes strongly that any system, which operates properly in an ocean environment, is the result of conventional engineering development coupled with extensive operational testing.

The objective for this project is to gain some actual experience in AUV construction and operation and to begin testing the utility and feasibility of various subsystems.

Mission

The intended AUV mission is:

1. Program the AUV with a desired search pattern.

2. Deploy the AUV in an appropriate geography.

3. Allow time for AUV to swim the pre-programmed path and mission while recording video.

4. AUV surfaces and then transmits recorded video via RF link to terminal either directly or via repeater.

5. If deployed from a boat or ship, AUV may be retrieved.

6. It is possible for a surface support buoy operating in conjunction with the AUV (and deployed by the same means as the AUV) to supply geodesy to the submerged AUV by means of

acoustic data transmission in conjunction with Super Short Baseline Nav systems in either the AUV or the Surface Support buoy.

7. A surface support buoy may also act as an RF repeater or relay between the surfaced AUV and terminal.

8. Streaming data from other instruments or sensors may be recorded in addition to or instead of video.

9. Multiple AUVs may be simultaneously deployed to cover a greater observation area.

In this first phase of the project, the low cost testbed was constructed and the first four mission components were run.

Background and Philosophy

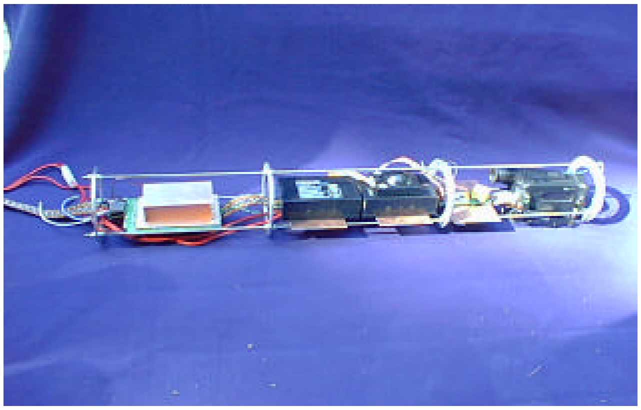
Given that the described mission may require an expendable AUV and that this project is, at present, self-funding, there is a strong motivation to keep costs very low. No titanium, carbon fiber, lithium batteries, processors that overheat, or overpriced software was used. Almost all materials were obtained at local hardware and building supply stores, hobby shops, or mass-market electronic supply houses. Exceptions to this are the flux-gate compass, pressure (depth) sensor and the camcorder which were recycled.

The total cost for materials for this AUV, excluding the laptop PC used to program missions, is less than $450 USD at retail prices. If the recycled compass, pressure sensor and camcorder were to be purchased new, approximately $425 USD would be added to the cost.

Basic Vehicle Design

The vehicle looks a lot like a very small torpedo. It has proven to be very effective as a means of initiating conversations with local residents and law enforcement officials in almost any testing environment. The vehicle weighs about 24 kg without ballast and is about 1.2 meters in length. An internal metal frame consisting of some sheetmetal bulkheads and some threaded steel rod is used as a support for all the electronics and batteries. The frame then slid into a piece of 6"ID Schedule 40 PVC well casing. Appropriate PVC fittings are used to close the ends of the pipe, thus forming the main compartment and hull of the vehicle. A transparent window is fitted in the nose. The camcorder is mounted in the nose, with batteries, controller and attitude sensors amidships in the main compartment, the UHF transmitter and antenna behind them. The drive motor, propeller, pressure sensor, control surfaces and actuators are mounted in the tail compartment consisting of a 4"ID PVC pipe section attached to the back of the main compartment. Thus all components requiring a shaft seal and other potential sources of leakage such as the pressure sensor are in a common compartment which is isolated from the main. This is a protective measure simply because maintaining the integrity of dynamic seals is the biggest difficulty encountered. If a seal fails about $100 worth of motor and servo get wet, but the video and control systems stays dry.

A variant of a "Basic Stamp", a BasicX ™ X24, is used as a controller. While somewhat lacking in graphics and multimedia capability, it is well suited for this application offering many useful



Internal AUV frame assembly

hardware I/O capabilities and an instruction set appropriate for a controller.

An old Sony Hi8 camcorder is used as a camera and video storage device; it is controlled by infrared commands from the controller, as well as direct connection. A monochrome camera with better low light sensitivity has also been used. In this case the camcorder acts as a conventional video recorder and is fed with NTSC composite video from the second camera.

The batteries are conventional sealed lead-acid batteries. There are two 6-volt batteries in parallel comprising 120 Wh. The camcorder, controller, sensor and actuators are powered from these either directly or via a low dropout regulator. The drive motor and UHF link transmitter are operated either from the 6-volt battery or from a third battery of 12 volts with an 85 Wh rating.

The pitch and roll sensor is a Schaevitz Accustar II with a range of +/- 20 degrees. This is the most expensive component in the vehicle other than the camcorder.

Futaba type hobby servos are used as control surface actuators. A brushed DC motor, of the Speed 600 class drives a low-pitch model aircraft propeller through a gear reduction of about 3.7:1. The motor is rated at approximately 90 W depending on voltage; claimed efficiency is about 60%. A conventional hobby type speed controller serves as throttle.

A conventional acoustic transducer is affixed internally in the nose, with its pattern nominally forward looking.

The UHF link transmitter is generic and has an output of approximately 1W PEP in TV service.

Software

The control software is fairly conventional. There is a main supervisory or housekeeping routine, which looks at important parameters such as attitude and direction several times per second. There are subroutines which maintain a given direction or attitude for lengths of time specified by the mission instructions. When at depth and traversing its pattern, the camcorder begins recording, while surfacing, the camcorder is rewinding, and at surface the recording is played back; the UHF link transmitter getting the signal out. Clearly, the vehicle could home to a specific pickup position in response to an acoustic or GPS signal; this may be implemented in future.

At present, the vehicle uses dead reckoning as it has no inertial nav capability and the surface support buoy mentioned previously has not yet been built.

A given mission pattern is simply a list of commands each containing a parameter such as heading, depth, or speed. Each command also contains a duration. At the end of a given duration, the next similar command is executed.

In the event of a fault condition such as low battery or water leakage, the mission pattern is immediately terminated and the vehicle is commanded to surface. This has not yet been tested in the water. Realistically, a low battery condition might be overcome by rapid surfacing, but based on an early experience, if there is any water leakage the vehicle will be lost if it is at any significant depth.

The software is written in a typical "control basic" which is supplied by the manufacturer of the controller. At present the software comprises about 3,000 lines. While not very fast by today's standards, the controller, based on an ATMEL CPU seems to have adequate bandwidth for the vehicle's various tasks. Although little used at present, the controller supports floating-point operations. This should help with more advanced navigational tasks n future.

Testing

As of this writing the vehicle has seen several tests in fresh water. While less exciting than an ocean, the sea-state is almost always calm and vehicle retrieval is simplified in the event of a loss. Mission patterns are loaded from a laptop at the dock through a connector in the tail housing. A small Avon inflatable serves as support.

The vehicle has executed missions successfully although not without incident. The longest mission duration to date has been 30 minutes. The biggest problem has been rotating shaft seals.

Videos have been recorded and transmitted out as per mission pattern. In the support boat, a portable television receiver and VCR record the video for later replay. Clearly it would be possible to simply remove the cassette from the camcorder, but this would not test the RF uplink.

Performance

The vehicle has a top speed of 2+ knots. Based on visual observation, it is thought that the propeller could be better matched to the motor.

The vehicle maneuvers reasonably well, but there is some oscillation in the tail, perhaps caused by the diameter transition between the two sizes of PVC pipe or perhaps by some construction approximations. The control surfaces are too large in area, as evidenced by sensitivity to inputs. At present small fixed stabilizing fins are being added at about amidships; it is hoped this will improve maneuverability.

Most importantly, though, the system works. It has provided a wealth of education with respect to AUV design issues and is therefore a success. Some of the problems were suspected or even foreseen, but a few were found only by doing.

As mentioned previously, rotating shaft seals, whether o-rings or adapted lip-seals, has been the biggest problem. Probably 20% of all time spent on this vehicle has dealt with seal issues of some form.

Economics

Greater depths require stronger hulls. The existing "plumber's delight" hull is estimated to be capable of a 100 meter dive. Conventional aluminum cases would probably add about $500-$1000 USD in cost and give perhaps a 1000 meter dive capability. As mentioned, the hull could be easily reduced to a 4" (10cm) ID if a modern camcorder costing approximately $1700 USD (at time of writing) was used instead. For a given cost-point, a depth rating is probably about double when going from 6"(15cm) to 4"(10cm) ID. It may be possible to mold or cast the entire hull assembly using various molding compounds. The electronics is as inexpensive at present as it is likely to get. The controller cost could be reduced about 20% by using a custom motherboard, but the effort would be worthwhile only in quantities over about 1K pieces. Although there are some who have disdain for "hobby" components, the fact is that many are of very high quality and would be extremely difficult economically to reproduce in small quantity

A brushless DC motor in a pressure equalized housing might increase mission duration about 75% in some cases, and would add about $600 USD to the cost.

In an expendable mode, alkaline primary batteries would provide acceptable performance. Cost would be about the same, but there would be no need to check battery state of charge.

Lithium or Lithium ion batteries could also be used with doubled mission duration at about $ 700 increase in cost. NiMh batteries are probably the next meaningful step in terms of performance. the present configuration.

Next

Now that the basic operation of this vehicle has been demonstrated, several improvements are planned. The first is to either find a more perfect prop shaft seal or to opt for a pressure equalized motor. Once this is done, tests can be performed in deeper open water. This is scheduled to be done by end of year (2001).

Experience gained with this prototype gives confidence in the concept of a low-cost air deployable production version. For depths of less than 1000 meters, various inexpensive molded plastic hulls may be possible. The almost 10 year old camcorder used here is the largest diameter component and required a 6" (15 cm) ID hull. All other components or equivalents would have fit in a 4"(10 cm) ID hull. Modern DV (digital video) camcorders are smaller and some will fit a 4" (10 cm) ID hull.

A molded plastic approach can also eliminate most of the internal framework while providing shock and vibration isolation

The surface support buoy mentioned previously in the mission description has been conceptually designed, but needs to be put into the water for real evaluation and test. In the support buoy, the costs are a bit harder to estimate until the mission envelope is defined.

Discussions with potential users of this system have begun. This is the most important task with respect to future development. Putting this vehicle together has been an enjoyable and rewarding task, but it has a future only if there are users. It is hoped that user interest and

requirements can be gauged in the next two quarters.

Conclusion

It is possible to build and operate a useful AUV with very modest tools and equipment. Use of radio control hobby equipment and plastic tubing give acceptable performance for small expenditures. A low cost micro-controller provides relative ease of development and good mission performance . Now that the low-cost vehicle has demonstrated that it is operational, further project phases involving augmented navigational capabilities and air deployability are warranted; assuming an adequate number of users can be identified.

Given that the present vehicle was built with simple structures, materials, and systems, various improvements in performance may be possible with a purpose built engineered hull. The present design lends itself to significant improvement in production using modern manufacturing techniques.

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