Design and Development of the AUV Harp

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Abstract

A mini AUV of length 4 [ft] and diameter 1 [ft], capable of locating and retrieving a semi-rigid plastic ring on the bottom of a pond, is designed and developed at Florida Atlantic University. The vehicle is named *Harp* as an acronym for Highly Autonomous Roving Projectile. A vectored thruster is used both for maneuvering and for forward propulsion at a maximum speed of 2 [knots]. A TCM2 precision compass is used for navigation. An acoustic homing system is used to detect the beacon and to provide the onboard computer with the bearing to that location. A vision system, consisting of a camera on a spear, is developed to recover the ring from the bottom of the pond. Two computers are used onboard, with the main computer dedicated for vehicle control and acoustic homing and the second one for the vision system. The vehicle, powered by lead-acid batteries, is designed to endure in water for more than 2 [hrs] and up to a depth of 30 [ft].

1. Introduction

As set forth by the Association for Unmanned Vehicle Systems (AUVSI) and the U. S. Office of Naval Research (ONR), the objective of the *3rd Annual International Autonomous Vehicle Competition, 2000* is to have a self-propelled underwater vehicle (AUV) locate an active beacon on the bottom of a pond and return with the recovery marker ring. The vehicle must be totally autonomous, with no help or influence from any person or offboard instruments. The objective of locating and recovering the marker ring, must be accomplished with any number of runs but all within 30 [mins]. The details of the competition are given in [1].

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We realized at a very early stage the need to design and develop a new vehicle, different from the existing AUVs such as *Ocean EXplorer*, *Morpheus* or *Squid* at Florida Atlantic University, in view of the competition mission and guidelines. Drawing from a pool of graduate and undergraduate students, a team consisting of 15 members was formed. The team has sought to the expert advise and help of faculty and staff, as mentioned in the acknowledgement section of the paper. In order to complete the project in an efficient manner, the team was sub-divided into groups each with specific tasks and assignments. The groups so formed include (1) administration and team coordination, (2) acoustics, (3) vision system, (4) mechanical design, (5) power and electrical-equipments and (6) vehicle control. The team as a whole met periodically, at the least once a week, to report progress, share information and deliver group products.

The AUV, named *Harp* as an acronym for <u>H</u>ighly <u>A</u>utonomous <u>R</u>oving <u>P</u>rojectile, was designed to be 4 [ft] in length and 1 [ft] in diameter and to have a maximum speed of 2 [knots]. The vehicle is powered by lead-acid batteries and propelled by a vectored thruster. The vehicle is designed to endure for more than 2 [hrs] and up to a depth of 30 [ft]. An acoustic-homing and a vision system are developed to detect and recover the ring. Two onboard computers are used, one for vehicle control and acoustics systems and the second for the vision system. In the following sections, the details of the design and development are given. At the timing of this paper, about 70% of the AUV has already been developed. The vehicle will be completed, tested and fine-tuned by the time of the competition.

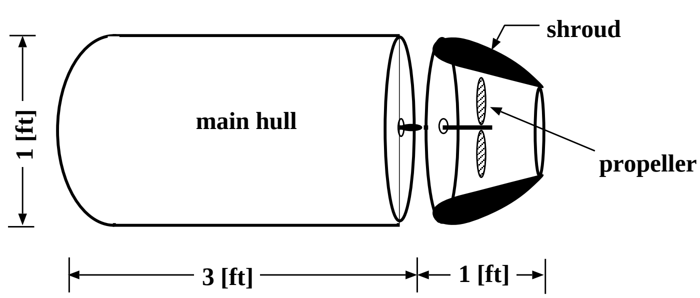

Fig. 1: A schematic diagram of the AUV Harp

2. Mechanical Design

The AUV Harp's main hull is made of an aluminum tank that was formerly a propane tank! The tank is 3 [ft] in length and 1 [ft] in diameter, as illustrated in Fig. 1. The vehicle is propelled and maneuvered by a vectored thruster, as done in our previous year design of the micro-AUV *Squid* [2]. Together with the vectored thruster, the total vehicle length is 4 [ft]. The weight of the vehicle with payload and sensors is estimated to be about 150 [lbs].

The hull is outfitted with a stinger, which houses a camera, to recover the ring from the bottom of the pond. The hull itself is made of aluminum and the shroud of the thruster of polythene. Off-the-shelf airplane model propellers, made of plastic, are used as blades of the thruster which can propel the AUV to a maximum speed of 2 [knots]. The thruster, used for both propulsion and maneuvering, is controlled by rotating the direction of its jet. The use of vectored thrusters thus precludes the need for fins which after all can work only at reasonably high vehicle speed. As a safety feature, the vehicle is fitted with a cut-off switch which can be activated magnetically from outside.

3. Electrical Hardware

The Harp AUV is powered by lead-acid batteries, meeting one of the stipulations of the competition. Two 12-volt 33 amp-hour batteries are used in series to provide 24 volts. A Pittman brushless DC motor is used for the propulsion. Two *Superior Electric* five-volt stepper motors are used to control to control the direction of the vectored thruster.

4. Computer Hardware

The vehicle is equipped with two onboard computers: (1) Jumptec 386 as main computer and (2) Jumptec 586 as the secondary computer. The main computer is used for vehicle control and acoustics communication, while the second computer for the vision system, to be explained later.

5. Acoustic Sensors and Systems

The hydrophones for the AUV are custom-made and graciously donated by International Transducer Corp. (ITC). Four such hydrophones are used on the vehicle. The hydrophones are centered at 27kHz which is the center frequency of the beacon. They are omnidirectional and with high sensitivity. The hydrophones, with hemisphere diameter of 0.5 [in], are quite small in size.

An acoustic-homing system is designed to detect the beacon (see Fig. 2) and to pass the bearing of beacon location to the main computer. The homing system consists of (1) four ITC transducers centered at 27 kHz, (2) four 3 stage preamps to discern very small amplitude signals, (3) four Exar 2211 tone detect circuits, each circuit with two tone detects, (4) four threshold detect circuits and (5) a Diamond timer/counter board as shown in Fig. 3.

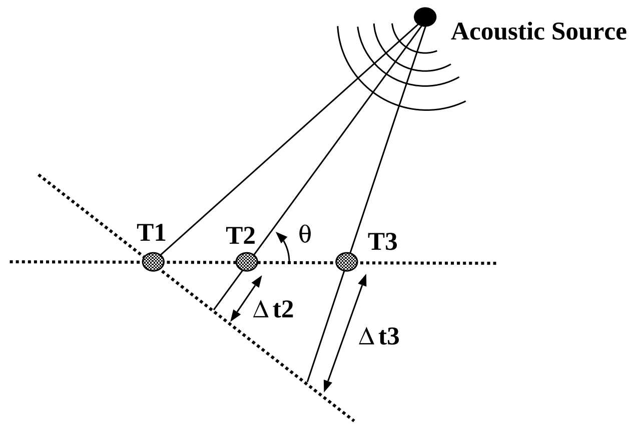

Fig. 2: Illustration of acoustic sensors

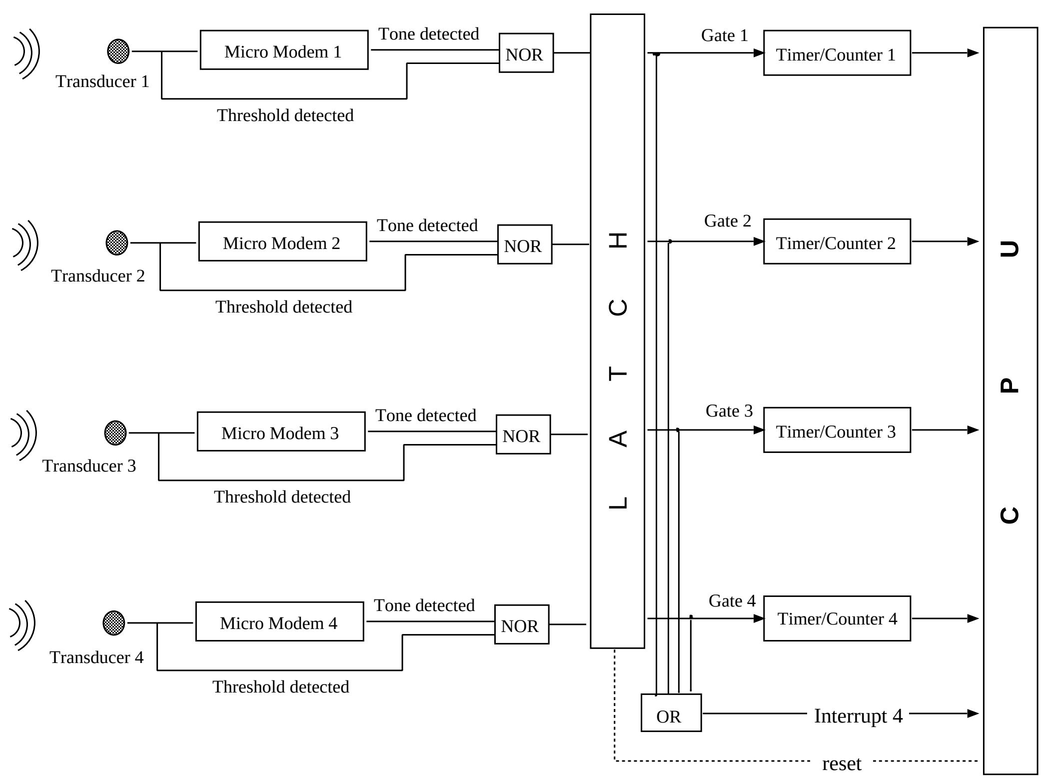

Fig. 3: Circuit diagram of the Acoustic homing system

The homing system functions in the following manner. The four ITC hydrophones are arranged on the vehicle in a known geometry. The signal arriving from the beacon excites each of the hydrophones. The signal is then amplified so as to detect low amplitude signals. At this point, we have included both threshold detect and tone detect logic. This allows us to know that there is a signal present and that it is also at the correct tone. For homing in on the pinger, we have set each of the four tone detects to the center frequency of the beacon, 27kHz. We then measure the time delay between each of the four channels using the timer/counter board. With this time delay and the known geometry of the sensor placement on the AUV, one can estimate the bearing to the pinger. This information is then passed on to the controller.

The Harp AUV can also be equipped with an acoustic modem, which is optional for the purpose of the present competition. The model would require (1) four ITC transducers (2) four 3 stage preamps to discern very small amplitude signals, (3) four Exar 2211 tone detect circuits, with eight tones enabled and (4) four threshold detect circuits. Each of the four channels can have two tone detects which allows the possibility of implementing an acoustic modem as well. For example with eight separate tone detects, one can use four tones to discern the pinger bearing and use the remaining four tones for an FSK based modem. With this FSK scheme, four tones will allow one to represent eight separate commands. In order to reduce incorrect receptions, we only accept signals once every second to allow the multipath effects to dissipate. The possible commands include: surface, continue operation, acquire image, check location, return to base, etc. It is important to note that without the homing operation the system is capable of eight separate tone detects giving 16 possible messages.

6. Vision System

A *visual-servoing* technique is developed to retrieve the ring which is an objective of the competition. The system involves an underwater camera mounted on the stinger that is used to *spear* the ring. The images from the camera are processed on a PC104+ format Pentium 166MHz computer. Vision algorithms with appropriate drivers are written in DOS for efficiency in processing. An algorithm that can recognize ellipses and give parametric equations to them is planned to be integrated into the system. This algorithm can provide the controller a target heading and the distance to the ring.

7. Vehicle Control

The software algorithm used for control consists of the following daemons:

1. Low level controller module that reads/writes to/from the A/D channels.

2. One RS232 module dedicated to the Precision Nav Compass I/O.
3. One RS232 module dedicated to the Video input from video group.
4. One Acoustics module that handles the Quartz timers and calculates heading and distance to target pinger.
5. A Position estimator module that finds the current location by integrating the navigation data.
6. A state manager module that decides and transitions the navigational parameters based on where the vehicle is with respect to pinger, flasher, and ring.

The state manager module allows five possible states:

State I While moving towards the center of pond, it listens for acoustic pings and changes position at a constant depth, towards center of pond.

State II Computes "track" heading from ping PI controller for heading at constant depth, gets new acoustic ping or timeouts and computes distance with relative pings received.

State III Changes heading to a north/south orientation in order to "spear" the ring at constant depth and slow constant speed and waits for flash acknowledgement from the vision system.

State IV PI relative pitch/heading from vision system and retrieves the ring.

State V Sets depth to zero and surfaces. This may also dead reckon to the origin position, which however is not required by the competition rules.

The modules communicate via proxy messages, which are extremely efficient and fast in QNX, and the modules share data via shared memory. There is no duplication of data between modules. Several modules have their own scheduling mechanism (pseudo polling) in addition to the Proxy messages.

Most sensors/actuators/batteries/etc (rudders, stern planes, thruster, compass, depth, altitude, heading, speed, pitch, roll, batteries) onboard the Harp AUV are controlled by A/D channels. The QNX Real-Time Operating System is used for all components except that of the vision system, which runs on DOS. All the s/w modules are written in the C programming language, and shared memory is used to exchange data between all s/w modules.

8. Tests and Trial

At the time of writing this paper, the vehicle is only 70% complete. Several difficulties, not foreseen, were encountered during the production of the vehicle. As we have allowed in our planning the time lost on such uncertainties, we expect the vehicle to be up and running for the competition.

9. Conclusion

An autonomous underwater vehicle named Harp is developed at Florida Atlantic University for participating in the 3rd Annual International AUV Competition. The unique features of the vehicle include (1) vectored thruster for propulsion and maneuvering at slow speeds, (2) acoustic-homing system to detect the beacon and (3) a vision system consisting of stinger with camera to spear the ring. As of May 2000, the vehicle is about 70% complete. The completion of the vehicle and pool tests are planned for June 2000, prior to the competition in July 2000.

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References

[1] Rules and Regulations of the 3rd Annual International Autonomous Underwater Vehicle Competition, 7-9 July 2000, Orlando, Florida.

[2] Y. LePage, "Hydrodynamics and control of an autonomous underwater vehicle equipped with a vectored thruster," *M.S. Thesis*, Department of Ocean Engineering, Florida Atlantic University, 2000.