A SMALL ROBOT SUBMARINE FOR OCEANOGRAPHIC APPLICATIONS

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Abstract

A small computer controlled submarine capable of carrying out various underwater tasks has been designed and built. The vehicle continues to be developed and improved. It has operated for many hours under computer control and has made test runs where oceanographic data have been measured, stored, and eventually printed out. The vehicle is approximately 2.3 m long, .37 m diameter, and weighs 110 kg, in air.

1. Introduction

A small robot submarine has been designed, fabricated, and operated with the main purpose of facilitating the collection oceanographic data. These data might include temperature, salinity, turbidity, and biological measurements. In addition, the vehicle could be used in survey and search tasks.

The general characteristics of the robot submarine are as follows:

speed	1.14 m/s	(2.2 kts)
design range	25 km	(15 statute miles)
design maximum depth	61 m	(200 ft)
weight (air)	110 kg	(240 lb)
payload	11.4 kg	(25 lb) depends on volume and density
length	2.31 m	(7.52 ft)
diameter	.37 m	(1.23 ft)

2. Hull and Structure

The outer skin of the robot is made of fiberglass nose and tail sections and a cylindrical aluminum center body. The aluminum skin is split along the horizontal centerline as shown in Figure 1. Inside the skin there are three compartments separated by aluminum bulkheads. The bulkheads are located on four 5 cm diameter poly vinyl chloride (PVC) tubes which are the main structural members of the submarine. The front and rear compartments have 10 cm and 15 cm PVC tubes arranged as shown in Figure 2. The middle compartment houses the battery and there is a hatch in the top aluminum skin over the battery to provide access.

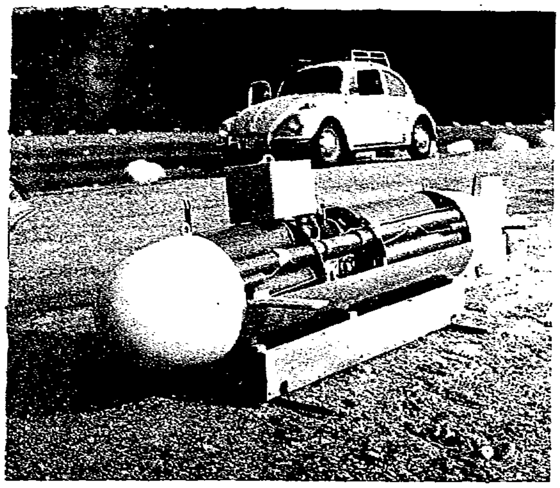

FIGURE 1 Robot Submarine with the Top Skin Removed (The Control Box is Resting on the Vehicle).

The lower 15 cm tube in the front compartment contains the autopilot while the similar tube in the rear compartment houses the mini computer. Another 15 cm tube on the centerline of the tail section contains the propulsion motor, reduction gear, and rear servomotors.

There are two small packages in the nose cone, one containing the bow servomotor and the other housing sensors.

All the tubes are sealed using PVC endcaps and O-rings. Watertightness is checked by pulling a vacuum through a small hole and making sure the vacuum is retained. Low cost waterproof

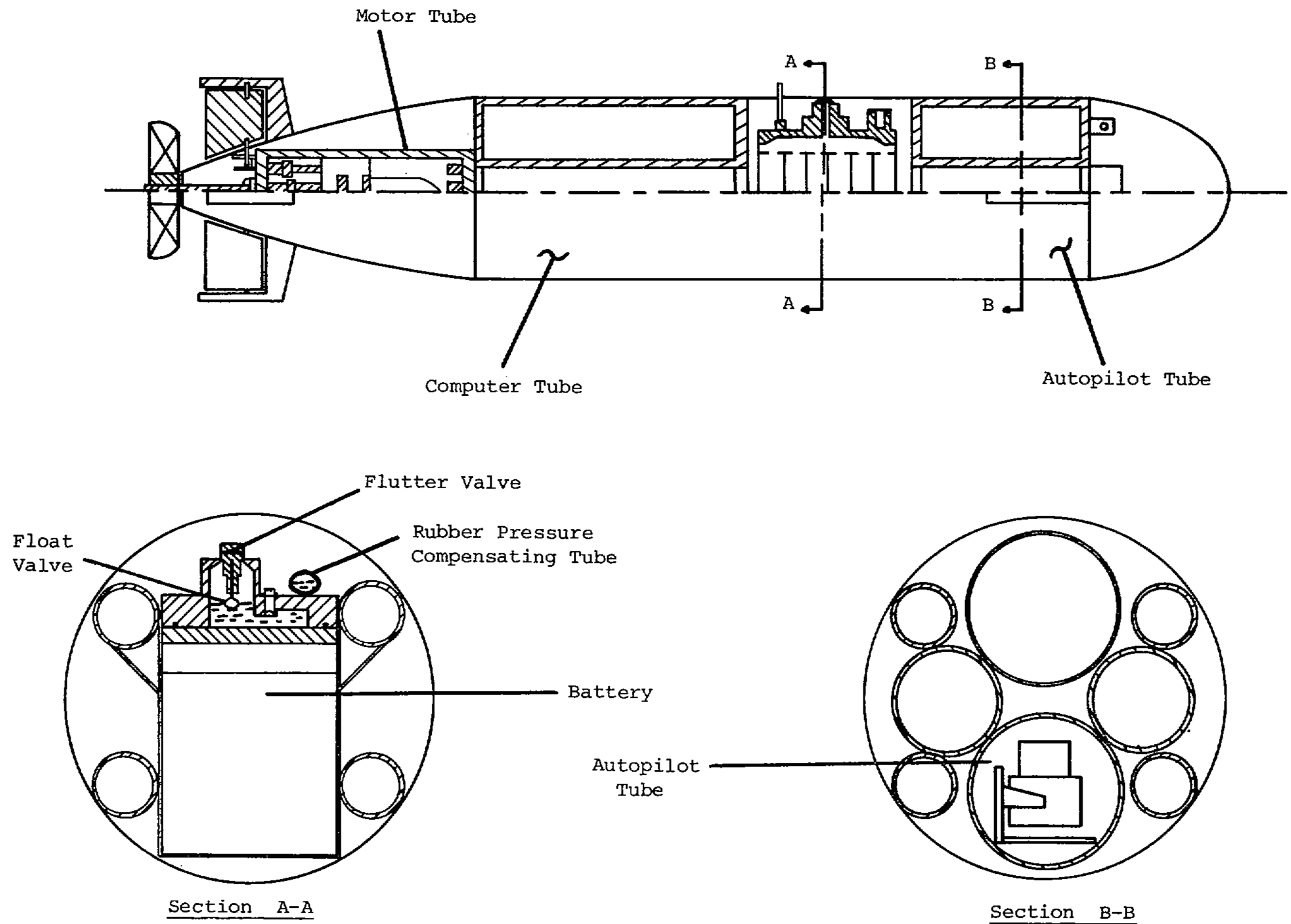

FIGURE 2 Arrangement of the Robot Submarine

electrical connections were made between the various PVC tubes using vacuum tube sockets, sealed with epoxy resin and vinyl tubing, Figure 3.

3. Propulsion and Control

The vehicle has a two bladed aluminum propeller 30 cm in diameter driven through a 10:1 reduction gearbox by a 12 V dc motor. The energy is supplied by an automotive battery modified for immersion in sea water.

The battery is pressure compensated by filling the space above the electrolyte with oil and by providing a rubber bag, partially filled with oil, to transmit the ambient water pressure (Figure 2). An unfortunate characteristic of conventional batteries is the continuous production of hydrogen which must be vented. It has proved to be a very troublesome problem to provide a venting system which does not expel oil with the hydrogen. Success was achieved by building a special top to the battery to contain the oil and fitted with a valve to vent the gas. The vent valve has a float valve and a flutter valve. The float valve prevents the oil from being expelled and allows the gas to vent when it eventually rises to the top of the casing.

There are four independently moveable control surfaces, the bow fins, the rudders, and the port and starboard rear fins. These are actuated by small servomators which have integral position feedback potentiometers.

4. Computer

The main purpose of the computer system is to control all the functions of the robot (Figure 4). These functions include the testing, checkout, and programming of the robot before an operation and also the control and navigation of the vehicle when underway.

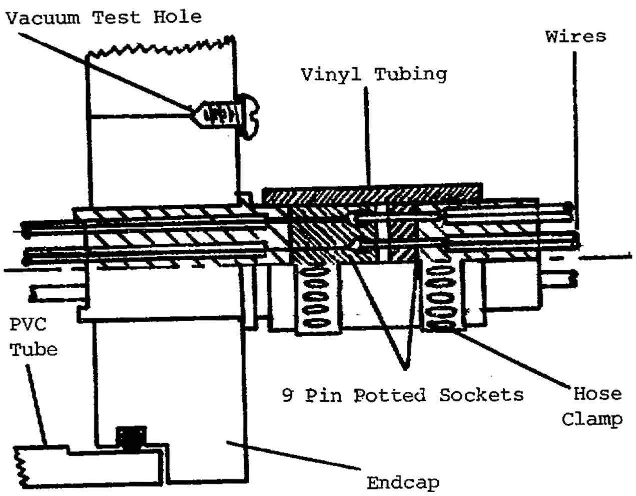

FIGURE 3 The Arrangement of the 9 Pin Waterproof Connectors

The computer consists of three main parts:

a. the central processing unit (CPU)

b. the memory

c. the interfaces.

The main components of the computer are housed in the computer tube although some of the interfaces are located in the autopilot tube.

The CPU is a 16 bit minicomputer built using CMOS integrated circuits. It is relatively slow with a cycle time of 23 μ s, but only takes 200 mW. Page zero (loc 0 - 527), relative (255,-256) and based addressing are implemented and these can be immediate, direct or indirect. There is one accumulator which is used with a variety of arithmetic, skip, and input-output instructions. One interrupt, a.1 second clock, is available.

The memory is 4K by 16 bits and the power consumption is 1.5 - 2.5 w. The cycle time is 2.9 μ s, constrained by the CPU.

There are three interfaces. All are connected to the computer by serial data links to reduce the number of wires. The submarine interface receives instructions from the computer to read or write analog or digital to or from the various lines in the autopilot. This interface utilizes three 8 bit D → A converters, a 10 bit A → D converter and a 64 channel analog multiplexer.

The teletype interface connects both the teletype (110 baud)* and the cassette tape recorders modified to store digital data (2000 baud).

The third interface is to the control panel. This is used for detailed manual control of the computer and the submarine.

When the submarine is in the water, before a mission, the information to and from the computer is transmitted through an optical coupler. An array of light emitting diodes (LEDs) and phototransistors in the optical coupler provide a signal path which eliminates the need to make-and-break electrical connections in the sea.

The computer is generally programmed in assembly language while small modifications are made in machine language. Several software programs were written to facilitate the development of the operational computer programs to control the robot. The software was developed in parallel with the hardware by utilizing a simulator for the robot computer written on a PDP 11 computer.

The 'editor' permits the teletype to be operated as an editing typewriter and enables the edited program to be transcribed onto paper tape.

The 'assembler' translates programs in assembly language into machine language code and generates a machine language tape. There is a self assembler for the robot's computer and a cross assembler on the PDP 11.

The 'loader' loads a machine language tape into the computer memory. The loaded program is then ready for execution.

The 'debugger' allows the examination and modification of machine language programs in memory via the teletype. In addition, it permits the controlled execution of the programs for error checking.

The software was used to write the programs to operate the robot. These programs have the following objectives:

a. to carry out instructions at prescribed times

b. to give control to the autopilot with set values of depth and course

c. to have direct control of the fins and rudders for special purposes

d. to record data in memory and to retrieve it.

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*Baud - bits per second.

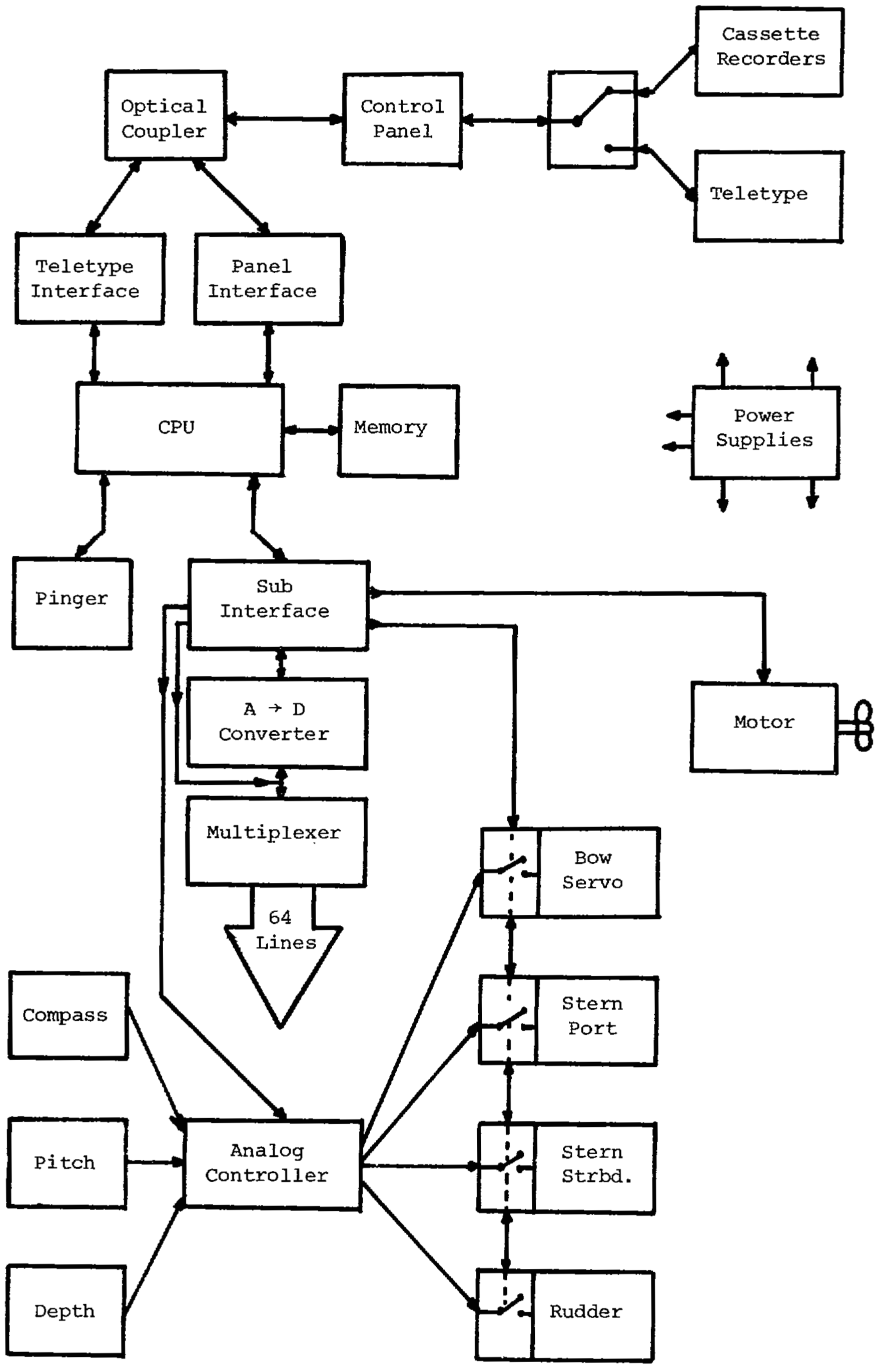

FIGURE 4 A Block Diagram of the Computer and Autopilot

These tasks are made easier by a set of standard subroutines. The operation of the robot is programmed as a series of statements calling the subroutines. Modifications to the instructions can be made in the field with the aid of the control panel. Such instructions would be to change course, depth, or timing of a mission.

5. The Autopilot

The autopilot has real time control of the robot; it carries out the computer instructions of depth and course, and in addition it controls the pitch attitude of the vehicle, as shown in Figure 4.

The autopilot has three sections:

a. the sensors, which sense the depth, attitude, and heading of the vehicle

b. the analog controller, which provides the control signals to instruct the control surfaces to move

c. the servo amplifiers, which utilize signals from the analog controller to provide the power necessary to drive the servomotors.

The sensors on the vehicle have output signals representing pitch, depth, and heading. Pitch is obtained from a pendulum attached to a potentiometer. The pendulum is in an oil filled container to give damping. Depth is determined by an absolute pressure transducer. Heading is obtained from a magnetic compass using photo-potentiometers placed below a compass card on which a spiral is scratched.

The analog controller is a proportional-derivative controller which utilizes the differences between the command signals and the sensor outputs to generate the control signals. The depth and heading commands come from the computer while the attitude command requires the robot to remain horizontal.

The servo amplifiers compare the voltages on the command lines with the position feedback voltages from the servomotors and provide power to move the motors until the voltages match.

6. Other Electronic Systems

The 12 V automototive battery is connected directly to the propulsion motor. The supply is then taken to the autopilot tube where several regulators are placed. (10 V, 5 V servo, 5 V instrument). There are additional regulators in the computer tube (± 12V, ± 5V, 9.1 V auxiliary), with small rechargeable batteries to provide an auxiliary supply for the computer.

A tracking system using a pinger is utilized to determine the position of the robot when underway. The pinger is a separate system housed in a small PVC tube placed in the battery compartment. The pinger transducer sends out a 4 m s burst of 10 KHz signal every second, timed by a crystal oscillator. The vehicle is tracked on shore using a sonar receiving system coupled to two hydrophones and a wet paper recorder with a precise one second sweep.

7. Current Status

The robot is being developed to make it more reliable. It has operated for many hours and has collected water temperature data which were measured and stored in the computer memory. Recent testing has been concerned with the measurement of the control characteristics of the vehicle.

A collision avoidance sonar and a navigation system are being developed. The navigation system is being designed to enable the robot to determine its own position relative to fixed transponders.

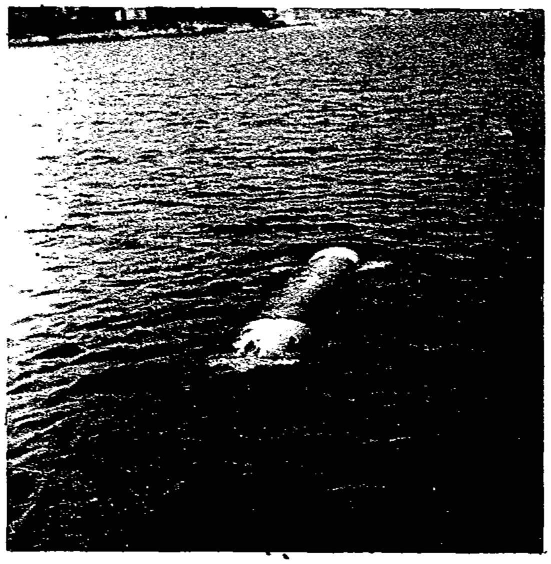

FIGURE 5 Robot Underway Under Computer Control

8. Conclusions

An inexpensive robot submarine with computer control has been designed, fabricated, and developed. The vehicle is capable of carrying out a variety of tasks in the ocean including the collection of oceanographic data, and some search and survey operations.

Problems have been encountered with many of the mechanical, electrical, and electronic systems. These have largely been overcome but improvements can be made.

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Intel Corporation of Santa Clara, California, kindly supplied the integrated circuits used in the computer memory.

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