The SDSU Autonomous Underwater Vehicle Project

AUV Team
San Diego State University

5500 Campanile Drive
San Diego, CA 92182-1309
(619) 594-3083 http://auv.sdsu.edu

Abstract

The SDSU AUV is ½ scale long surfboard equipped with two side mounted Minnkota 30lb thrust trolling motors and three vertically mounted leveling motors. The conceptual design was fabricated in house using epoxy resin with fiberglass, carbon fiber, and Kevlar. The result is a 42" x 18" x 8" hull capable of withstanding changing water and pressure environments as well as impact damage.

The competition requires that the vehicle navigate a course and deliver a payload to a specified target without outside communication. The SDSU AUV is designed to meet these requirements by interfacing a central processing unit to 6 peripheral devices for intelligent control of the vehicle. The peripheral devices are passive and active sonar, which assist in navigation by sensing the edge of the facility and the end target; inertial navigation guides the vehicle in a flat and straight motion, the depth sensor provides vital information on the depth of the vehicle; vision locates targets, and motor control provides smooth movements of the boat.

The team goal is the completion of a fully autonomous submersible vehicle to compete in the 2004 International AUV competition.

Problem Statement

The Association for Unmanned Vehicle Systems International and the Office of Naval Research are hosting the seventh International Autonomous Underwater Vehicle Competition to be held at the Transducer Elevation Center (TRANSDEC) facility at the Space and Naval Systems Center, San Diego this July. The goal of this unmanned system competition is to advance the technology of Autonomous Underwater Vehicles (AUVs) by challenging students to complete realistic underwater missions and to help young engineers develop relationships with industry professionals.

This year's competition mission has three stages: basic vehicle operation, autonomous marking, and autonomous recovery. The staging ground for the competition is the TRANSDEC facility at SPAWAR, which is a large elliptical pool with a reflective lining and shape designed specifically to test transducers, see Figure 1. The outer rim of the pool where the competition will take place has a depth of 16 feet. Additionally there is a circular section in the middle of the pool that continues to reach a depth of 38 feet, but this area will not be used in the competition.

Figure 1: TRANSDEC Facility

The first of the three stages requires that the vehicle be able to pass through a validation gate. The gate is an up-side-down U-shaped structure constructed with PVC pipe. The gate is 10 feet wide, 6 feet tall and the top of the inverted-U is at water level. Successfully passing through the validation gate demonstrates that the vehicle has the ability to perform basic functions necessary to complete the rest of the mission. A picture of the mission course can be seen in the following figure.

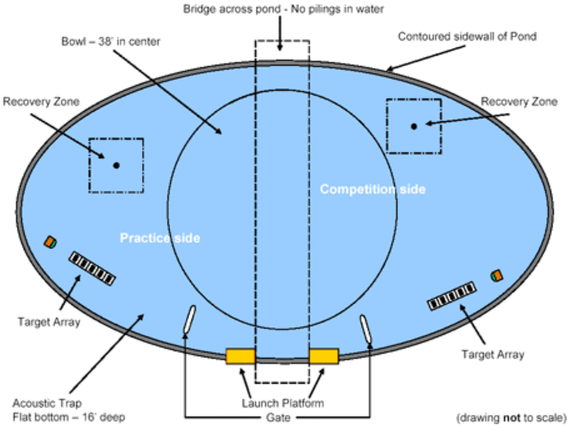

Figure 2: Competition Course

In the next stage, autonomous marking, the AUV is required to locate and proceed to the target zone and deliver its payload. The target zone can be located by identifying the horizontally projected flashing light. At the base of the light there are five target bins, each worth a different amount of points ranging from 100 to 500. The vehicle has the opportunity to drop two markers into the target array.

The final stage, autonomous recovery, requires the vehicle to utilize sonar to find the recovery zone, and surface within a 20-foot square area. The recovery zone consists of a submerged pinger that is in the center of recovery area and is enclosed on the surface by a floating line. The vehicle must surface within the designated recovery zone in order to receive all of the points.

Introduction

The San Diego State University (SDSU) AUV has been designed and developed by the students of the Electrical and Computer Engineering department to successfully complete the mission set forth by the competition requirements. The vehicle is designed to navigate through the validation gate, release the payload over the illuminated target and finally return to the recovery area to surface.

This is SDSU's first year competing in the underwater competition, thus all design and system integration has been done from scratch. The budget for the vehicle was approximately 5,000 dollars; therefore, the vehicle fabrication and most of the peripheral devices were made in-house using resources available at SDSU.

Overview

Structural Design

The hull of the vehicle is a custom lightweight design fabricated using fiberglass for structure and carbon fiber and Kevlar for strength and support. The design of the vehicle was based on a ½-scale long-board surfboard model developed using AutoCAD. The completed design resulted in a neutrally buoyant vehicle weighing 50 pounds that satisfies mission specifications, and can withstand impacts at operational speeds.

The shell of the vehicle as seen in Figure 3 was developed by cutting foam to the desired shape and size, and using epoxy resin and fiberglass to encapsulate the foam. After the resin was cured, a hole was cut into the top of the shell, and the foam was removed using chemicals. A combination of glass, carbon fiber and Kevlar layers were then added to give the vehicle additional structural integrity where needed.

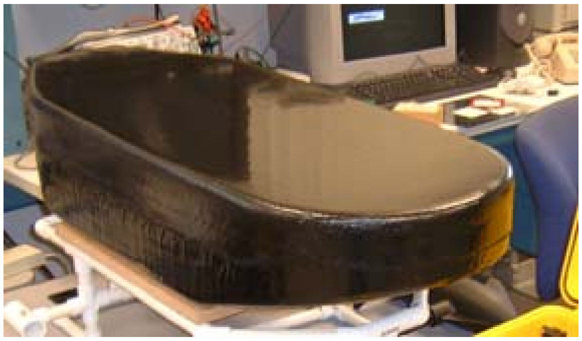

Figure 3: AUV Hull Fabrication

The majority of the system electronics are housed in a waterproof Pelican case that is mounted inside the hull. The Pelican case is attached via a rail system that allows the case placement to be adjusted to ensure proper leveling of the AUV. Furthermore, four ABS pipe capsules have been integrated into the design of the vehicle to provide more accurate leveling and ballast control. The capsules can be filled with air, water or heavy material in order to achieve the desired vehicle balance. The thrusters, payload delivery system, camera and external sensors connect to the Pelican case using watertight connectors.

The housing for the camera consists of two acrylic tubes four inches in diameter located in the nose of the AUV. A groove was cut in the front of the vehicle and the outer tube was carefully glassed in place. Another fully sealed acrylic tube that holds the camera and associated electronics carefully slides inside the other tube that is permanently attached to the vehicle.

The payload delivery system and the active sonar system are both attached to the underside of the vehicle. The passive sonar system has three hydrophone units, one attached to each motor and one attached to the front of the vehicle.

Two lateral thrusters and three vertical thrusters are used to control vehicle motion. The two main thrusters are mounted on the side of the vehicle with aluminum plating while the three vertical thrusters are mounted inside fiberglass tubes inset in the hull. A three-dimensional rendering of the AUV can be seen in Figure 4 below.

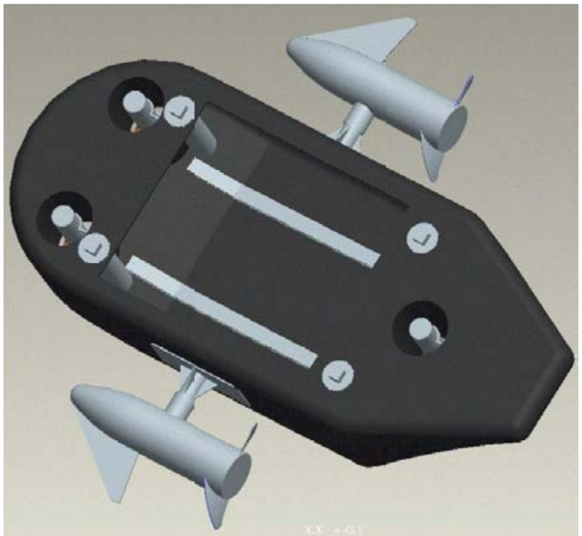

Figure 4: Three-dimensional Rendering of AUV

Main Thrusters

The main thrusters used are Minkota 30lb-thrust trolling motors. These motors were selected because they were more than sufficient to meet the system requirements and because they were inexpensive and easy to acquire. The main thrusters control the forward and reverse motion of the vehicle when they are operated in the same direction, and they control the azimuth when operated in opposite directions. The main thrusters are also responsible for maintaining the speed of the vehicle.

Vertical Thrusters

Three Pittman Lo-Cog servomotors with three-inch diameter propellers were enclosed in aluminum casings and used as vertical stabilizers in our vehicle. When operated together the vertical motors allow the AUV to control depth, pitch and roll. Two of the vertical motors are located in the front of the vehicle, while the other is located at the rear of the vehicle.

Motor Control

The propulsion and control system is composed of three primary blocks, the RC/CPU interface, the Mixing Control Module, and the Pulse Width Modulators. These three modules work together to control the power and direction of all five motors.

The RC/CPU Interface is used to communicate with the CPU or receive commands from a Radio Control Receiver during testing. The Mixing Control Module receives five commands corresponding to throttle, azimuth, pitch, roll and depth used to control the vehicle's movement. Finally, the Pulse Width Modulators translate the desired commands into motor operation by using a pulse modulated clock signal to control the average DC voltage that the motors receive.

The main propulsion is powered by three 12 volt, 3000 milliamp-hour batteries and a 30 amp Vantec Electronic Speed Controller.

Batteries

The vehicle contains six Nickel Metal Hydride (NiMh) batteries. Four of the batteries consist of ten cells with a 3000 milliamp-hour rating that supply the electronics with 14.4 volts. The remaining two batteries contain 12 cells with 2200 milliamp-hours to supply the thrusters and stabilizers with 12 Volts.

Two sets of batteries are maintained at all times so that there is always power available for the vehicle. One set of batteries can be recharged using the Watt-Age dual-output battery chargers while the other is used for practice runs and mission execution.

Power Supply

The Nickel Metal Hydride batteries are interfaced to the system via a power control module with multiple voltage regulators that enable accurate voltages to be delivered throughout the system. The power control board is a 1 by 4 inch custom-designed and built circuit board with multiple headers for easy integration into the system. This allows a safe distribution of varying voltages such as delivering 5 volts to the microcontrollers and delivering 3.3 volts to the FPGA devices.

Pelican Case

The Pelican 1400 case is the main storage for the vehicle electronics and batteries with the exception of the vision and sonar systems. The case measures 13.38" L x 11.62" W x 6" H and has the following inner dimensions 12.12" x 9.12" x 3.97". The case is built for up to 30 feet of water and air tightness. A picture of the case can be see below in Figure 5.

Figure 5: Pelican Case for the Electronics

Electrical Connections

The main wet connections are located on the rear panel of the Pelican case. The connectors are Bulgin 400 series buccaneer style connectors as shown in Figure 6. The connectors are IP68 rated and tested at 10 meters for 2 weeks for dust and waterproofing. Each peripheral device is terminated at the case with a Bulgin connector.

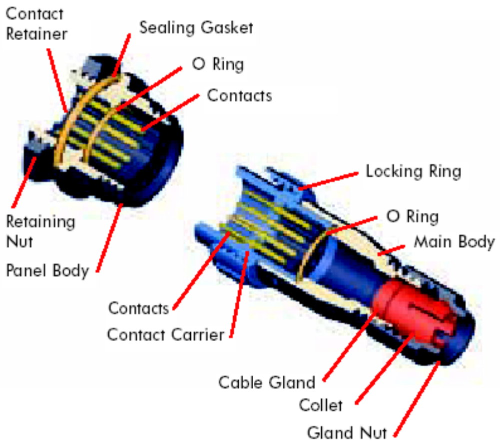

Figure 6: Bulgin Watertight Connectors

Vision

The AUV utilizes the Omni-Vision 7120 (OV7120) camera to acquire 8-bit grayscale digital video data. The camera is integrated into a Pegasus development board with an onboard Xilinx Spartan-II FPGA.

The FPGA processes and stores the data received from the camera. The grayscale video data is converted to a black and white image in order to locate the light in the target zone. The FPGA detects the presence of a light source by determining the location of the white pixels within the black and white image. The position of the light source within the data array is used to determine the appropriate instruction to be sent to the central processing system.

Sonar

The vehicle sonar systems consist of two distinct types, passive and active. The active sonar sends and receives data that is translated into distance using a transducer removed from a handheld underwater Fathometer. The transducer is integrated into the system via complex analog circuitry designed and built specifically for this function shown in Figure 7. The signal received by the transducer is amplified and re-transmitted to a CPLD device for digital processing and communication with the central processing system.

The passive sonar system was designed to direct the vehicle to the pinger located within the recovery zone. The passive sonar is based on a triangulated set of hydrophones. Each hydrophone has analog circuitry designed to amplify and filter the target frequency. The vehicle will be directed toward the pinging device based on which hydrophone receives the pinged signal first. The difference in time it takes for each of the port and starboard hydrophones to receive the signal can be translated into a heading that allows the AUV to home in on the recovery zone pinger.

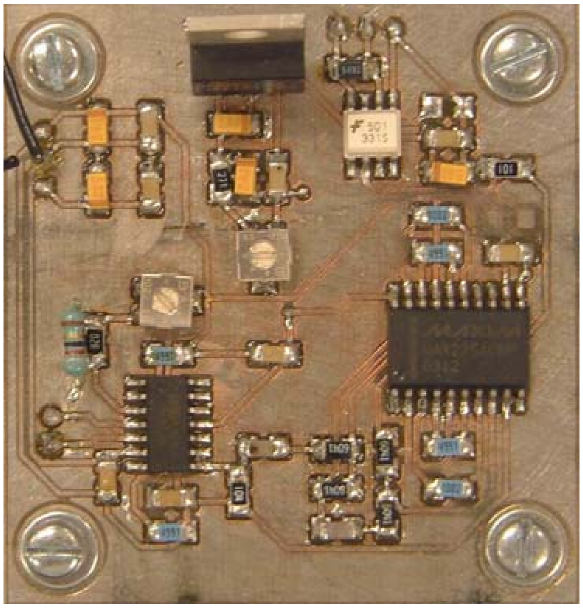
Figure 7: Analog Sonar Circuitry

Depth Sensor

The depth sensor system is designed around a Motorola MPX 2100GP piezo-electric pressure sensor. The small sensor is built into analog circuitry that amplifies the pressure signal for further processing using a PIC microcontroller. The microcontroller converts the analog signal to a digital one and delivers an 8-bit binary value to a FPGA device that has a lookup table to correlate the value to a depth in inches. The result is a low cost system that can report the depth of the vehicle down to 33.46ft with better than one inch accuracy.

Tilt Sensor

The tilt sensor was developed using Analog devices ADXL 202E iMEM accelerometers. The ADXL is a two-axis accelerometer with a duty cycle output that eliminates the need for A/D conversion. The accelerometers are interfaced into the system with an FPGA device that translates the duty cycle into an 8 bit binary value. The binary value corresponds to a tilt angle. A binary value of 128 represents 0° of tilt and 255 represents 90° of tilt.

Payload Delivery System

The payload delivery system was developed using a combination of permanent and electro-magnets. When the vehicle detects a target location, a signal will be sent to the payload delivery system that will generate a magnetic field. The magnetic field generated by running current through a coil will reduce the strength of the permanent magnets hold on a stainless steel pinball, and result in its release from the vehicle.

Computer System

The central processing system of the autonomous underwater vehicle needed to be small, flexible, robust, maintainable, and have low power consumption in order to fit within the small electronics enclosure and run off a limited power supply. Furthermore, it needed to be able to gracefully handle data input and output with added hardware devices, and have a soft core so design modifications could be done quickly and easily. To satisfy these design constraints the Altera Nios Development kit was selected because it met our design requirements as well as provided added advantages such as the ability to support the MicroC/OS-II real-time kernel. Another benefit provided by the Nios Development kit was that it contained all the development tools needed to successfully develop an embedded system. Figure 7 shows how the central processing system is required to interact with the other systems of the AUV.

The central processing system, which is responsible for sensor communication, drive control and decision-making was developed using an Altera Apex 20k200E FPGA device as the baseline system. The system core includes a 32-bit processor, an SDRAM controller, and parallel input/output lines. Additional modules include the cs8900 Ethernet controller, a customized serial communications board, and a modified port of uCOS-II.

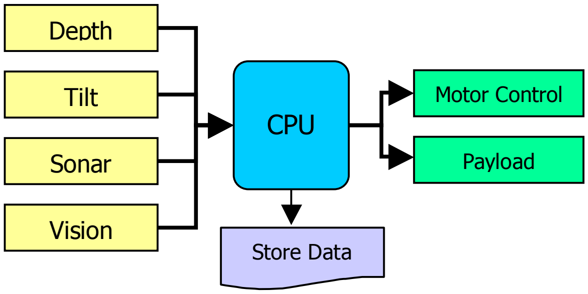

Figure 7: System Overview

Mission Processes

The peripheral sensors which include the depth sensor, tilt sensor, sonar system and vision system all communicate to the central processing system using serial communication. The communication protocol is based on I^2C and all usable sensor data is eight bits in length. Since eight bits was selected has the data length, it provided a range of values from zero to 255. The peripheral devices have all been designed to send an instruction byte to the CPU with 128 as a neutral value. Based on the values received, the CPU determines the appropriate values for motor control and payload delivery.

The vehicle is designed to navigate the course based on a state machine. Once the AUV is given the command to go, it will dive to a target depth based on the values provided by the depth sensor. It will then proceed forward through the validation gate and begin searching for the light indicating the target zone. Once the light source has been found, the vision system will guide the AUV to the target array and the payload delivery system will be sent a signal to drop the markers. After both markers have been released, the vehicle will move into the pinger homing state. The AUV will continue to track the pinging signal until it is above the pinger. The AUV will then surface above the pinger in the recovery zone. After the vehicle breaches the surface, the motors will be shut off.

Conclusion

An education in engineering is only valuable if the knowledge learned can be applied to real world systems. The SDSU AUV allowed a team of students to apply theory and skills learned in the classroom to a project with real world implications. AUV's are utilized in defense, for mine extraction and reconnaissance missions, and in the private sector for mapping of the ocean floor and various research applications. The development process of the AUV's various subsystems gave the team members first hand experience designing, redesigning, fabricating, and testing technology.

The primary objective of this year's entry in the competition is to develop the backbone system to accomplish the basic vehicle operation and environment sensing. The future and opportunity for redevelopment of all subsystems will present an equally challenging task to all those involved in next years team.

Acknowledgements

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