Team Nautilus Autonomous Underwater Vehicle C.A.S.I.U.S.: Public Release of Design and Process

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Abstract- C.A.S.I.U.S. is an AUV developed by a team of undergraduate students from Temecula and the surrounding areas. The submarine was designed in a 6 month time period using Autodesk Inventor and Solidworks. All aspects of the vehicle were developed with cost, simplicity, and originality in mind. Improvements from Nautilus I include, a light weight frame, easy access vessel, and low power consumption. C.A.S.I.U.S.'s control sensors consist of Microsoft HD cameras, moisture sensor, and an Inertial Measurement Unit (IMU). Returning features include, CO2 powered torpedoes, stereoscopic vision, and LED headlights.

Introduction

The Compact Assistive Specialized Independent Underwater System (C.A.S.I.U.S.) is the second autonomous underwater vehicle (AUV) developed by Team Nautilus for the International RoboSub Competition. The 17th annual competition, hosted by the Association for Unmanned Vehicle Systems International and the Office of Naval Research, is held from July 28, 2014- August 3, 2014 at the SSC Pacific TRANSDEC in San Diego, California. The team is made up of eight undergraduate engineering students attending various institutions in Southern California: University of Irvine, University of Riverside, San Diego Mesa College, and Mount San Jacinto College.

The objective of the 2014 competition is to design, manufacture, build, and program a completely autonomous submarine that will complete specific tasks in the "TRANSDEC 17" mission. The mission is designed to simulate tasks that would be performed by industry level AUVs. Tasks required to be completed by the submarine include following a designated path, aligning to buoys and changing their lighting, firing torpedoes, maneuvering around structures, recovering an object, as well as other tasks. Due to the vehicle being unmanned, the control systems must robust and reliable.

Technical Field

This product relates to robotics and more precisely autonomous underwater vehicles.

Background

In the field of search & rescue, exploration, and military, Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) have become a necessity in many unmanned missions. ROV and AUV's can reach depths that humans will never be able to.

I. Design

This year's vehicle was designed as an improvement over the last generation. Features include a lightweight aluminum frame and an omni-directional thrust pattern. The drive system is not only distinctive, but also very maneuverable; allowing the vehicle to move in all directions, rotate on its central axis, strafe, and move diagonally.

The objective for C.A.S.I.U.S. was to design an AUV that would be practical in real world applications. Due to the nature of the competition and the need for unmanned vessels, Team Nautilus aimed to design a vehicle that would satisfy the needs of both civilian and military uses.

II. Mechanical System

C.A.S.I.U.S.'s mechanical system consists of the frame, motors, electronics enclosure, and pneumatic system.

A. Frame

The frame of C.A.S.I.U.S. is made of 1" boxed 6061 aircraft grade aluminum. The chassis was designed as straight forward as possible in order to keep weight, cost, and complexity to a minimum. Components are attached to the frame using clamp style, or quick connections to allow for hot swappable units. Since C.A.S.I.U.S. was designed to be easily transportable, straps on the bottom of the frame were attached to resemble a backpack. Easily accessible management was a goal for the submarine, for that reason, strapping it to one's back as opposed to hauling a large submersible is more ideal.

B. Motors

The vehicle is propelled by six 350 gallon per hour (GPH) bilge pumps that were 'hacked' to become low cost, high output thrusters. These thrusters *(see Figure 1)* only cost $20.00 for the pump, prop, and prop adaptor. In order to achieve maximum maneuverability, four of the six motors are attached to the corners of the frame each at a forty-five degree angle. The position the thrusters are angled creates a holonomic drive system that allows the submarine to effortlessly sway and surge. Two of the six motors are placed on the front and back of the submarine for easy heaving motions.

Each of the six brushed motors is powered by twelve volts of direct current (DC). Under heavy load, each motor draws approximately two amperes of current per hour.

Figure 1: Customized motor; bilge pump with propeller.

C. Electronics Enclosure

The electronics enclosure *(see Figure 2)* is a Pelican 1450 case mounted to a quick release system that is not only for ease of use, but allows the center of gravity (CG) to be lower. The interior dimensions of the Pelican Case are (LxWxD) 14.62"x 10.18"x 6" (37.1 x 25.8 x 15.2 cm). The exterior dimensions of the case are (LxWxD) 16" x 13" x 6.87" (40.6 x 33 x 17.4 cm). The small case is ideal because there is less of a need to compensate for buoyancy.

Due to the transportability and accessibility factors of the vehicle, all of the items inside of the enclosure are secured in their tailored fit compartments. Each compartment is modular in order to easily modify any components when necessary.

In order to relay information from the motor controllers placed on the inside of the enclosure to the motors located on the frame, waterproof connections were drilled to the top front of the Pelican case. Each connection has a designated purpose:

1) Motor controllers
2) Tether
3) Cameras

Figure 2: Pelican case enclosure housing the electronics.

D. Pneumatic System

The pneumatic system is used to control torpedo regulation. The system consists of two air tanks *(see Figure 3)*, single action solenoids, and rubber hosing. The air tanks are pressurized to 150 PSI of Carbon Dioxide. CO_2 is used because of the density and quick fill. There are two single action solenoids that send a burst of gas to the torpedoes, allowing them to shoot up to 20 feet in perfect conditions.

Figure 3: One of the two air tanks used for the pneumatic system.

III. Electrical System

C.A.S.I.U.S.'s electrical system provides the vehicle with run time power.

A. Power

The battery *(see Figure 4)* consists of one 12 volt, 18 ampere hour lead-acid. The battery weighs 15 pounds (6.8 kg) and allows the vehicle to have a low and centralized center of gravity.

Figure 4: 12 volt battery powering the AUV.

B. Microcontrollers

Microcontrollers control many of the systems, including: movement, sensor feedback, data-logging, and diagnostics. The microcontrollers on C.A.S.I.U.S. are based off of the Arduino™ UNO *(see Figure 5)* platform. The open source platform provides availability, accessibility, and support, allowing easy implementation.

Figure 5: Arduino™ UNO microcontroller.

C. Motor Controllers

The motor controllers are designed to convert a digital PWM wave into smooth and continuous motor speeds. Talon SR speed controllers (see Figure 6) are used to control the submarine's motors, with a maximum input voltage of twenty-eight volts direct current and a peak current of 100 amps. The motor controllers have a maximum two milliseconds at 333 Hz PWM signal and simple calibration, this combination results in ideal motors for C.A.S.I.U.S.'s purposes. A Smart LED that blinks proportional to throttle with an obvious change from 99% to 100% presents exceptional feedback for motor testing purposes.

Figure 6: Talon SR motor controller.

D. Central Processing Unit

The BeagleBone *(see Figure 7)* microprocessor was chosen as the central processing unit (CPU) for C.A.S.I.U.S. The microprocessor was chosen over a conventional system, such as a mini-ITX, because of the low power consumption and cost. Specifications include:

- 512 MB DDR3 RAM
- 4 GB 8-bit eMMC on-board flash storage
- 2x PRU 32-bit microcontrollers

Linux provides the submersible with a fast and minimalistic operating system. The BeagleBone runs on Ubuntu, a Linux based operating system (OS).

Figure 7: BeagleBone Black, central processing unit.

IV. Sensors

C.A.S.I.U.S.'s sensors include analog and digital, as well as visual.

A. Cameras

C.A.S.I.U.S. is equipped with 3 HD Microsoft LifeCam Studio cameras *(see Figure 8)*. There are two in the front to act as stereoscopic vision and one in the back looking underneath the vessel. These cameras have 1080p vision with autofocus capabilities.

Figure 8: HD Microsoft LifeCam Studio camera, three will be used on AUV.

B. Inertial Measurement Unit

The purpose of the IMU *(see Figure 9)* is to keep the vehicle leveled and stable during its mission. The IMU is a 9 degree of freedom Razor model, purchased from sparkfun.com for $79.95. Based on the pitch and the roll, it is determined which motors are going to be in use.

Figure 9: 9 DoF Inertial Measurement Unit

C. Depth Sensor

The depth is regulated and logged by an AST20PT depth sensor *(see Figure 10).* This sensor is capable of taking pressures up to 50,000 PSI. The sensor is analog and consists of a resistive diaphragm that changes voltage readouts as pressure increases or decreases.

Figure 10: AST20PT depth sensor

D. Moisture Sensor

The purpose of the moisture sensor is to keep track of the overall humidity inside of the electronics vessel. The moisture sensor is controlled by an Atmel attiny84 microcontroller. This was used because of the low power consumption, size, and ease of use.

The theory behind the sensor is that the probes on the bottom of the case would ‘short’ when submerged in water. This connection would then send a signal to a piezo element that would buzz for audible feedback. Making contact with the probes will send a signal that triggers a relay to send the vehicle into a complete shutdown, thusly preventing any electronic and water damage.

E. Data Logging

As a result of debugging problems that occurred on *Nautilus I*, C.A.S.I.U.S. contains a data logging system that allows seamless navigation through issues. The data logging system consists of an Arduino™ UNO and a SEEEDStudio SD card shield. The system logs everything from time and mission length to moisture levels. It records everything in a .csv file and can be opened in a standard spreadsheet program.

VI. Software

The software used for C.A.S.I.U.S. is a combination of Arduino™ C and C++.

A. Visual Software

The submersible navigates through obstacles with the use of detection via USB webcams. Using Open Source Computer Vision (OpenCV) the webcams are able to be programmed to detect user defined objects and shapes. Colors can be detecting by using either red, green, blue (RGB) color spectrum or hue and saturation values (HSV). In order to widen the tolerance, a Gaussian blur is overlaid the frames, by doing so images are not as sharp but processing is much smoother.

B. Movement System

The movement system was developed in the Arduino™ Integrated Development Environment (IDE) using Arduino™ C as the primary language. This system is designed to react to readings relayed from the IMU to the Arduino™, then as outputs to the motors.

C. Sensors

Sensory input output (IO) is controlled by microcontrollers based on the Arduino™ UNO platform. Both analog and digital sensors are programmed in Arduino™ IDE using Arduino™ C. The analog sensors are read by interpreting voltage feedback and the digital sensors are programmed using Inter-Integrated Circuits (I^2C). I^2C based sensors benefit because they do not require individual voltages due to information being stored in memory addresses.

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