ORCA-XI: An Autonomous Underwater Vehicle

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Abstract

ORCA-XI is a fully autonomous underwater vehicle built to compete in the 2009 International AUV Competition. ORCA-XI is 48 inches long and has a mass of approximately 27.5 kilograms. The vehicle is equipped with the following sensors: a water pressure depth sensor, a magnetic compass, a color machine vision video camera, and an ADF for passive sonar. The vehicle has four maneuvering thrusters, two positioned horizontally on the sides and two positioned vertically near the bow and aft.

Just as the team was restarted this year primarily with new members, the vehicle itself underwent drastic modification and almost complete reconstruction. However, many elements from old designs remain: a modular structure; a single main hull, dual battery pack design; allowing for external, movable sensors; analogous – and in some cases identical – sensors to previous years; a customized, simple electronics stack and computer; and similar programming.

1. Introduction

ORCA-XI is designed in accordance with the guidelines of the 12th International Autonomous Underwater Vehicle (AUV) Competition, “Divin’ Dozen.” The competition will be held from July 28th to August 2nd, 2009 at the SPRWAR TRANSDEC facility in San Diego, CA.

The competition arena is a 320-foot long by 200-foot wide oval pond, and it is 16-foot deep everywhere except for a 60-foot radius, 38-foot deep semi-spherical depression located in the center. The competition will take place only in the 16-foot deep, flat-bottomed section of the arena.

Each vehicle has up to 15 minutes to complete the mission, which consists of several tasks situated throughout the arena. These tasks include: (1) passing through a validation gate, which must be completed first; (2) striking a 9-inch diameter red buoy, or “flare”; (3) navigating under “barbed wire” composed of two parallel PVC pipes; (4) choosing between dropping markers on a “bombing run” and deploying torpedoes through a “machine gun nest”; and (5) surfacing within a pinger-marked octagon in possession of a PVC-constructed “briefcase.” Segments of flat PVC sheeting on the pond floor constitute the path between these tasks.

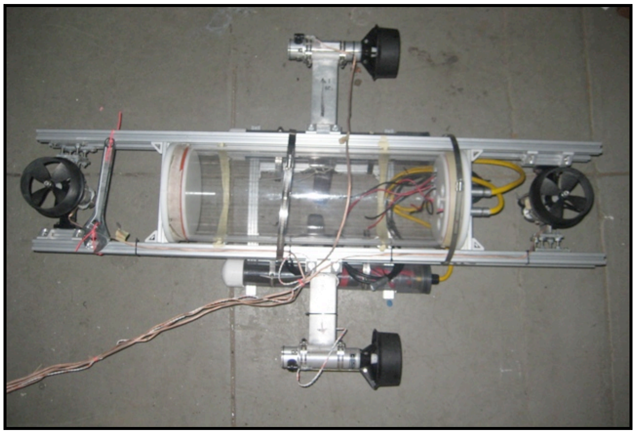

Figure 1: The ORCA-XI vehicle.

ORCA-XI was designed and constructed to complete components of this mission consistently and safely. The robot’s modular design increased the efficiency of the production process by allowing for rapid testing and modification. Both individual modules and the entire system were repeatedly tested to insure excellent functionality and safe operation.

2. Mission Strategy

In choosing which and how many tasks to pursue, a balance between attempting as many tasks as possible and devoting the necessary time to reliably completing those tasks must be found. For us, the final balance included the following tasks: the validation gate, the “flare,” and surfacing through the correct octagon. This section outlines the basic sequence of maneuvers the vehicle will use to complete these tasks, as directed by a pre-programmed state machine.

The figure on the following page illustrates the fundamental navigation strategy for the course, with a sequence of arrows representing the basic travel path. The color and line-style of each arrow corresponds to the primary sensor used to navigate each section of the mission.

Once activated, the vehicle will dive to 5 feet, which will remain its cruising depth until the conclusion of the mission. This depth allows the vehicle to contact the flare without risking interference with other equipment in the arena. The vehicle will then travel on a straight path from the loading platform to the validation gate using compass-guided dead reckoning. After passing though the gate, the vehicle will execute a short range, zigzag search pattern until the forward-facing camera locates the flare. This motion will also be guided by the compass. Next, the vehicle will use the forward-facing camera to home in on and eventually come in contact with the flare. To get to the octagon, it will detect pings and regularly correct its heading to face the acoustic beacon. Finally, the vehicle will center itself within the octagon and then surface. The sensors and their processes will be described in greater detail in Sections 4 and 5.

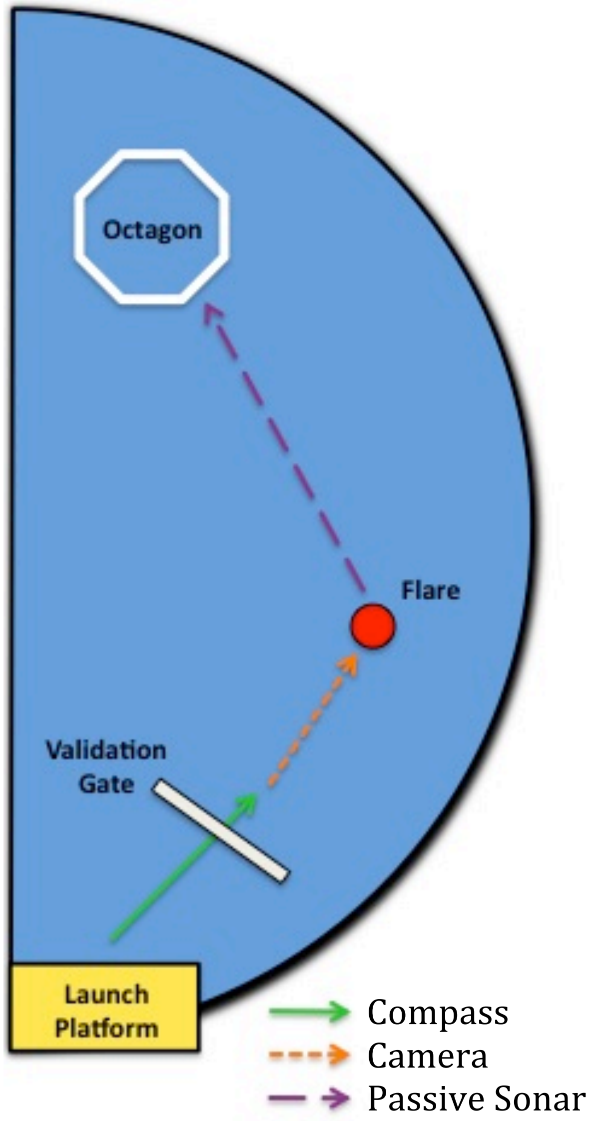

Figure 2: Mission strategy for the ORCA-XI vehicle.

3. Vehicle Design

Despite numerous mechanical, electrical, and programming redesigns from previous ORCA iterations, ORCA-XI adheres to the old design philosophy that emphasizes simplicity and modularity.

3.1. Mechanical Design

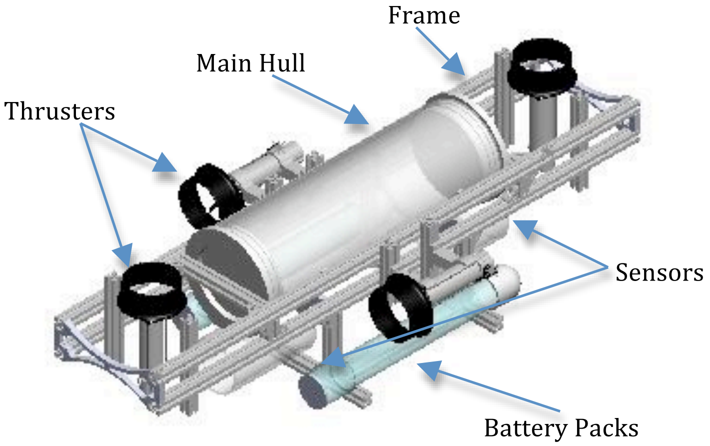

Figure 3: SolidWorks model of ORCA-XI.

ORCA-XI consists primarily of the following mechanical components: the frame; the main hull, a watertight housing for most of the electronics and internal sensors; outboard sensor packs; and battery packs. Although most of these components were constructed from scratch, they derive much of their form from the proven designs of previous ORCA models.

The frame both holds together all of the other parts and protects them from impact. It is principally constructed of 80/20 10-series T-slotted aluminum extrusions. This versatile strategy allows for easy modification in that few holes are drilled into the frame itself, so components can be added and moved without much hassle. All four thrusters are held to the frame with hydrodynamically shaped thruster mounts, each consisting of three welded aluminum pieces. Every other component is either mounted directly to the 80/20 aluminum or to a form-fitting, water-jetted piece of aluminum that is in turn attached to the 80/20 aluminum. The entire frame was designed to minimize mass while still reliably and safely bearing the expected loads.

The main hull encloses a waterproof compartment that houses the vehicle's electronics and computer. It is comprised of a 23-inch long, 8-inch diameter, ¼-inch thick acrylic pipe and two delrin end caps. The end caps are each sealed to the hull with two O-rings and redundant bolts for added protection. Each outboard electrical component connects to the hull via its exclusive receptacle in the aft end cap. Electrical connections through that end cap are made with hermetically sealed locking multi-pin Fischer Connectors, each rated to 80 meters deep.

The batteries are attached in two separate compartments located about 5 inches below the main hull. This placement has two distinct advantages: it permits rapid battery replacement and increases the vehicle's righting moment, making ORCA-XI passively stable in pitch and roll.

3.2. Thrusters & Thruster Drivers

ORCA-XI uses four maneuvering thrusters provided by Inuktun Services Limited. Two of the thrusters, which are mounted vertically near the bow and stern, control the vehicle's depth and pitch. The other two thrusters are mounted horizontally on the vehicle's sides, and they control yaw, forward motion, and backward motion. Each thruster draws 7 A at 24 V to produce a maximum of approximately 15 pounds of thrust.

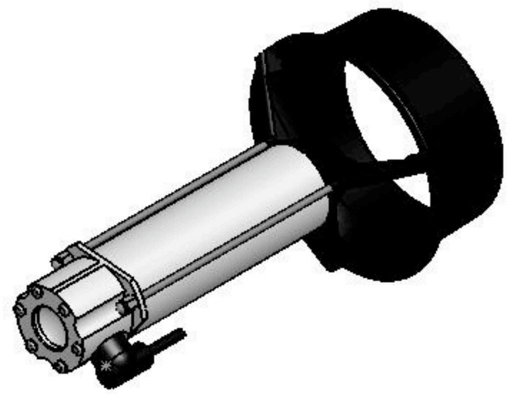

Figure 4: Inuktun thrusters used on ORCA-XI.

The driver circuit for each thruster is similar to those used in previous years, namely a modified version of the Open Source Motor Controller (OSMC, which can be found at http://www.robot-power.com/osmc_info/). This driver is a versatile and robust H-bridge amplifier that allows for operation over a large input voltage range and at high currents. The controller uses four power MOSFETS – each in parallel with one of the H-bridge's switched legs – and an HIP4081 driver chip as a gate drive for the MOSFETS. TVS and Zener diodes protect the components from potential motor transients.

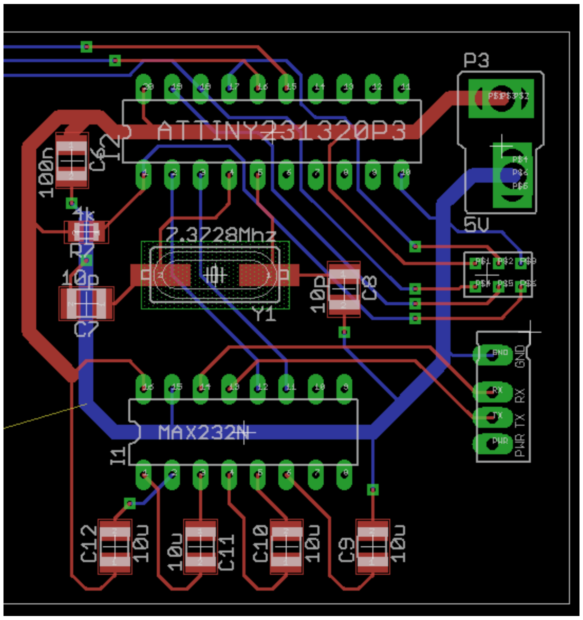

Figure 5: Motor controller circuit diagram.

The OSMC are controlled by AVR microcontrollers, programmed in C, which communicate with the computer through a DB9 serial connection.

3.3. Power Distribution & Monitoring

The vehicle is powered by two battery packs, each containing 21 Elite 4000 SC NiMH batteries in series with a total nominal voltage of 25.2 V and total capacity of 4.0 Ah. NiMH batteries provide the ideal balance of a higher energy density than lead acid batteries without the safety hazards of Li-Ion batteries. The port battery pack will power the thrusters and thruster drivers, whereas the starboard battery pack will power the electronics, computer, and sensors.

ORCA-XI is outfitted with its own power monitoring system in the form of a Battery Power Board (BPB). The BPB is equipped with fuses in case of battery/circuit failure, multiple capacitors to smooth out ripples, and an AVR microcontroller that reports voltage values to the computer through a serial interface. A waterproof magnetic kill switch can be used to power down the motors.

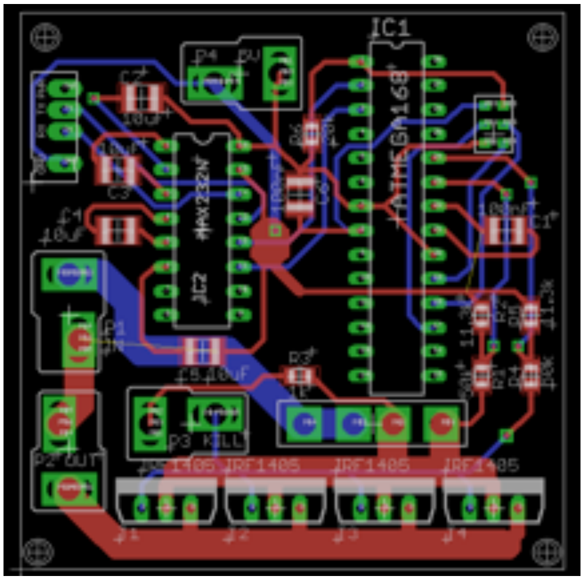

Figure 6: Battery Power Board circuit diagram.

3.4. Onboard Computer & Electronics

The majority of the electronics and the computer are housed in the main hull, mounted on close-fitting parallel plates. These aluminum plates are connected to each other to form the electronics stack, which can slide out of the hull for easy access. The AUV connects to an external computer via a standard Ethernet crossover cable.

ORCA-XI's custom-made computer, which was fabricated by VIA Technologies, Incorporated, runs all navigation and control code under Linux. This platform represents an inexpensive computing solution with adequate processing power and RAM to perform the required functions. Specifically, it is equipped with a 1.5 GHz processor, 1 GB of RAM, and an 80 GB hard drive. Additional advantages of this computer include its relatively small footprint, sufficient quantity of input and output ports, and stable and familiar programming environment.

4. Sensors

4.1. Navigational Sensors

ORCA-XI uses two navigational sensors: a depth sensor and a magnetic compass. A Honeywell-Sensotec TJE series analogue output pressure sensor measures the vehicle's depth. A PIC microcontroller converts the data to digital form and communicates to the computer though as serial interface.

A True North Revolution GS gyro-compass measures the vehicle's heading, roll angle, and pitch angle at 28 Hz. Inside the compass, a 3-axis precision solid-state magnetometer, two angular rate gyros, and a dual-axis electrolytic tilt sensor combine to produce accurate measurements. We also considered including an inertial measurement unit in addition to the compass, but we determined from previous years' experience and the nature of the tasks the vehicle would be attempting this year that measuring angular velocity and linear acceleration would be unnecessary.

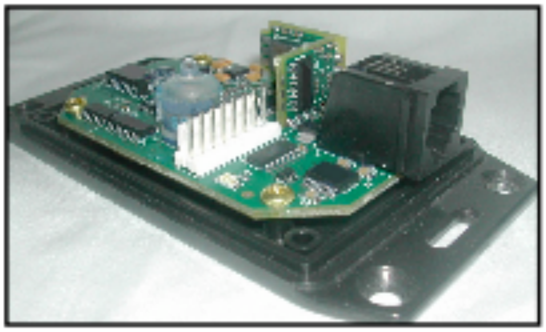

Figure 7: The vehicle's True North gyro-compass.

4.2. Imaging Sensor

ORCA-XI employs a forward-facing Prosilica EC750C camera for imaging processes. The camera is mounted in an external compartment to allow for on-site adjustment. It was chosen primarily for its flexibility: unlike with other cameras, custom exposure times and gains suited to the mission and environment can be programmed ahead of time. Machine vision algorithms running on the main computer analyze the images and provide real-time targeting information to higher-level control programs.

Figure 8: The Prosilica EC750C machine vision camera.

4.3. Passive Sonar

ORCA-IX also includes a custom-made passive sonar system to determine a bearing to the acoustic pinger. The passive sonar unit is mounted to the frame with a neoprene cover to ensure acoustic decoupling from the frame. This acoustic system detects pings using four hydrophones mounted in a pyramidal array. The hydrophones are mounted to the bottom of a waterproof enclosure, which also contains the necessary processing electronics. The system communicates with the vehicle computer through an RS-232 serial port. For each ping received, the unit transmits the bearing and elevation angle to the transmitter in degrees, the frequency of the ping, and the time in milliseconds since the last ping. The system computes the angle to the pinger by measuring the delay between the times the ping signal is received at each of the hydrophones. Each hydrophone signal is digitized and sampled by a DSP microcomputer. The DSP applies bandpass filters and thresholds the signal from one of the hydrophones to find the starting time of each ping. The system captures the next 2 ms of signal from each hydrophone for further processing.

5. Software

The computer will run predominantly Python programming. ORCA-XI will have two levels of control: the Low Level Controller (LLC) and High Level Controller (HLC). The LLC manages all of the real time tasks, namely: depth control, altitude control, heading control, velocity control, and pitch control. Upon interacting with new sensor input, it will use a PID (proportional-integral-derivative) algorithm to minimize error from desired set points, using one or more of a library of low-level commands. Similarly, the HLC translates sensor data into a command.

Unlike the LLC, however, the HLC implements mission-level control. For each state (different for each of the tasks the vehicle is performing), the HLC uses pre-programmed algorithms to establish new set points. In other words, the HLC determines the path, whereas the LLC ensures that the robot remains on that path.

6. Conclusions

The new ORCA-XI vehicle follows the suit of previous ORCA vehicles with its simplicity, modularity, and reliability. This vehicle will not only be a fully functioning entry this year, but will also serve as a platform for more complex designs in future years. After building and refining this AUV and executing much testing, we look forward to participating in the 2009 International AUV competition.