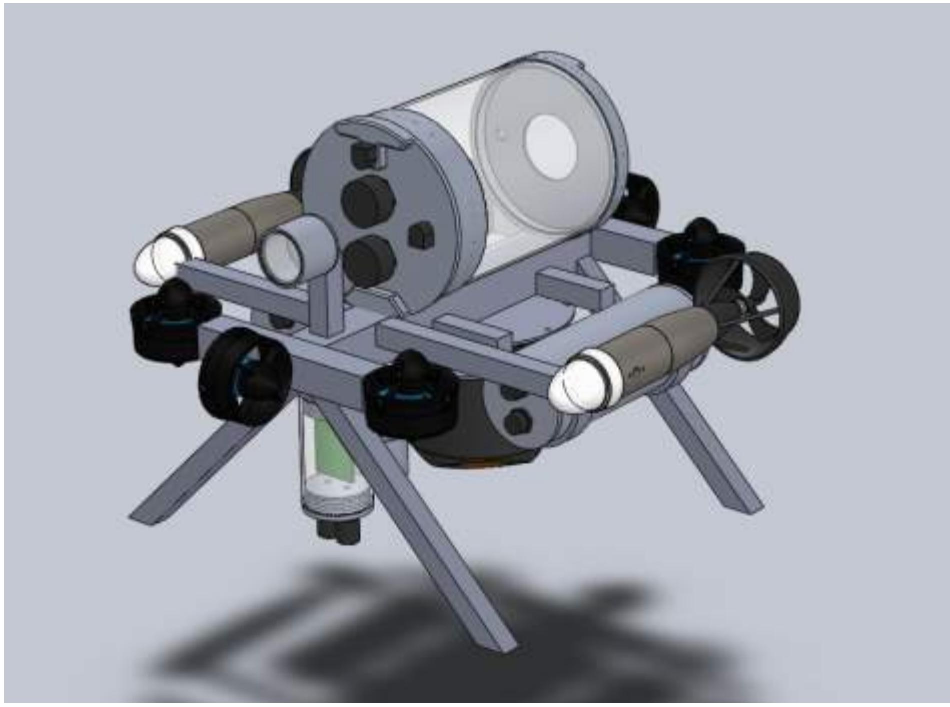
University of Colorado Boulder RoboSub Team: WaterBuffalo II



Abstract

The University of Colorado Boulder RoboSub Team is proud to unveil its all new 2015 competition vehicle, WaterBuffalo II. The team is made up of approximately 18 undergraduate students from the colleges of arts and sciences, engineering, and business. Team members span first years to fifth-year seniors. The team comes together in a dedicated lab where meetings are held, and vehicle assembly takes place. WaterBuffalo II is built from the ground up, using the valuable lessons from the team's first time in the competition last year. The vehicle is comprised of six custom waterproof electronics enclosures and propelled by eight brushless motors. With two cameras, a Sparton AHRS-8, a Phidget Spatial IMU, a GeoTech Pressure-Transducer, and a new to the team Teledyne Doppler Velocity Logger WaterBuffalo II is more capable than ever. The team hopes to see you in San Diego while we stretch the abilities of our vehicle and ourselves at RoboSub 2015.

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I. Mechanical

The mechanical structure of WaterBuffalo II was built from the ground up. After having several issues due to leaking with a Pelican case last year, the team decided to create all custom electronics enclosures this year. Key concepts for this year's mechanical design were purpose-built enclosures, low-cost materials, and reduced machining time. Since the team intends to continue to build a new vehicle every year, this year was a great learning experience, such as figuring out what was theoretically machinable, and what is machinable with the machines and tools at our disposal, and to make sure to get orders in as early as possible, because shipping estimates are truly just estimates, and much of the team's efforts earlier in the year went into the mechanical design.

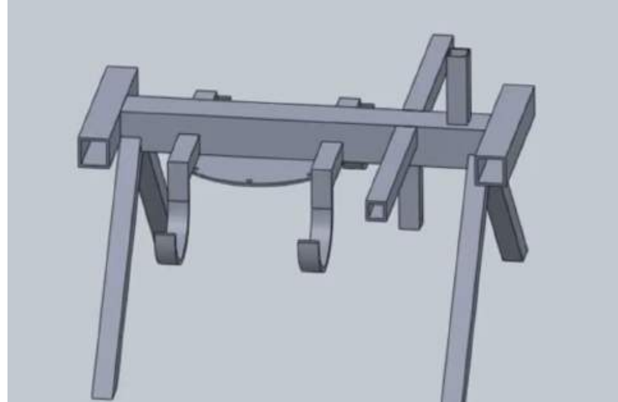
A) Propulsion

WaterBuffalo II uses eight motors to have six degrees of freedom control. There are two VideoRay Pro 4 Thrusters mounted on the left and right sides of the vehicle. These thrusters control the vehicle's fore-aft movement and heading. The VideoRay Thrusters were selected because of their high power output, which allows the vehicle to traverse long distances rapidly. WaterBuffalo II also uses six Blue Robotics T100 Thrusters. Four of the motors are used to control the depth, pitch, and roll of the vehicle. They are mounted on the four corners of the frame. The other two T100 thrusters are located at the front and rear of the vehicle that enable strafing movements. The mounts for T100 thrusters are 3D printed in white ABS. The mounts are specifically designed to interface with the square tubular aluminum of the frame. 3D printing was used over machined aluminum because the specialized shape of the motor mounts would require a lot of machine time, and the tradeoff of time over strength was worth it. All eight motors are on a single plane through the middle of the vehicle. This design greatly simplified our control system. The team originally intended to use Blue Robotics T200 thrusters, however due to Blue Robotics' development delays the T200 would not be released until just weeks before the competition. This delay put the team's mechanical and software team's development greatly behind.

Video Ray Pro 4 Left
Bluer Robotics T100 Right

B) Frame

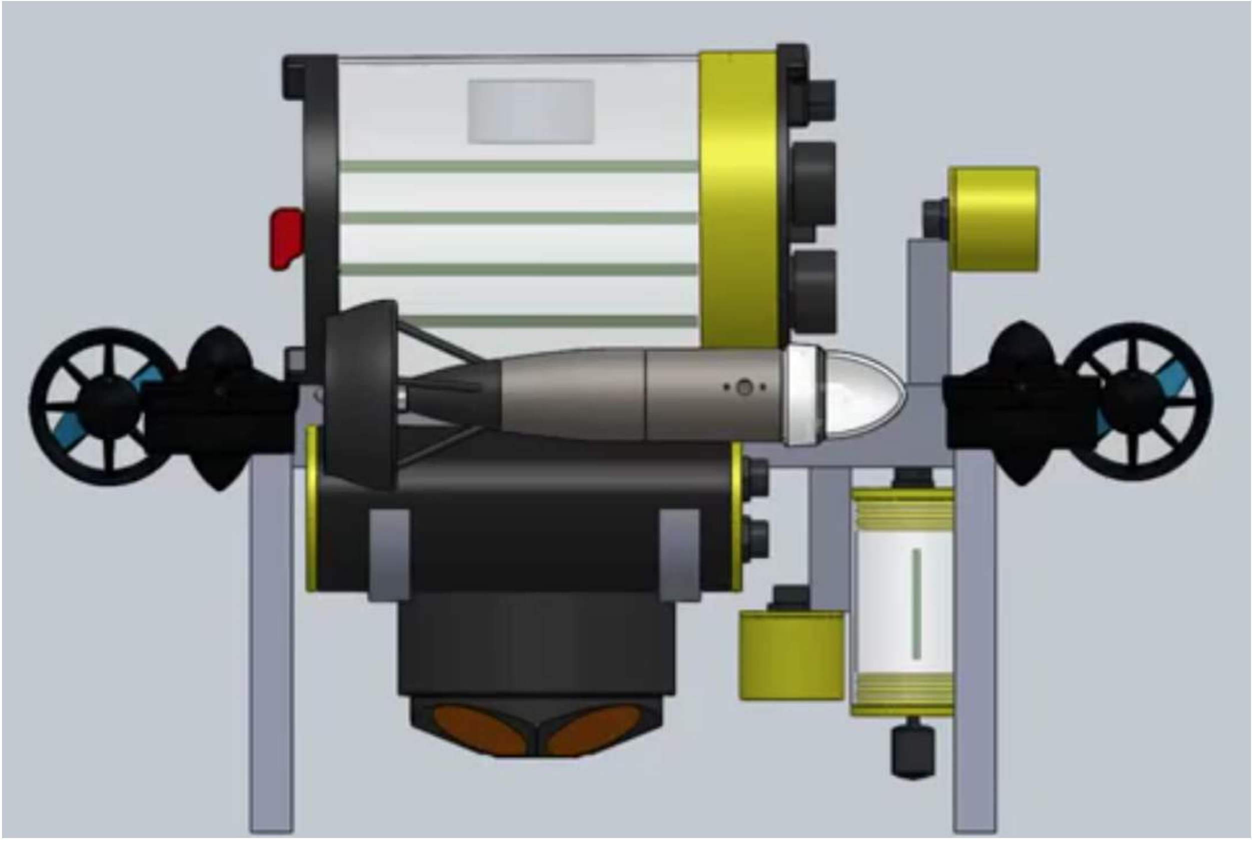
The frame of WaterBuffalo II is designed with simplicity in mind to make it less susceptible to failure The frame is built around a single backbone made of 2" square aluminum tubing. Many "limbs" of 1" square aluminum rods are welded onto the backbone to support motors and electronic enclosures. This design minimized machining time to less than one hour on a mill, kept the cost of materials under 30 US dollars, and weighs less than 5 lbs.


CAD render of frame

C) Main Hull

Water Buffalo II has a number of electronic enclosures. The largest of these enclosures is the main hull at 8.5 inches in diameter. Our main hull houses the majority of the vehicle's electronics, such as the main computer and inertial measurement units. The main hull breaks down into four components: the front endcap, electronics rack, the back endcap, and acrylic tube. To minimize the chance of leaking, the acrylic tube is epoxied into the back endcap. This process reduces the number of possible places for a leak to occur, while also decreasing weight, as less material is required to support additional o-ring seals. The rear endcap has a 3-inch diameter window made out of acrylic, which enables the diver operating the sub to read error messages from the vehicle. During testing, this window also allows programmers on the side of the pool to quickly and clearly communicate instructions to the person in the water. The vehicle's kill switch is also mounted on the rear endcap of the sub. It is an oil-tight washdown switch sold by McMaster-Carr with a red safety cover similar to the one used on WaterBuffalo I, our 2014 vehicle. The front endcap has four SeaConn connectors, two "Pie" connectors which each have six seven pin connectors built in, and two eight pin low profile connectors. The Pie connectors connect to the eight motors, our hydrophone enclosure, the batteries, and bench power. One eight-pin connector connects to the vehicles two cameras. The other eight-pin connector allows an ethernet cable to be attached to the vehicle for testing or programing out of water without opening the electronics enclosure. The electronics rack is mounted off of the main end cap, thus eliminating the need for difficult rack connectors in the vehicle by allowing the electronics to be attached directly to the SeaConn connectors. The electronics rack ensures easy access to the electronics in the main enclosure. In case of any maintenance issues components can be easily accessed just by removing the acrylic tube and rear endcap. The front endcap seals onto the rear tube assembly through a double o-ring bore seal between the front endcap and an aluminum collar that is epoxied onto the acrylic tube.


Seaconn Connectors
Front "Pie" 7x6 connector



CAD render of the Full Vehicle showing all the custom enclosures

D) Ancillary Enclosures

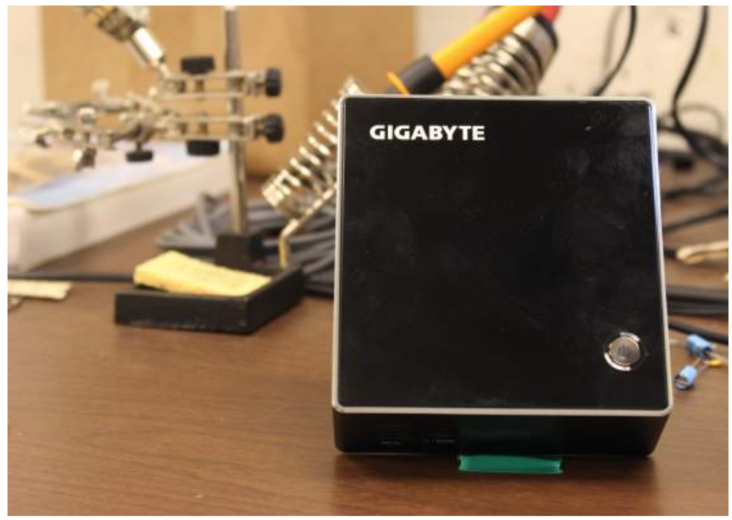
In addition to the main hull there are five ancillary electronics enclosures on WaterBuffalo II. They are two battery enclosures, two camera enclosures, and the hydrophone enclosure. The battery enclosures house the vehicles batteries. These are kept out of the main electronics enclosure as they will need to be changed frequently. Keeping them in a separate enclosure helps maintain seal integrity on the main enclosure. One goal of the vehicles design was to never have to unseal an enclosure. So, batteries each have their own enclosure, and can be charged without the need to break the seal. Due to competition rules the batteries will be charged in the open air while at the competition site. The camera's are each stored in their own enclosure, which gave us more positioning options when designing the sub. The enclosures are made from a single piece of aluminum with a clear acrylic disk epoxied on in front of the camera. This design reduces the mechanical complexity and likelihood of leaking at the cost of being unable to remove the cameras from the enclosure after sealing. Both the battery and camera enclosures use bulkhead penetrators sold by Blue Robotics to enable electrical signals to lead into the connectors on the main hull. The fifth ancillary enclosure on WaterBuffalo II is the hydrophone enclosure. The hydrophone processing board is kept out of the main computer and in a 4-inch diameter aluminum tube with aluminum endcaps and double o-ring seals. The enclosure acts as shielding from electromagnetic interference, which could adversely affect the sensitive electronics used in our hydrophone array. The hydrophone signal exits the enclosure through a three pin SeaConn Connector. Sealing surfaces on the ancillary enclosures and throughout WaterBuffalo II are all cylinder bore seals. This design simplified the machining process and allows for more consistent sealing.

II. Electronics

A key design concern for WaterBuffalo II was using as little custom electronics as possible. Our teams size and budget this year made the use of custom printed circuit boards inadvisable. We were successful in building a working electronic system, capable of completing our goal tasks this year, with entirely off the shelf electronics. This saved production time and costs.

A) Main Computer

The main computer of WaterBuffalo II is a Gigabyte Brix GB-BXi5H-4200 with 16 gigabytes of RAM and a 64GB solid state hard drive. The Brix was selected for its combination of high power, with a 2.6 GHz processor, and small form factor, being 4.5 in. on its largest dimension. The quad-core processor gives the team enough power to conduct vision processing, while simultaneously running the vehicle's control system.



Main Computer Gigabyte Brix GB-BXi5H-4200

C. Power

Pololu Mini Maestro

WaterBuffalo II is powered by two 24-volt 5 amp-hour Nickel Metal Hydride battery packs. These two battery packs are ran in parallel, giving a typical run time of one hour depending on motor power levels. Power from the batteries is split into two branches, one going to power the motors, and one to the main computer and sensors. The Motor power branch uses electronic speed controllers to send power to the brushless motors. 30 amp rated ESCs power the two VideoRay Pro 4 Thrusters and six Blue Robotics T100s. The ESCs are controlled by a Pololu Mini Maestro which interfaces with the main computer by USB. The main computer branch sends power into a Mini Box USB programmable DC-DC converter. This can take input voltages ranging from 6 to 36 volts and has a user selectable output between 5 and 25 volts at up to 10 amps. The versatility of this premade solution combined with the ease of use of the USB interface make it the perfect choice for our vehicle. After the battery voltage was reduced to the 19 volts needed for our main computer and pressure transducer, it is routed through a Y-Power Hot Swap Load Sharing Controller. The Y-Power Controller allows the team to easily implement a bench power solution. By controlling the power delivered from each channel we can safely plug the vehicle into a 19 volt supply on the bench, and unplug the batteries and vice versa without power loss. Having a bench power solution allows WaterBuffalo II's main computer to stay on without using batteries to ease programing and record data after a run. The power system's complexity is kept low because the IMU's and other communication peripherals interface and are powered by USB.

24volt 5AmpHour NiMH Batteries

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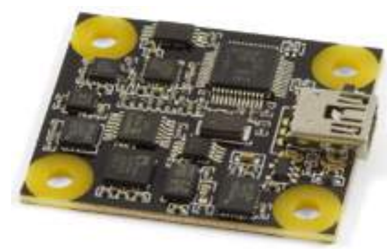
D) Sensors



Phidget IMU

Sparton AHRS-8

WaterBuffalo II uses a number of sensors to interpret the world around it and its own position. A crucial sensor to the team's long term goals of achieving high performance in the competition is the team's new Doppler Velocity Logger or DVL. The DVL is a 2001 RDI/Teledyne Workhorse DVL purchased used from Cornell University Autonomous Underwater Vehicle Team. This sensor measures the vehicles velocity with a high degree of precision by bouncing acoustic signals off the bottom of the pool and measuring the doppler shift of the returning signal. The vehicle integrates the velocity to determine its position. The DVL is an essential tool for success in the RoboSub competition. For 2 of last 3 years every team in finals had one and the winner for the last at least the last 6 years has had one. To determine the orientation of WaterBuffalo II there are two inertial measurement units or IMUs, one Phidget High Precision unit and a Sparton AHRS-8, each with 3 axis gyroscopes, magnetometers, and accelerometers. The two IMUs are used to determine the 3 dimensional orientation of the vehicle. To determine the depth of the vehicle it is equipped with a GeoTech 0-35PSI pressure transducer, this is a highly accurate sensor capable of determining the depth of the vehicle to within inches. A pair of Logitech C270 webcams allow competition tasks to be seen in front and below the vehicle.

Teledyne RD Instruments Doppler Velocity Logger

E) Digital Signal Processing and Hydrophones

To accomplish the high-points recovery tasks, WaterBuffalo II is equipped with a pair of Aquarian Audio H1c hydrophones. The hydrophones are a low-cost option, but are capable of locating the pinger used in competition. The hydrophone signal is passed into am 8th-order Chebyshev Anti-Aliasing filter and amplified before being passed into an off the shelf microcontroller. This microcontroller is an Arduino DUE which has an 84MHz clock and a 16:1 multiplexed 12-bit, 1 MSPS ADC, which is well above the Nyquist frequency, allowing for oversampling, which in turn enables higher resolution. With our sampling techniques we are able to characterize sound signals as weak as 178uPa.

Aquarian Audio H1c Hydrophone

III. Software

The software team had two distinct focusses. The first focus was achieving an accurate mission control system to guide WaterBuffalo II through the various tasks of the competition. The secondary focus was creating efficient digital signal processing and sensor fusion. Due to the small size of the summer software team and numerous hardware delays, the team focused on optimizing open source solutions where possible.

A. Operating System and Languages

In order to optimize the central computer, we chose to use a Linux-based operating system. This gave us better control over assigning tasks real time processes. Also due to our team's smaller size, we chose to use Python 2.7 as the main language in order to make the most efficient use of our development time.

B. Controls and Mission Planner

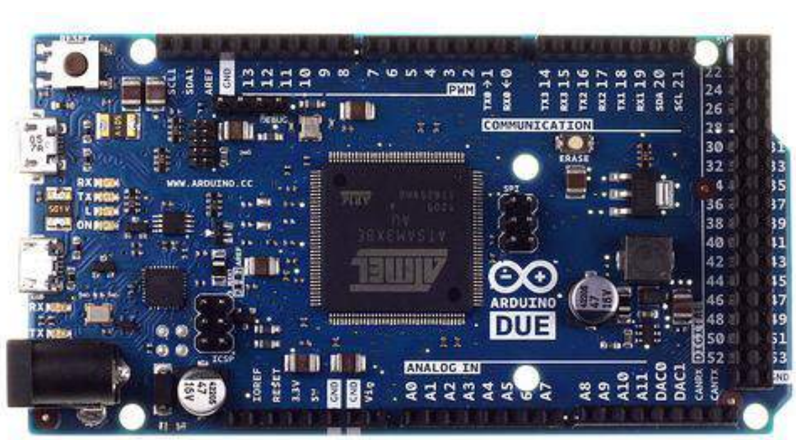
WaterBuffalo's mission control system or MCS was built completely from the ground up. The MCS monitors the vehicles status and controls what tasks are being worked on at any given time. By monitoring the run time used, stage of the task being completed, time in stage, and position of the vehicle, the MCS can determine the probability that a task is being completed correctly. From that information it is able to cancel or restart a task. Also based on the run time remaining, the MCS will reprioritize tasks. For instance if there is a lot of time remaining, the MCS will attempt the Check the Flux Capacitor (buoy), Time Portal, and Surface in the Octagon. If only limited time remains, the MCS will determine which tasks it is most likely to succeed in to achieve the most points, based on the time remaining and the vehicles location. The vehicles control system is a branch of the MCS, and it is based on a standard Proportional Integral Derivative or PID control algorithm. This responds to the current status of the vehicle, as interpreted by the IMUs, pressure sensor, and DVL, and adjusts the motor speeds with respect to a portion of the error, the sum of previous errors, and change in error. The MCS also receives the configuration file for each run, and sets the appropriate values for desired colors in the Check the Flux Capacitor (buoy) task, as well as the frequency for the recovery task.

C. Computer Vision

Open CV is the foundation to computer vision on WaterBuffalo II. The open sourced Open CV greatly accelerated the development of computer vision filters. WaterBuffalo II is attempting to use computer vision in 3 places, Check the Flux Capacitor (buoy), Time Portal, and surfacing in the octagon. For both the Check the Flux Capacitor (buoy) and surfacing in the octagon the vehicle uses blob detection to find the largest source of a single color, and then center the source of color in the frame. The vehicle then surfaces or rams the buoy, depending on the task. For the Time Portal task the vehicle determines the center of all neon yellow in the image and navigates through it. To account for changing lighting conditions color ranges for each color can be adjusted in the configuration file sent to the MCS.

D. Digital Signals Processing

WaterBuffalo II uses a Phase Difference on Arrival to determine the angle to the pinger from the hydrophones. The acoustic signal from the hydrophones is fed into the Arduino through the onboard ADC; it is then processed on the board through decimation, discretization, and finally filtering, before sending the heading to the pinger of the main computer. The on board processing consists of digitally filtering out all frequencies except the competition frequency of the day. Then the voltage of the ping at each phone is compared to determine a phase difference, which is used to determine the heading. This heading is then sent to the main computer using a Universal Asynchronous Receiver Transmitter (UART) serial communication protocol.



Arduino DUE

IV. Special Thanks

The University of Colorado Boulder would like to thank the following people and groups for their assistance with the competition this year.

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