The Underwater Robotics Team at The Ohio State University *Riptide AUV*

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***Abstract*—The Underwater Robotics Team (UWRT) is a student led and student driven engineering project team at The Ohio State University. Currently consisting of twenty four active members, the team has been involved in the design of both remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV), the latter being its current focus. Autonomous underwater vehicles are underwater vessels often used in the exploration of the oceans. This includes surveying sea floors for the oil and gas sector, mine detection for military applications, and research applications such as recording carbon dioxide levels and microscopic life activity. The Underwater Robotics Team is competing in the 2017 AUVSI Robosub Competition in San Diego California. To compete, the team has updated the previous years AUV, *Riptide*, to improve on last years performance.**

Notable improvements to *Riptide* consist of: chassis redesign, electrical system redesign, and the addition of a control panel to the AUV. The chassis was rebuilt to allow for better maintenance and proper thruster operation. *Riptide's* electrical system was improved upon to address fundamental design flaws and increase system robustness. The control panel consists of multiple switches to start mission runs, reset the computer, and reset the electrical system. With these improvements, *Riptide* should be able to complete competition tasks efficiently.

I. INTRODUCTION

LESSONS learned for future team members.
The Underwater Robotics Team at The Ohio State University (OSU) began with a group of engineers who had previously participated in the MATE International ROV competition (1) in 2010. They decided to build a team at OSU in order to gain experience with submersible robotics. After five years of participation in MATE, the team chose to participate in the Robosub competition. This competition offered more technical challenges for the team while adding talent and skills.

With growth, the team built its presence in the community. Throughout this year, the team had participated in multiple community outreach events to introduce community members to robotics and engineering. These events included demonstrations for the Boy Scouts of America, COSI Academy science museum (2), and the Ohio State Fair.

Last year was the team's first time competing in AUVSIs RoboSub competition. The team encountered engineering challenges that pushed their knowledge and capabilities. By continuing to compete, the team strives to gain as much experience as possible to improve its design systems while learning from past mistakes.

TABLE I
PHYSICAL CHARACTERISTICS

Property	Dimension
Length	35.50 in
Width	18.75 in
Height	15.25 in
Dry Weight	67 lbf
Tested Depth	17 ft

II. DESIGN STRATEGY

The vehicle used this year was an improved and modified version of *Riptide* from last years competition. *Riptide* was designed using the knowledge from previous MATE competitions. The design aimed to be over-actuated, modular, and stable . After working with the vehicle for a year, areas for improvement were identified. Primarily, the chassis, electronics, and the emergency stop switch.

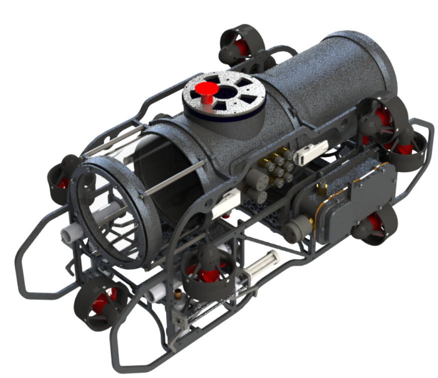

Fig. 1. CAD rendering of *Riptide*.

Riptide's original design strategy involved two main ideas; a redundant and over-actuated systems. An example of redundancy would be having 2 battery housings providing hot swappable functionality and power source independence. This strategy allows for the robot to function if one of the units experienced a failure. The other principal design concept was over-actuation, which was exemplified by *Riptide*'s thruster array. The ten thrusters offered a platform that could be controlled easily by software. The team had implemented thrust vectoring in previous years, but it was decided that an over-actuated system of fixed thrusters would offer an improved chance of success. These two design fundamentals paired with the modular approach provided a good starting point for this years competition.

This competition season, the design strategy shifted from looking to build and design a vehicle from scratch, to improving *Riptide*. Already, the robot was built with redundancy, modularity and over-actuation in mind. So the team could hone in the details and improve from what was learned at last years competition. The main focus was improving the ability to access the robot and maintain it.

III. Electrical System Design

The electronics from last years competition were completely redesigned. Previously, the backplane was circular and mounted vertically. There were enough drawbacks in this system that justified a completely new design. The three main improvements included an increase in experience, logical board spacing, and backplane mounting. Last years electrical system was the first iteration of custom circuit boards, and had numerous small mistakes. These mistakes included choosing microcontrollers that had no pre-written libraries, incorrect connections, and board layout issues. With the gained experience this year, team members were able to create more pragmatic boards with components that suited the robots power requirements. When plugged in, the previous Electronic Speed Controller (ESC) boards were stacked one on top of the other, making it impossible to intuitively route the wires. This created difficulties to troubleshoot and replace the thruster controllers. With the new design, the boards are spaced with ample room on either side where the ESC wires will line up with the correct board on each side. Any member of the team could assemble the electronics system. Finally, the mounting system in the previous system was bulky and inefficient. It took up a large portion of the inside housing, and did not allow for easy mounting of the motherboard. This new design allows for the electronics rack to slide out and provides access to the motherboard without taking apart the entire electronics system.

A. Backplane

This year, the backplane has two fundamental changes. First, the raw power lines do not run through the backplane. This allows the backplane to have more space for other traces, reduces noise from large currents, and increases safety for team members. Next, the backplane has a new edge connector. Instead of only 14 pins, the new edge connector has 56 pins, allowing the electronics team to increase the amount of interconnections. This improvement was the greatest advantage, since it allowed the team to easily replace boards and use spare pins to increase system robustness.

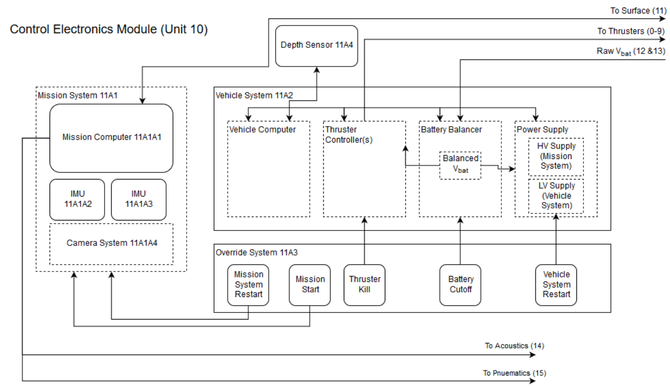

Fig. 2. Block Diagram of *Riptide's* custom electrical system.

B. Co-Processing Board

A major addition to the electrical system is a co-processing board. The main function of this board is to handle the vehicles subsystems. The mission computer talks to the co-processor and the co-processor completes specific tasks that the mission computer specifies. For safety features, the co-processor also takes in all of the switch signals so that each system knows the status of the kill switch and mission start switch. The processor is an STM32F405. By choosing this processor, there are multiple input and output pins that gave the team room to add additional features. Some key features that were added to the board were: IMU, barometer, SD-card slot, and a LCD debugging screen. The IMU and barometer were additional sensors that gather as much information about the robot as possible. The SD-card slot was used to dump error logs for when the robot fails, and the LCD screen displays error messages, temperature warnings, and operating parameters for the switches.

C. Power Supply

The team also redesigned the power supply system for the robot. Originally, powering on the robot would cause spikes in the power and resulted in the team blowing fuses and burning up relays. The new power supply was designed to be stress tolerant[1] and consists of two circuit boards. The first board takes raw battery voltage ranging from 22.5V to 18V from both batteries and balances the voltage. The second circuit board takes the balanced working voltage and converts it to 12V, 5V, and 3.3V. In the vehicle, the mission computer and acoustics system takes in 12V, while the co-processor runs on 3.3V, and 5V runs the thruster controllers and the sensors that monitor the electrical system. One of the main issues with the teams previous design was power spikes when attaching the batteries. To address this, the team built in timing circuits so that the sensors and data controllers will power on before the mission computer and thrusters. Furthermore, the switch system has a power control switch that will allow the converters to turn on and power the entire vehicle.

IV. Mechanical System Design

A. Chassis

A new chassis was created using the teams experience from previous years to alleviate downsides. *Riptide's* original chassis caused the aft heave thrusters efficiency to decrease. To resolve this, the heave thrusters on both sides were placed below the battery housings. See Figure 2.

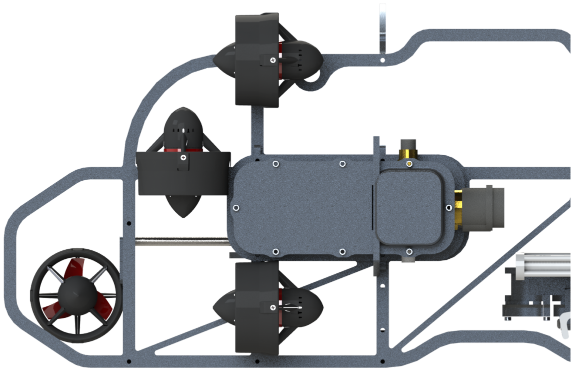

Fig. 3. Close up of the updated thrust placement on *Riptide*'s chassis.

Next, the main housing was flipped upside down. This allows pressure sensor to face downward which means the pressure sensor to never above the surface when the AUV is in operation. Two cross bars with curvatures equal to the main housings radius were designed to connect the main housing and the chassis on the top and lift the housing in place. The mounting around the forward and aft sections of the main housing was expanded to facilitate easier removal of the housing.

The battery housings were placed on an independent frame extended out of the chassis. This allowed for more room to attach the power wires.. Rubber latches were added to secure the battery housings for easier access, which replaced the old metal latches.

B. Kill Switch

Since the chassis was redesigned and the main housing was rotated, the kill switch is now placed on the top of the robot. The main function of the kill switch is to disable power to the thrusters in an emergency. A major difficulty for this switching method is its ability to operate underwater. To combat this, the team opted to use reed magnetic sensors so that the switches could be activated based on the proximity of a magnet as opposed to having actuators penetrate the main housing. When the switch is activated, the magnet is removed from the main housing, the electrical system triggers solid-state relays to cut power to the thrusters. In addition to shutting down the power to the thrusters, the co-processor sends a zero thrust value to the controllers. In case the relays fail, the thrusters receive no power signal.

Additional switches were built into the design to interface with the robot. A computer reset switch, mission start, and battery power switches were added. From last year, the team learned that being able to reset the battery power and mission computer aids in the debugging process.

For the mechanical design, there are two plates stacked on top of each other. The bottom plate holds the magnetic sensors and seals the main housing while the top plate is magnetic stainless steel and holds the 3D-printed actuators.

C. Internal Electronics Mounting

In designing the new electronics assembly, the team worked to improve upon the deficiencies of the old design. The main issue was the inaccessibility of the electrics once inside the robot. This problem was amplified when debugging the electronics. The backplane of the robot would have to be completely removed for any access, and the entire electronics mount had to be disassembled completely if the motherboard needed to be reached. See Figure 3. The new designed aimed to facilitate ease of access while securely anchoring the internals of *Riptide*.

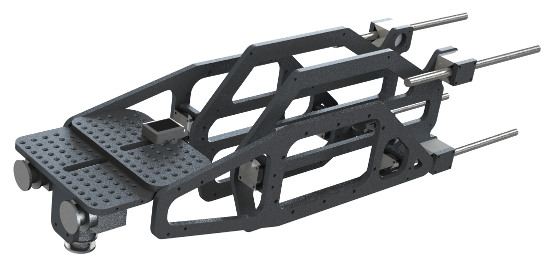

Fig. 4. CAD rendering of *Riptide's* previous electrical mounting system.

The current design has three main focuses: rigidity of cameras and inertial measurement unit (IMU), ease of access to the interior electronics, and maximizing the space inside the robot. *Riptide* performs intricate maneuvers through three dimensions, so its was imperative that neither the motherboard or cameras moved in operation. Two pins were inserted into the rod that the motherboard rests on to ensure that the cameras stay locked. Notches were cut in the center mount to fit the motherboard and keep it from rotating within the housing. To increase the ease of access to the motherboard, the mount slides out of the main housing. With the original design, many unnecessary frame components were used to hold the motherboard. The new design replaces these with a center mounting piece the motherboard affixes to, made to allow for maximal space for wire routing. See Figure 4.

Along with the redesign of the motherboard mount, the custom electronics mount needed to be updated. Again from last years experience at AUVSI Robosub, the team faced challenges working on the electronics while they were installed in the robot. The original *Riptide* design had each circuit board supported only by an edge connector with no locking

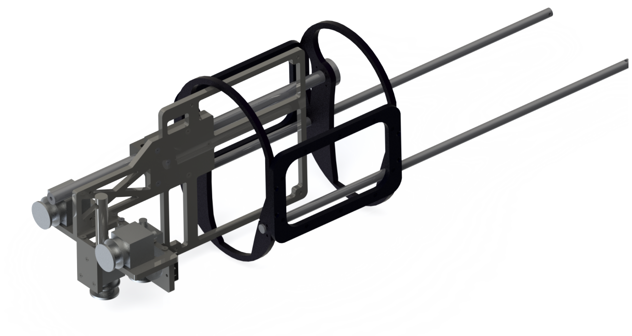

Fig. 5. CAD rendering of *Riptide's* updated electrical mounting system

mechanism. This problem was remedied with the backplane designed as a rectangle over the circular design used last year. This allowed for the team to standardize the board size and increase the stability of each board. Using card guides and the upper supports to mount card latches within a sliding frame, all circuitry is secured on a mission but can slide out for maintenance on the surface. By redesigning the mounting system, the team could limit each boards movement and increase stability while providing much better access to internal systems.

Fig. 6. Close-up of a CAD rending of motherboard mounting system, with cameras in place.

D. Auxiliary Housings

1) Batteries: There are two battery housings placed on the port and starboard sides of the robot. These housings offer protection to the batteries and allow for easy removal of the batteries. The battery housings are machined from 6061 aluminum to act as a heat sink for the batteries during testing and the run. Separate battery compartments increase safety. If something were to go wrong with the batteries they would not damage anyone or any electronics. Additionally, these housings have a pressure release valve in case the batteries swell.

2) Acoustics: An acoustics housing was built to house the hydrophones and the acoustics processing system. The system was put into an external housing due to its sensitivity and noise isolation. The three hydrophones penetrate the housing and allow for subsequent designs of the robot to move the hydrophones to the best location on the chassis

3) Actuators: The thrusters selected are blue robotics T200. These thrusters are relatively small and offer adequate thrust. There are ten thrusters on the vehicle for an over- actuated system. Four thrusters are placed in the corners of the vehicle vertically allowing for an increase and decrease in depth and a way to stabilize the vehicle. Four thrusters are placed horizontally allowing for the robot to move forward and backwards. Finally, there are two sway thrusters that allow the robot to translate left and right as well as to rotate around the vertical axis.

Last year, the system created was never properly tested. This caused the design switch from a pneumatic system to localized external waterproof solenoids. These wires were routed directly to the processing board which allowed a simplification to the system, increasing reliability.

V. Software System Design

A. ROS

Robot Operating System (ROS) is a robotic software platform that is developed and used at numerous research institutions and industry. ROS excels in its modularity and offers a variety of libraries and tools, which allow the team to collaboratively work on developing software. With its modularity, the team can select pre-existing packages or implement its own packages to be used in the software. As pre-existing packages were developed by industry experts, the team learned from that work and gave back to ROS community by providing feedback. As development time and resources were limited, the team took advantage of ROS in order to develop software that could complete tasks in the International RoboSub Competition.

B. State Machine and Autonomy

The State Machine was the high-level, decision-making system the computer relied on to control the AUVs behavior. The state machine, a ROS Python library called SMACH (3), was used for its versatility in creating a hierarchy of simple to complex state machines, each composed of states that allowed for complete control over every AUV action. For instance, a concurrent state machine was utilized because it allows for simultaneous operation of the two most crucial state machines safety and mission control, each composed of appropriate states or other state machines. The safety state machine monitored the AUVs status of primary electrical components and the mission state machine controlled how the AUV completes course tasks. Furthermore, a configuration file contained a possible order for specific tasks to complete could be edited to make quick changes to the vehicles operation about the course.

C. Computer Vision

Critical aspects of the vehicles mission depended on computer vision, including navigation, estimation, and task serving. For this, the team utilized the OpenCV computer vision library. The library contained thousands of reliable CV algorithms and data structures that greatly simplify the task of image processing. Typical tasks for this library included object detection, classification, and tracking.

In addition to the OpenCV library, a number of openly available ROS packages were utilized which enabled monocular and stereo odometry, depth estimation, and point cloud generation. While the team had experimented with these packages, they have not yet been fully integrated with the current software. In the future, these packages could be used in tandem in order to obtain reliable velocity information in lieu of a DVL or other such

D. Controls

The vehicle control was handled in three ROS nodes. First, the acceleration reported by the IMU was fed into a PID acceleration controller node. This controller determined the error between the desired acceleration and the actual acceleration. This error was published to the thruster controller node, which utilizes Googles Ceres (4), which was a non-linear least squares solver library. This controller solved for the thrust and each of the ten thrusters should output, in order to achieve the desired acceleration. Finally, this result was published to the thrust calibration node, responsible for converting the desired thrust to a PWM signal to be sent to the Thruster Control Board via serial communication.

TABLE II
CONTROL CHARACTERISTICS

Device	**Model**	**Count**
Thrusters	BlueRobotics T200	10
Inertial Sensors	Microstrain 3DM-GX4-25	2
Cameras	PointGrey BlackFly	4
Depth Sensor	BlueRobotics Bar30	1

E. Simulation

The ability to simulate *Riptide's* behavior accurately was an integral part of the development of software for the vehicle. With a simulation, code was developed and debugged without necessitating a trip to the pool, and multiple developers could test their code at the same time. For this task, the team had chosen Gazebo 7, an entirely free, open-source, and widely used robot simulation software.

A custom Gazebo plugin was developed that bridges the existing control stack to the simulation. This was accomplished by applying the control stacks desired force output directly to thrusters in the simulation. In the future, this plugin could be extended to allow for the addition of noise or irregularities in force output to more accurately model real world conditions. Additionally, a depth sensor plugin was created to mimic the vehicles pressure sensor. Several other sensors were simulated, including the cameras and IMUs, using pre-existing plugins created by others.

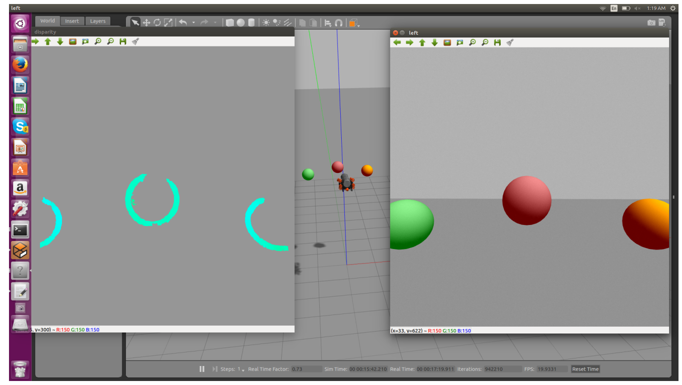

Fig. 7. Example of simulating the stereo camera system in Gazebo. Pictured is a disparity image (left), the simulated scene (center), and the raw image from the simulated left camera (right).

VI. EXPERIMENTAL RESULTS

Since the team performed major redesigns of the electronics and chassis, *Riptide* was not water-tight and able to be put in the water. To write the software, the software team utilized the simulator in order to test and perform mission runs. The circuit boards for the electronics system are being routed to fix initial design errors. The electronics team has been focused on testing and altering amplifiers and filtering methods for the acoustics system.

ACKNOWLEDGMENT

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APPENDIX

OUTREACH ACTIVITIES

The Ohio State Underwater Robotics Team represents a unique niche in the local community. The team engages in the community by participating in events such as the Ohio State Fair. As a participant in the Ohio State Fair, the Underwater Robotics Team designs and builds an exhibit to educate the local community about marine engineering. This involves small remotely operated vehicles (ROV)which guests can actively control and engage within a small pool. The past year, the team moved from using the classic PVC and bilge pump ROV to a more innovative vehicle. This new vehicle, the STEMbot, replaces PVC pipe construction with an aluminum housing, swaps the bilge pumps out for brushless hobby motors and is controlled using a Raspberry Pi and PlayStation controller instead of the typical switch box. The STEMbot is more maneuverable and its controls are more intuitive than previous PVC based vehicles. This enhances the entertainment value for many guests; both young and old, while providing more thought provoking and relevant discussions with young persons interested in STEM. Although not a quantifiable metric, the joy the exhibit brought to everyone was a rewarding experience, engaging teachers and encouraging them to incorporate the aspects of underwater vehicular design to their classroom. The team has seven engaged younger interested individuals with special needs to encourage them to pursue their underwater interests.The Ohio State Underwater Robotics Team has reached out to the PAST Foundation and Metro Early College High School to plan and create subsea activities for students. With the PAST Foundation, for example, the team has aided in three ROV competitions as competition judges. This year, the team has been helping the PAST Foundation transition their events to MATE regional qualifiers. Having competed at MATE, the team was able to provide unique guidance to the PAST Foundation and local teams as they prepare to get involved with MATE.

In addition, the team help out a local cub scout group to obtain their robotics belt loop. The scouts were able to meet and learn about our AUV. Also, a presentation was given to encourage and inform the scouts about what robots do in industry.

Finally the team has worked for many years with COSI, the Center of Science and Industry, to help educate and excite visitors for STEM. COSI has touched over 33 million people since the Center of Sciences opening. The team actively participates in an after school program where students come to COSI after school, and each week a guest comes to share what they do. This event started with a demonstration of the robot in COSIs dive well. This was a great experience as the students could see the robot through the glass and ask questions. After this demonstration, the team ate with the students and encouraged the students in STEM.