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Tiburon & Danger 'Zona^2 Design Overview

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ABSTRACT
For 2018, we have designed and fabricated a new robot, integrating previously successful systems with newly created ones, with an eye toward modularity and future incremental improvements. The mechanical layout has been fully re-designed with ease of access to the electronics in mind, and the electronics themselves are arrayed in a simpler and more efficient way. The software system is currently similar to 2017, but has been updated to ROS Kinetic and components have been re-designed with eyes toward machine learning additions in the future.

1 INTRODUCTION

For the 2018 RoboSub challenge, the Autonomous Underwater Vehicle team at the University of Arizona (AUVUA) presents Tiburon, a new robot created over the course of the 2017-2018 academic year, and designed using insights gained from our previous robot, Danger 'Zona^2 (DZ^2). Tiburon is designed with modularity in mind, and the new frame, electrical housing, and software configuration all simplify future additions to Tiburon's capabilities without requiring major components to be re-designed.

The software setup is similar to DZ^2, but the ROS version has been updated to Kinetic Kame, as Jade Turtle reached EOL in May 2017. As DZ^2 is competing alongside Tiburon at RoboSub, Tiburon had to be fully fabricated without using old components. Tiburon's capabilities were decided based on the 2018 RoboSub draft tasks, and features from DZ^2 including markers and torpedoes were deprecated, as they are no longer required. Tiburon's new capabilities include a suction-based golf ball hold-and-release mechanism, and . Unlike DZ^2, Tiburon's components can be swapped out at will, giving us a competitive edge over time, as more parts are made to fit each year's competition.

2 MECHANICAL DESIGN

The main goal of the mechanical team this year was to create a new robot using the lessons learned from DZ^2. Most important of those lessons, we learned that high-density polyethylene (HDPE) is an inexpensive, neutrally buoyant, and easily machined material. However, it tends to warp when thin and long, so the team took material thickness and geometry into account during the design process. The two main issues with the primary hull were visibility (i.e. scratches caused by frequent removals) and inner diameter (hard to maintain), which were solved with a cast acrylic tube. However, the acrylic tube was split into two segments for the new design, making it easier to access the electronics without having to take the robot apart completely during maintenance.

2.1 Frame

A CAD diagram of Tiburon is shown in Figure 1. The frame is constructed using HDPE for the "wings", aluminum 6061 for the interior supports, connector, endcaps, and stainless steel brackets to hold the wings together. Aluminum is used to create a rigid structure, while minimizing the weight of the robot. The stainless steel is used to rigidly connect the wings while preventing rust.

The frame was designed with ease of access and modularity in mind, since the unique shape of DZ^2 made

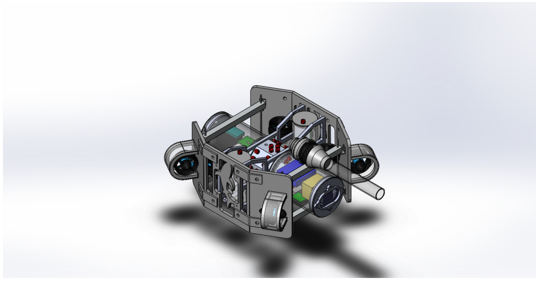

Figure 1. CAD diagram of Tiburon.

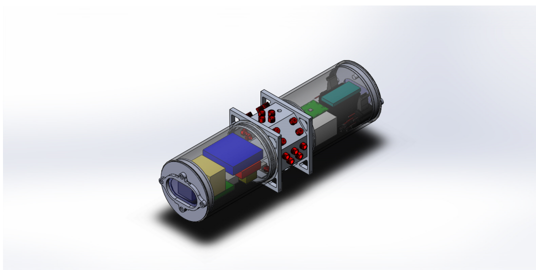

Figure 2. Electrical housing for Tiburon.

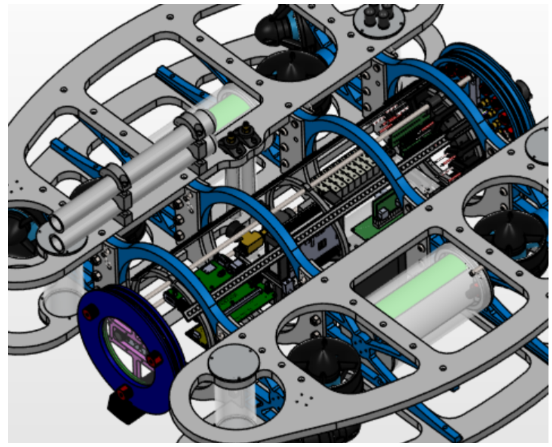

Figure 3. Close-up of DZ^2's electrical housing.

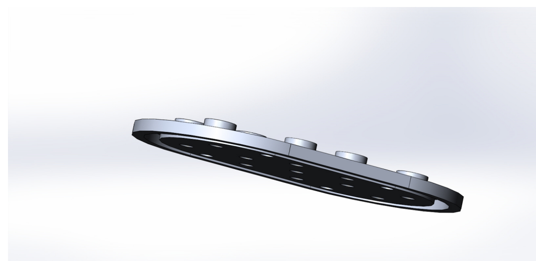

Figure 4. Front/rear endcaps for Tiburon.

it difficult to make adjustments to the frame and new mechanisms. After continued use of DZ^2 in past competitions, we realized the accessibility of the design had not met expectations. In order to conduct maintenance on the electronics, the robot needed to be taken nearly completely apart and it also left the electronics tray dangerously exposed to possible damage in the process. On Tiburon, one of the two acrylic covers needs to be removed to access the necessary electronics for maintenance. The electronics tray remains fixed to the frame at all times.

Another issue with DZ^2 was that its unique shape caused difficulty in adding task-oriented mechanisms. With this in mind, the new design focused on allowing the robot to rest solely on the frame when not in use and to have extra space for mounting various mechanisms as needed.

2.2 Housings

Tiburon's electrical housing (shown in Figure 2) is split into two components; the primary hull and the battery hulls. The primary hull is composed of two 0.25" wall, 7" OD cast acrylic tubes which house three connecting rods for mounting electronics and pneumatics. The tubes are mounted to the vehicle main connector for easy access. Felt attachments on the connecting rods ensure a smooth positioning of the tube, a feature brought over from DZ^2 (a zoomed in view of DZ^2's electrical housing is shown in Figure 3, for comparison) to avoid excessive scratches which could impede vision. Both endcaps use double o-ring bore seals.

The primary hull is secured with three sealed bolts at the front and rear endcaps (Figure 4). The bolts thread into a plate which is rigidly attached to the main connector via three threaded connecting rods. This allows the hull to be closed without external rods or clamps. The main centrally located connector (Figure 5) contains all bulkhead connections for the primary hull, including 10 cable penetrators for thrusters and batteries, six auxiliary penetrators, eight push-to-connect fittings for pneumat-

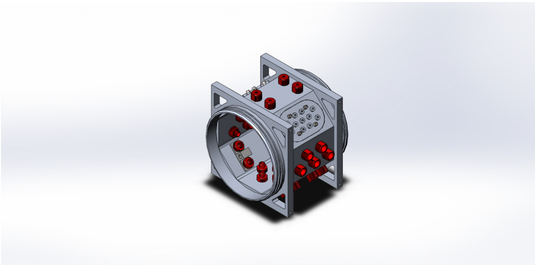

Figure 5. Central connector for Tiburon.

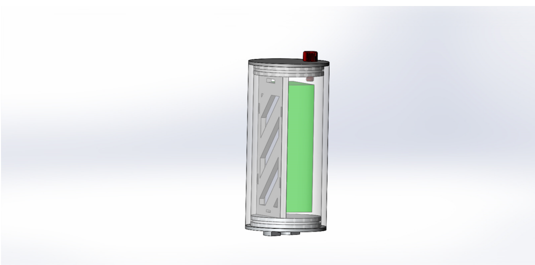

Figure 6.

ics, one large SubConn connector for the ethernet tether, charging, and venting ports for the pneumatic system.

The front endcap contains a thin polycarbonate window with an o-ring face seal. A retaining plate ensure a robust connection. The camera mount performs the same function for the front endcap as the rear spacing bracket, while also providing threaded connections for the sealing bolts. A thick polycarbonate sheet is used to support all electronics and pneumatics in the hull, with the exception of the LEDs. Mounting of the electronics is accomplished with 3D printed brackets specially designed for each component. This allows for easy positioning of tightly integrated parts, and the rapid prototyping means adjustments to the design are less cumbersome. The LEDs are mounted along rails attached to 3D-printed rings.

The battery housings (Figure 6) are mounted on the sides of the vehicle. Cutouts to the longer aluminum stabilizers are used to captivate the tube while clevis pins retain their position, making for quick re-installation. Each compartment houses one battery, and a cable penetrator supplies power through the main bulkhead.

2.3 Actuation

For the first time, this year the team made a push to include actuation beyond movement. Onboard actuation controls both the movement thrusters and a ninth thruster for the golf ball acquire/release mechanism.

Tiburon uses eight Blue Robotics T200s, four for vertical movements, and four for translational movements. The T200 thrusters are mounted in a vectored arrangement at 30 degrees from forward for a simplified and symmetrical thrust scheme. Frame components such as the vertical supports are designed to allow unobstrucuted water flow through the vehicle. The thrusters are all mounted in the same plane to minimize vehicle height and on the outer corners of the vehicle. These design choices provide the opportunity to orient the vehicle with little cost on energy to maintain the position. The symmetry of the thrusters and frame components increases the natural stability of the vehicle, making its movements more predictable and easier for the software to control.

The acquire/release mechanism is a new component added specifically for the 2018 competition. It is operated using a T100 Blue Robotics thruster located at the center of the mechanism, which pulls water toward the center of the robot to acquire golf balls, or away from the robot to release them. There are 3D-printed parts on both sides of the thruster to help control the flow of the water with a 2" OD, $\frac{1}{8}$" thick acrylic tube to help gather and hold the golf balls. The mechanism is placed on the front end to take advantage of the tracking cameras to increase the accuracy of collections and release.

3 ELECTRICAL DESIGN

Tiburon's electrical design is largely interchangeable with that of DZ^2. The goal was to improve the modularity of electrical connections for ease of access to the electronics. The team started this process by modifying existing custom PCB designs and by looking at the overall electrical system. A flowchart (shown in Figure 7) was created in order to clarify and organize the layout of our overhauled system.

3.1 Custom PCBs

With generous donations from Altium and Advanced Circuits, the team has created five custom boards for both DZ^2 and Tiburon. The power distribution board is used to supply current from lower voltage rails, and for sensitive electronics. The actuator board (shown in Figure

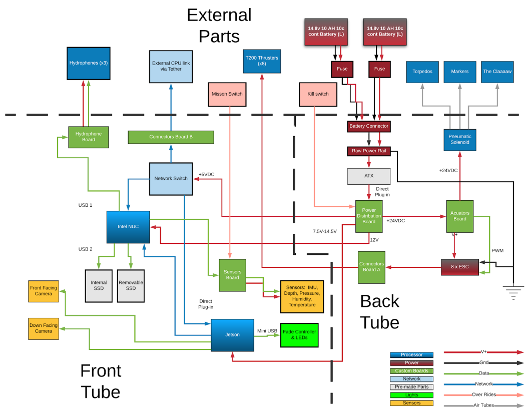

Figure 7.

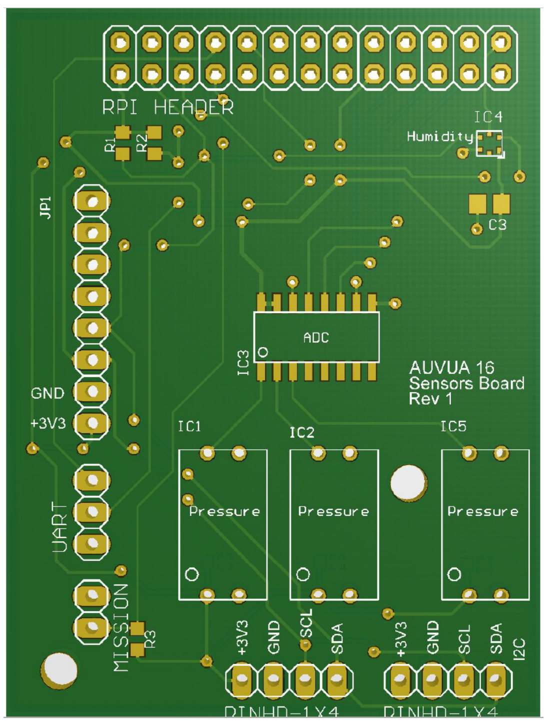

Figure 8.

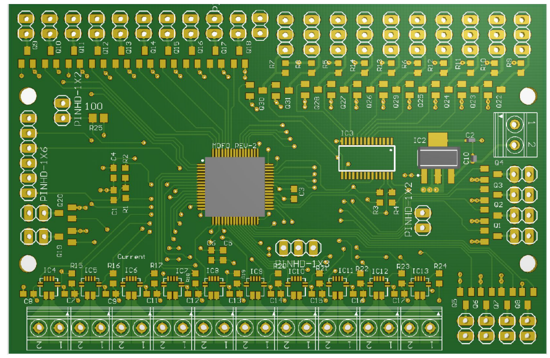

Figure 9.

9) is responsible for handling software-generated PWM signals sent to the electronic speed control (ESC) units, and to power pneumatic solenoids and auxiliary switches. The sensor board is designed to attach to a Raspberry Pi 2 or 3, and interfaces with a 9-axis IMU, depth sensor, two pneumatic pressure sensors, and humidisty sensors, feeding data to the system software.

Each vehicle also features two quick disconnect boards, which were made for providing quick-disconnect functionality to all electrical interfaces in the main hull. These boards are crucial for maintenance of the electronics, which would otherwise be tethered to the rest of the vehicle.

3.2 Electrical parts

Each vehicle has two 14.5V 10A lithium batteries, which provide up to three hours of continuous vehicle runtime. The sensors used in Tiburon are the same as those previously used in DZ^2, with one exception: the previous IMU has been replaced with a Kauai Labs NavX micro-navigation 9-DoF IMU, providing more accurate position and orientation data. Tiburon has three on-board cameras; one downward facing to verify robot orientation with markers, and two forward-facing cameras. Each of these cameras is a low-light HD USB camera provided by BlueRobotics.

In contrast to DZ^2, computing on Tiburon is distributed over three computers rather than two. Tiburon retains the Raspberry Pi 3 for interfacing with sensors and actuators, and an Intel NUC i7 for mission processing. The forward cameras in previous years did not work well with the Raspberry Pi when attempting stereoscopic vision (thus, one of the two cameras was disabled during competition). Owing to the generosity of NVidia corporation, we have moved both the camera connectivity and vision-processing to our new third computer: an NVidia Jetson TX2 embedded processor.

4 SOFTWARE DESIGN

The software design has changed relatively little from DZ^2. Aside from having to write an I^2C interface for the new IMU, the embedded system level design has been brought over from DZ^2 in its entirety. The transition from custom Java middleware to ROS in the last two years was made with the intention to simplify the middleware and make software extensions simple and easy to troubleshoot. If DZ^2 provided a strong proof of concept, Tiburon is final confirmation. It would have been quite difficult to add another processor with the previous middleware, but with ROS, the difference is only the addition of a single node in the computation graph. DZ^2 used ROS Jade Turtle, which reached end-of-life in May 2017. Tiburon is using the current LTS version of ROS, Kinetic Kame.

4.1 Agent and Mission Software

The mission planner for Tiburon is similar to that for DZ^2. It is still implemented as a two-tier state machine running inside a control loop (enabled by a physical mission switch on the robot). Missions are loaded as ROS parameters using YAML files, which are read by the agent node when the mission switch is enabled. Each mission is further decomposed into a linear set of subtasks. Since the robot is acting without a physical or wireless connection to any external device, a series of LEDs along the acrylic tube are used to indicate success or failure in a task during pool tests (red for failure, blue for task in progress, green for success, and white for waiting for task). Once the mission is completed, the agent continues to run in wait mode, until either the mission parameters are changed, or the mission switch is removed.

Inside each mission, the subtasks include sub-parameters that control both time on task, hardware interface (e.g. activate a set of thrusters, engage the acquire/release mechanism), and camera streams. For vision based tasks including the set of dice and the golf ball roulette challenge, the subtask utilizes openCV with a set of mission appropriate filters (themselves parameters in a separate YAML file) to find objects of interest, and once found, it compares the filter match to a reference image, and if the match exists but not where the mission planner wants it to be, the robot lines itself up, and acts once there is sufficient correspondence between the reference image and the camera stream.

4.2 Machine learning: looking forward to the future

Several cutting edge advancements in artificial intelligence are coming via deep learning algorithms, in which training data is used to "teach" a system to act independently. Initial software designs for Tiburon were made with a plan to implement deep learning algorithms to handle the image processing and reinforcement learning for the motion controller (the latter of which was recently proposed theoretically and simulated by Cui et al. 2017). These algorithms require a great degree of training data to make effective, and we were not able to obtain sufficient training data before the 2018 competition. In its place, the pre-existing controller for DZ^2 has been re-purposed for Tiburon. Machine learning implementation remains a high priority for Tiburon in the coming year, and we expect the high processing power of the Jetson TX2 and great deal of training data we obtain at competition and in continuing pool tests afterward to provide fertile ground for a machine learning-based implementation in 2019.

5 CONCLUSION

Tiburon has been built from the ground up for modularity and later extensibility for all three subteams; mechanical, electrical, and software. The lessons learned from DZ^2 have been implemented in its design, and with DZ^2 competing alongside Tiburon, we expect to learn even more at RoboSub.

REFERENCES

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This paper has been typeset from a TeX/LaTeX file prepared by the software subteam.