1. Abstract

The Prospero Mark II.I is BeaverAUV's submission to the 2018 RoboSub Competition. The AUV was designed and created by a range of students from 9th-12th grade at Beaver Country Day School. The sub was designed to participate in the 2018 Robosub Competition in San Diego. Prospero Mark II.I reuses the same structure of Mark II.I, BeaverAUV's submission to the 2017 Competition. This structure is defined by its external battery structures, dynamic trim system, and strategic thruster layout. We made the choice to reuse the basic structure in order to take the design to the next level. These improvements come primarily in a streamlined electronics system and a general software redesign. They are inspired by the need to have a more manageable design, which can be modified and changed whenever necessary. Prospero Mark II.I was developed to be a functional robot, capable of completing all of the Competition's obstacles and versatile enough to embrace improvements. The purpose of this paper is to explain in detail how BeaverAUV designed and created Prospero Mark II.I to achieve all of these goals for the 2018 RoboSub Competition.

2. Competition Strategy

Being a high school team with limited resources both temporal and monetary, we often had to sacrifice our ambitions for practicality. Our core, and most achievable ambition, getting through the gate has already been achieved by previous iterations of our, and as such we feel confident that we will be able to clear the gate at the 2018 competition as well. For the sake of qualifying, we likely will just put our sub in the water and point it toward the gate to begin with. However, upon qualifying we will utilize our vision system through electing to do the coin flip to gain some extra points. After doing this, Prospero will search for the gate, and go through once its vision system indicates that its in the correct position.

Due to abandoning our pneumatic and grabbing ambitions, our ability to participate in the slots and gold chip aspects of competition will be highly limited. For that reason, our primary post-game objective is shooting craps. In fact, we believe that shooting craps best utilizes our vision system and will allow us to test its ability to properly recognizes different faces of the die.

3. Design Creativity

BeaverAUV designed Prospero Mark II.I to reuse the effective structure of the 2017 AUV, while iterating on previously problematic electronic and software features. In order to keep the same basic operational principles as the 2017 vehicle, Prospero Mark II.I maintains the same frame design and thruster layout as the 2017 vehicle. The major structural adjustments can be summarized as the following: replacing our previous neural network with the You Only Look Once(YOLO) system, utilizing our trim system, streamline electronics, and the use of a Nvidia Jetson T2X as a new state machine. Finally, we redesigned our electronic systems, and are splitting it into two major components: the computer and the serial backplane electronics rack.

Mechanical Design

Prospero Mark II.I's design is comprised of an aluminum frame mounted to a center console, which provides the central structure of the AUV. Two acrylic hulls are mounted to the center console and are capped by two aluminum end caps to form a water-tight enclosure within the acrylic hulls and center console. Eight thrusters mount to the frame and provide six degree-of-freedom movement. Four hydrophones are also mounted to the frame for a passive sonar array, external battery enclosures, and pneumatic equipment.

A. Center Console

Inputs and Outputs

Prospero Mark II.I features a custom aluminum center console which serves as the mechanical core of the AUV. All additional hardware is mounted to the center console. This allows all individual components to be removed from the center console without disassembling any other portion of the AUV. The center console holds an aluminum tube with four CNC machined aluminum hull boxes welded to the sides. These hull boxes provide all of Prospero Mark II.I's inputs and outputs. Two sets of console legs serve as the feet of the AUV and provide mounting positions for the frame of the structure.

Frame Mounts

The center console has two sets of console legs mounted to each side of the hull boxes. These function both as legs for the AUV and mounts to connect the frame to the center console. Each of the four main frame panels attach to the console legs, and are fixed in place with two screws. This allows the wings to be detached very easily, while providing a very sturdy connection between the center console and the frame.

Console Feet

The center console legs feature mounting points for interchangeable feet. Feet can be added for both functional and aesthetic purposes. Different sets of feet were designed to make Prospero Mark II.I sturdy on a workbench, to soften impacts in case of collision with the walls of a pool, and to add wheels for ease of transportation.

B. Frame

Thruster Layout

Prospero Mark II.I's thruster layout was not changed from the 2017 vehicle. Two Blue Robotics T200 thrusters mount to each half of the frame in a horizontal orientation to provide translation in the surge and sway directions, and rotation in the yaw direction. The horizontal thrusters are located in the corners of the AUV. They are mounted in a vectored configuration and rotated 45 degrees around the Z axis. This was designed to increase the ease of use of the robot by not having any thrusters in front of either of the end caps, and to ensure that the AUV remains as compact as possible. Four Blue Robotics T100 thrusters mount to the frame in a vertical orientation to provide translation in the heave direction. The thrusters provide minimal control of roll and pitch; however, the robot is designed and trimmed to be very stable and to prevent rotation in the roll and pitch directions. Since maneuverability in these directions is insignificant, it was not prioritized and is not controlled throughout the RoboSub course. Prospero Mark II.I uses the same thruster layout as the 2017 AUV because extensive testing and operation at the 2017 RoboSub competition proved to provide ample maneuverability, speed, and efficiency in the water.

Dynamic Trim System

Prospero Mark II.I features an integrated trim system to allow for easy modification to the trim and buoyancy of the sub. Built into the the bottom panel of each wing are two rails which radiate from the center of the AUV. Custom cast lead weights can be easily attached and slid along these rails, effectively changing the trim of the sub. This offers substantial usability benefits because each weight can be moved by loosening just one screw.

Hull and End Caps

Two 7.5” ID x 8” OD acrylic tubes serve as Prospero Mark II.I’s main hulls. They form axial o-ring seals with both the center console and two custom aluminum end caps. Unlike the 2016 AUV in which the hull was structurally essential to the AUV, Prospero Mark II.I’s hulls function solely as a cover for the electronics. The end caps were designed to remain permanently in one side of each hull. The hull and end cap assemblies can be removed and replaced without disconnecting any electronics or removing any screws. This has proven to provide a drastic increase in ease of usability.

External Battery Enclosures

Two Blue Robotics 4” Diameter hulls mount to the frame as external battery enclosures. This allows batteries to be easily swapped without disassembling the robot. The enclosures also contain additional ballast weights.

C. Electronics Mount

Prospero Mark II’s electronics rack is split into two sections. The stern hull contains a custom a mounting system for our computer. The bow hull contains a rack for all auxiliary electronics on a custom I2C interface. Building upon last year’s design, we made an effort to made the system more open to modifications.

Electronics Rack

Our electronics mount has changed greatly from last year. Rather than having six breakout boards to mount electronics, we have a one single acrylic mount designed for us to screw in our auxilly electronics. This effectively removes much of the cluttering issues we experienced last year.

Computer Mount

Due to the fact that we are using a prepacked computer, in contrast to last year’s competition were we made our own custom computer, the creation of the Computer Mount proved to be many times easier. Our Computer Mount is simply an article base with screw holes to attach the Jetson into, and a strip of LED lights for the sake of indicating weather or not our programs are running properly. Through this simplification, we were able to clear out a ton of clutter inside our sub. Although we sacrificed a little individuality and custimibly by getting a premade computer, overall, it makes the electronic system far more manageable, giving us the opportunity to iterate and made adjustments whenever we deem necessary.

III. ELECTRICAL DESIGN

Power Distribution

The power distribution system provides the correct voltages to all of the electronics. Two 4-cell lithium ion batteries supply power to the AUV. When power enters the sub, it is brought through (xxx) buck boosters converters, which outputs 20V. Power then goes to the distribution board where it splits up to power various parts of the sub. Power is regulated by a series of amp adapters. 19V are supplied to the Jetson, and 9V are supplied to the network switcher. Both the Raspberry Pi and ESP2068 are supplied 5V. The combined 20V output is used to power the computer and all other electronics.

Computer

Jetson

Kill Switch

Prospero Mark II.I has three kill switches managed by a custom kill switch control PCB. The primary kill switch is a "Soft Kill," which triggers the software state machine to enter a "kill" state which sets all thrusters to off. This switch is used as the mission control switch to begin and end the mission. The second kill switch is a "Hard Kill" switch, which switches a large relay to disconnect power to all ESCs. This is used if the robot is behaving erratically. The final kill switch is an "Emergency Kill" switch, which switches the ESC power relay, and shuts off the buck boosters converter which power all other electronics—including the computer. This is only to be used during major leaks because of the damage which can be caused by suddenly disconnecting power to the computer.

Sensors

Prospero Mark II.I is equipped with two main sensors to detect movement. A 9 axis VectorNav VN-100 Rugged IMU (Inertial Measurement Unit) is used to provide accurate acceleration and rotation data. The IMU records acceleration gyroscope, and magnetometer data. The IMU is very capable of providing an accurate heading while filtering out any mag-
netic noise which would otherwise impede the functionality of the magnetometers. Prospero Mark II.I also uses a Blue Robotics depth sensor to detect the depth of the AUV. It is used both to set depth waypoints throughout the mission and to ensure that the robot does not surface before the mission is complete.

IV. SOFTWARE

Prospero Mark II.I's software allows the AUV to operate autonomously. Robot Operating System (ROS) is the core of the software system. ROS is used primarily as a communication interface to link together the various different programs which are executed on the AUV. ROS also allows for easy implementation of configurable launch files and monitoring of task data. All code is available on github.com/beaverauv.

State Machine

Prospero Mark II's state machine is the main controller for the AUV's mission code. It is written using the C++ Machine Objects (MACHO) library [1]. It provides an object-oriented approach to mission code which allows individual tasks (states) to be written independently of each other, and then intelligently switched between. The state machine provides hierarchical control of the AUV. Each task within the top-level Task Manager state machine is also its own state machine, which in turn can contain multiple states and additional state machines. Switching between tasks can be handled both within each individual task and by the Task Manager. The state machine also allows the AUV to continuously monitor the mission without interrupting a task. For example, the state machine constantly checks the depth of the AUV to ensure it does not surface before the mission is complete. This persistent code can be run both at the level of the Task Manager and at each individual task.

PID Controllers

All of Prospero Mark II's movement is handled by six PIDcontrollers, one for each degree of freedom of the AUV. In the 2016 AUV, the roll and pitch PID loops were disabled because they were not needed and provided unnecessary burden on the computer. As of the time of writing this journal paper, they are enabled on Prospero Mark II because there is far more computational power available on the new computer; however, if they prove to be unnecessary in extended testing they will be disabled.

The information sent to the PID controllers is managed by a PID manager. The PID manager provides functions to set the setpoint, current state, and the input type for each PID controller. The input type tells the PID controller which input data (i.e. vision or IMU data) to use to control the current state of the controller. It also provides functions such as checking if a PID loop is stable at the given setpoint.

Serial Interface

The serial interface is controlled by I2C. The Rasberry Pi master sends and receives data to and from the six slaves. The arduino slaves run auxiliary code which interprets sensor data, controls mission indicator LEDs, monitors the AUV's power, and switches pneumatic valves.

Vision

Prospero Mark II's vision system is primarily based on You Only Look Once(YOLO) system a machine learning algorithm developed by the Cornell University Department of Computer Science. We choose to replace our previous Faster-RCNN (Faster Rapid Convolutional Neural Network) primarily due to its efficiency. Rather than repeatedly assessing each frame for a new object, once YOLO identifies a certain object it will stopping looking and begin continuously tracking the object. As a result, it is exponentially more efficient, especially when analyzing live video. The the main driver behind this efficiency is the fact that it's a 106 layer, fully convolutional, neural net in YOLOv3 that only looks at an image (frame) once. Additionally, from a performance standpoint, is far superior to R-CNN and Fast R-CNN(1000x faster and 100x faster respectively).

In order to capitalize on the previous work put into our summlimetal system, OpenCV, we are re-using the system to support YOLO. The neural network is supplemented by OpenCV. The machine learning algorithm primarily recognizes the contours of objects. This makes it challenging to identify similar objects of different colors, especially the multiple buoys. OpenCV is used to identify colors within the region detected by the neural network to specifically identify these similar items.

Although, the machine learning approach requires a large amount of computational power, through replacing YOLO with Faster-RCNN we have been able to dramatically decrease the necessary power. However, the switch to YOLO was not without some issues, the primary issue being the binary nature of object recognition. Often times, our system is too uncertain in terms of labeling an object. This can clearly be promiatic, since there have been instances were the object is directly in the sub's vision range, and then the sub fails to see it. However, this issue tends to disappear as we train more and more images. But overall, we achieved a massive goal by drastically decreasing the necessary computational power from what it was last year.

Thruster Control

The thruster controller receives translation and rotation data as percentages from either the PID controllers or directly from the mission code. From these values the thruster controller computes how fast to run each thruster. The thruster controller applies the necessary translations to the data to accommodate the vectored thrust configuration. This data is then sent to the ESC Controller Breakout Board through the Serial Backplane.

V. EXPERIMENTAL TEST RESULTS

As of the time of the submission of this journal paper, Prospero Mark II has been in the water for approximately five hours of watertight testing. It does not yet drive, which has limited our ability to collect experimental test results. The test results used to inform our design come from a combination of BeaverAUV's experience at the 2017 competition with a very similar robot, and through testing of individual components in isolation of each other.

2017 Competition

The BeaverAUV team competed with the Prospero II AUV in the 20th RoboSub competition. This provided much of the insight necessary to complete an effective redesign of the AUV for the 21st competition. Testing of the Prospero II AUV showed it to be exceptionally stable and maneuverable. Its flat, symmetrical design combined with a low center of mass allowed it to remain very balanced in the water. Our tests with the 2017 robot demonstrated that Prospero could achieve adequately high speeds for the majority of the mission while running at approximately 30 percent of the available power, which allowed Prospero to be very energy efficient. Our tests of the 2017 AUV caused us to keep these aforementioned features in the Prospero Mark II.I AUV.

Testing of the 2017 AUV also revealed several design flaws to be fixed in the 2018 AUV. The overly complicated, and often jumbled, electronics setup needed to be improved. For that reason, we streamlined the electric system by used a non-custom computer and by minimizing computing power in order to remove our water cooling system. Now our repair and downtime has been dramatically decreased, allowing for more time in the water.

Watertight Testing

So far, our watertight testing has proven wholly effective, as we have yet to experience any water leakage into the sub's hull. However, we have yet to test while the sub is moving, so this is subject to change.

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