San Diego City Robotics: Research and Development of the Scarborough Autonomous Underwater Vehicle Platform

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Abstract – **San Diego City Robotics is a long participating member of the AUVSI Foundation and ONR International Robosub competition. This year the team is presenting it's latest Autonomous Underwater Vehicle, The *Scarborough*. The vehicle was constructed over the course of an eleven-month build period, and features new team advancements such as: custom 3d printed end caps, utilization of the Robot Operating System (ROS) software system, custom-built PCB boards, and a further developed and tested PID system. This year's AUV was manufactured almost entirely in-house, and represents an overall improvement on previous competition vehicles in mechanical, electrical, and software design.**

I. Introduction

San Diego City Robotics is a community college based robotics organization dedicated to the development and implementation of an Autonomous Underwater Vehicle (AUV) platform. This year the team is proud to present its latest AUV, the *Scarborough*. This vehicle is constructed by a small team of about 15-20 students and community members that are broken into 3 main sub-teams: Mechanical, Electrical, and Software design. Community Outreach efforts are conducted by team leaders from each group. Efforts for development were spent primarily in creating a new modular underwater robotic platform utilizing low-cost open source innovations in autonomous robotic technology. New technologies were implemented for vehicle construction, with most parts designed and manufactured in-house by team members. This years vehicle is intended to complete the buoy and gate tasks, with a large focus on developing a modular vehicle mounting system and attaining skills and community relationships within the team that would assist in further vehicle development These tasks required development of inter-team communications, community networks, resilient low-cost mechanical design, accurate visual detection of competition elements, obstacle avoidance, and custom built PCB developments.

III. Paper contents

1. Design strategy

This year's Autonomous Vehicle was designed and constructed within the build period as a departure from previous systems. A modular mounting system was utilized, allowing frequent adjustments throughout the construction and testing phases in response to the vehicle's performance. Previous errors and difficulties were taken into account during construction to ensure optimum performance. Due to budgetary constraints, and the loss of the previous year's vehicle due to changing member rosters, the team was required to move towards innovative and inexpensive manufacturing techniques. A facilities sponsorship was acquired early in the build period, gaining the team access to manufacturing tools and equipment such as 3d printers, power tools, and a wood CNC mill. Due to these reasons and the rapid nature of the technology, 3d printed parts were utilized heavily in the vehicles creation and implementation. This allowed the team to create a much more sophisticated vehicle than prior endeavors.

IV. Vehicle design

1. Mechanical design

The AUV went through many phases in mechanical design throughout the build period before a final configuration was selected. Each phase focused heavily on ensuring watertight integrity of the main pressure housing, in response to difficulties encountered in prior years.

During the first phase the team designed and constructed an entirely metal vehicle chassis, utilizing a galvanized steel keg as the main pressure housing. This design was utilized due to the keg's pre-designed capability to contain pressure and inexpensive cost. Water tightness was ensured via a hand-poured aluminum end cap constructed with a homemade forge, and a thick rubber strip was utilized as a watertight seal. The team collected 25 pounds of aluminum cans and ingots for the forge, and utilized a sand-casting method to form the end-cap. This phase was not utilized in the final design due to the uneven surface of the final part, which made waterproofing difficult. This led to the decision to move towards 3D printed end caps, in an effort to attain higher quality parts at a low cost.

The next iteration of the design utilized an acrylic tube as the main pressure housing, which provided a more stable surface less prone to warping. Hollow 3d printed end caps were manufactured, then filled with four pounds of epoxy to provide a high quality waterproof plug for about $50 per end cap. After the end caps were designed and tested for maximum watertight integrity, aluminum 8020 frame was placed around the waterproof pressure housing to create a modular, easily adjustable, bracket based mounting system for all exterior components. This allows the team to continue developing the sub further in years to come, without compromising the main pressure housing. Blue Robotics T200 thrusters were added to the modular frame due to their high performance and ability to communicate via I2C. Custom 3d printed brackets were created to mount each component to the vehicle's aluminum frame, creating a precisely manufactured, low cost mechanical design.

2. Electrical design

Unlike mechanical and software designs, this years vehicle went through a single phase in electrical design and construction, with electrical components chosen early in the build period. Construction of electrical systems was conducted throughout the academic year, with development of new technology and ideas blending into prior designs and implementations. Custom-built PCBs were created for wire management, resolving multiple issues encountered in multiple competition vehicles in prior years. This led to a sophisticated electrical design that improved upon prior developments (fig. 1).

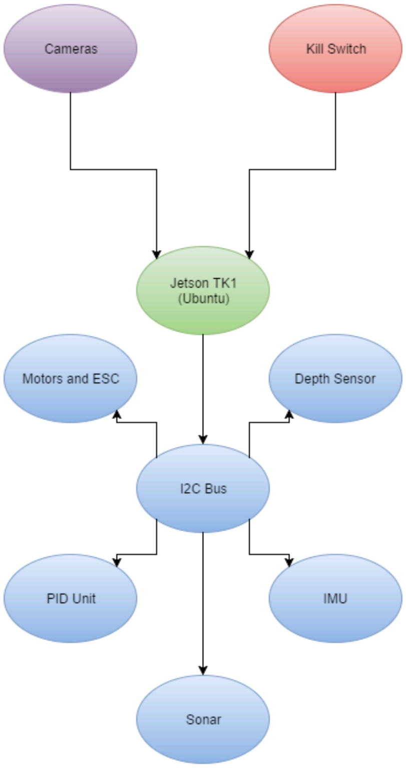

Figure 1: *Scarborough* electronics Flowchart

The *Scarborough* is run mainly on the Jetson TK-1 computer, which was generously provided as a component sponsorship from Nvidia. This board was selected due to its small profile and onboard GPU, which enabled the team to compute large amounts of data in autonomous decision-making processes. This computer is assisted by an Arduino Mega microcontroller for PID based thruster control, and a MPU 6050 IMU for movement and orientation detection. Depth measurements are conducted by a Blue Robotics Bar30 High Resolution 300m Depth/Pressure Sensor, providing a similar size profile to the waterproof connectors utilized by the vehicle. These components were selected due to their ease of use and familiarity to the team, and connected via a custom PCB adaptor plate manufactured in-house by the electrical design sub-group. This enables multiple rail connections of differing pin sizes to be easily connected between the boards, and allow proper I2C connections to occur.

Power management to the Blue robotics motors is controlled via three Thirty-Amp Five-Volt logic relays attached to Thirty-Amp automotive fuses, and connected via a home-built T-connecter PCB adaptor. This eliminated multiple points of failure within the vehicle's electrical design and split the required current for motor control into three separate boards, reducing cabling and battery concerns. T-connectors were utilized due to ease of use, providing an easier platform to connect electronics with lower concerns of wire detachment and exposed electrical connections. A final PCB was designed and constructed to connect the Arduino microcontroller board to the MPU 6050 and logic level shifter to reduce wire clutter and enable I2C communications with the blue robotics motors.

Wire management was largely conducted via the aforementioned PCBs, which were designed and constructed at the Fablab facility. Boards were designed in the Eagle CAD PCB program using team created components and component libraries. Othermill compatible files were created utilizing the Othermill's Otherplan software, before the final boards were carved from single layer copper-coated circuit boards. Board components were then placed and soldered by hand to create the final PCB. This enabled the team to make significant progress in electronic development for the *Scarborough* autonomous vehicle platform while maintaining the vehicle's low budgetary profile.

3. Software Design and Development

Due to difficulties in data collection this year's vehicle went through multiple distinct phases in software construction, with the final iteration utilizing the Robot Operating System (ROS) to coordinate and control the *Scarborough*'s electrical systems. This operating system was utilized to shorten vehicle response times to sensor measurements via a publisher and subscriber data sharing method; eliminating sensor lag time in decision making and removing previous points of failure. Small programs were created in C++ to simultaneously control each component while sharing data via simple multi-threading.

During the first major iteration of software development, serial communication devices were used as the vehicle's primary data sharing method. A PID system was programmed onto an Arduino Mega to dynamically control the Vehicle's motor speeds to match desired direction and endpoint. The Jetson TK-1 board was utilized to determine via sensor measurements the vehicle's yaw, pitch roll, and depth, which were passed onto the microcontroller to determine the thruster motor values. Response times with this method were slow however, due to excessive data flow through the microcontroller and compounded serial communication times.

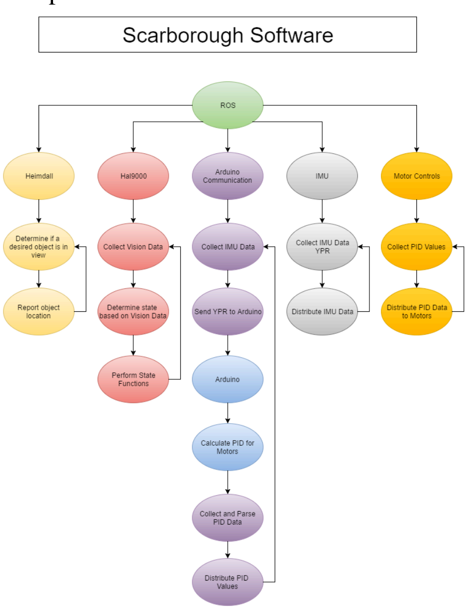

Figure 2: Early Software Development flowchart. Hal9000 program now part of Heimdall vision recognition program.

Due to these issues, several communication methods were explored, with the final design utilizing I2C communication. This adjustment allowed the Jetson TK-1 board to convey variables to the PID system in large messages in under a millisecond, improving vehicle response to near real time. This configuration utilizes an event-based system for determining vehicle motion, with reactions occurring in response to recognized competition course obstacles. Objects are identified and determined in relation to the vehicle via the Heimdall Open CV system. This data is then paired with information received from the MPU 6050 IMU to determine the *Scarborough*'s location in relation to it's selected tasks, and actions necessary to complete the chosen competition challenges. These advancements provide a significant development upon last year's dependencies on hard values, allowing the team to further develop the vehicle's positioning systems in years to come.

V. Experimental Results

In response to difficulties encountered in prior years, vehicle testing focused largely on water-tightness and waterproofing techniques, with each AUV phase undergoing multiple water tests utilizing a trial and error methodology. Large storage containers were utilized to replicate an underwater environment, and qualitative observations were made regarding each method's performance under simulated competition tasks. These were then utilized in further end cap development, until waterproof integrity was achieved.

The first method utilized in waterproof vehicle testing employed two rubber pipe sealers as end caps, which were clamped into place onto the acrylic tube. This method was deemed unsuitable to the competition due to insufficient pressure on the clamps, causing water to enter the main pressure housing. This proved insightful however as observed water level was lower than that in prior configurations fielded by the team, leading to the development of the final 3d printed end cap.

The next methods deployed by the team focused on the development of the aforementioned end cap, focusing heavily on the utilization of 3d printing technology. Different percentages of plastic infill were tested on a single part printed end cap, with printing fail rates noted with each design. Difficulties were observed in overcoming the layering process of filament based 3d printing, which left many small channels and holes in the final manufactured part. Resin printing was explored, however the rate of failure and high economic cost proved unsuitable to the team's purposes. These issues led to the final end cap design, which utilized a multi-piece printing process and epoxy coating that resolved prior competitive issues with waterproof integrity.

VI. Acknowledgements

San Diego City Robotics would like to thank all of its sponsors and donors, without whom development and implementation of the AUV would not have been possible. The team thanks San Diego City College and the San Diego City College Associated Students Government for funds, support, and promotion on-campus. The team would also like to extend its thanks to Fablab, which provided the team with critical facilities and equipment that greatly assisted the construction and design of the current vehicle. In addition SDCR would like to thank: Robo3d, Wingware, Nvidia, Patricia Shanahan, Solidworks, and the team's gofundme donors. Finally San Diego City Robotics would like to thank Kaari McBride and San Diego City College Newscene for creating this year's team video.

IX. Appendix A – Outreach Activites

During the year the team was present for many outreach opportunities, both independently and in partnership with the team's facilities sponsor Fablab. Team leaders assisted in the development and implementation of education material with the facilities sponsor, with students reached including local architectural students (3d modeling and printing), Dis-advantaged Youth (Arduino programming/Access Program), and members of the general public (basic electronics). Team leaders were also present at offsite outreach opportunities, presenting programming courses in Scratch and Scratch Jr. at Jefferson Elementary both with Fablab and the non-profit organization Treobytes. Team leaders also volunteered at Fablab as local Geeks In Residence, assisting Fablab members and the general public with engineering and equipment concerns. Booths were maintained at several local engineering events, including the First Annual San Diego Maker Faire, where the team was featured on a San Diego news report shared on the Mayor of San Diego's Facebook page. The team is currently organizing further outreach plans and opportunities, and looks forward to being an active member of the larger San Diego Community in the upcoming year.

X. Appendix B – Resources

Many Resources were utilized in the development of this year's vehicle, without which the team would not have been able to complete the autonomous robotic project. The team would like to specifically acknowledge the following resources, which proved crucial to the Scarborough's design and development:

http://wiki.ros.org/ - Utilized by the software design sub-group to resolve issues encountered with ROS and to properly implement the operating system.

http://elinux.org/Jetson_TK1 - Utilized by the software and electrical design sub-groups to implement usage of the Jetson TK-1 and the design of attached electrical systems.

http://docs.bluerobotics.com/ - Utilized by the electrical and mechanical design sub-groups to design electrical motor control systems and mounting brackets.

http://robotics.ee.uwa.edu.au/theses/2006-AUV-Gerl.pdf - Utilized by members of the mechanical sub-group to further comprehend mechanical aspects of AUV design.