University of Victoria AUVic: Development, Design and Implementation of the 'RED HERRING' AUV

Authors:
Ann-Kristin Blanken, Andrew Bates, Chris Carpenter, Ashwin Sira, Kyle Treloar

Team Members:
Ann-Kristin Blanken (President), Chris Carpenter(Vice-President & Mechanical Lead), Andrew Bates (Electrical Lead), Kyle Jordan (Software Lead),Ashwin Sira (Systems Engineer & Project Manager), Andrew Tran, Anuraag Sinha, Ethan Hansen, Alper Ozcetin, Micaela Simpson, Keifer Edelmayer, Kyle Treloar, Jared White, Jacob Lower, Tristan Riddy, Trevor Yonkman
Faculty Advisor: Dr. Brad Buckham

Abstract— **AUVic is an Autonomous Underwater Vehicle undergraduate student team from the University of Victoria (UVic). The team is designing and building an AUV (Autonomous Underwater Vehicle) with the goal of competing in the 2016 AUVSI RoboSub competition held at the SSC Pacific TRANSDEC facility in San Diego. This year marks the return of AUVic to RoboSub after a six-year absence. AUVic is competing with an entirely new team. While the team inherited a few components from previous vehicles, it is essentially a completely new vehicle. The new team has moved away from the rigid cast acrylic frame that has been used in the past and is instead opting to use an open frame design. The new AUV, Red Herring, is a compact robot based on an adjustable frame with a syntactic foam float. Design choices are based on optimizing for the specific tasks that will be feasible with the materials, budget, and skills at AUVic's disposal. AUVic's biggest goal for 2016 is to have a vehicle that is able to enter the RoboSub competition. Therefore, the design priorities are focused on the power system, motion and navigation, as well as the vision system. With these systems in place, the AUV will be able to complete several of the competition tasks at RoboSub. The two main goals of the team are to give students the chance to practice real world applications of the material learned in classes and to build a competitive AUV for the RoboSub competition. AUVic, one of seven competition teams at UVic, is currently benefitting thirteen undergraduate students directly involved in the team and many more through their outreach activities.**

I. INTRODUCTION

AUVic is one of seven active engineering competition teams at the University of Victoria. The team is made up of thirteen undergraduate students from electrical, mechanical and computer engineering as well as computer science and physics. The main purpose of the team is to give students the chance to practice real world applications of the material learned in classes. It also allows students to gain experience with projects outside of their main discipline. This experience is beneficial to students in several ways: It helps with the understanding of class material and allows students to see the applications of this material to real world problems. Students gain valuable hands on experience designing, building and testing electrical, mechanical and software systems. For a university located on an island, learning about underwater technology and underwater instrumentation and systems is particularly relevant. This is the first time that the current AUVic team is competing at RoboSub, therefore, the team opted for the design of a simple vehicle that can complete several tasks on the course. While the main focus of AUVic is to give students hands on experience, AUVic is also determined to build a competitive AUV for the RoboSub competition. Ideally, the AUV will be able to complete all the tasks on the course, however, for this first time AUVic is aiming at completing the scuttle ship and navigate channel tasks. By focusing on these tasks the needed systems can be the focus of development and can be more rigorously tested.

II. DESIGN PROCESS

AUVic designed their vehicle 'Red Herring' from January 2016 to July 2016. For the current vehicle, a ROV frame, which included lights and two pressure housings was donated to the team. These had to be modified to accommodate the extra components needed for autonomous power and intelligence. An existing IMU and depth sensor inherited from the old team's vehicle were also able to be used after some repair. The team designed the remaining components and intelligence needed for the RoboSub competition. While AUVic has team leads for the separate sub-disciplines, team members are encouraged to work on all aspects of a project to gain skills outside of their specific field of study. Rather than divide into subgroups, specific projects are designated as mechanical, electrical, software or business and anyone can take on these projects. The team leads provide guidance and co-ordination of all projects. All team members meet once a week to share progress and discuss how to proceed.

III. Design and implementation

A. Design Strategy

For 2016, AUVic's strategy is to compete with a simple, lightweight vehicle that has fewer features which are tested rigorously. The design choices made for the competition run are to rely on the vision system and the navigation system for most of the tasks and to focus on the tasks that can be completed using those systems. Choosing those two systems has several benefits for AUVic:

1. With navigation and vision we can complete two of the tasks on the course, the channel and the scuttle ship task
2. The navigation and vision system provide a good base for improving the vehicle in the future. They are essential systems without which the AUV could not do anything
3. By leaving out other peripherals, focus is on making the vision and navigation system work well and also keep the vehicle more lightweight
4. The communications from the main computer as well as the power harness are designed in such a way that it is simple to add more peripherals.
5. It allows for the use of a smaller main computer on this version of the vehicle, which generates less heat that needs to be dissipated.
6. It allows the AUV to be finished quickly.
7. If time allows we will be able to add a weight dropper, hydrophones and a grabber arm.

There are of course drawbacks to these design choices:

1. By leaving off peripherals the AUV's capabilities are quite limited and it is not possible to fully complete all competition tasks.
2. The frame used for the current AUV is quite small and lightweight which limits the number of peripherals and sensors that can fit.
3. Modifying an existing frame is limiting some of the choices we can make. It constrains the design to given parameters.

The vision system relies on processing the images from a forward facing camera by using edge detection, color detection and combing those elements for object recognition. The objects are recognized by using an LBT classifier. The navigation system uses 5 thrusters to get forward, backward, up and down as well as roll and pitch motion. The thrusters are controlled by in house designed motor drivers that will give us position data for each motor on startup. Data from an inertial measurement unit (IMU) and a depth sensor is used to calculate the commands to the thrusters to be able to travel in a straight line as well as to travel towards a task on the course. To communicate with different devices different communication protocols are used depending on the type of protocol associated with each peripheral. All communication goes to a junction box. In the junction box the different protocols get converted to RS 485 to go to the main computer. The junction box allows us to be able to easily add extra peripherals when we have them.

B. Vehicle Design

AUVic's current vehicle design is a departure from the style of vehicle that the team has deployed in the past. The last AUVic vehicle that competed in RoboSub featured a solid acrylic flooded hull in which the components lived in their own pressure housings.

Figure 1 Old AUV Frame

With a rigid hull like that it was not possible to add different sized pressure housings and options for improvement of the vehicle were very limited. For RoboSub 2016, AUVic is working with a frame that had originally been intended as an ROV, but that is now being developed into the competition vehicle.

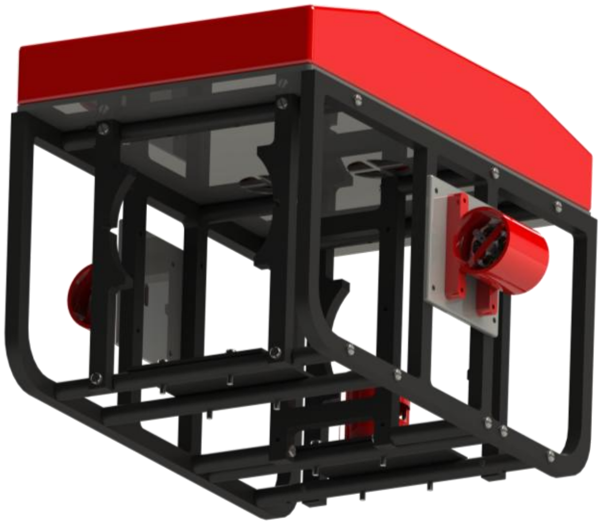

Figure 2 Current frame - a more flexible design

The main idea behind the design is to keep the vehicle as simple as possible in order to have a working vehicle that can run the competition course and that can act as a base to improve on in the future.

The AUV is controlled by an ODROID-XU4 computer. The ODROIDwas chosen because it is about twice as powerful as the Raspberry Pi 2. Testing of the Raspberry Pi2 showed that it could do the required computations, but only one at a time, and the vehicle would be required to stop moving while the system figured out what to do next. The ODROIDis expected to be able to handle the control of the system as well as the artificial intelligence.

C. Power system–Electrical

The power system is the first priority of the design, since it enables us to turn the vehicle on. It is based on a battery pack of 10 lithium ion batteries that are wired in parallel banks providing 22.2 volts for 7.5 amp hours. The larger of the existing housings was chosen to hold the batteries so that there is room to house the cells with spacing between them for airflow. The battery housing also contains a solid state switch for the main pack output. The pack switch is implemented as part of a soft start circuit. The soft start circuit restricts current flow during the initial power up to limit the system's inrush current. Due to the large amount of capacitance on the main battery bus the startup transient current would be extremely large and potentially damaging to certain components. The vehicle is turned ON and OFF by using a magnetic read switch. The switch is activated by holding a magnet close to it. When the magnet closes the reed switch for more than 5 seconds the switch state is toggled on or off. This is preferable to a push button switch, since a push button is likely to be pushed by the water pressure and can lead to unwanted switching of the system power. From the battery housing, the power distribution harness distributes power to the rest of the vehicle. The power is mainly distributed through a junction box that manages both power and communications to most components of the vehicle. The power from the batteries is regulated down to 12V in the junction box and distributed from there. The motors require more current than the other components and therefore get their power directly from the batteries.

D. Power system –Mechanical

Mechanically, the power system is composed of the battery housing which is an existing housing that was donated to AUVic. It is circular aluminum housing with two end-caps that use O-ring seals. One end cap is aluminum and the other is acrylic. This allows us to observe any swelling of the batteries or leakage without needing to open up the sealed housing. A threaded penetrator was designed to fit the hole in the existing end-cap. The power harness cables are potted into the penetrator to exit the battery housing. The batteries are mounted in a support structure that fit directly into the housing. Two battery packs are used which allows us to easily change battery packs between runs.

E. Motion and Navigation System – Electrical

The AUV has five thrusters that are constructed using 3 phase brushless DC motors. These motors are wound such that they produce more torque, and have a lower maximum RPM. Data gathered from the IMU and the depth sensor is used to direct the motors. The motor controllers are designed in house by AUVic, using an Allegro A4960 ASIC to handle the back EMF driven commutation logic. This allows for closed loop speed control without requiring external Hall Effect sensors making the design more compact. This comes at the cost of occasional inconsistent startup, as the position of the rotor relative to the stator is unknown at startup. This is one of the drawbacks of using back EMF commutation over a direct positioning approach. To overcome this the controller is commanded to provide maximum torque at startup until the rotor's orientation can be determined, and then scale back to the torque required to maintain the commanded speed.

F. Motion and Navigation System – Mechanical

The motors were fitted with cut down quadrotor propellers. These propellers are thicker at the base and therefore don't bend nearly as much under load. They have a lower pitch ratio than boat propellers which is better for underwater use. The motors are enclosed in circular nacelles with solvent welded shrouds. The motors were tested for thrust power and for propeller shape, size and materials. The motor controller housings were designed to be able to transfer heat generated by electrical components, particularly the computer and motor driver FETs, to the water. The housing is rectangular and is filled with mineral oil to pressure balance it with the surrounding water.

G. Motion and Navigation System – Software

The data from the IMU and the depth sensor are used to calculate the current orientation of the vehicle. This data is compared to the location of the target object and a trajectory to the target object is calculated. To follow this trajectory each motor needs to be set to a certain speed and the computer calculates the appropriate speed for each motor and sends the commands.

H. Communication System - Electrical

Communication from the peripherals goes to a Junction box. The junction box distributes both power and communications to the peripherals. It converts signals between RS485 and RS232 communication protocols using an i^2c interface in order to be able to communicate with each component on board the vehicle. The data is then sent to the main computer over a standard USB serial interface.

I. Communication System – Mechanical

The junction box is housed in a rectangular housing. It uses a combination of penetrators and cable glands to let the communication and power cables enter and exit. A penetrator is used to connect the junction box to the main housing and between the batteries and the junction box. Cable glands will be used to connect the junction box to all of the peripherals. This will allow for easy upgrading of our peripherals in the future.

J. Communication System- Software

The computer of the AUV uses Linux mint running ROS, the Robot Operating System. ROS nodes and nodelets are used to control the sub. The computer sends commands with an address for the specific peripheral. The junction box receives this command and reads the address to figure out whom it is addressed to. It then converts the message to the right protocol for the intended recipient and sends the message to the peripheral. If the message is addressed to the junction box itself, it reads the message and carries out its commands.

K. Vision system- Electrical

The vision system uses a wide angle lens USB camera. The camera is powered through the USB connection from the computer power. To help the camera see there is a 6 LED light ring that came with the pressure housing and was repaired to be used for Red Herring.

L. Vision system- Mechanical

The vision system lives in the main housing which is a cylindrical aluminum dry housing holding the camera, light ring, computer and IMU. The housing has a penetrator connector to allow cables to enter and exit. The cables are potted into the penetrator and connect to the junction box. The housing has one aluminum end-cap and one acrylic end-cap facing forward so that the camera can see. Both end-capos use o-ring seals. The LED lights are set into a thick aluminum ring to allow heat dissipation to the surrounding water through the housing walls.

M. Vision system- Software

Vision processing is done with OpenCV, which integrates with ROS. The vision process is broken down into four parts. Objects are recognized from a combination of edge detection and colour recognition. To recognize a specific object, a classifier is created for that object an trained to recognize the object by using several images with the object present as well as images of the background with the object not present. A GUI was created to adjust the colour and edges for training the classifier. The classifier allows for detection of a generalized object and the recognition can be done with little logic needed. The colour of the object in the classifier is not reliable enough and it is helpful to run colour detection on the image to confirm a positive identification. The classifier also does not recognize an object when it is rotated, so the frames need to be looked at four times, once in each orientation, to see if the classifier matches the object. [1]

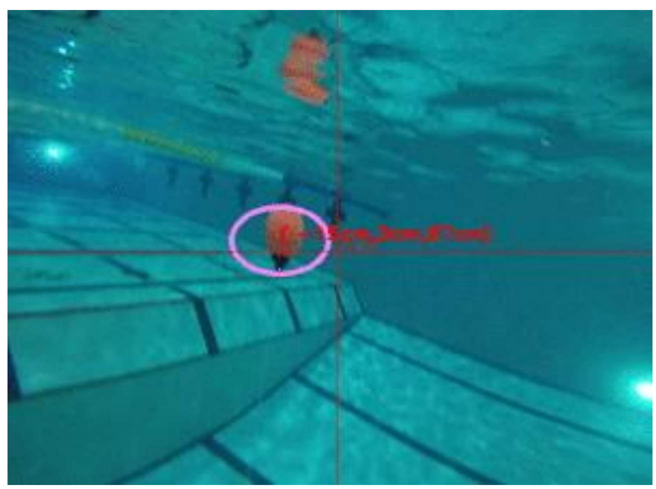

Figure 2Positive Object detection

N. Peripherals and sensors

The AUV contains two electrical sensors that are deemed critical. An Inertial Measurement Unit which provides accelerometer, Gyroscope and Magnetometer data. This data is used for navigation control. And also a depth sensor which provides data used for navigation. There are three peripherals that could be added to the AUV this year if time permits. The first peripheral we would like to add is a weight dropper. An electrically driven grabber hand as well as a hydrophone array is also considered as possibilities.

O. Peripherals and Sensors – Electrical

Two sensors were inherited from the previous team's vehicle. The IMU and depth sensor were tested and repaired to be used on Red Herring. A weight dropper peripheral could be implemented electrically by using a combination of a permanent magnet and an electromagnet. The permanent magnet cancels the field of the electromagnet and the weight drops. Initially, a halbach array of permanent magnets was considered, however it encountered several problems. It was quite large and it proved very challenging to arrange the servo arm in the box to turn the halbach array. In the end, this simple and small system proved itself to be much easier to implement.
The vehicle could add an electrically controlled grabber arm. The control board for the grabber was designed and built in house by AUVic, due to the fact that we inherited a unit that contained no information on how to use it. Since it proved too challenging to understand the existing controls, the team opted to design new ones.

P. Peripherals and Sensors – Mechanical

Both The IMU and depth sensor came with pressure housings, so they had to be fitted on the vehicle frame. The grabber hand was redesigned two have a two prong hand that will be added if time permits.

Q. Peripherals and Sensors – Software

Most of the peripherals have two set of software. One is embedded code on a microcontroller to control the actual operation of the peripheral. The microcontroller reads the messages from the main computer and turns these messages into PWM signals that operate the devices. The peripherals get their instructions from the task routines in the main control software.

R. Experimental Results

AUVic has tested the pressure housings in the pool overnight at a depth of 12ft. Most housing seals survived the testing just fine, however one box had to be abandoned and redesigned since it leaked at that depth while dry. AUVic has also taken underwater test footage of replicas of the competition targets. This footage is used to train the vision system to recognize the targets. The vision system's object recognition is able to locate and identify the targets even with the underwater distortion. The thrusters have been tested in a test tank to determine the best propellers to use in terms of the best propeller shape and materials. The software is currently being tested by simulation of the competition pool in gazebo. This simulation includes the pool with all targets and a simulation of the AUV so that it can be driven through the pool, either by joystick or with its own artificial intelligence. Extensive testing of the vision system has shown that LBT Classifiers are preferable to Haar classifiers since they are a lot less computationally intensive with only a small loss in accuracy.

S. Acknowledgements

AUVic would like to thank our sponsors for their support.

Platinum
- Prototype Equipment Design

Gold
- Solidworks
- Mathworks

Silver
- Nvidia

Bronze
- APEGBC
- Noctua
- AP Circuits

Brass
- Altech Anodizing
- General Metals and Plastics

IV. Appendix A—Outreach Activities

AUVic has participated in several community Outreach events. Team members have delivered presentations on marine engineering and use of AUV's and ROV's and workshops at Ocean Networks Canada's annual Ocean Science Symposium. The Ocean Science Symposium is an annual event that is designed to showcase marine biology, oceanography and marine engineering to high school students who have demonstrated an interest in the oceans.

Figure 10 AUVic Presenting at the 4th annual Ocean Science Symposium

Team members have also presented workshops for the Science Olympics, an event that sends high school student to different stations throughout the university to learn about sciences and engineering.

AUVic participates in UVic IEEE's SkillDev workshop series by hosting a very popular soldering workshop when the series runs.

Figure 3 AUVic 2015 Soldering SkillDEV

Additionally, team members have worked with Ocean Networks Canada Staff and local high school science teachers to assemble an OpenROV kit to test the feasibility of a high school class taking on that project.