ECEN 5458 Project Summary 1

Kyle Harlow, Akshay Iyer

May 18, 2018

1 Introduction

The RoboSub competition is a yearly student competition where teams create Autonomous Underwater Vehicles (AUV) to compete in an obstacle course sponsored by the Office of Naval Research (ONR), and the Association for Unmanned Vehicle Systems International (AUVSI). For the past four years the University of Colorado has entered this competition with a RoboSub team.

One of the largest challenges of the competition is accurately controlling the AUV. Many tasks involve fine manipulation of the vehicles pose in order to pick up, run into, or avoid obstacles. In previous years the team has primarily used hand-tuned continuous approximation PID loops in order to control the vehicles 6 degrees of freedom (6DOF). While this has worked in some cases it often causes problems, especially considering our sampled data system providing feedback has sensors operating as low as 8Hz.

As such we propose a project to model and design a digital control system for the AUV's more troublesome DOF, focusing on the coupled pitch, roll and depth of the vehicle.

1.1 Vehicle Model

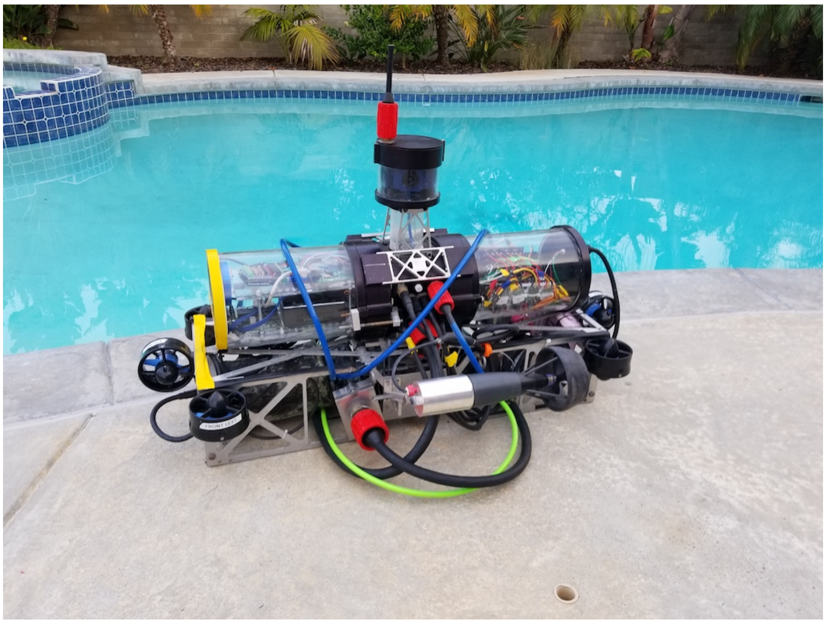

Figure 1: Picture of the Current Vehicle

The AUV has 8 motors arranged as follows:

1. Two motors pointed forwards along the vehicle for thrust
2. Two motors pointed horizontally along the vehicle for strafe and yaw
3. Four motors arranged in a quad-copter arrangement at each corner to control depth, pitch, and roll.

This specific motor arrangement gives the vehicle 6DOF with redundancy in each axis. In our worst case scenario we can loose 4 motors, the thrust and strafe motors, and still control the vehicle. In general, we assume that the three sets of motors are decoupled, so long as the vehicle has only small pitches and rolls throughout operation.

The vehicle can be approximated by the following differential equation, based on the Handbook of Marine Vehicle Dynamics:

$$\boldsymbol{M}\dot{\boldsymbol{v}} + \boldsymbol{C}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{D}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{g}(\boldsymbol{\eta}) = \boldsymbol{\tau} \tag{1}$$

The matrices and vectors defined in equation 1 are as follows. M is a matrix of moments, v is the velocity vector of the vehicle, $C(v)$ is the Coriolis Effect matrix, $D(v)$ is the drag matrix, $g(\eta)$ is the gravity and buoyancy of the vehicle based on global pose η, and τ is the torque on each axis from the motors.

One of the main challenges of this project will be turning this model into a state space model for the vehicle.

1.2 Hardware: Sensors

The vehicle is equipped with several digital sensors providing feedback. All sensors operate based on a zero-order-hold model, where if the controller requests a pose from the state estimation it will be accurate to the last sensor sample.

The primary sensor is the Inertial Measurement Unit (IMU) which provides rotational velocities, and linear accelerations around all three axis. This sensor samples at approximately 30Hz in it's current configuration. As the fastest sensor the vehicles state estimation is based on this frequency.

The next sensor is a Doppler Velocity Logger (DVL) which provides linear XYZ velocities. This is the most accurate sensor but it samples at 8Hz. The state estimator combines these velocities, as well as the integrated velocities from the IMU in order to get a total velocity pose estimation, estimating values at 30Hz between each DVL sample.

Finally the system is equipped with a pressure sensor, which gives the depth of the vehicle. At the moment this sensor samples at the same 30Hz as the IMU.

The DVL and IMU both provide 32 bit quantized digital samples, which are truncated to 16 bits. The pressure sensor provides the depth to 10 bits.

1.3 Hardware: Actuators

The vehicle is currently using 8 Blue Robotics T200 motors. These motors have a maximum thrust of approximately 12 lbf. They are controlled by electronic speed controllers using PWM which can be adjusted in quantized steps of 10pwm ranging from 1100us (full reverse) - 1500us (stopped) - 1900us (full forward). Each 10pwm represents approximately .1-.15 lbf.

2 Project Goals

- Numerically model and design the differential equations for the AUV by making assumptions based on prior experience and papers on marine vehicle dynamics, as well as converting the model into a state space model.
  - We hope to simplify and linearize equation 1 in order to fit into the standard state-space controller arrangement, and then approximate the Z-Transform for the three most coupled DOF, pitch, roll, and depth.
- Design a discrete-time digital controller for the AUV based on the model we derive.
  - Design digital controller for the plant(AUV) in discrete-time space using the sensor outputs at different sampling rates, sampling them and giving output to the actuators accordingly.
  - We plan to implement the numerical methods such as forward rectangular rule, backward rectangular rule, zero-pole mapping, zero-order-hold equivalent.
- Create a Simulink model of the AUV and simulate control of pitch, roll, and depth.

  - Compare the performance parameters like roll, pitch and depth control of the digital controller with state-space model to the continuous PID controller which is already implemented in the current vehicle model.
  - Check and achieve stability, holding roll, pitch, as close to 0 as possible during depth maneuvers
  - Increase depth stability, reducing oscillations that occur by potentially introducing feed-forward control to counteract buoyancy
  - Use the implemented control law, to lower settling time and lower maximum peak overshoot when the vehicle dives in the water in response to a step response for depth

- To test the implemented control design physically using the hardware listed in Section 1.
  - Test the controller on the actual vehicle and compare the results with the Simulink model results.

3 Time-line and Roles

- We plan to complete modeling the equations of the AUV by February 21 together.
- We plan to design a digital controller and completing the goals stated in The second bullet by the first week of march.
- We plan to complete design and testing of the Simulink model by first week of April.
- We plan to perform hardware tests of the model by mid April, until the presentation.

We plan to do the modeling of the AUV and design for the AUV controller together Then we will split the work into testing the controller in Simulink, adjusting parameters based on different coefficient matrices, and implementing the digital control system onto the hardware using Python and Numpy and the vehicles implemented Robot Operating System (ROS) core. Akshay will work primarily on the Simulink tests, and Kyle will work primarily on the hardware tests.