The Coeur d'Alene Catfish: Research Portfolio

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Autonomous Robotic Submarine Project
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Contents

1 Introduction

1.1 Goal

Autonomous navigation and sampling of lake sediment in North Idaho lakes up to 1200 feet in depth. Project is being operated in cooperation with Gizmo and CDA Maker Space

1.2 Project Summary

The western region of the United States has been home to expensive mining operations, and there is an abundance of abandoned hard rock mines that fill this landscape. These mines contain dangerous toxins that contaminate nearby soils and water. Thus a large portion of headwater streams in the Western United States have been effected by this. These toxins and metals can be transmitted to lake basins, which can become repositories for a large quantity of sediment associated metals. Coeur d'Alene lake in Northern Idaho, where silver and lead mining in the South fork of Coeur d'Alene River has carried heavy metal contaminated sediments to the lakebed. Thus in Coeur d'Alene lake this is a prominent issue, and while these issues are apparent there, it is not just this lake that has this problem. Legacy Contamination within river beads is a problem on an international scale. Computer models also do not provide an accurate characterization of the transport of contamination, a more direct sensing of contamination is required. This is where the research for this project comes into play, to develop the Coeur d'Alene Catfish, which is an autonomous robotic drone that is capable of reading water quality information from Coeur d'Alene lake, and other deep water lakes. The end result then should be the development (key word is development, not completion) of a submarine that can provide autonomous deployment within Coeur d'Alene lake and other deep water lakes. Reservoirs are also desired as well, which can be fairly difficult to navigate due to the problematic kinetic nature of the environment. This in turn allows public to the supervision of water bodies in local communities as well. The results from such surveys conducted by the drone will be shared with other interested stakeholders, this will include the Idaho Water Department of Environmental Quality (IDEQ) and Coeur d'Alene Tribe.

The research focuses on creating and/or starting beginning development into the infrastructure of an autonomous submarine (and sensor technologies). Thus the long term goal is a fully functional autonomous submarine that can collect water quality data in deep-water lakes and reservoirs. The short term goal is to develop the "CDA Catfish", submarine that can perform underwater surveys by continuously sampling a variety of water quality variables (oxygen, pH, temperature, etc).

Interested parties/sponsors for pursuing this research include the Idaho Water Resource Research Institute, the United States Geologic Survey, and the University of Idaho. The research is also in cooperation with Gizmo, Coeur d'Alene Maker Space.

Documentation and code for the project can be found at https://github.com/TimetoPretend54/The-Coeur-d-Alene-Catfish

1.3 Document Purpose

This document is a research portfolio for the University of Idaho Research Project for the Computer Science Department pertaining to underwater autonomous navigation. The purpose of this documents is to outline the methodology, design, decisions, evaluations, and to keep a record of this project. It defines the terms used, outlines the scope of the project, details of specific design choices, meeting minutes, project learning, design goals, specification and constraints, system diagrams, analysis of alternatives, engineering modeling, manufacturing/assembly plan, experimental design, data analysis, balance sheet, and other items.

1.4 Definition of Terms

- **G2X** - A remotely operated underwater vehicle developed by Gizmo-cda, a makerspace located in Coeur d'Alene Idaho. The vehicle itself operates with 5 thrusters, with a Raspberry Pi (Model 3) as the SBC (Single Board Controller), alongside additional components. Components are located within the navigation module of the G2X. The vehicle can be operated via a controller (using the Pygame Python library and a Playstation 4 Controller), requiring a tether (handling gear) to provide the input, or can be run autonomously with a program, running on the G2X's Raspberry P (no tether), or a host computer (tether required). Operational Time is 6 hours on full charge, thrusters and raspberry pi operate on separate batteries, 8 hours for Pi, 6 hours for thrusters.Software for operating the software is provided courtesy of Gizmo, located at https://github.com/gizmo-cda/g2x-submarine-v2
- **Navigation Module** - Module located within the G2X that houses the the primary components of the vehicle, components are a Raspberry Pi 3, PiSenseHat (sensor module that includes internal pressure, temperature, compass, accelerometer, and gyroscope readings), a PWM Hat (for handling the PWM thrusters), an Arduino Nano for reading voltage, 5 Electronic Speed Controllers (ESC), a power regulator, pressure, temperature sensor for external treadings, and a Pi Camera V2 NoIR (video streaming).
- **ROS** - Robot Operating System. It is a robotics middle collection of software frameworks for robot software development. ROS Node is just an executable file within a ROS package, utilizing the ROS client library to communicate with other nodes (https://en.wikipedia.org/wiki/Robot_Operating_System)
- **Raspberry Pi** - Single Board Computer (SBC) that is a small, compact (about the size of credit card), and affordable computer that promotes a wide variety of applications. The Operating System (OS) that runs on the Pi is Raspberian, which is based on the Debian operating system (Linux Distribution). (https://en.wikipedia.org/wiki/Raspberry_Pi)
- **Arduino** - Open source computer hardware and software company, project, and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and

control objects in the physical world
(https://en.wikipedia.org/wiki/Arduino)

- **Handling Gear** - Gear and metal frame for lowering the G2X into the water (via a wench), a fiber optic tether that provides video streaming, alongside controller output (Playstation 4 Controller). The gear provides simple switches for retracting and extracting both the wench and tether. Powered by a 12V car battery, and operational for more than 36+ hours. The handling gear has the communications module attached.
- **Communications Module** - A module that houses an additional raspberry pi, the module is a network interface for transferring data between the G2X and a host computer. It contains the Pi, external pressure/temperature sensor, 1 GB fiber optic media converter, 4-port GB switch, Wide-angle camera, real time clock, power supply (12V from handling gear).
- **TurtleBot** - TurtleBot is a low-cost, personal robot kit with open-source software. With TurtleBot, youll can build a robot that can drive around, see in 3D, and create applications.The TurtleBot kit consists of a mobile base, 2D/3D distance sensor, laptop computer or SBC(Raspberry Pi), and the TurtleBot mounting hardware kit.
(https://wiki.ros.org/Robots/TurtleBot)
- **Octomap** - An efficient probabilistic 3D mapping framework based on octrees. It is a ROS Library that implements a 3D occupancy grid mapping approach providing data structures and mapping algorithms in C++. The map implementation is based on an octree (tree data structure in which each internal node has exactly eight children).
(https://wiki.ros.org/octomap)
- **Moveit!** - A motion planning framework.It is a software framework for mobile manipulation, including utilizing advances in motion planning, manipulation, 3D perception, kinematics, control and navigation. Thus providing a simple platform for developing robotics applications.
(https://moveit.ros.org/)
- **SLAM** - Simultaneous localization and mapping. SLAM is a computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it. There are several algorithms known for solving it (at least approximately).
(https://en.wikipedia.org/wiki/Simultaneous_localization_and_mapping)

1.4.1 ROS - Additional Info

The Robot Operating System contains many essential features, including: hardware abstraction, low-level device control, message-passing between processes, and package management. ROS nodes are written in either C++ or Python. ROS is primarily supported on Ubuntu Linux, with other major OS being designated as "Experimental". The underwater research project will be using ROS Kinetic Kame (2016) as its ROS version, due to its supported features and stability.

2 Meetings and Minutes

Weekly action items and summaries of progress made are detailed below. Furthermore, subsections discuss what was helpful and what was not during these meetings. Discussion of attendance and participation, as well as contribution and discussion topics are discussed below.

2.1 5/15/2018 Team Meeting 1 Notes

Adrian and Samantha present at 9:00 am, Dr. Shovic joined at 9:03 am. Meeting was held at the Innovation Den in Coeur d'Alene, everyone was accounted for and prepared. Purpose of the meeting was to discuss beginning of the research project, to outline goals, expectations, and any other additional information required to start the research project.

Project Scope Breakdown (Dr. Shovic, Adrian, Samantha started 9:05 am):

- Submarine Delivery
  - Submarine in Gizmo office
  - Will be delivered tomorrow
    - Keep submarine in lab
- Notebook
  - Samantha and Adrian need one
- Research
  - Need to write a research paper
  - At end of summer
  - All teammates
- Logbook
  - Need to write about everything done to submarine
  - Clearly designed and obvious
- Three Main Items to Research
  1. Do Field Trials
     - June = testrun of Gizmo Submarine
     - July = team software running on it
  2. Get Team's Software Running on Submarine
  3. Fully Document Submarine

    - Research Paper

- Goals
  - Adrian - head of project
    * Allocate resources to make goals
  - Get current toolchain working (Gizmo)
- Documentation
  - Essential for project
  - Set up our own Google Drive for University of Idaho Catfish
  - Blank documents for what we know we need
  - GitHub Repo
  - Research portfolio
  - Operations manual
  - Need good documentation as Submarine may be senior project for next academic year
  - Document Sub-systems of submarine
- Cooperate
  - University of South Dakota has expressed interest in similar research
- Events
  - Bayview visit, Dr. Shovic will be visiting next week on Monday
  - 26th of July
    * Vice President of Research
      · Presentation for her
    * Schedule when Field Tests Occur
      · July 24th = Trials
- Architecture
  - Graphic with items labled on it
  - Two types:
    1. With downward camera
    2. Without downward camera
- Trials

1. June-Week of the 25th
   - Provide more for operations manual and get experience
2. July - Late July (25th)
   - Alternative Date: August 8th
   - Also still tethered
3. So what for 2nd Field Test?
   - Some amount of autonomous navigation
   - No GPS system at that point

- Submarine
  - Sensors, communicator, actuator
  - Sensor
    - Camera in front
      - Edited a lot, multiple resolutions
      - Have 2TB disk on hand
    - Compass/Accelerometer
      - Next to useless
      - Due to metal casing
    - Sonar
      - Need to look at research papers
      - Four sonars? (up, down, left, right)
      - Up = GPS station keep (water drone with GPS receiver)
      - Listen to sonar and center itself
    - Acoustic Modem (ACM)
      - Status data up
      - GPS data down
      - 30 k/bits a second or 90 k/bits
      - Might be able to use as navigational thing
    - Before 2nd Trial
      - 100 ft range with these sonars - Can we test?
      - Large water through?

        - Not large enough or submarine likely
        - But can test sonars at least
  - Document all the wires
- Pod
  - Built by folks in Boise
  - Wireless interference from pod to submarine is a concern
  - Create software to communicate data (bi-directional link)
  - Arduino for Pod
    - Thus don't need ROS for Arduino
    - TCP/IP packet data sending
    - 1,024 bytes of data packages
  - RPI (Raspberry Pi 3)
    - Wifi
      - 2.4 GHz
      - highest water absorption frequency
      - Tens of centimeters
    - Wifi Arduino Shield on Arduino (Pod)
      - Where data comes from
  - Metal Issue
    - Nothing can transmit in/out usually
    - Piece of metal between submarine and pod
      - Maybe cut out circular hole in metal probably?
  - Accuracy for sensors in Pod
    - 10 Bits
  - Prototype GPS data to submarine through laptop
- Effort
  - Take a look at: Drone Controller Cards
    - Card that stabilizes drone
    - Corrects yaw, roll, pitch
    - Keep submarine flat

- Submarine will act like a flying drone (just underwater)
- Interfaced with ROS

- Will have accelerometer
- Simplify control system

- Research Questions
  - How the heck can we build a navigation system (with a cheap sonar)?
  - Debugging?
  - Implementing full tool-chain
    - Turn into ROS interface
- Boise - Conference Call
  - Next Wednesday May 23rd
- Other Questions
  - What type of computer?
    - Which OS, specifications, required software, etc?

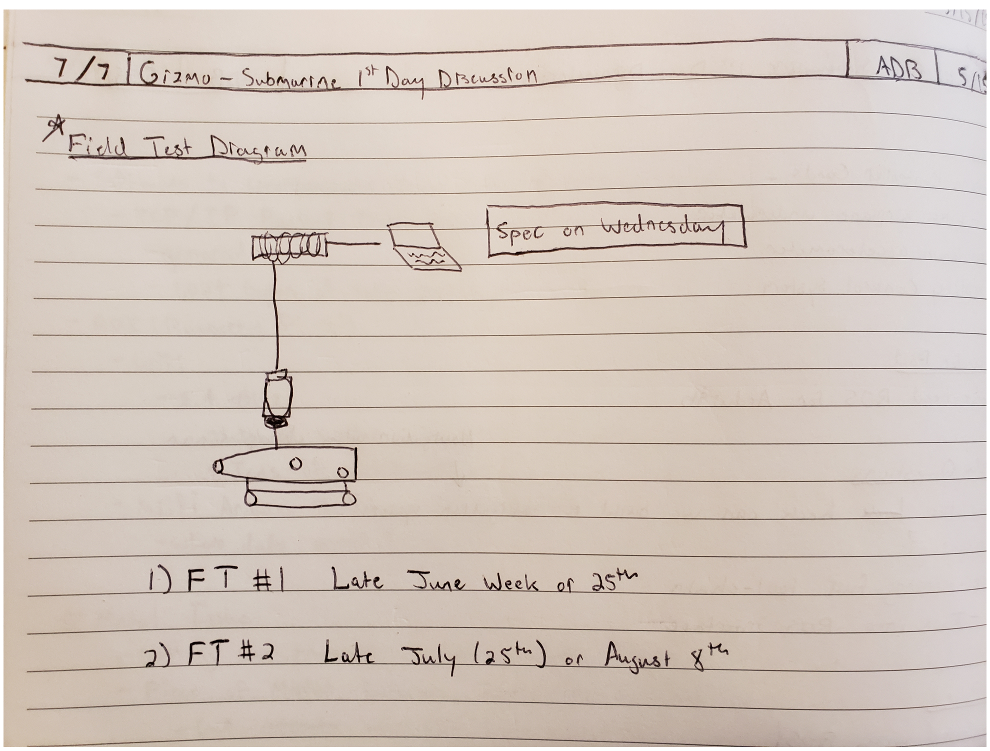

Figure 1: 5/14 Field Test Diagram

Meeting concluded at 11:00 am

2.2 5/24/2018 Team Meeting 2 Notes

Adrian and Samantha present at 9:30 am, the meeting was held in the classroom at the Innovation Den, Dr. Shovic arrived at 9:29 am. Meeting attire was required to be professional/formal, thus both teammates wore appropriate attire. Meeting agenda were printed out beforehand to keep meeting organized and structured.

The purpose of the meeting was to discuss ideas about the project, such as the acoustic modem, GPS system, water tanks, laptop specs, Wi-Fi in water, sonar sensors, Gizmo assistance, and budget decisions.

Meeting began at 9:31 am, everyone present, with printed meeting agendas for everyone

- Requirements for Catfish Logo
  - Clean and abstract
  - University of Idaho "I" logo involved
  - Needs to be easily recognizable to "know" submarine
  - Mascot = catfish (maybe think like GitHub)
  - Color and black and white versions
  - Decal on side of submarine
- Awareness of Project
  - Scientific vs creative
  - Depends on the environment
  - Scientific community vs general public
- Bayview - Submarine Tour
  - Tours only for American citizens
  - Huge submarines (20 ft long)
  - Project with them?
    - Maybe, they have fully autonomous submarine
    - Navigation, buoys hung 3-4 miles under lake, it gets GPS signals from them and send the data to the submarine
    - Trilateration to determine submarine location
    - Use their system to navigate the Gizmo submarine
    - Very difficult to get research money
    - Office of Naval Research

- DIY Boat
  - Took boat of some kind
  - Circular boat with four propellers
  - Maybe just provide a design/feasibility of building one
  - Propellers separated by 90 degrees
  - Four motors allows to stay in one position
  - Need to know feasibility but not practical/physical use (block diagrams)
- Sonars
  - Naval Base might be able to donate sonars
  - Have currently 3 Maxbotix sonars, need 3 more
  - So 6 total sonars (up, down, left, right, forward, backward)
  - 3D print sensor holders
  - Need to publish/subscribe all of them
- Acoustic Modem
  - Want it on the boat when launching submarine
    * Wi-Fi connection on boat?
    * 1-Mile connection
  - Simulate:
    * Functions receives info
    * Receives info from socket
  - Modular manner (one routine and swap it out)
  - Idea:
    * Analog to digital
    * Transmit low data
    * Sonar ultrasonic sensors
    * Ultrasonic transducer?
- Water Tank
  - Get water tank (small)
  - What about docking?
  - Will have to determine a location

  - Gizmo tank will be best!
- June Trial
  - Figure out where we want to take it
  - So need Field Test 0!
  - Launch before June 26th for testing
- Laptop Specs
  - Get laptop ordered ASAP
  - Have Tim set it up (Ubuntu 16.04, ROS, Gazebo, Octomap)
- Available Wires for Submarine
  - Three to four needed for Acoustic Modem
  - Two lines for sonar sensors
  - Two antenna lines (sensor pod)
  - One external Wi-Fi antenna
  - Twenty three extra wires
- Wi-Fi
  - Arduino Wi-Fi shield good to go!
  - Need peer-to-peer connection
  - Need another Wi-Fi dongle with external atenna
- Goals
  - Capability, NOT complete product
  - Demonstrate some Autonomous Navigation
  - Expected results: capability and results!
  - Design and document: future

Meeting concluded at 10:50 am

2.3 5/31/2018 Team Meeting 3 Notes

Adrian and Samantha present at 9:27 am, the meeting was held in the classroom at the Innovation Den, Dr. Shovic arrived at 9:28 am. Meeting attire was required to be professional/formal, thus both teammates wore appropriate attire. Meeting agenda were printed out beforehand to keep meeting organized and structured. Had some printer errors for the agendas however, team had to reprint the agendas.

The purpose of the meeting was to discuss the operations manual, the media event, upgrading the raspberry pi, and discussing the sensor pod. Also during the meeting address the sonar ideas about the submarine. Adrian provided handouts/diagrams about the sonar ideas. During the meeting went onto discuss the ideas of sonar and how to properly get data and properly navigate with it.

Meeting began at 9:15 am, everyone present, with printed meeting agendas for everyone. Ready for the meeting again, team is formally dressed.

- Next Wednesday
  - Status meeting next week
  - Water through
- Operations Manual
  - Get done by next week
  - Need to have some assistance from me
- Media Event
  - Field Trial One
- Wi-Fi Side
  - Sensor pod being developed
  - PVC pipe
  - Two plastic pipes (make Wi-Fi transmission better)
  - Metal bottom of submarine (issue)
- Raspberry Pi 3B+
  - Currently have Raspberry Pi 3B, the "+" version provides a slightly higher clock rate
  - Also need to upgrade to Raspbian Stretch (currently sub is running Jessie)
  - Duplicate current image of submarine SD card
- Sensor Pod
  - Arduino AtMega2560 (tons of I/O)
  - 8K of RAM

Meeting concluded at 10:20 am

2.4 6/5/2018 Team Meeting 4 Notes

Adrian and Samantha present at 9:27 am, the meeting was held in the classroom at the Innovation Den, Dr. Shovic arrived at 9:28 am. Meeting attire was required to be professional/formal, thus both teammates wore appropriate attire.

The purpose of the meeting was to discuss the operations manual (software side), discuss some short-term goals, current GitHub, a voltage monitor, taking apart the submarine, discussing trials next week, communication Arduino and Raspberry Pi, and finally Wi-Fi testing.

Meeting began at 9:30 am, everyone present, with printed meeting agendas for everyone. Ready for the meeting again, team is formally dressed, everyone ready as ever.

- Operations Manual
  - No legal stuff need to be included in it
- To-Do
  - Add battery voltage sensors
  - Monitor voltages and current (low: 11V, high: 13V)
  - INA 3221 Grove Board
    - Monitor current and voltage
    - Measuring voltage possible
    - Current difficult to measure
- GitHub
  - Clean up code and put additional items in
- Next Week
  - Take tube out (where all components are)
  - Anything we do
  - Labeled neatly and clearly
- Software Operations Manual
  1. Current Software
  2. Our Software (ROS) Version -¿ be well documented
- Next Week - Trials
  - Next Friday Field Trail 0, June 15th
  - Field Trial One (End of June)

- Code
  - Communications between Raspberry Pi and Arduino
  - TCP/IP packets
  - Or perhaps MQTT packets
  - Mosquito on Raspberry Pi (publish/subscribe system)
- Field Trial One
  - Arduino in battery and baggie
  - Strap it on the bottom of submarine
- Test Raspberry Pi Wi-Fi Range
- Ping Wi-Fi
- Need to carry submarine around!
- Will tell us how "leaky" the signal is

2.5 IWRRI Meeting - July 26th Launch Discussion

Meeting located at the Harbor Center, Adrian and Samantha arrive at 10:00 am, the meeting was originally held in room 242 at the Harbor Center. Other guests were Charles Buck, Alan Kolok, and a few other individuals. However, Alan did not arrive on time, and was supposedly going to be 20 minutes late. Thus, we first went out to the dock at the Harbor Center and examined the boat. Then after 20 minutes Alan arrived.

The purpose of the meeting was to discuss the operations and schedule for the July 26th launch. In particular discuss guests, procedures, timing, location, and other details.

Once Alan arrived we all sat outside on a table by the dock and the official meeting began at 10:20 am.

- Operations Manual
  - No legal stuff need to be included in it
- To-Do

  Meeting concluded at 10:50 am

3 Project Learning

Technologies used to solve problems are described below. Further discussion of these technologies are left in each section's subsections.

4 Design Goals

Client needs and project goals are discussed below. A Timeline for these is also included. Discussion of revision of goals, and addition of any new goals is also discussed below.

5 Specifications and Constraints

Discussion of client interviews, pictures, measurements, etc. are provided below. Design specifications and constraints are also presented. Reasoning for any constraints is also mentioned.

6 System Diagrams

Discussion of symbols used, the diagrams themselves, and the software used for the diagrams is discussed below.

7 Analysis of Alternatives

Discussion of possible alternatives and why some alternatives are better is described below. These topics include: safety, moving parts, cost, durability, compatibility, and reliability.

8 Engineering Model

Discussion of the physical, chemical, and biological system modeling. Also discusses modeling criteria, expected accuracy, and pitfalls. Section of modeling software used is present, as well as data needed and how the data was obtained. Lastly a validation scheme for the model is shown.

9 Manufacturing/Assembly Plan

Discussion of the fabrication need, a flowchart of process oriented projects, a bill of materials, and the estimated manufacturer and delivery time is discussed below.

10 Experimental Design

The characterization of the purpose of the experiment, model validation, data gaps, and performance measurement are discussed below. Also the details on documentation, instrumentation, and measurements are also described.

11 Data Analysis

Documentation on statistical tools used, accuracy of data, and experiments shown below. Discussion on confidence is results also discussed below.

12 Balance Sheet

Discussion on initial budget, estimated cost for materials, components, labor, and spending plan are all described below.

13 Other Items

File management, archiving, documenting any issues, reports of accidents/incidents/near misses/precautions are described below.