Autonomous Hydrographic Survey Vessel

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I. Introduction

The goal of this project is to develop an autonomous boat that can be used for taking depth measurements of a body of water. The Tennessee Tech Water Center requires an inexpensive alternative to the commercially available options. The solution is to design a boat either from scratch, or using hardware and components that the Water Center is already using for this purpose. Designing a new boat entirely provides a solution to the expensive cost by building only the features that are needed specifically by the Water Center, as well as adding a reproducibility feature that will allow the Water Center or other organizations to reproduce this boat fitting only their needs. The boat will comply with the following specifications. These are consistent with what the Water Center is expecting and they provide the ability to take depth measurements autonomously, which allows for easier use by the technicians.

The boat will be no smaller than 3 feet by 2 feet, and it will be no larger than 5 feet by 3 feet. This is to allow for easy transportation and high maneuverability in the water. The boat will be able to carry a load of 10-20 pounds, which includes the hardware and circuitry. The boat will be able to travel slow enough to collect viable data, but also fast enough for normal travel on the water body. The battery life of the boat needs to be long enough that Cane Creek Lake, a body of water approximately two million square feet in size, can be completely measured in one attempt. The battery life suggested by the Water Center is one hour. This battery life will serve as the starting point for battery size and power consumption, and will be the minimum requirement for the battery. The boat will be designed with as long a battery life as is physically and financially feasible, but will be required to be at least one hour. If it is determined that Cane Creek Lake cannot be fully measured in one hour, then the design of the boat will be updated to increase the battery life as necessary. The number of completion attempts required for any body of water is dependent on both the battery life and the data collection speed.

The boat will also transmit the depth measurements it takes in a live data feed to the on-site technician for monitoring. This is for the technician to ensure that the data the boat is collecting is valid data and does not run unnecessarily for a long time, collecting invalid data. In the event that the data being transmitted from the boat is invalid, the technician will have an option to abort data collection remotely. This allows them to analyze the issue and either reset the data collection process, or choose to fix the system off-site. The boat will be able to withstand slight weather problems, such as light rain or wind, but it will not need to be in operation when weather is severe.

The current methods and techniques used to take depth measurements are inefficient, time-consuming, or too costly. These methods include manual measurements, manned HSVs, remote-controlled HSVs, and autonomous HSVs. Manual measurements are typically taken with a weighted line or a measuring rod. This is very labor intensive and prone to human error. Depending on the size of the body of water, it could take several days to collect all of the necessary data. The resolution of the data is also too low to create a useful bathymetry map.

Using a hydrographic survey vessel allows more data to be collected at a fraction of the time. They are equipped with sonar technology and a GPS system in order to accurately measure depth and location. HSVs are rather large in size since they are commonly used for oceanic bathymetry. Because of their size, it is difficult to use these HSVs to navigate smaller bodies of water.

To fix the navigation problem, there are remote-control HSVs that are much smaller in size since they are unmanned. They can maneuver through smaller bodies of water much easier and they can still take accurate depth measurements. However, the issue with these HSVs is that they are very costly and prone to human error.

This is where the autonomous HSVs come in. They are able to efficiently collect accurate bathymetry data without the need for human input. These boats are too costly for the purposes of the Water Center which is why this project has been undertaken. The goal is to provide a low-cost, error-free, autonomous hydrographic survey vessel.

This document provides the full scope of the what this project entails. It also serves as a guideline for taking steps to complete the project.

II. Ethical Considerations

With the process of designing autonomous machinery, it is crucial that every possible scenario is taken into consideration. This boat will be operating without close supervision, so every safety concern must be addressed before it is placed in the water. One of these concerns is the potential risk of a short circuit leaking current into the body of water. The boat will operate on a battery with a voltage range of 12-24 V. While these voltage ranges are not an issue on land, the resistance of the human body drastically decreases from as high as 100 kΩ to 1 kΩ in water according to the National Institute for Occupational Safety and Health (NIOSH) [1]. A current of 10 mA in the water is enough to cause paralysis in water, which can result in Electric Shock Drowning (ESD) [1]. 100 mA of current is considered fatal in freshwater. Based on the limited research found about ESD, the amount of current present in the water due to a potential short circuit is currently inconclusive; therefore, current leakage will need to be addressed [1]. To rectify this issue, there will be a breaker system that will detect any overload and short circuit and turn off the boat to eliminate any risks of ESD.

Furthermore, additional safety protocols must be taken in regards to people, animals, or objects, within the vicinity of the boat. The team will be creating an obstacle avoidance program that will update the boat's mapped course to avoid contact with any object in its path. If there are any potential scenarios that the avoidance program could not detect, there will be an abort feature that will cease all automated controls, and the boat will then be control via the team on land with a remote control.

An objective heavily emphasized by the Tennessee Tech Water Center is that the bathymetric boat must be cost-efficient and easily replicable for any communities interested in using this project to take their own data measurements. While some materials are already provided by the Water Center (e.g., Bathymetric sensors), it will not be guaranteed that these materials will be within other teams' budgets. The team will create a system that will operate with any sensor. The data points received by the GPS and sensor will be sent to a microcontroller, which will then be sent to the team on land rather than relying on certain components that are already equipped with that feature. Additionally, any programming created will be created using open-sourced software. This will allow teams to add any modifications that they see fit within the scopes of their projects at no cost. Other communities can also provide feedback to the team to help further improve the optimization of the boat.

III. Block Diagram Descriptions

A. *Wireless Observation of Data Collection*

To meet the requirement to observe data in real-time as it is collected, a system will be designed to collect the measured data and transmit it to a local computer system so it can be viewed by the user.

1) Data Transmission Module

a) Transmission Microcontroller

A microcontroller will be used to read serial data from the depth data acquisition system and to control a radio frequency module that transmits a radio wave encoded with the collected data. Analysis of this system will include verifying that the selected microcontroller can read the serial output of the acquisition system. Confirming that the specific use case aligns with the manufacture's intended use will ensure that the desired functionality is achieved. Functionality will be verified by connecting a controlled serial input identical to the serial output of the acquisition system and testing for correctly transmitted data samples.
Input: USB connection to a serial port on the depth data acquisition system, 7-12 V [2]
Output: Collected serial data samples

b) Radio Frequency Transmitter

A radio frequency transmitter module will receive serial data from a microcontroller and transmit a message signal encoded with collected data. The transmitter will have an open-area transmission range of around 1 km. Analyzing data sheets and validating that the specific use case aligns with the manufacture's intended use will confirm the products applicability. Transmission experiments at varying distances and positions will confirm that data is being transmitted correctly.
Input: Data encoded message sequence, 3.2 - 5.5V, 200mA [3]
Output: 433.4 - 473.0 MHz message signal

2) Data Reception Module

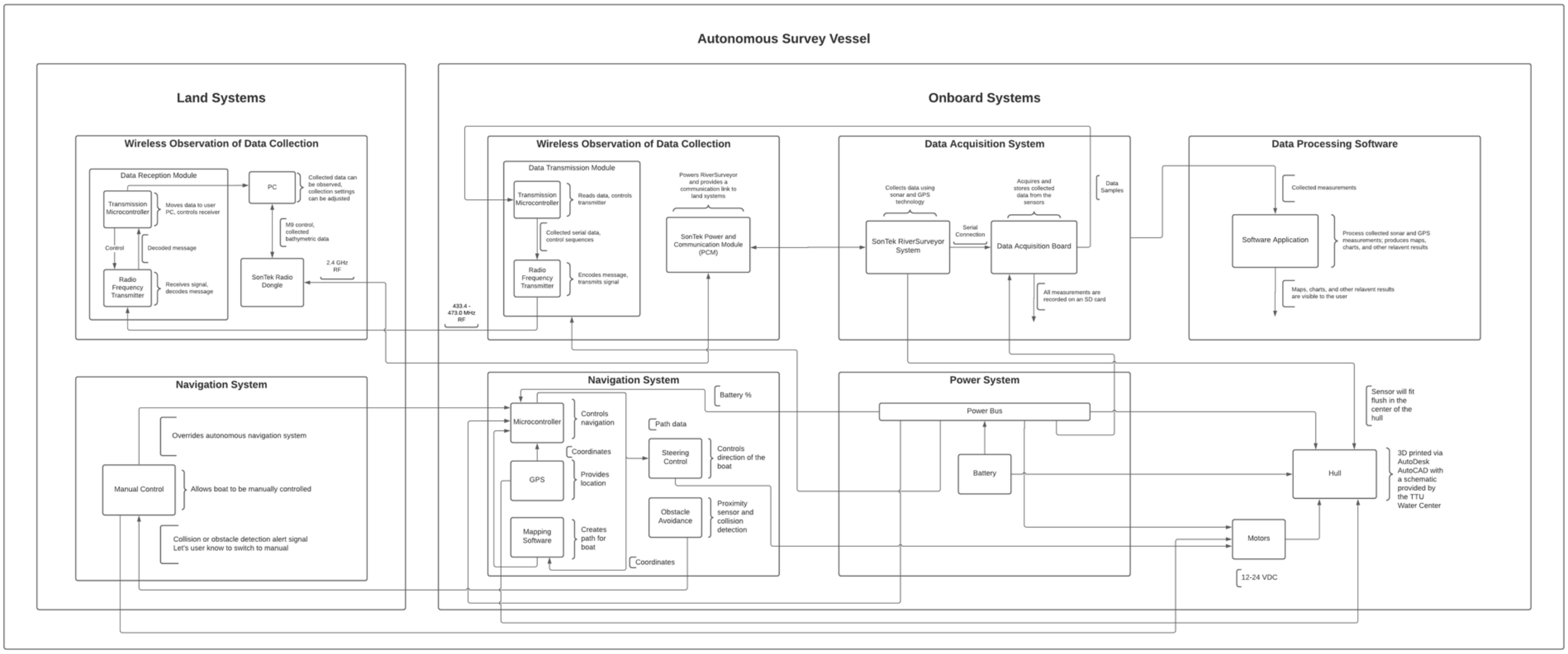
a) Radio Frequency Receiver

A radio frequency receiver module will receive a message signal encoded with collected data and will decode the signal to extract the measurement data. Analyzing data sheets and validating that the specific use case aligns with the manufacture's intended use will confirm the products applicability. Transmission experiments at varying distances and positions will confirm that data is being received correctly.
Input: 433.4 - 473.0 MHz message signal, 3.2 - 5.5V, 200mA [3]
Output: Decoded measurement data

b) Reception Microcontroller

A microcontroller will be used to control the radio frequency module that receives an encoded radio wave. The microcontroller will transport the received measurement data to a connected computer once it has been decoded. Analysis of this system will include verifying that the selected microcontroller can decode the received data and write it to the user's computer in a way that is readable and intuitive. Confirming that the specific use case aligns with the manufacture's intended use will ensure that the desired functionality is achieved. Functionality will be verified by sending a controlled RF message signal identical to the message signal of the transmission circuit and testing for correctly received data samples.
Input: Decoded measurement data, USB communication line to a computer, 7-12 V [2]
Output: Samples of data collected by the depth data acquisition system

Block Diagram



3) <u>SonTek Power and Communication Module (PCM)</u>

A power and communication module will be used to create an additional communication link between the onboard acquisition system and the PC on the land. The PCM unit will be on the boat and will provide power to the onboard sensor and GPS. The PCM unit is manufactured with two battery compartment packs that hold 8 AA batteries each. For the convenience of the user, the PCM will be powered with the AA batteries instead of the onboard power system. This allows the user to insert the batteries into the battery pack before going into the field and simply load the PCM onto the boat. This alternate power option was addressed due to the attention of Team 1 during the presentation of the design. The onboard PCM will transmit collected data to the SonTek radio dongle on the land via 2.4 GHz radio and the dongle will be connected to a PC running the processing software. Confirming that the specific use case aligns with the manufacture's intended use will ensure that the desired functionality is achieved.

B. Data Acquisition System

This system will receive input from the sonar sensor and the GPS system in order to record depth measurements along with their location. This data will then be stored in an SD card to be processed.

C. Data Processing Software

1) <u>Data Acquisition Board</u>

This system will receive input from the sonar sensor and the GPS system in order to record depth measurements along with their location. This data will then be stored on an SD card. Samples of the collected data will be transmitted by the designed data transmission module. Analysis of this system will include verifying that the acquisition board can handle the serial output of the acquisition system. Confirming that the specific use case aligns with the manufacture's intended use will ensure that the desired functionality is achieved. The analysis will be confirmed by verifying that the data stored by the board matches controlled serial input.

2) <u>SonTek RiverSurveyor System</u>

This system will acquire bathymetric data using a 9 beam sonar system and a high precision GPS. System power will be provided by the onboard PCM unit, and collected data will be both stored by the acquisition board and transmitted via the PCM radio link. This product will be utilized according to the manufacturer's documentation on the system, and the analysis conducted by the vendor will be referenced as the system is implemented.

D. Power

A single battery will provide power for each system on the vessel, and the appropriate power will be distributed through a power bus. The battery used for the boat will be decided by a series of analytical tests calculating Watt-hours. The mathematical model will receive as input the load on the battery, the type and size of the battery, and calculate approximate battery life. The necessary size and type of battery needed to meet the boat's specifications will be determined by applying approximate load values from each system to the model, evaluating the results, and comparing the results to the desired behavior.

The power bus will distribute power to the data acquisition system, the propulsion system, the navigation system, and the transmission system. The data acquisition system will require approximately 10-20 VDC [4] and will send the depth data from the sonar device to the transmission block for the live data stream. The propulsion system will require approximately 12-24 VDC [5] and this will be adjusted by the steering control system to change the motor speed depending on the current direction. The navigation system will require approximately 10-20 VDC and will also receive input from the microcontroller to maneuver the boat.

The microcontroller will keep track of the current power level of the onboard battery. If the boat is still in autonomous operation when the battery level begins to drop below a percentage that risks the boat being left inoperable in the water, the boat will automatically stop data collection and begin navigation back to the starting point. This issue was addressed due to the attention of Team 1 during the presentation of the design.

E. Navigation

The navigation portion of this project will be responsible for creating a path for the boat to travel for data collection. A map of the body of water will be generated either by satellite imaging or by having the boat travel around the perimeter of the lake to obtain boundaries. The boat will travel in parallel lines in order to efficiently collect depth measurements.

1) Microcontroller

In terms of navigation, the microcontroller will receive inputs from different components and software. Data from the GPS, mapping software, steering control, etc. will then be used to control the direction of the boat as it travels along the generated path for data collection. The starting point will be stored by the microcontroller so that the boat can return to the user after the boat has finished collecting data. In the case of the boat having low battery, the software will remove all other waypoints in the path except for the starting point. The boat will then use the remaining battery life to return to the user. This issue was addressed due to the attention of Team 1 during the presentation of the design. The functionality of the microcontroller will be tested by ensuring that the desired outputs are provided with a given input. For example, if the boat steers off the path, the output from the microcontroller to the motors will need to be measured. These outputs will be analyzed to determine if they are sufficient for adjusting the direction of the boat. This testing process will be done for each input and output that the microcontroller receives and sends. Multiple experiments will be done to ensure that the microcontroller can coordinate each system to do what it needs to do to navigate the boat.
Input: GPS location, direction, waypoints, manual control override, battery percentage
Output: motor control, location to mapping software

2) Steering Control

The steering hardware and software will control the direction of the boat and keep it on the generated path. It will keep track of the angle at which the boat is traveling in reference to its launch point so that it will travel in parallel lines. The direction of the boat will be detected, and signals will be sent to the motors to correct the direction that the boat is travelling. This system will consist of the propellers, motors, and motor control circuits. To test that the steering system will work, the ability of each component to communicate with each other will need to be determined. The inputs and outputs of each component will need to be analyzed. Once this is done, multiple experiments will be done to verify that the steering system can control the boat. This will involve manually forcing the boat in the wrong direction. It should be able to correct its direction and put itself back on the correct path. Multiple experiments will be required to ensure that the steering system functions properly.
Input: direction
Output: motor control

3) GPS System

For the GPS system, it will need to be much more accurate than a typical car GPS. The required accuracy will be determined by the Water Center. The most likely choice for a GPS will be a Real-Time Kinematic Global Navigation Satellite System (RTK GNSS) receiver [6]. These can detect locations that are accurate to a few centimeters. This will allow the boat to follow the generated path very closely. The GPS data will be sent to the mapping software and the steering control to create a map for the boat and to control the direction of the boat. The GPS system will be tested by observing the format of the output data to determine if the mapping software is capable of processing that data. An experiment to test the system will consist of manually placing the GPS system in different locations while observing the information that is being sent to the mapping software. This experiment will be repeated until the system is deemed to be reliable.
Input: GPS satellite information
Output: location

4) Mapping Software

For this project, there will need to be software that generates a map of the body of water and creates a path for the boat to travel. The software to receive GPS coordinates for the boundary of the body of water. This boundary will be used to generate parallel lines for the boat to travel for data collection [6]. To test the mapping software, the output from the software to the microcontroller will be analyzed. The data will need to be compatible with the microcontroller so it can process the information and send instructions to the steering software. Multiple experiments will be done to test the software. Experiments will be conducted where a map will be generated by the software and movement of the boat will be observed to see if it matches the generated path.
Input: GPS location

Output: waypoints

5) *Obstacle Avoidance*

The boat will need to avoid any obstacles that are not accounted for when the map is generated. These include rocks, people, and animals. There will be a proximity sensor and a collision detection system on the boat that will detect obstacles in the water. If an obstacle is detected, the autonomous navigation system will be temporarily halted and switched to manual control. An alert signal will be sent to the user, and they will need to then find the boat so they can manually drive the boat around the obstacle. The boat will then be switched back to autonomous control and the boat will continue to travel on the set path. Multiple tests will be done to ensure the functionality of this system. The proximity sensor alert will be tested by placing objects near the sensor to observe if the alert signal is received and heard by the user. The collision detection will be tested by suddenly stopping the boat while it is moving to observe if the alert signal is received.

Input: proximity sensor, collision detection

Output: alert signal

6) *Manual Control*

The boat will need to be manually controlled in certain cases. If it is required for the boat to trace the perimeter of the body of water to generate a map, it may be necessary for the boat to be driven manually. In the case of a malfunction of one of the navigation systems, the boat will be switched to manual control. For obstacle avoidance, the boat will need to be switched to manual control so that the boat can be driven around the obstacle. Multiple tests will be conducted to ensure that the manual control functions properly. To test the functionality of the manual control system, the input signal from the remote control will be observed to determine if it can properly control the boat. Testing will also be done by switching the boat to manual control after it has already begun collecting data. The manual control system should override the autonomous control system without any interference with the data collection process and the mapping software.

Input: manual control switch

Output: motor control

F. *Physical Structure*

This section will discuss the physical characteristics and traits of the construction of the boat.

1) *Hull*

The hull of the boat is responsible for protecting the components that will be used to take bathymetric measurements. It will be 3D printed via AutoDesk AutoCAD with a schematic provided by the Tennessee Tech Water Center. The team can modify the original CAD file if the team believes this would be beneficial to the boat's overall performance.

2) *Configuration*

This section will provide insight as to how the individual components are configured inside the hull. Further details will be provided after meeting with Dr. Kalyanapu on Tuesday October 19, 2021 where previous iterations of the boat could be observed and schematics could be given.

IV. Gantt Chart

The chart below details the schedule that we will follow in order to complete this project.

References

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