Coral Tile - CSE 145 Final Report

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Contents

1 Abstract

A significant challenge in the 3D mapping of coral reefs is geospatial positioning. Currently, depth and orientation data must be recorded manually by divers wearing dive computers. This process introduces the potential for measurement error, data loss, takes extra time, and separates the spatial data from the 3D maps. The Coral Tile is a tablet-like device which offers a better alternative to this process. It can be placed in the mapping area and will display relevant spatial information on a large screen, which would be recorded into the map imagery, embedding spatial data directly and permanently into the 3D maps. This new automated process forgoes the need to manually record or save data elsewhere, simplifying and speeding up the mapping process.

Figure 1: First Prototype

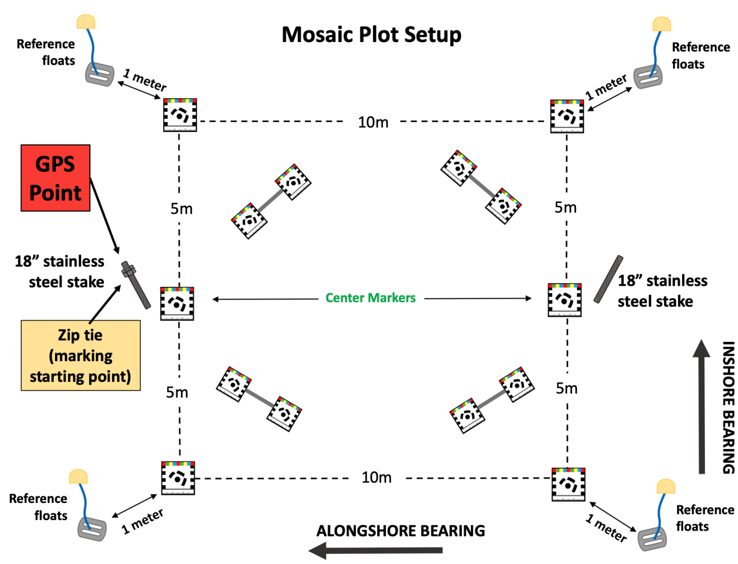

Figure 2: Mosaic Plot Setup

2 Introduction

Coral reefs are a vital part of marine ecosystems. Coral reefs can be likened to rainforests, as they harbor a staggering amount of biodiversity and contribute to the overall health of the planet. Coral reefs provide shelter for millions of aquatic species and are a critical source of food for many communities. They also provide a barrier from erosion. Their significance cannot be overstated, as their effect on the ecosystem far exceeds their direct effects or their direct economic impact. For these reasons, coral reef conservation is extremely important. [1]

Coral reefs have been experiencing an uptick in the frequency of events known as "bleaching" for over four decades. [2] These events are triggered by warming temperatures and often result in the loss of otherwise perfectly healthy reefs. Coral are not a single organism, but are themselves a microcosm of many different organisms. The structure of a coral is provided by a calcium deposit layer and the living part of the coral consists of a colony of polyps and a symbiotic algae that resides inside them. These algae are a vital source of food for the coral, but when waters warm, they flee the coral - leaving the coral starving and un-protected from radiation. These bleaching events have become more common over the last several decades as a direct result of the warming of the oceans.

An important aspect of coral conservation is the monitoring of reefs. Monitoring and tracking changes over time is a necessary part of the research process as it helps researchers build an understanding of reefs. The 100 Island Challenge [4] is a collaborative effort based at the Scripps Institution of Oceanography to describe the variation of coral reefs from across the globe. They are adding to the body of knowledge on coral reefs by developing 3D maps of coral reefs using underwater mapping camera systems at sites that span across 100 different islands around the world.[5] During their expeditions, they first lay out a grid of spacial markers in a specific mosaic pattern (Fig. 2, then they conduct a dive in which they use sophisticated imaging equipment to generate a large dataset of highly detailed images which are then patched together by software to generate a 3D map. The imaging software and camera systems are unable to provide data about depth and magnetic orientation, so this spacial data must be recorded manually and added into the maps after the fact. This opens up possibility for human error and takes extra time to complete, and is a technological bottle neck in their workflow. An embedded and automated solution was requested by the researchers to implement a more robust process which would be less prone to errors.

The Coral Tile is an embedded device which offers a solution to this challenge. It is a tablet-like device (Fig. 1) which can be placed at key locations in the mapping area and will display relevant spatial information such as depth and magnetic orientation on a large screen. This information can then be recorded into the imagery by the mapping cameras, to embed spatial data directly and permanently into the 3D maps. The Coral Tile will also log this data in addition to collected data about temperature and various system parameters and make it accessible through a WiFi based interface. Through this process, spatial data collection can be automated, foregoing the need to manually record or save data elsewhere.

There are a number of technical challenges associated with building such a device. Environmental conditions impose a number of constraints on many of its operating parameters and implementable features. The biggest constraints are waterproofing at depth and manufacturing capability. Some solutions for these problems have been developed and an overall design has evolved around them to overcome these constraints in a mass manufacturable package.

The Coral Tile will simplify the process of orienting 3D maps of coral reefs and it will provide an example for the development other low cost embedded devices to be used in environmental research.

3 Technical Specifications

3.1 Features

Depth Measurement

The main feature of this device is underwater depth sensing, which is done using a hydro-barometer. This provides greater spacial awareness to researchers developing 3D maps of Coral reefs. The depth is displayed on an LCD in meters to an accuracy of 10cm. The depth measurement is calculated by taking a median pressure over 1 minute of data starting when the fluctuations in pressure measurement decrease to <3 meters. This is done to average out the wave height. Before the data is displayed, the screen will flash to indicate it is processing.

Magnetic Compass

A magnetic compass is utilized to provide another degree of spacial awareness in the form of magnetic orientation. On the device, this takes the form of a number representing the offset from north, relative to the top of the device. With this data, the 3D maps of Coral reefs may be more accurately positioned. This is one of the 2 primary features. The azimuth is displayed on the device. This is the positive offset from north to the top of the device ranging from $0°$ to $360°$ as is the standard in navigation. A small compass is also displayed to eliminate any ambiguity. The value displayed is updated at 5 Hz when changing or significant motion is detected, and reduced to once every 5 seconds when the value has remained stationary and no significant movement is detected in order to conserve power. For each updated value displayed, 5 measurements are taken from the magnetometer and averaged out for precision.

Large Display

A large LCD display is used to provide researchers with data that can be referenced during a dive and from within 3D scans of the Reef. The display used is a monochrome LCD similar to those found in dive computers and common LCD watches. This is used for its reduced power consumption, low cost, and long lifespan. The display is approximately 9cm x 9cm with numbers large enough to be read clearly from at least 3 meters away. Only the depth and bearing will be held to this metric. The device serial number, error code, and battery indicator will be smaller as they are not essential to underwater operations. This is a custom LCD display designed for use with a wide array of LCD drivers.

Wireless Charging

A device intended for use in a marine environment presents many challenges, but especially with respect to waterproofing and corrosion resistance. With the intent to provide greater durability and overall device longevity, this device is charged using any standard smartphone wireless charger based on the Qi standard. A dedicated Qi based IC is used for this feature. This is tightly integrated with the battery management system and utilizes a large coil to receive power. Once Qi charging is detected, wifi is enabled and data retrieval can be done. This is done as the power demands from wifi are large and will cause issues if run from the internal battery alone. After 20 seconds of charging, the wifi will be turned off. This allows for an occasional lapse in charging without risking data loss. The IC used will be a BQ51013A from TI.

Data Logging

To provide data after resurfacing, a log of data is kept and can be accessed via Wi-Fi. Data will be saved to an EEPROM chip accessible to both the main micro controller and the wifi chip allowing for wifi data downloads in a CSV format.

Wi-Fi

In order to provide data log access without compromising the waterproof seal of the device, it has been equipped with wireless data retrieval. Upon charging, it launches a Wi-Fi network through which data can be downloaded using any Wi-Fi enabled computer. Time-Stamps are given to the data when a user connects to the device through any modern browser. The users system time must be accurate to ensure the accuracy of the time stamps. This will be implemented using an ESP32 and open source code to run a server. Data will be stored on an EEPROM accessible to the ESP32 which will be available for download. This will be the only point of access for data on the device to remove all exposure to the elements.

Long Battery Life

The operating requirements for this device demand that it operate for at least 6 hours at a time. For added convenience however, this operating time has been extended to a minimum of 14 days of continuous use. With stand-by, this period is expected to be much greater. Standard Lithium Ion batteries will be used. A large capacity will ensure that the device will be usable even after years of battery degradation.

Motion Activation

As there are no buttons on this device, motion activation provides the simplest user experience with no additional risk of device degradation. Once the device detects motion, it will determine if it 1.5 meters underwater for greater than 5 seconds. If sustained water is detected, the device will fully activate and log data, if not, it will display battery level and other relevant information. If motion is not detected but the device is still underwater, the device will still fully activate as a redundancy measure. This device is fitted with an accelerometer which activates the device when it is moved. The same IC which provides magnetometer readings for compass data is also fitted with a motion sensor, so this feature will be provided at no extra cost.

3.2 Sub-System Overview

To reduce ambiguity, subsystems are referred to using names and they are outlined below. Subsystems are formed on an abstraction of components based on function. While some components are mentioned below, the components themselves are not design critical, rather the functionality they provide is.

Yosemite

This sub-system is the 'brain' of the device. It is responsible for almost all system events, with the exception of battery management. When the device is moved, an interrupt from the motion sensor wakes up Yosemite which sends reads the sensors and sends the appropriate data to the display. Yosemite also is responsible for switching on and off power to the subsystems as deemed appropriate in order to preserve power. This can be implemented using a low power variant of the STM32 micro-controller or any other low enough power microcontroller with the necessary peripherals and includes an EEPROM chip to store data.

Redwood

This subsystem is responsible for battery management including charging and safety/protections and is where the cell is contained. In the event of overheating, a short circuit, or other potentially damaging events, this subsystem can restrict battery usage or disconnect the cell from the rest of the system entirely. This is implemented using 2 independent microchips for redundancy as is standard industry practice.

Alpine

This subsystem is the implementation of the Qi based wireless charging feature. It utilizes an inductive charging coil, a dedicated Qi-controller microchip, and many supporting passive components. This subsystem is linked with the Redwood subsystem as this is the only way to charge the device. This is the input for power, and every other component is downstream of this subsystem.

Lassen

This subsystem is the implementation Wi-Fi feature which utilizes an ESP32 for a cost effective solution both in terms of dollar amount and programming time. The rich community surrounding this device provides many open source solutions to this design challenge.

Sierra

The Sierra subsystem includes both the display and the the display driver. The display for Sierra is a large custom made monochrome LCD. This is similar to the displays in dive computers, although much larger for greater readability. The LCD provides data on depth, magnetic orientation, battery status, error codes, and a programmable on device serial number.

Muir

This subsystem contains all the sensors on the device. This includes at a minimum, the hydro-barometer, magnetometer, and accelerometer.

3.3 Minimum Viable Product

Figure 3: Development Platform

The first minimum viable product for the Coral Tile takes the form of an extensible mockup design with similar funcitonality (Fig. 3). This design does not include an actual sensor as it is not waterproofed, and it contains buttons on the sides to help with event triggering and mode selection. It also carries a USB plug to make programming easier. The purpose of this prototype is to enable further software development and get a feel for the product while there is no actual hardware to develop on.

Reduced Feature Set

This initial prototype contains almost all the software relevant components and has a significantly reduced feature set compared to the finished product. The WiFi functionality, wireless charging, and display are retained as well as the battery system. These elements are at the core of the device and by implementing these first, we can determine the usability of the product in general. The feedback from this device will guide future changes made to the final device.

Different Components

This initial prototype contains a heavily modified Bill of Materials and uses vastly different technologies to the subsequent runs for almost all components other than the WiFi, and main microcontroller as these are important for software development. Fortunately, the LCDs were sourced in time and are present in the device, providing an accurate portrayal of what the final device will look like. The battery is significantly larger on the initial prototype as power efficiency is not a priority, and a compromise w.r.t. battery volume must be made in order to support the less power efficient system. The motion detection mechanism is also implemented differently. Instead of using a MEMS technology to provide an IC based solution or a tilt switch as in the shippable prototype, a button can be pressed on the side. For testing purposes, this is a more deliberate option.

3.4 Constraints

The constraints on this project come from many angles, but the primary constraints are imposed from 3 areas. The working environment of the device, user requested functionality, and manufacturability. Care must be taken to develop the device within these constraints so that it will in the end be a feasible product delivered in a reasonable timeframe.

Environmental

The primary functional constraints on this device arise from its use in harsh ocean environments. Both saltwater and bright sunlight pose several challenges and the success of the device will depend on finding solutions to them. Saltwater presents two challenges, salt and water. The high salinity environment poses a challenge with regards to selection of device materials. The casing/coating of the device will need to be chemically stable and there can be no exposed metal contacts. This limits the choice in materials and in combination with water, the form-factor has to remain waterproof under pressure. Sunlight presents an added challenge as UV radiation will degrade the materials. Rather than trying to avoid degradation entirely, the only approach here is to construct the device with materials that will resist the degradation for as long as possible, although longevity will not be a factor in developing the initial MVP and it will not be a significant consideration in the first run of prototypes.

Feature Set

Although the requested features are fairly straight forward, the implementation may be tricky as the technologies themselves are possible points of failure. One major risk is in the accuracy of the depth sensor. Divergence in measured depths over time may make this product completely inviable should a replacement sensor not be found. Software is another point of failure, however, the core feature set is not complicated and if any advanced features become too difficult to implement, they can be cut. This would include WiFi updating or time adjustment.

Manufacturability

This device is constrained heavily by what will be viable to manufacture at low cost. For a device with a run of such a small volume (<500 units), traditional mass manufacturing methods are not viable, as they depend on scale to offset the large tooling costs. The primary goal on the manufacturing front is to enable the creation of a small and inexpensive form factor at a similar quality to what could be produced at mass scale. The electronics does not present an issue in manufacturability as they are already optimized for manufacturability, however production and assembly of the form factor present a bigger challenge. Many processes are being explored to make the device easily manufacturable.The method under development involves the over-molding of a glass screen in epoxy using a rubber mold. Epoxy with UV inhibitors has been selected as this material gives the best performance given environmental and manufacturing constraints. Automotive pearl pigment has been selected to provide the best light-fastness and 4-6mm borosilicate glass has been chosen to give the best structural characteristics at low cost. Implementation of repairability will involve the use of over-molded threaded inserts, high grade stainless steel bolts, and rubber gaskets.

3.5 Design Philosophy

The design guidelines developed by Dieter Rams [7] were adopted to provide direction on design decisions. Some of his 10 guidelines are listed below and they are briefly elaborated on to provide context and show how they have each influenced and/or reinforced the design.

1. "Good design is innovative"

We attempt to innovate in this project by developing a manufacturing and assembly process suitable for conservation and research devices built to withstand challenging environmental conditions. Our success here would open up more possibilities for researchers who could benefit from relatively low-cost and 'home-built' embedded devices for their research.

3. "Good design is aesthetic"

The aesthetics of the current target design goes unnoticed due to its neutrality and simplicity. The alternative to this simple and neutral design would be a chaotic or unpleasant one which would receive negative attention and leave a bad impression on the viewer. A pleasantly aesthetic design builds credibility and establishes trust, as it conveys that the design has been created with care and been given sufficient attention to detail.

4. "Good design makes a product understandable"

By incorporating usability features such as auto-wake, auto-water detection, an easy to read display interface, and a simple web GUI, we can make the product usage self explanatory and facilitate a frictionless user experience that comes without the need to read a manual.

5. "Good design is unobtrusive"

By making this device as thin and light as possible while remaining negatively buoyant, it becomes trivial to handle, store, and transport. In this way, the device can be minimally obtrusive outside the context of its use. We can further extend this principle to encompass pursuits such as power efficiency as a long battery life will minimize obtrusiveness on daily operations as the researchers will need to charge the devices less frequently before or during expeditions.

7. "Good design is long-lasting"

An emphasis has been placed on maximizing the overall lifespan of this device. This is done by carefully selecting components to be well within their operating margins and creating a robust case to protect them.

8. "Good design is thorough down to the last detail"

Attention is given to every aspect of the design such as the parameters for every electrical component, the light-fastness of the pigment used in the form factor, and the positioning of the WiFi antenna to maximize its signal strength and thermal performance.

9. "Good design is environmentally friendly"

The greatest environmental cost in the life of this design comes from the manufacturing and shipment of the raw materials and the eventual disposal of the device. By incorporating repairability and minimizing the amount of materials used, we can reduce the overall environmental impact.

4 Milestones

4.1 Initial Milestones and MVP

Initially, the goal for the MVP was to create a highly flexible development setup with completed base software, akin to those used in industry when developing complex products. The challenge here came from the integration and implementation rather than the design itself. Without the aide of PCBs, soldering the electronics together was expected to be a time consuming endeavor, and given the time constraints at the beginning and based on my own availability, I determined that it would be doable with some padding for unexpected delay. The milestones were split by each individual subsystem (6 subsystems + motherboard), as well as the relevant software that could be developed when those were implemented.

4.2 Pivot

I received word that all the components had arrived, so in the interest of the overall project, I decided to stop working on the original MVP and focus on the form-factor, software, and team development until I could assemble the actual PCB. I was to pick up the first set of components on a Wednesday, and the remainder on the following Monday. The only components not included in the Wednesday pickup were the PCBs and all of the electronic components, so I would wait until Monday to retrieve the rest. I was unable to get into contact right away with the person I was to pick them up from, but I expected a response soon so I did not switch back to the original MVP.

4.3 Failure of Pivot

Once it became clear that the PCB would not be in my possession in time to solder it and write software, I decided to develop a middle-ground option in order to have something completed. Almost 2 weeks had also been lost already, so the original MVP was no longer an option. At this point, my own time became constrained due to a project failure-necessitating non-stop work in another class which is critical to an on-time graduation. This was partially accounted for in the original MVP schedule in the form of padding, but at this point I had no such padding.

After the final viewing party, I got back into contact with my contact Scripps and it was made aware to me that the PCBs and Electronics order did not go through successfully in the beginning, and has still not arrived. At the time of making the initial decision to change from the original MVP and pivot, I fully did not anticipate this outcome. In the future when faced with a similar situation, I will attempt to verify the situation more before making a decision that could have such negative consequences. In hindsight, the pivot was a massive risk, although I did not see it as such at the time. Furthermore, I did not consider that there could be such severe problems with another class would have a domino effect. Better planning would not have made this situation work out, as my assessment of the potential risks of the situation did encompass such extreme problems from unexpected places, and I am still not sure how I could have handled that differently given that an excess of risk aversion would slow progress in general.

4.4 Achieved

The primary goal in the end was achieved which was to create and integrated development platform to assist with software development while there was no hardware, which will prove to be useful given recent developments.

4.5 Not Achieved

The full dev cube style flexible setup was not completed. For now, hardware changes will be made by soldering the completed unit directly and precise measurement will be harder and more time consuming to do. Furthermore, the actual hardware system itself isn't being validated in this compromise version of the MVP, as completely different hardware is implemented inside it.

5 Conclusion

Coral reefs are a vital part of marine ecosystems. They harbor a staggering amount of biodiversity, provide shelter for millions of aquatic species, and are a critical source of food for many communities. [1] Coral reefs have been experiencing an uptick in the frequency of events known as "bleaching" for over four decades. [2]

An important aspect of coral conservation is the monitoring of reefs. Monitoring and tracking changes over time is a necessary part of the research process as it helps researchers build an understanding of reefs. Researchers develop 3D maps of reefs to monitor changes over time, however some aspects of 3D mapping need improvement. One of these aspects is the orienting of the developed maps spatially, which is done via an old fashioned manual approach that is susceptible to errors and needlessly time consuming.

The Coral Tile offers a better solution to this archaic approach. The Coral Tile is an embedded device which can be placed at key locations in the mapping area and will display relevant spatial information such as depth and magnetic orientation on a large screen. This information can then be recorded into the imagery by the mapping cameras, to embed spatial data directly and permanently into the 3D maps, foregoing the need for the previous time-consuming process.

To assist with the overall goal of the Coral Tile project, a development setup has been created to facilitate with software development ahead of the delivery of the final hardware. This device also provides a mock user experience to find any possible issues with the design before they come up. Two issues have been confirmed so far using this setup. First, thermal dissipation of the wireless charger and WiFi system will need closer scrutiny as the development setup heats up significantly during Wireless charging. Secondly, a color scheme will be needed to differentiate between up and down, as some digits can be misread as other digits upside down, such as 2 and 5 which are rotationally symmetrical.

Development of the Coral Tile will continue until a series of shippable units is developed and shipped, along with a plan for manufacturing more. After completion, the Coral Tile project will provide a framework for the development of more devices in this category of low-cost and 'home-built' embedded devices for environmental research.

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