D-SEA: The Underwater Depth Sensing Device for Standalone Time-Averaged Measurements

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***Abstract*—Access to accurate depth information is important for a wide variety of oceanographic science applications. For example, it is crucial in the creation of 3D models. Currently, divers are manually measuring the depth by using dive watches, but this method is inconsistent because of variable depth readings caused by changing wave heights and human errors. To combat these problems, we created the Depth-Sensor Enclosed Application (D-SEA) to automatically collect and average pressure data while displaying the calculated depth readings underwater. To use D-SEA, the user places it on top of the area of study to measure and gather the underwater depth readings over time. We are working on an affordable, waterproof prototype with a display that is readable underwater, an automatic transition between on and off states when submerged in seawater, and automatic data logging onto an SD card. From testing the recent prototype, results show that D-SEA lasted for weeks in the sleep state and days in the wake state while under depths of 4.40 meters.**

***Index Terms*—Depth sensor, underwater, standalone time-averaged measurements**

I. Introduction

The surge of creating 3D virtual environments has been increasing due to the convenience of observing an environment virtually without having to physically be in the actual location. The creation of 3D virtual environments has specifically impacted broad fields of science, including oceanography. For example, researchers at the Scripps Institution of Oceanography (SIO) [4] are currently creating 3D interactive models of coral reefs to help preserve the visual integrity of the underwater environment and observe the reefs from a remote location. This allows researchers to monitor and study coral reef health and the effects of weather damage on coral reefs over time. To build these interactive environments, depth information is essential to accurately depict the structure and levels of the reef but gathering this data is cumbersome and expensive.

3D mapping of coral reefs and other underwater environments in general is fairly new. The current method of data collection proves to be challenging as the only current way of capturing underwater depth readings is by manually reading it from a dive watch. These watches can be costly, troublesome, inconsistent, and prone to error when measuring from a specific point. In order to gather the data, divers have to lower the measurement device to the same level as the coral reef and log the data. Dive watches do not have the complexity to support data logging nor do they account for the changing heights from wave swells underwater.

In this paper, we present the Depth-Sensor Enclosed Application (D-SEA). Our compact, low-cost device captures depth and pressure underwater and displays the information every 20 seconds on a display module with high visibility. D-SEA accounts for differing wave heights on the surface and logs the raw data onto an SD card to be able to be accessed via above water. To use this device, the user places it on top of the area of study (e.g. a coral reef) and leaves it there to measure and average the depth submersion reading while accounting for differing wave heights on the ocean surface.

The main contribution of this paper is an embedded device that does the following:

- Logs depth
- Calculates and clearly displays the information underwater
- Comes in a convenient form factor and is capable of operational depths of 10-15 meters underwater

D-SEA presents a solution for accurate underwater depth sensing over time. With this in mind, this device can be used for other applications such as capturing depth on autonomous underwater robotics as well as 3D mapping for other underwater environments. This paper elaborates on the proposed technology and components that are integrated into the method of gathering depth data. It also covers the concepts behind our design of the D-SEA architecture along with experimental results and future approaches for this device.

II. Related and Prior Work

Despite the vast number of developments on underwater technology, surprisingly little has been done in terms of capturing stable underwater depth measurements within diving ranges. In this section, we discuss the related work and challenges that arose in the development of D-SEA. For overall underwater 3D mapping, depth sensors were not needed as current 3D mappings only get the structure of the environment rather than integrating the levels and differing depths along a coral reef. In terms of general diving devices, Jean-Francois Ruchonnet [5] created a patent for a depth measuring device within diving watches, which involves a sensor measuring external pressure. The displacement of the pistons in the

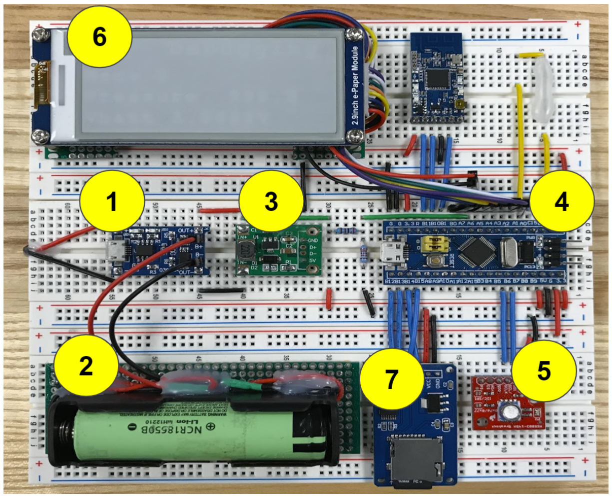

Figure 1. Breadboard prototype layout

device is used to calculate the pressure which is connected to a chronograph and a control system in order to calculate the depth. Currently, divers employ watches with these depth gauges in order to manually measure the depth underwater. However, many of these watches require divers to record the data by hand. In order to improve data acquisition, we want our device to remain accessible price-wise, to calculate the average depth while ignoring differing wave heights, and to save the data to an SD card.

In summer 2018, Dan Sturm and Robert Barlow designed the very first prototype of our device. Their work [8] has been essential in this project and most of our design ideas rely heavily on their product. After a few days of testing, a few issues occurred: the epoxied prototype stopped functioning [2]. To make debugging easier, we are using breakout boards instead of manually soldering everything on the board. This approach keeps the design as simple as possible, making it less likely to break and easier to debug.

Liren Chen and Xuanyi Yu built their version of this project in Spring 2019 [1]. They used an E-Ink display [9] for displaying depth information [6] and the STM32f103 as the microcontroller. Through our research, we found that the E-Ink does not react well with the heat during the process of epoxying [3]. To further eliminate the heat factor, we put the PCB into a scuba box to encapsulate it and make it waterproof while also making it easy to debug. Our work can be seen as a continuation of this project as we are further developing their product. We talk more about how we improve this version in our Design section.

III. Design

Price, power consumption, waterproof rating, and reliability were the most important factors for making design decisions. The components included in the hardware implementation of D-SEA are shown in Figure 1, and each component is referred to below with their corresponding number from Figure 1. After each component is introduced, we will elaborate more on why we chose each component.

The components labeled from 1 through 3 are used for power:

1) TP4056 Li-Ion Battery Charger
2) 3.4Ah Li-Ion Battery
3) Voltage Regulator

The STM32 microcontroller is turned on using a reed switch:

4) STM32 Microcontroller and Reed Switch

A pressure sensor is used to calculate depth measurements:

5) MS5803-14BA Pressure Sensor

An E-Ink display module is used to display the depth readings in real-time:

6) E-Ink Display

An SD Card is used for data logging:

7) HiLetgo Micro SD TF Card Adapter Reader Module

A. Power: 3.4Ah 18650 Li-ion, TP4056 Li-Ion Battery Charger, Step-Up Regulator

We use a 3.4Ah Li-Ion battery. This satisfactorily meets our power requirements as the device can last for days while in the wake state (underwater) and weeks in the sleep state (on land).

B. MCU

The microcontrollers under consideration were STM32F103C8T6, MSP430, and Arduino. Among the choices, we chose the STM32 because it provided an I2C bus, SPI bus, and multiple USART ports. The STM32 also has enough pins to connect to a wide range of peripherals. The power consumption during runtime is about 50mA, which is acceptable.

C. Cylewet Reed Switch Normally Open (N/O) Magnetic Induction Switch

A reed switch is a device that opens or closes an electrical circuit when a magnet is nearby. This is used to turn on and off the device. A reed switch was used to save the battery consumption. To save battery, D-SEA is turned on before diving and turned off when the device is back on land. Also, the device can be turned on or off without needing to expose any pins or a switch. We talk more about the on/off mechanism in the Firmware Implementation section.

D. MS5803-14BA Pressure Sensor

The MS5803-14BA Pressure Sensor Breakout is a high-resolution pressure sensor with an I2C interface. Using a gel membrane, the sensor measures the absolute pressure of the fluid surrounding it. The measurements are programmed to be converted from mbar to meter. The sensor is accurate to about 30 mbar pressure which is sufficient in coral reef environments which on average has depths of 10-15 meters.

E. E-Ink Display

A display is needed to view the depth data in real time while divers swim back and forth to perform photomosaic surveys and capture images of the device and data shown on the screen. As a result, the display must have little to no glare, and the information on the screen must seen from different angles. Diving conditions at coral reef communities are relatively shallow and highly-illuminated. Variables include sunlight, wind, and wave changes over time. As a result, the display module should display the depth information as clear as possible under different conditions to make sure the information can be retrieved from the images accurately.

From testing different displays [8] [1], we saw that numeric LEDs are not legible from a camera on highly illuminated days and LCD displays become hard to read when viewing it at angles greater than around 45. On the other hand, the E-Ink display was able to be read at more extreme angles and had much better contrast. Because of this, we decided to use the E-Ink display for D-SEA.

The depth information is displayed on a three-color 2.9 inch E-ink display module with 296x128 resolution. We programmed it to have a refresh rate of 20 seconds. The E-ink display has ultra-low power consumption and can passively reflect sunlight.

F. Data Logging: HiLetgo Micro SD TF Card Adapter Reader Module

In case researchers fail to retrieve accurate depth information from unclear images or want to look more in detail on the data collected, a data storage module was added for backup consideration. The data logging feature is implemented via a HiLetgo Micro SD TF Card Adapter Reader Module interfaced with SPI. Each use of the device produces a unique .csv file where the pressure and depth data can easily be read in a tabular format. Sample data is shown in Figure 2.

G. PCB

We designed a PCB for all the components to be mounted on. This makes debugging and assembly easier and allows for the board to be much smaller. The PCB was also designed so that it can be used in future versions and includes space for the components that we have decided to omit for the current version.

H. Scuba Diving Dive Waterproof Orange Dry Box Case Container

The average depth of coral reefs is 10-15 meters under water. We need a device that can withstand up to 30 meters of pressure underwater for maximum waterproof protection. We decided to use a commercially available scuba box instead of epoxy potting. One of the main disadvantages with epoxy potting is that it is difficult to debug as the components cannot not be reached and the cause of problems can only be hypothesized through observations. Moreover, epoxy potting introduces an element of heat on the components which may potentially damage the electrical components. By using a scuba box which can be opened after being submerged, we still have access to the components after underwater testing. This design choice also allowed us to avoid using components such as a wireless charger and Zigbee module. This greatly reduced the cost and complexity of the device since the data can be easily accessed and the battery can be charged by opening the box. We decided to use a commercially available scuba box as opposed to a custom designed box to save on costs. One of the downsides of using a waterproof box as opposed to epoxy potting is that it is more likely to leak and has a lower maximum depth. However, the box that we used is rated to be waterproof for three times the expected depth the device will be used at (rated for 30 meters depth, expected is about 10 meters depth), so this should not be a problem. Another potential issue is the durability of the box during field use. Epoxy potting would be more durable, but because of the previous issues we had with potting we decided to first make a reliable product using a box and figure out the best potting method later on.

IV. Firmware Implementation

After having discussed the hardware design of our device in the previous section, we will now describe the software design. The software implements the STM32 Standard Peripheral Libraries to program the MCU and the driver code to program the E-Ink display. This section also describes how the data was calculated and saved on an SD card.

A. Library

Our firmware is fully dependant on STM32 Standard Peripheral Libraries since we are using a STM32 microcontroller. For basic components, we use GPIO, USART, I2C, SPI, ADC, EXTI, PWR, and RTC in STM32 Std Peripheral libraries. The driver code for each module is developed separately. Most of the breakout sensors are provided with Arduino libraries that could instantly plugin. Basically, we are rewriting these libraries with STM32 backend. Most of the user logic is defined in main.c file. The embedded software is modularized and extendable for future teams.

B. E-Ink Display

The code for the E-ink module is developed based on Arduino libraries. In our design, we implemented a sleep mode to power off the display when not in use in order to preserve the E-Ink display functionality and power.

C. Depth Sensor

The code for depth sensor is developed based on Arduino libraries.

D. SD Card

The data logged on the SD card will store the information to be transferred later. The code for the SD card used the FatFs filesystem module and the low level disk I/O skeleton both developed by ChaN. Each time the device is turned on, a unique .csv file is created to store the pressure and depth data. After the device is turned off, the user can remove the SD card safely from the scuba box.

	A	B	C
1	Depth(m)	Pressure(mbar):	
2	0	999.5	
3	-0.136	986.2	
4	-0.141	985.7	
5	-0.156	984.2	
6	-0.143	985.5	
7	-0.02	997.5	
8	0.016	1001.1	
9	0.069	1006.3	
10	0.254	1024.4	

Figure 2. Sample SD data log

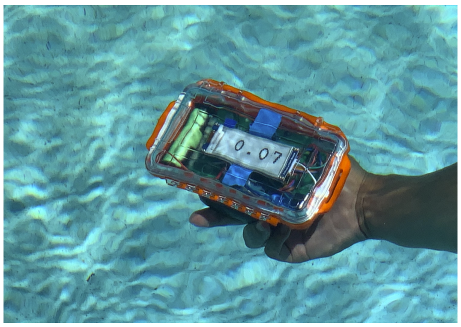

Figure 3. Above water view of initial D-SEA prototype underwater test.

E. On/Off Mechanism

For turning off the microcontroller, the standby mode was implemented. To bring the MCU to standby mode and to bring it back to on state, we are using the WKUP pin as the external interrupt and switch. The current prototype has two types of turning on/off mechanism. The reed switch we are using is normally open. When we put a magnet closer, the switch closes, which connects 3.3V to the WKUP pin (PA0). This causes a rising edge external interrupt on the MCU.

V. Experimental Results

We constructed and tested a prototype of our device in a pool using a scuba box encasement. The goal of this testing was to check the durability, accuracy, and visibility of our product. The accuracy and visibility was tested in comparison to a diving watch.

In terms of durability of our scuba box encasement, this test was successful as the device did not malfunction when submerged underwater and the depth was being displayed on the screen. Everything worked as expected: refresh rate, on/off switch, depth value. The refresh rate of the E-Ink display was consistently 3 seconds. We tested D-SEA by placing the device at 4.40 meters underwater and compared the values to a diving watch in order to test for accuracy as shown in Figure 4. The diving watches have a reported accuracy of 0.1 meters. When D-SEA displayed 4.40 meters, the watches displayed 4.3 meters, but the watches do not go to the hundredths place so we do not know if the watches truncate the depth values. To test visibility, underwater cameras provided by the Sandin Lab at Scripps Institution of Oceanography were used. This test

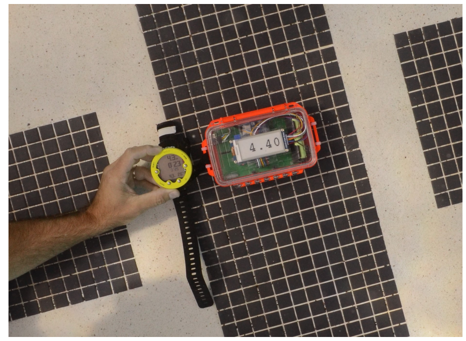

Figure 4. D-SEA vs diving watch underwater comparison.

was to mimic how divers would capture images of the device by swimming back and forth while performing a photomosaic survey. This underwater camera was used to take photos of the device from different angles to observe the glare and visibility of the display. When comparing the values underwater, there was a drastic difference in viewing the depth as it was easier to view the numbers on D-SEA as numbers were bigger had more contrast in the display. However, we found that the sunlight/temperature affects the pressure sensor. The device displayed an average of 4.40 meters when the device was turned on in the sun. The device displayed an average of 4.38 meters when the device was turned on in the shade. Possible solutions for this include attaching the depth sensor somewhere else on the device or attaching a form of protection around the sensor. We can also fix the calibration of the depth sensor and find the absolute pressure. Right now, the absolute pressure reading is initiated at 0 once the device is turned on.

VI. Conclusion and Future Approaches

This paper covers D-SEA, a waterproof device that can measure underwater depth and clearly display it on a screen when underwater. Through our tests, we showed how an E-Ink display clearly shows accurate depth information under direct sunlight. Our prototype implemented our PCB within a scuba box for easy access to the components. Additionally, the SD data logging feature was integrated to provide researchers information for later observation. We have tested the prototype in the lab and underwater in order to mimic the real working condition of the device. In the future, we are continuing to test the scuba box prototype for accuracy, reliability, and durability. We will test how much pressure and depth the scuba box can take as well as the depth sensors accuracy in averaging the depth measurement. As far as durability, we will be testing the PCB within the scuba box to see if the components are secured when taken out in the field such as in rough terrain. We are also replacing the breakout board and placing all the components directly on a smaller PCB for easier and cheaper mass production. We plan to implement a magnetometer for information about sense of direction when underwater. For power, a wet/dry circuit is in the works for the next prototype. The wet/dry circuitry used to turn on the device when placed in water is based on work done for the Smartfin [7]. This circuit relies on the use of two exposed pads that become electrically connected when placed in water. Once the prototype is robust, accurate, and has all the added implementations, we will be handing the final device to researchers to have it tested in the ocean.

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