Wireless Water Monitoring System and Portable Analysis Platform Product Development Progress in Academia

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Grace Tsai graduated with bachelor degrees in Psychology and Anthropology from the University of California, San Diego in 2011. She is currently a Ph.D. candidate in the Department of Anthropology, Nautical Archaeology Program at Texas A&M University. She served as an industry advisor and stakeholder in the capstone team, Submersible Exploration Aquatic Labs (SEAL), given her nautical archaeology background, and guided the team by explaining archaeologists' needs in the field, desirable ROV specifications, and current technology used during field work. She has also led students as a business mentor for water monitoring systems, and guided and tracked students' progress collecting customer interviews through the NSF I-Site program.

Her personal research focuses on understanding post-medieval seafaring life through analysis of diet and physical labor on sailors' health. Her most recent field work includes the Gnaliç Project, an excavation of a sixteenth-century Venetian galley that sank off the coast of Croatia, the Burgaz Harbor Project, an excavation of Hellenistic harbors in Turkey, and the Shelburne Steamboat Project, an excavation of a steamboat graveyard in Vermont. She has also helped catalogue lead fishnet weights from Uluburun, a late Bronze Age shipwreck, in Turkey. In her free time, she works as the co-founder and CDO of Bezoar Laboratories LLC, a R&D company focusing on probiotic supplements.

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Rogelio Casas Jr. was an ESET student at Texas A&M University and graduated in the Fall of 2018. He was the Project Manager throughout the project and is currently working at General Motors in Austin, Texas as a Software Developer. He plans on continuing his education through hands-on training and a potential Masters in Computer Science.

Erika L. Davila

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Abstract

Clean water is important for public health and people have become more vigilant of monitoring potentially contaminated drinking water. In this project, students were advised to seek a solution to detect contaminated water by conducting market research on the industry and the public's needs, then based on these results, to engineer the device. After extensive customer discovery through the Texas A&M University National Science Foundation Innovation Site Program (NSF I-Site) that focuses on technology commercialization, students found that water quality is especially important to the everyday health-conscious consumer and to people working in the brewing industry. However, the value propositions of clean water differed greatly between these two promising customer segments which caused the project to pivot to focus on the brewing industry. The resulting device prototype was created with the market needs in mind as an affordable reusable device with real-time chemical analysis capabilities. This paper focuses on the educational progress and best practices students learned on engineering practical solutions to meet people's needs. It then introduces the resulting water monitoring system and its variant wireless portable analysis platform that is in development, the latter which was created as a response to the needs identified from market research.

I. Introduction

"What is truly in the water I am drinking?" A rise in sales of water filters such as Brita or PUR, bottled water, and safer reusable drinking containers (e.g. BPA-free plastics) reflects this concern in drinking water, along with the recent Flint, Michigan water crisis that made headlines [1]. However, there are still very few accurate and cost-effective ways to test water or beverage quality. To address this problem, an interdisciplinary team with students from the Engineering Technology, Anthropology, and Entomology departments tackled the problem of designing a device that fit the needs of the market.

II. Multidisciplinary team and educational benefits

This project and team began from an offshoot of another project that had created a barrel-monitoring system as a part of a larger study researching historical food preservation. The team consisted of a faculty member from Engineering Technology, a graduate student from Anthropology with a Certificate in Entrepreneurship, an undergraduate student in Entomology who specialized in biology and organic chemistry, and an undergraduate student in Engineering Technology, who worked on device development.

This initial device tracked time, temperature, humidity, and allowed researchers to withdraw liquid samples using a peristaltic pump from a barrel without needing to open it. The goal was to understand nutritional degradation and microbiological changes in the food within the casks on the ship, and to track factors such as temperature and humidity that affect food quality [2]. While researching and designing this device specific to the barrel project, the students realized that this device could potentially be of value in the beverage or bottled water industry. At the suggestion of one of the authors, Grace Tsai, who had participated in the National Science Foundation Innovation Corps (NSF I-Corps) program before, the team enrolled in the Texas A&M University National Science Foundation Innovation Site Program (NSF I-Site) that focuses on teaching students the basics of technology commercialization [3].

III. NSF I-Site Spring Cohort 2018 experience

The initial barrel-monitoring technology was selected to participate in the NSF I-Site program in Fall 2018, as the students believed there may be a market for such a device in various industries related to liquid monitoring. The NSF I-Site program is aimed at teaching students technology commercialization through market research and is the introductory program required to progress to the main national program, the NSF I-Corps (Innovation Corps). This program allows students to assess how well potential products garner interest and sales in various customer segments (i.e. product market fit). This was done through testing value propositions, or the value the product could bring to those who might use it, and asking people in the separate segments which features mattered most to them and the reasons behind their answers. This would allow the students to determine if their current barrel-monitoring device fits any industry's needs, if modifications need to be made to better fit an industry's needs, or if the entire product is not worth pursuing. Students were encouraged to ask open-ended questions and to not bias interviewees with their opinions. Questions include:

"What is the greatest challenge you face in [insert industry or relevant task] today?"
"If you could change one thing about how you go about daily operations [or other relevant task], what would it be?"
"Please describe your usual procedure in detail when testing your water for chemicals [or insert relevant task]."

Two students, R. Casas Jr. and E. Davila, partook in the program as the entrepreneurial leads, and attended weekly courses that focused on teaching the lean startup method [4]. They began the program under the assumption that the health-conscious consumer and managers of water treatment companies and plants would be interested in purchasing liquid monitoring devices similar to the one used for the barrel, but miniaturized with more chemical-tracking functions. The hypothesis was that the health-conscious person would want it to have peace of mind over what they drink, given the hysterical level of media coverage on water contamination. Meanwhile, water treatment companies and others in the water treatment industry take water contamination seriously, so if the current methods to test contamination are tedious, this is also another segment that was hypothesized to have interest in such a device.

The two students were required to conduct a minimum of 30 face-to-face interviews with potential customers, starting with their hypothesized segments: health-conscious direct consumers and water treatment facility managers. They were able to confirm that people were concerned about water quality in the beverages they drink and that most people filter all their water or drink bottled water. However, most also stated that as long as their water was filtered or came from a reputable bottling company, they had peace of mind and would not pay for more expensive solutions. Meanwhile, water treatment facilities have standardized procedures they use to test water quality, but these are tedious and there is no streamlined way to do this yet. However, even given the need for new technology, this segment noted that there would be

	Brewing industry	Oil and gas companies	Underwater researchers	Health Conscious Consumer	Water Treatment Facilities
Portability	3	3	2	1	3
Accuracy	2	1	1	2	1
Ease-of-use	3	1	1	3	2
Cost	3	3	2	2	2
Volume of liquid able to test	1	1	2	3	1
Ranking	12	9	8	11	9

Table 1. Value proposition (green) and customer segments (pink) and their ranking.

several bureaucratic regulatory challenges for them to bypass to implement new methods of water testing. While conducting the first few interviews, the students were recommended to also speak to those in the brewing industry, oil and gas companies, and marine/underwater-related researchers because these groups are also concerned about the chemical makeup of liquids. After each interview, the responses were logged and consolidated to present an overview of the market environment for such a device. The results of the customer discovery can be seen in Table 1. The most promising customer segments in the end were the brewing industry and health-conscious consumers.

The brewing industry, specifically the sector that focuses on brewing craft beer, was the most promising market in the end. Many craft breweries start off as small businesses and are unable to afford the ideal machinery to monitor and adjust the water and environment needed for the best beer brewing conditions. This is the reason that smaller breweries often have trouble standardizing their brews, and different batches of the same recipe sometimes taste different. Generally, these companies outsource water testing and send off their samples to analytical testing companies. A device that could provide real-time information on the chemical makeup of the water used in the mashes, and allow for monitoring changes without opening the barrel (if it is barrel-aged) in which the beer is kept, would be highly successful in this industry. The main reason brewers were interested in monitoring water and liquid contents was to maintain a good tasting brew, and not for health reasons. To fit what the brewers want, the device would need to have greater portability (be miniaturized) as most in this segment wanted something small, have high accuracy in ppm of carbon dioxide, oxygen, volatile compounds, and glucose, measure temperature and pH, and be relatively affordable and easy to use (preferable something that would automatically give readings without many steps and therefore room for error).

The health conscious consumer was the second most promising sector, but results were mixed on the exact features consumers wanted. While users indicated a need for water monitoring for health reasons, the overall results are inconclusive for this segment because people had varied ideas and standards on what constituted as clean and healthy water. Further, many people mentioned they cared about clean water, and that although somewhat inconvenient, they

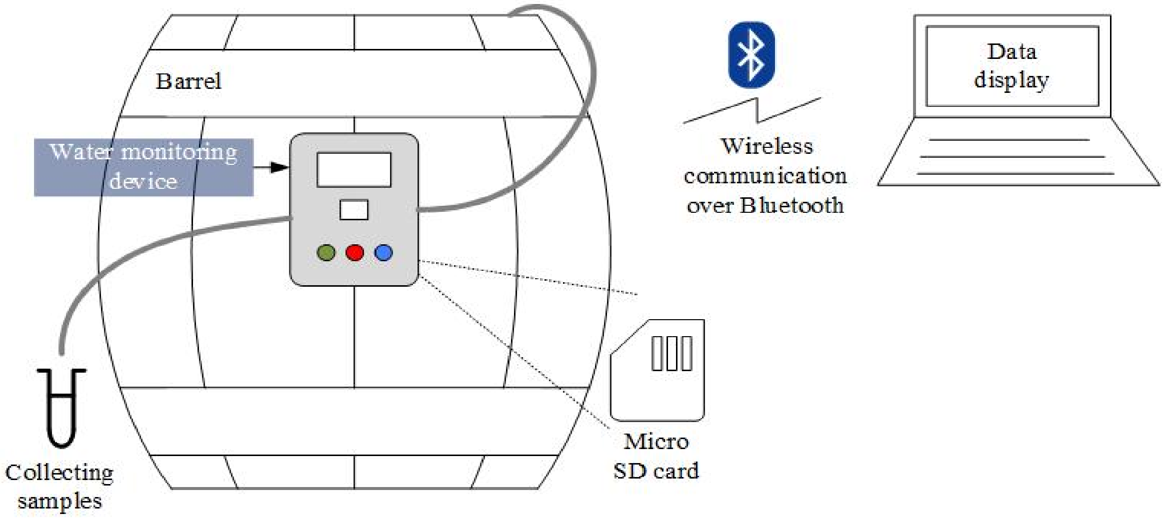

Figure 1. Block diagram of the barrel-monitoring system.

currently buy water filters and/or bottled water and trust that these are adequate for their needs. Many seemed to be reluctant to spend money on more devices given the cheap solutions that already exist, although several people indicated that they did not know how healthy the water from these other sources truly were. In order to convince these users to purchase a water monitoring device, students would need to not only demonstrate that current water quality is unsafe to the average health-conscious consumer, but also determine a filtering device that could accurately remove unsafe chemicals, otherwise simply monitoring without providing a solution would be futile. In the case that a filtering device is identified, the monitoring device could be a complement to the existing product (i.e. GE water filtering systems, Brita, Pur etc). In short, the results were too varied and partnering with a water purification company is beyond the scope of the team at the moment, so the group decided to pursue modifying the device for the brewing industry.

IV. Water monitoring system applied in a barrel

Before describing the improved prototype, the initial water monitoring system in a barrel is described in this section. This system had sensors that measured temperature and humidity, as well as a peristaltic pump that collected liquid samples. The purpose was to gather data for a project related to food nutritional degradation and microbiological growth in shipboard environments [2]. This device was used to extract liquid samples without exposing the barrel's contents to the environment, therefore preventing the food's further oxidation, while simultaneously tracking changes within the food.

The block diagram of the water monitoring system in a barrel is shown in Figure 1. The monitoring system can measure temperature, humidity, and pH of liquids. The measured data stored in a microSD can be sent wirelessly to devices via Bluetooth. In addition, the apparatus can remove liquid from the barrel for sampling using a peristaltic pump. The device has three buttons for ease of use. The green button activates the peristaltic pump for liquid removal. The red button reverses the direction of the peristaltic pump so to remove blockages from the other

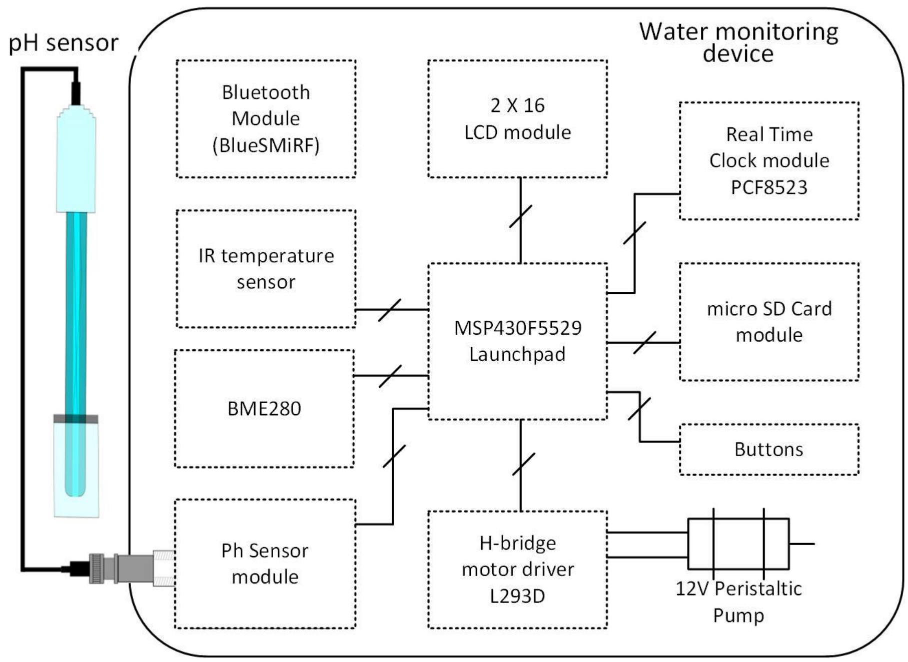

Figure 2. Block diagram of the electronics of the water monitoring system in a barrel.

Figure 3. Water monitoring system (middle) on the barrel in *Elissa* (left) in Galveston, TX. The inside of the water monitoring device is shown on the right.

end of the tubing. The blue button activates the Bluetooth function to send the data wirelessly. It is a battery powered device, which is capable of measuring data over the span of a week (recording data every 10 seconds) without needing a battery replacement.

The block diagram of the electronics is shown in Figure 2. The pH sensor module was used and the measured data were processed by a MSP430F5529 Launchpad. It received the data from a

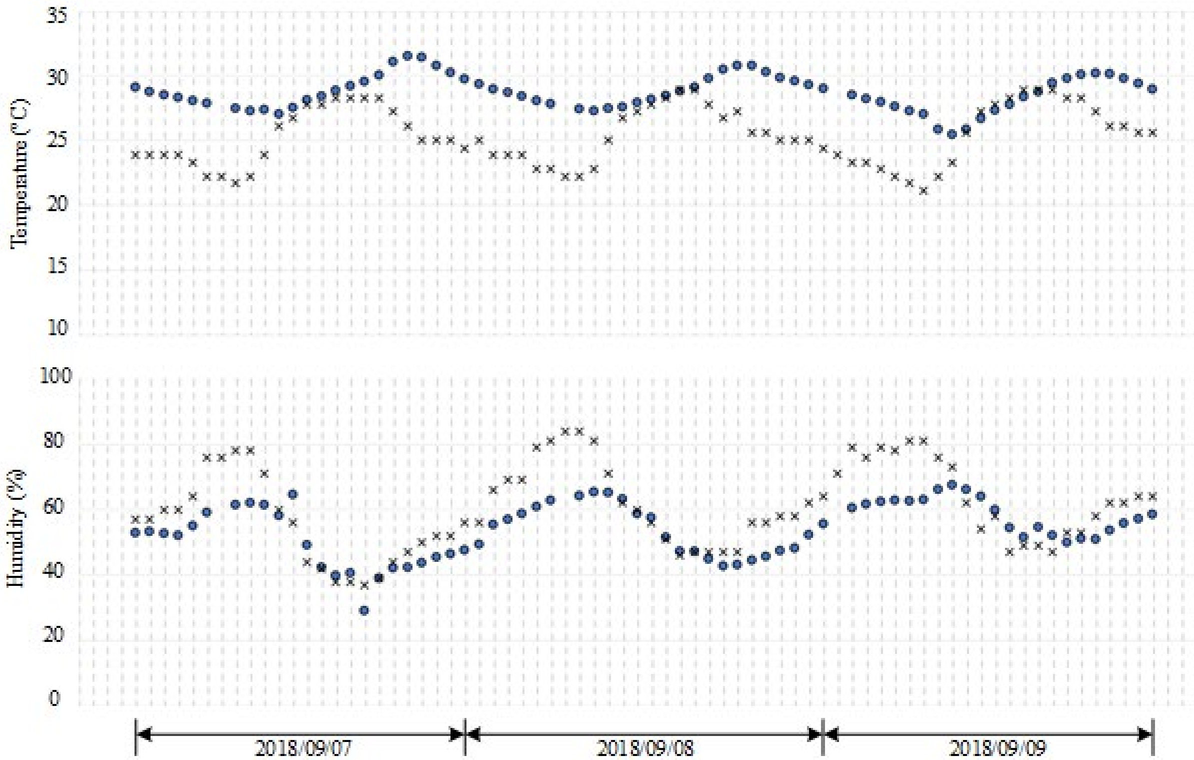

Figure 4. Measured data (2018/09/07 ~ 2018/09/09). The blue circles indicate data from the barrel device, while the dark crosses are data from Weather Underground.

BME280 IC module which can measure multi-environmental factors including temperature and humidity [5]. In order to operate the peristaltic pump in both directions, an H-bridge motor drive was used.

This water monitoring system in a barrel was applied to one of the barrels on *Elissa*, the 19th-century tallship docked in Galveston, Texas. *Elissa* can be seen on the left side of Figure 3. This monitoring device was attached to the barrel as shown in middle of Figure 3, and the inside of the water monitoring device is shown on the right.

The data had been collected over a span of six weeks. A selected three-day window of the measurements is displayed in Figure 4. The blue circles show the data measured by the water monitoring device, while the dark crosses show the data from Weather Underground, a commercial weather forecast service website [6]. The temperature and humidity data show the differences between the Weather Underground data and the measured data from the attached water monitoring device, indicating that the hull environment differed from the outside weather even though the device was inside of the hold which was partially open to the elements. However, the graph shows the correlations between the two sets of data, and proves the usefulness of the monitoring system in this shipboard food case study.

V. Wireless Portable Water Monitoring System

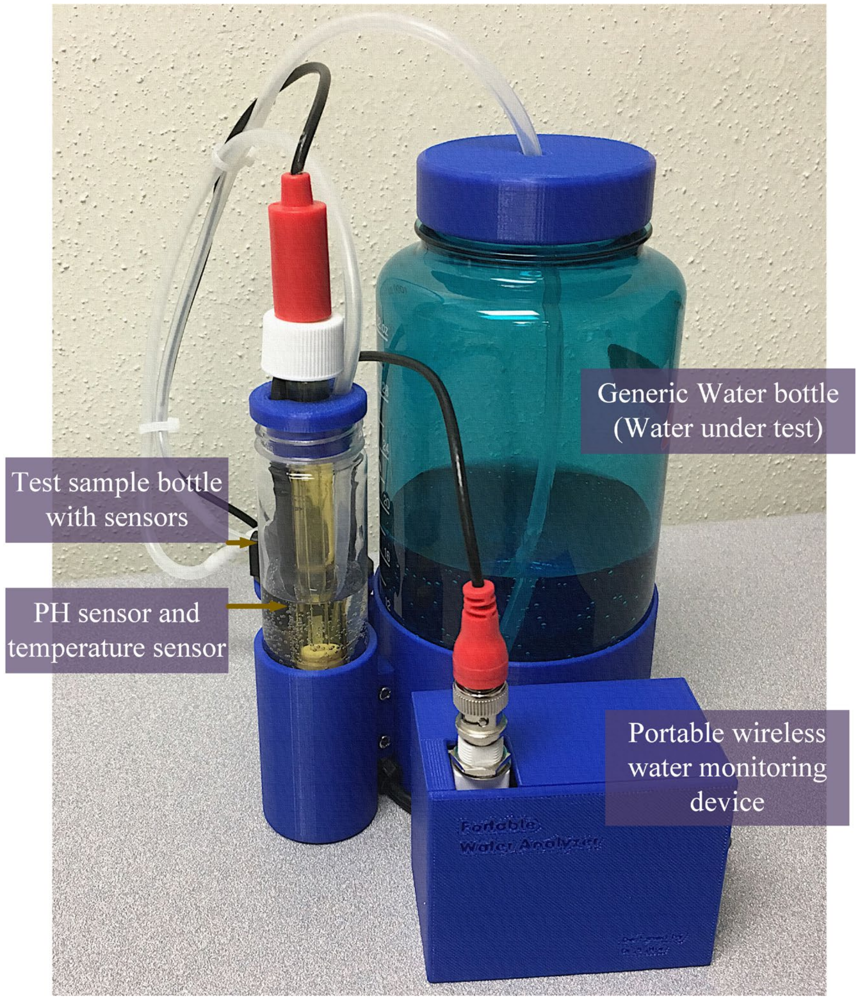

Figure 5. Portable wireless water monitoring kit. Generic and sample bottles are disposable.

In the following phase, the water monitoring device was miniaturized for analysis of contents within a portable water bottle. This wireless portable water analysis platform includes some of the features of interest logged from customer interviews; however, it does not include all desired features of the brewing customer segments yet. Potential applications of this device as confirmed via the NSF I-Site extend to use in the brewing industry where water quality and pH control are critical.

The portable water testing device is shown in Figure 5. A generic water bottle was used, which was filled with the water to be tested. On the left of the figure, the test sample bottle is shown. It needs be inserted in the base and covered with the cap that has the sensors and hose. The enclosures and test devices were designed and manufactured using 3D printers. The water testing electronics component is attached to the front, which measures the sensor data and sends the information via Bluetooth communication.

The inside of the portable water monitor and analyzer electronics enclosure is shown in Figure 6. A custom MSP430F5529 module, BH5529 module, was adopted as the main intelligence [7].

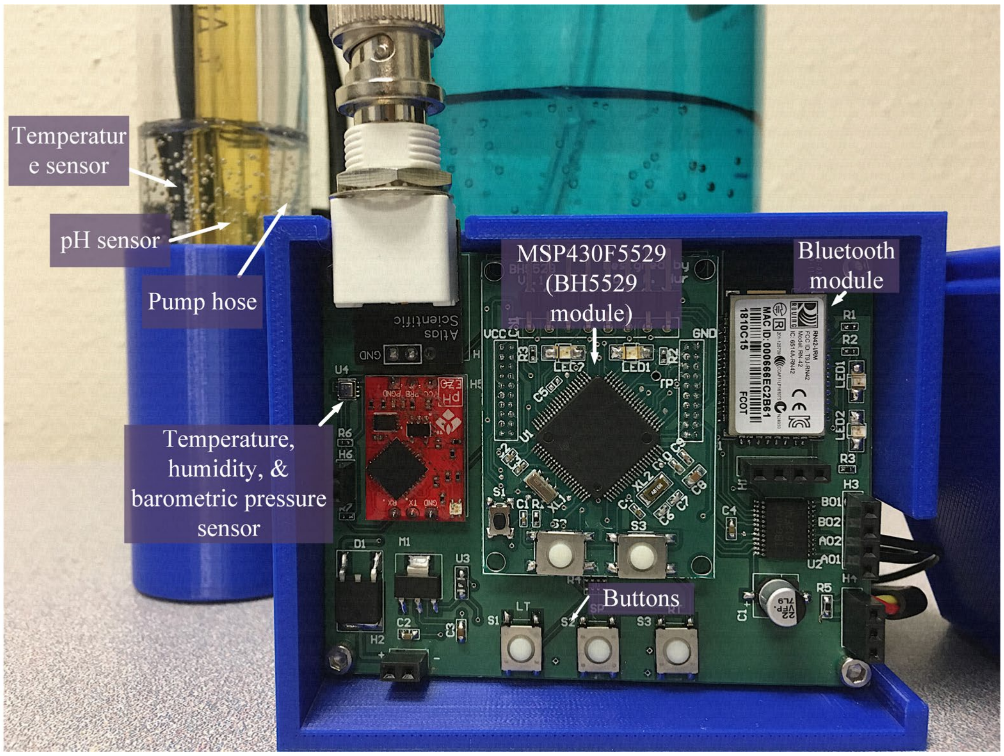

Figure 6. Portable water analysis test electronics.

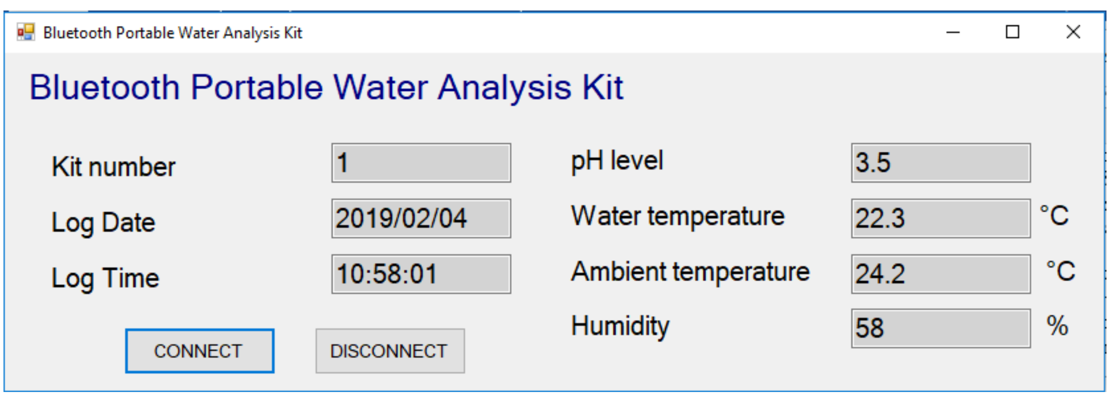

Figure 7. GUI screenshot and real-time measurements.

This is a low-power microcontroller module that is suitable for battery applications. The pH sensor, water temperature, and multi-environmental factor sensor are also shown in Figure 6. Further, it can measure ambient temperature, humidity and barometric pressure. The pump was used in transferring water samples from the general bottle to the sample bottle or vice versa.

Figure 7 is a screenshot of the GUI (Graphical User Interface), showing the real-time measurement data that were transferred wirelessly over Bluetooth communication. It displays the information about the kit such as the kit number, date, and time, as well as various measured sensor data including pH level, water temperature, ambient temperature, and humidity.

This wireless portable water analyzer is a functional prototype but still needs further development and improvement for commercialization. Desirable features such as tracking carbon dioxide, oxygen, and glucose values, and the volatile compounds (aroma) by incorporating components of gas chromatography into the device, are still in the process of being added into the final product.

VI. Discussion & Conclusions

Wireless water monitoring systems were developed and presented in this paper. The first water monitoring system was applied to a barrel, and it successfully monitored the desired data on *Elissa* over a period of six weeks. The second wireless portable water monitoring system was developed, which is a miniaturized water analysis kit. This device was produced after industry data and customer interviews were gathered, and was made to measure some of the environmental factors brewer's desire. These include pH, water temperature, ambient temperature, and humidity. This portable water monitoring system is still in development, and will eventually include the ability to monitor carbon dioxide, oxygen, glucose values, and volatile compounds. Students gained significant educational value and insight into product-market fit and how to create and gauge the value of new innovations through the NSF I-Site program. They learned from the added business learning component in this project which is rarely offered to non-business majors. The authors are continuing to improve this wireless water monitoring system to meet the various needs of the water analysis applications.

Acknowledgements

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