Final Project Report
BENG 3000 - Bioinstrumentation

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Final Project – Monitoring Algal Biofilm Growth

— By —

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Introduction

Data logging involves collecting data over a period of a time and at set intervals. It is commonly used in most scientific experiments whether they are less than an hour in duration such as many chemical reactions or they take several years or decades to complete such as climate change monitoring [1]. Most data logging systems incorporate a microprocessor or other computer device and sensors made for the specific application [2]. Sensors play a key role in the data logging process and can measure parameters such as light, temperature, pressure, pH, humidity, and much more. It is likely that there exists a sensor for most situations and needs of scientific experiments. Two important distinctions exist in sensor types when making a monitoring system. These are analog and digital sensors. Analog sensors often output changing voltages as the parameters they measure change. Digital sensors output a digital signal that most computers can directly understand. Most data logging systems involve both analog and digital sensors with an interface box or controller converting between the two as needed. Historically data logging often required being present during most of the logging period and manually taking measurements. Recent decades have improved the ability to perform remote data logging where readings are stored directly to a computer then downloaded when visited by the scientist. Remote logging has improved tremendously in the last few years as it's now easier than ever to setup devices to upload their data online to websites or other cloud storage locations [3]. This helps reduce the number of needed visits to sensor sites which is extremely helpful in remote locations. An important aspect of any datalogger is that it will perform reliably over the desired time and withstand the conditions it's placed in.

One location where data logging is needed is in monitoring rotating algal biofilm reactors [4]. The Rotating Algal Biofilm Reactor (RABR) operates as a semi-submerged bioreactor with a substrate on which an algal biofilm culture develops [5]. A pilot scale RABR is currently being tested at Central Valley Wastewater Reclamation Facility (CVWRF) in Salt Lake City, Utah to evaluate its nitrogen and phosphorus uptake. Many factors are important to the biofilm growth and past research has shown that a key factor influencing growth of microalgae and cyanobacteria in wastewater is light including availability, duration, and intensity [6]. The most important light to measure is photosynthetically active radiation which is light from about 400-700 nm. Other factors such as temperature, dissolved oxygen, and pH are also important to growth and performance of a microalgae biofilms [7]. The purpose of this project was to develop and construct a data logging system for remote and reliable monitoring of the RABR.

A company specialized in data logging applications is Campbell Scientific. One of their most used dataloggers is the CR1000. It is designed to be open to many possible configurations and sensors and perform reliably even in extreme conditions. In this project it will be used to monitor parameters of the water and air around the rotating algal biofilm reactor. It is well suited for this application as there are easy to use temperature probes, dissolved oxygen probes, and pH probes compatible with the CR1000. It is also best used in this project as past research on algal biofilms has used the same technology [5]. This device will be used together with a Raspberry Pi computer to offer remote monitoring.

Raspberry Pi (RPi) computers were initially made with the intention of teaching children how to program. Since their start they have come to be used in a wide variety of applications from remote gardening systems to home automation [8]. They have come to be a staple of hobbyists and tinkering looking for a quick and relatively low-cost way to experiment. There are also now a variety of sensors available for the RPi making them a good choice for remote data logging and monitoring. A major factor that makes the Raspberry Pi useful is its ease of integration with wireless networks [9]. The CR1000 and Raspberry Pi data logging systems together with other sensors allow for robust and reliable monitoring of the parameters of a rotating algal biofilm reactor.

Experimental

Below are listed the materials used in the project:

- Raspberry Pi systems (Quantity)
    - Raspberry Pi Model 3 (2)
    - Adafruit BME280 I2C or SPI Temperature Humidity Pressure Sensor (1)
    - Adafruit DS3231 Precision RTC Breakout (2)
    - Waterproof DS18B20 Digital temperature sensor (5)
    - Raspberry Pi Camera Board v2 - 8 Megapixels (2)
    - Atlas Scientific EZO™ pH Circuit (1)
    - Atlas Scientific pH Probe (1)
    - Atlas Scientific BNC Connector (1)
    - BNC Cable (1)
    - Waterproof Hard Case from Walmart (2)
    - 5V 2A Switching Power Supply (2)
    - Half-size breadboard (2)
    - Premium Male/Male Jumper Wires - 40 x 6"
    - Premium Male/Female Jumper Wires - 40 x 6"
    - Premium Female/Female Jumper Wires - 40 x 6"
    - Campbell Scientific ENC16/18 Weather-Resistant Enclosure (1)
    - Extension Cords (3)
    - Large Black 285 Dri-Box Weatherproof Connection Box (1)
    - 4.7 kΩ Resistor (2)
    - 15-foot HDMI Cable (1)
    - Arducam CSI to HDMI Cable Extension Module with 15pin 60mm FPC cable for Raspberry Pi Camera Specific (1)
    - Neodymium Disc Countersunk Magnets (10)
    - ¾ Inch PVC Pipe
    - SanDisk Ultra 16GB Ultra Micro SDHC UHS-I/Class 10 Card with Adapter (2)
    - DampRid 42 oz. Fresh Scent Hanging Moisture Absorber (1)
- Campbell CR1000 system (Quantity)
    - Campbell Scientific ENC16/18 Weather-Resistant Enclosure (1)
    - CR1000 Measurement and Control Datalogger (1)
    - CS511-L Dissolved Oxygen Sensor (1)
    - 109SS-L Temperature Probe (1)
    - CSIM11-L pH Probe (1)
    - 108 Temperature Probe (1)

  - PS200 12 V Power Supply with Charging Regulator and 7 Ah Rechargeable Battery (1)
  - CM106B 10 ft Galvanized-Steel-Tubing Tripod with Grounding Kit (1)
  - 41303-5A 6-Plate Solar Radiation Shield (1)
  - 6714 Four-Unit Desiccant Bags (3)
  - Neodymium Disc Countersunk Magnets (4)
  - ¾ Inch PVC Pipe
- YSI ProODO Optical Dissolved Oxygen Instrument
- Apogee Scientific SQ-520 Full-Spectrum Smart Quantum Sensor with AL-120 Solar Mounting Bracket with Leveling Plate (2)
- Additionally, typical hardware such as two-by-four wood pieces, PVC connectors of various sizes, mounting brackets, camera tripod release plates, and a security camera mount

The first part of setting up the project was configuring the Raspberry Pi (RPi). First the Raspian operating system was downloaded onto a 16 GB microSD card and put in the RPi. After the computer was up and running it was connected to a monitor with an HDMI cord and plugged into power source. A mouse and keyboard were also connected to the RPi. The RPi was connected to the internet by updating its boot file directory to connect to WPA2 internet protocol. All necessary communications protocols were setup including i2c (https://learn.adafruit.com/adafruits-raspberry-pi-lesson-4-gpio-setup/configuring-i2c), camera connections (https://thepihut.com/blogs/raspberry-pi-tutorials/16021420-how-to-install-use-the-raspberry-pi-camera), gpio pins, VNC Server remote connection (https://www.realvnc.com/en/raspberrypi/), time zones were updated, and sensors were wired to the computer. Next all programs for sensor operations were input into the Raspberry Pi including those for the BME280, DS18B20, DS3231, Pi Camera, and pH probe. These were each made as individual programs which a central program could call on for values. Next the connection to Google Drive was setup on the RPi. This was done following instructions provided by the Home Automation Community (http://www.home-automation-community.com/google-drive-on-raspberry-pi/).

The next part of the project involved putting together sensors with the CR1000. First, all sensors were cleaned, and calibrated following standard operating procedures provided by Campbell Scientific. The membrane and electrode solution of the CS511 dissolved oxygen sensor was also replaced with a new one to provide accurate measurements. The power supply was then connected to the CR1000 and a USB cable used to connect the data logger to an external computer. Next the PC200W Datalogger Starter Software was used to determine wire connections of the CR1000 and sensors. Then the Short Cut Program Generator for Windows (SCWin) software was used to create and upload code to the CR1000 that would sample each sensor every minute and average the values every fifteen minutes. The averaged values were then saved on the internal storage of the data logger until retrieved by an external computer. The Apogee Scientific SQ-520 Full-Spectrum Smart Quantum Sensors were also programmed to take measurements and record the fifteen-minute averages. The quantum sensor was programmed using the Apogee Connect software provided by Apogee Scientific.

Next the mounts for all the sensors were setup and all hardware were attached. The CM106B tripod was first placed in the desired location next to the rotating algal biofilm reactor. One weather resistant enclosure was mounted on the tripod and the other placed below. The first Raspberry Pi system along with all wires and breadboards was placed in the mounted box. The first system consisted of a Raspberry Pi Model 3 computer connected to three DS18B20 temperature probes placed in the water of the reactor in a PVC pipe mount, one DS18B20 temperature probe exposed to the ambient air, a camera, and the Atlas Scientific pH probe. The camera was mounted in a separate waterproof case on the top arm of the tripod and connected to the RPi using an HDMI extension. In the ground enclosure the CR1000 along with all wire connections and power supply was placed. The CR1000 was connected to three 109SS-L temperature probes, one CS511 dissolved oxygen probe, and one CSIM11-L pH probe which were all placed on a PVC pipe mount in the water. It was also connected to a 108 temperature probe mounted in a radiation shield on the arm of the tripod. The second Raspberry Pi system was placed in a specially made water proof box along with its camera, one BME280 sensor, a DS3231 clock, a DS18B20 temperature probe, and required wires and breadboard. One of the SQ-520 Quantum Sensors was mounted on the arm of the tripod and the other was placed on a specially constructed mount over the RABR. The YSI ProODO Optical Dissolved Oxygen Instrument was used to take measurement during trips down to CVWRF but not used as a data logging device. Once all mounts and connections were made each Raspberry Pi, the CR1000, and the quantum sensors were connected to power.

Data for each of the Raspberry Pi systems was retrieved simply by downloading information from the Google Sheets they are synchronized with. The data from the CR1000 and SQ-520 sensors had to be downloaded onsite when visited the water treatment facility. On each trip approximately every other week the data will be collected and stored securely. Analysis of data logging information as well as other measurements of the algal biofilm will be done using JMP® Data analysis software for Windows.

Results and Discussion

The rotating algal biofilm reactor before addition of the sensors can be seen below in Figure 1. The device consists of eight rotating discs that provide attachment surface for algal biofilms. The bottom half of the reactor is filled with wastewater effluent from the Central Valley Wastewater Reclamation Facility. The water is high in nitrogen and phosphorus and the goal of the research is to use microalgae to take these nutrients out of the water and clean it.

The wiring and programming of the Raspberry Pi systems was the first part of the project that was completed. The basic wiring of each system is seen in Figures 2 and 3 respectively. The physical implementation at the facility of the first RPi system is seen in Figure 4. All wiring, sensors, and the Raspberry Pi functioned when first setup at CVWRF except for some difficulties in connecting to wireless internet. The second RPi system was setup in its enclosure as shown in Figure 5. It functioned correctly except for wireless internet connectivity issues as well. After a couple of weeks, the BME280 sensor was also damaged by humidity and had to be replaced. The output of the first RPi system that was monitoring pH, temperature at varying water levels, and atmospheric temperature can be see in Figure 6. An important outcome of this was the ability to see when pumps malfunctioned by drops in temperature in the water. An example of noticing low water temperature, fixing the pump, then seeing a rise in temperature is seen in Table 1. A section of the output of the second RPi system monitoring atmospheric parameters can be seen in Figure 7. The cameras on both systems also functioned well and have become useful in determining if there is algal growth before taking trips to CVWRF. A sample of what can be seen from the camera connected to the first RPi is seen in Figure 8. By analyzing pictures and seeing changes in color it is possible to get a rough qualitative idea of the RABR's performance.

The Campbell CR1000 was wired according to the diagram in Figure 9. Initially there were problems in getting the dissolved oxygen sensor to return measurements, but this was solved by replacing the electrode and cleaning the sensor. The final setup of each sensor and data logger is seen in Figure 10. The enclosure on the ground houses the CR1000 and the enclosure mounted on the tripod houses the first Raspberry Pi. On the arm of the tripod is an air temperature probe, camera, and quantum sensor as seen in Figure 11 from left to right respectively. The mounts for the probes placed in the water are seen in Figure 12. In the left PVC pipe are the sensors connected to the CR1000 and on the right are the sensors connected to the first Raspberry Pi. The same mounts are seen in Figure 13 after they were placed in the RABR water. The mount for the SQ-520 Quantum Sensor that was initially placed under the RABR cover is seen from overhead in Figure 14. The same sensor is seen placed in the RABR with its mount in Figure 15 on the left.

Overall after some troubleshooting and minor difficulties the data loggers are running well and adding to a useful research project. An example of the output from the two different quantum sensors is seen in Figure 16. It is observed that when a cover was placed over the RABR fifty percent of incoming light wasn't reaching the algae. This provided significant reason to remove the cover which was done on April 24, 2018. The YSI ProODO Optical Dissolved Oxygen Instrument also has provided valuable information about the water conditions which are seen in Table 2. It revealed that the dissolved oxygen content of the water is extremely low due to sludge buildup. All these data obtained will be valuable in determining the performance of the rotating algal biofilm reactor and improving future iterations of the technology.

The biggest information gained from the project is that no matter the application there is most likely a sensor for any need. Due to the decrease in price of reliable computers and sensors in recent years data logging and information gathering is more accessible than ever. Each device or system comes with many benefits and downsides. Raspberry Pi computers while cheap and flexible in their use are limited by their durability and reliability. I found that power issues can quickly cause them to go offline and, in some cases, lost a couple of weeks of data collection due to this. They are also not ready to go out of the box and require a bit of work to get functioning correctly. The Campbell CR1000, SQ-520 Quantum Sensors, and YSI ProODO Optical Dissolved Oxygen Instrument have all proven to be reliable and durable in addition to providing exact measurements. Each of them also has intuitive and easy user interfaces which makes them quick to setup and use. The downside of these latter devices to many will be there cost. For labs lacking enough budget and even more so for home hobbyists they are not likely to be a practical option depending on the number required.

Figure 1: The rotating algal biofilm reactor after initial setup in November.

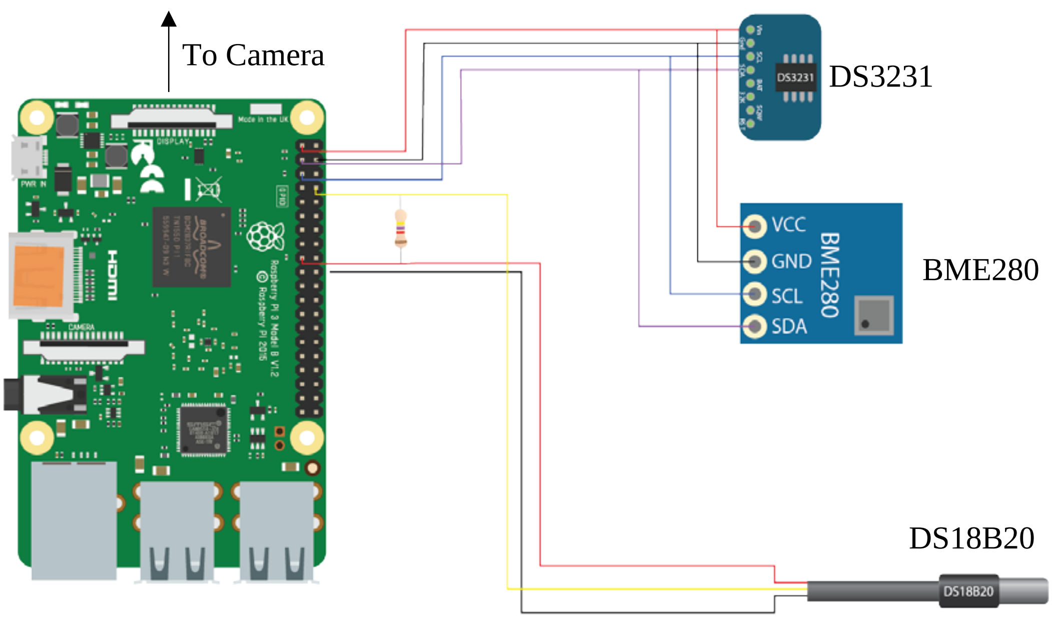

Figure 2: The wiring of the second Raspberry Pi system.

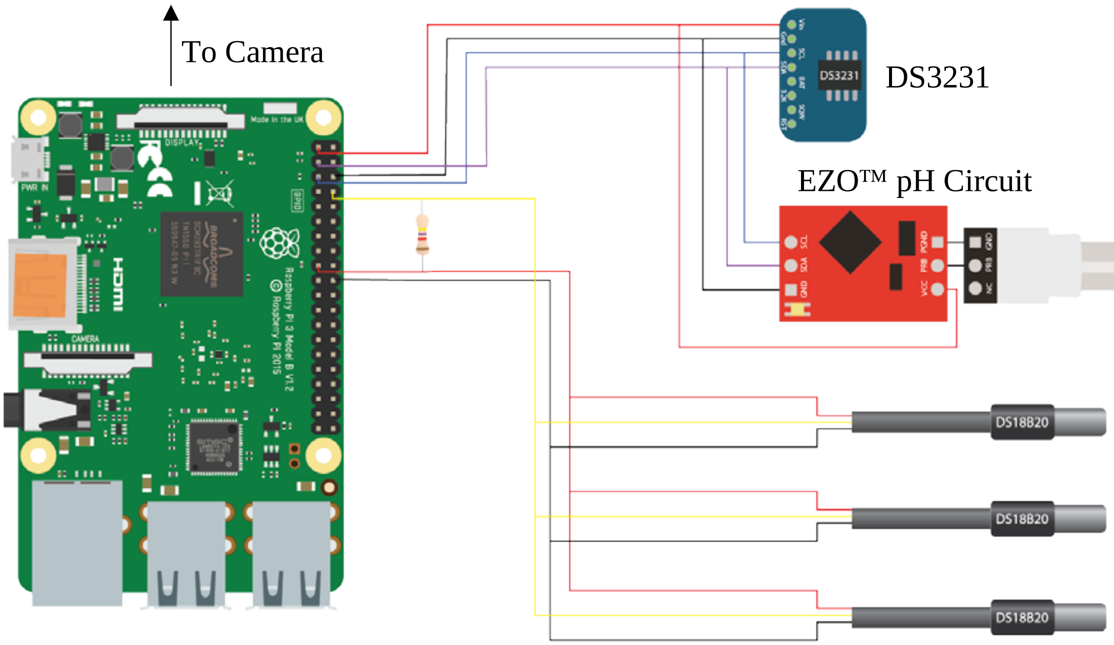

Figure 3: The wiring of the first Raspberry Pi system.

Figure 4. The first Raspberry Pi system in its weatherproof enclosure.

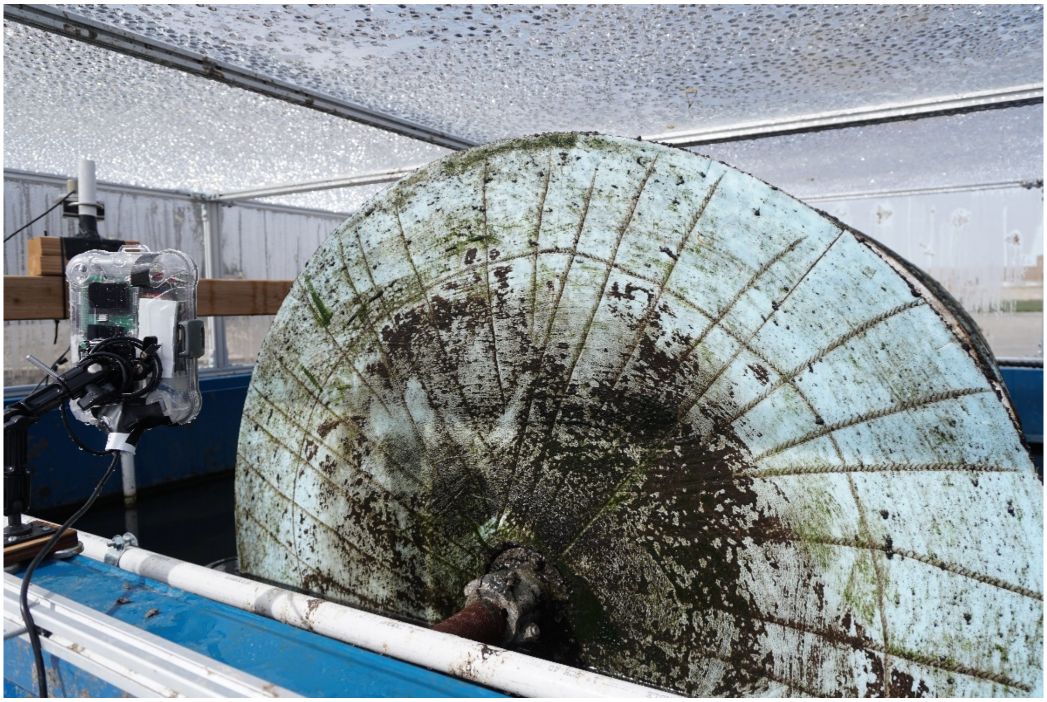

Figure 5: The second Raspberry Pi system in its weatherproof enclosure as seen on the left.

https://docs.google.com/spreadsheets/d/1AuZabVAH4NepZvowzQ7GnbYh0aAof12VBSHWZMsroQ8/edit#gid=0

Pi_Outside

File Edit View Insert Format Data Tools Add-ons Help

	A	B	C	D	E	F
1	Time	Lower Temp (C)	Middle Temp (C)	Upper Temp (C)	pH	Outside Temp (C)
2	2018-01-20 13:01:12	7.625	7.5	7.937	5.531	0.437
3	2018-01-20 14:01:09	7.5	7.562	8	5.592	0.5
4	2018-01-20 15:01:11	7.5	7.75	8.187	5.769	1.312
5	2018-01-20 16:01:10	7.562	7.875	8.312	5.836	0
6	2018-01-20 17:01:10	7.625	7.875	8.25	5.628	0.312
7	2018-01-20 18:01:09	7.562	7.75	8.125	5.673	-0.937
8	2018-01-20 19:01:11	7.5	7.687	8.062	5.594	-0.687
9	2018-01-20 20:01:11	7.437	7.625	7.937	5.717	-0.687
10	2018-01-20 21:01:11	7.375	7.625	7.937	5.583	-0.687
11	2018-01-20 22:01:10	7.312	7.562	7.875	5.787	-1.25
12	2018-01-20 23:01:11	7.25	7.437	7.75	5.55	-1.625
13	2018-01-21 0:01:10	7.125	7.375	7.687	5.516	-2.375
14	2018-01-21 1:01:11	7.062	7.25	7.562	5.541	-2.312
15	2018-01-21 2:01:11	6.937	7.187	7.437	5.663	-2.687
16	2018-01-21 3:01:11	6.812	7	7.312	5.693	-3
17	2018-01-21 4:01:11	6.687	6.875	7.125	5.612	-3.875
18	2018-01-21 5:01:12	6.562	6.75	7.062	5.717	-2.937
19	2018-01-21 6:01:12	6.5	6.75	7.062	5.74	-3.125
20	2018-01-21 7:01:10	6.437	6.687	7	5.605	-2.25
21	2018-01-21 8:01:10	6.375	6.687	7	5.688	-2.062

Figure 6: The Google Sheet used for logging the first RPi’s sensors.

https://docs.google.com/spreadsheets/d/1xdN

Pi_Inside

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fx Time

	A	B	C	D
1	Time	Temperature (C)	Pressure (hPa)	Humidity (%)
2	2018-01-20 16:0	12.06	866.883417	63.39843769
3	2018-01-20 16:1	11.95	866.9112905	63.89921821
4	2018-01-20 17:4	7.93	867.9966057	77.62471074
5	2018-01-20 17:4	7.94	867.994728	81.56084504
6	2018-01-20 17:5	7.82	868.0596187	82.38212312
7	2018-01-20 17:5	7.9	868.0737338	83.40651943
8	2018-01-20 17:5	7.9	868.0271773	82.0344669
9	2018-01-20 17:5	7.89	868.0365472	82.06753171
10	2018-01-20 17:5	7.89	868.1302398	80.70580847
11	2018-01-21 19:3	7.46	879.1741776	94.29502587
12	2018-01-21 19:4	7.01	879.2371334	89.42883513
13	2018-01-21 20:4	6.63	879.4050601	98.73035497
14	2018-01-22 7:06:	3.32	879.9108775	100
15	2018-01-22 8:05:	2.64	880.0906629	96.74581084
16	2018-01-22 8:06:	2.69	880.0416007	97.05253814
17	2018-01-22 9:30:	11.41	879.8959346	55.48619229
18	2018-01-22 10:2	11.98	880.2502783	50.08998572

Figure 7: The Google Sheet used for logging the first RPi's sensors.

Figure 8: An example of what is seen from the camera connected to the Raspberry Pi.

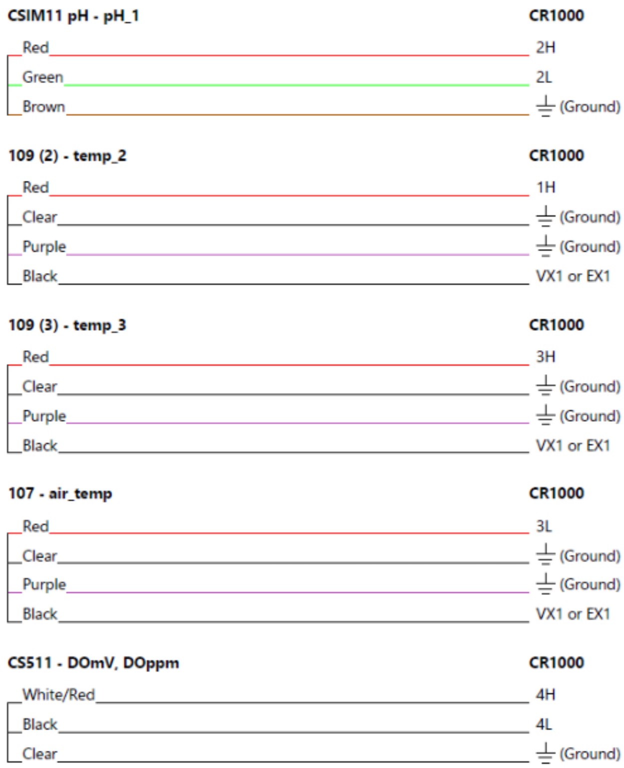

Figure 9: The wiring diagram used with the CR1000 and each sensor.

Figure 10: The finished setup of the data loggers with the RABR.

Figure 11: The arm of the tripod with a temperature probe, camera, and quantum sensor mounted on it.

Figure 12: The water sensor mounts used with the CR1000 and Raspberry Pi.

Figure 13: The water sensor mounts when placed in the RABR.

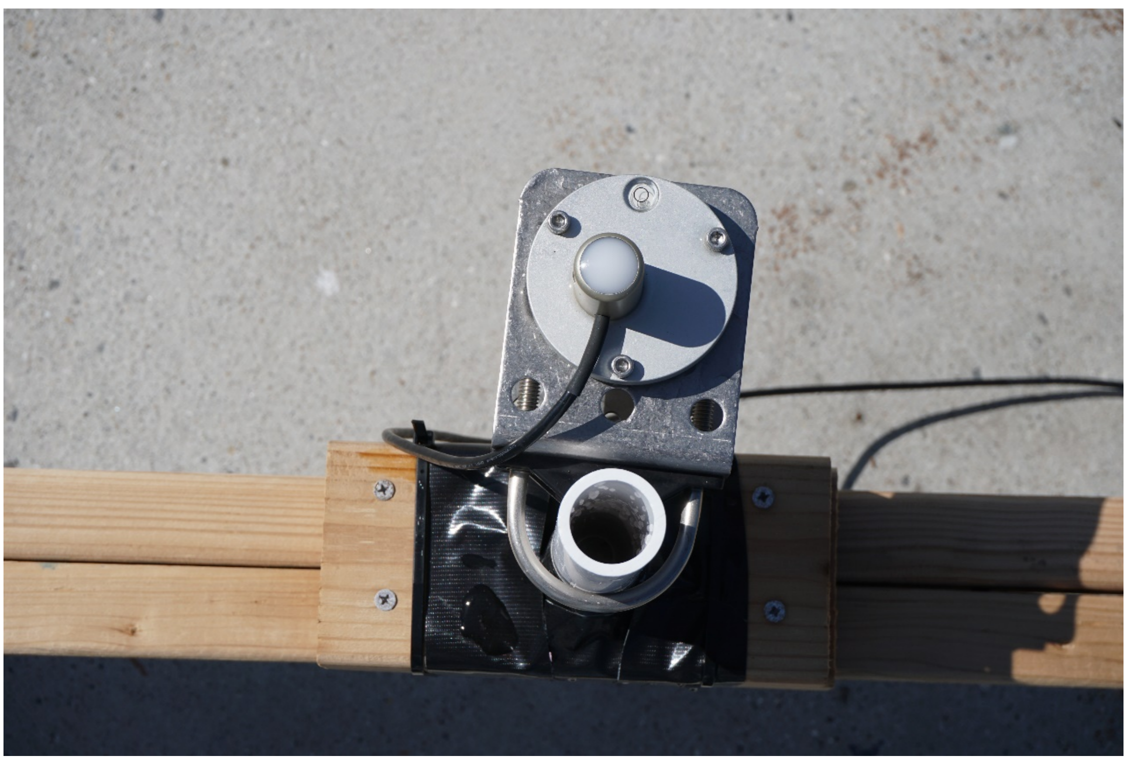

Figure 14: The SQ-520 sensor on the specialized mount before placing over the RABR.

Figure 15: The weatherproof wire connector box as well as the quantum sensor mount under the cover of the RABR.

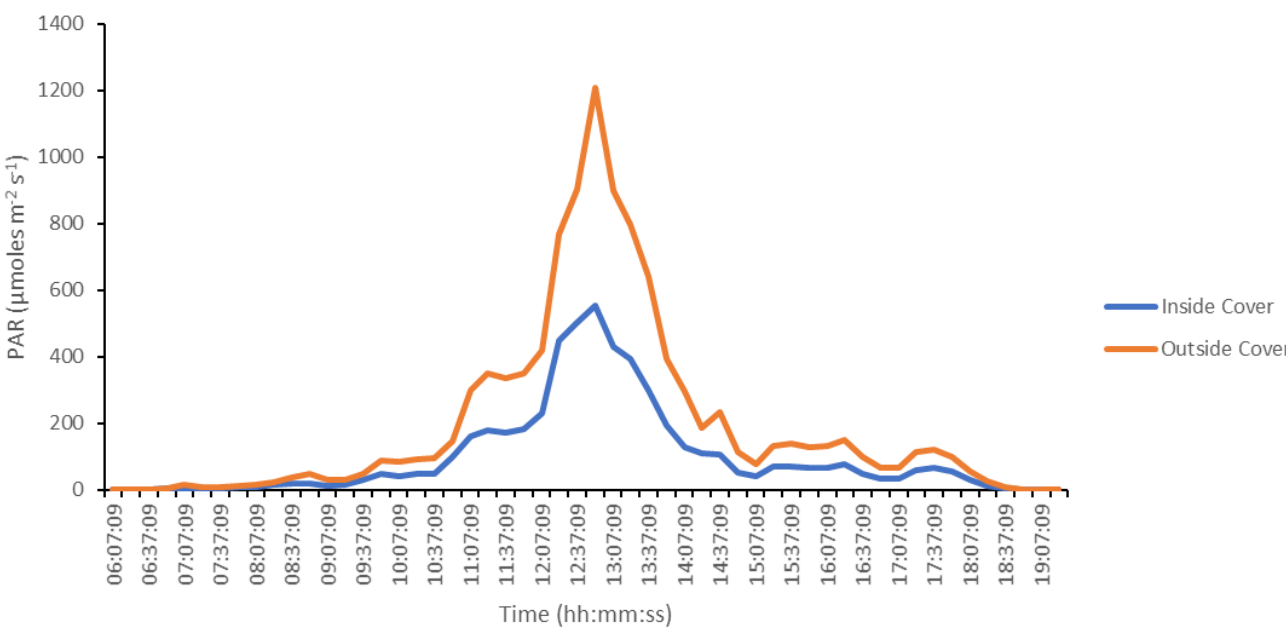

Figure 16: Photosynthetically active radiation values at Central Valley on 3/17/18.

Table 1: Water temperature rise in the RABR when a pump was fixed where the first three temperatures are for different water depths.

	Lower Temperature (°C)	Middle Temperature (°C)	Upper Temperature (°C)	pH	Atmospheric Temperature (°C)
1/27/18 12:10 PM	5.062	6.062	6.812	5.96	6.625
1/27/18 1:10 PM	5.75	7.062	7.687	6.128	8.25
1/27/18 2:10 PM	7.187	10.187	10.75	5.892	9.125
1/27/18 3:10 PM	9	12.562	13.062	5.901	7.687
1/27/18 4:10 PM	10.562	14.312	14.75	5.863	6.687
1/27/18 5:10 PM	11.812	15.437	15.75	5.537	5.875
1/27/18 6:10 PM	12.687	16	16.25	5.527	4.25
1/27/18 7:10 PM	13.375	16.437	16.687	5.668	4.125
1/27/18 8:10 PM	13.875	16.75	17	5.625	3.625
1/27/18 9:10 PM	14.25	17	17.25	5.702	3.937
1/27/18 10:10 PM	14.562	17.25	17.5	5.718	3.5
1/27/18 11:10 PM	14.875	17.437	17.687	5.446	3.375
1/28/18 12:10 AM	15.062	17.5	17.75	5.637	3.625

Table 2: The measurements obtained from the YSI ProODO Optical Dissolved Oxygen Instrument

Temperature (°C)	Pressure (kPa)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)
21.4	87.88	3.7	0.32

Conclusion

This project taught me a great deal about sensors, programming, and electronics. All of these are topics which I did not understand well before beginning. I've learned how to do basic Python programming and use Raspberry Pi computers for a variety of uses. I've also learned how sensors function, proper maintenance, and how to perform calibrations. I've also gained skills in working with Campbell Scientific products such as the CR1000 and build custom sensor mounts in order to place devices where measurements are needed. There were many problems and solutions throughout the process of this project. Some of these include power supply problems with the Raspberry Pi, malfunctioning dissolved oxygen sensors, dealing with large amounts of data to analyze, and figuring out how to mount sensors in the right locations. All of these were dealt with by reading through manuals, looking up ideas online, and talking to other people about possible solutions. I will be continuing to improve the systems and add sensors over the upcoming months. My main goal will now be to analyze the data and look for significant items using JMP® Data analysis software for Windows.

Team Member Contribution

All contributions to the project were mine. I used programs from sources online and modified them according to my needs. Most of the learning needed for the project came from online searches and instrument manuals provided by companies. Setting up the mounts and sensors was largely trial and error.

Acknowledgments

I would like to think Iegor Pererva for helping point me in the right direction of sensors that work with Raspberry Pi and are accurate. Dr. Ronald Sims helped through the Sustainable Waste to Bioproducts Engineering Center (SWBEC) to purchase almost all the supplies need for the project. Members of SWBEC were also helpful in setting up the mounts at the Central Valley Wastewater Reclamation Facility when extra hands were needed.

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