Portable Nutrient Data collection system

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Final Report

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Contents

List of Abbreviations and Terms

MEMS: Micro Electronic Mechanical System
USB4000: The spectrometer used in this project, made by OceanOptics.
TTL: Transistor-transistor logic.
BLE: Bluetooth Low Energy

Problem Statement

MEMS sensors, as a bio-compatible sensor, have been used widespread to measure data of pressure, humidity, etc. Smartphone is a very good interface to carry easy-access interface applications. Considering Managing nutrients in agriculture continues to be a major challenge in ecosystem science. In the project, the group will design a system that using integrated MEMS microplasma-based sensors and a spectrometer with microcontroller to collect and transmit data wirelessly to a smartphone app with an easy-access interface.

System Requirement

3.1 Functional Requirement

1. The whole process should take less than 4 minutes
2. Display concentration of different elements(N&P) in water sample with precision
3. Accurately distinguish between good/bad measurements
4. Transmit data wirelessly to smartphone
5. With water and soil proof
6. Application is based on Android
7. Have database for the history

3.2 Non-functional Requirement

1. **Portable**, **low power** and **safe**
2. Easy-use-interface. (tutorial, easy to find settings)
3. Be shielded from water and dirt damage
4. 10ml water is acceptable amount to test with
5. Be able to remain powered wirelessly for 50 trials
6. 90% accurate with reading

7. Smartphone app size should be less than 6MB
8. Total time of analyzing water sample on smartphone application should take less than 30 seconds
9. Communication from device to smartphone should take less than 2 seconds
10. Wireless range should be up to 2 meters

Concept Sketch

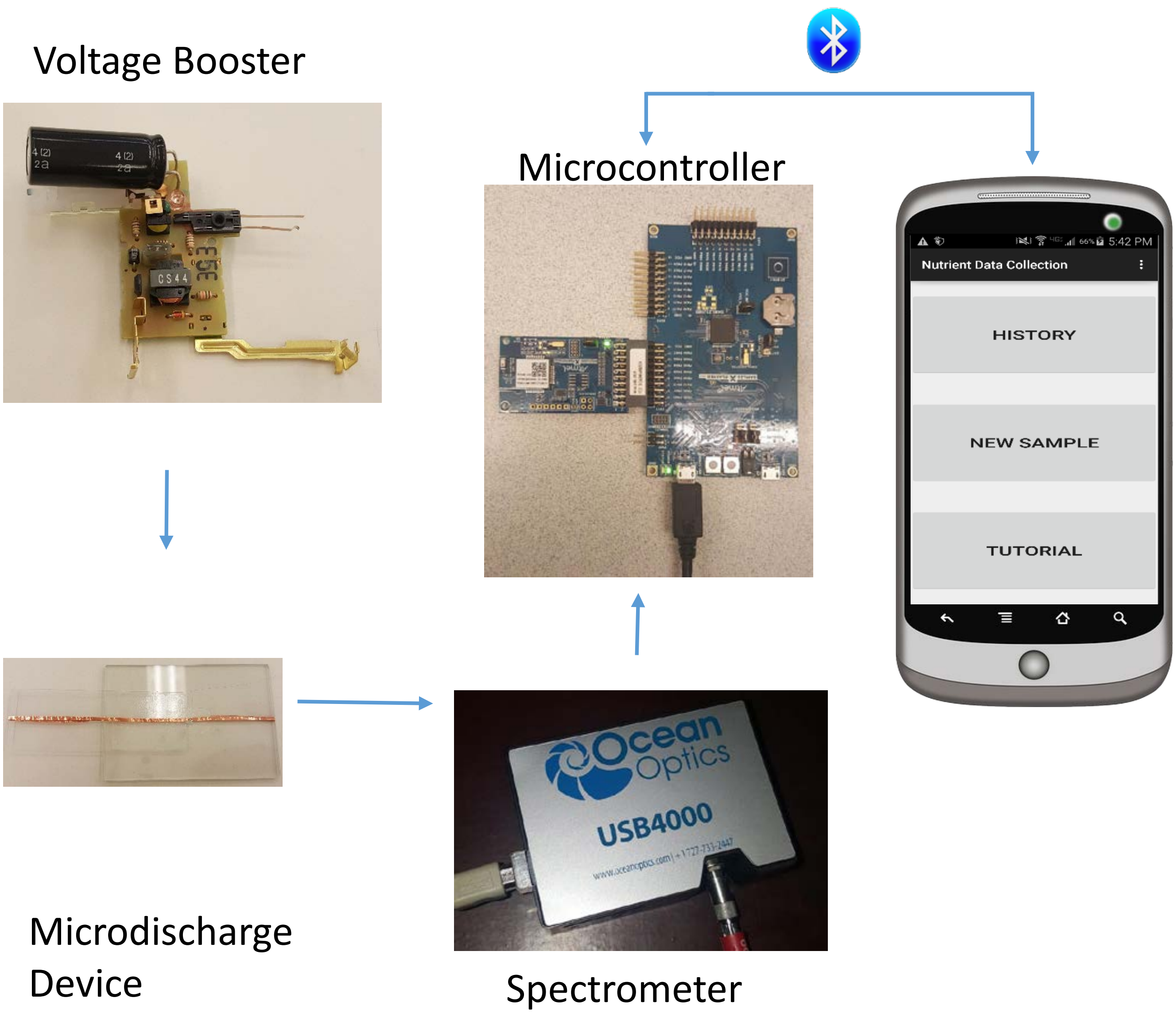


Figure 1: concept sketch

Subsystem specifications

Voltage booster

We use the voltage booster in order to boost the voltage in the micro-discharge device to 300V in short period. With this voltage, we can stimulate fluorescence in the solution contained in the micro-discharge device. The circuit of the voltage booster we designed is shown in the figure on the right, we use the xft-5683-3v 3v to 300v transformer, 2sd882 n-p-n 30v 3a transistor and c450-1000u 450v 1000uf capacitor.

Micro discharger

The Micro-discharge device is used to generate electrical breakdown between two metal electrodes and stimulate the fluorescence in the solution. Exploded schematic of the liquid electrode discharge spectral emission chip (LEdSpEC) is on figure on the right, which is a stacked microchip, and the associated control circuit and detector arrangement. Short arrows indicate the stacking order for the microchip whereas long arrows indicate the two orthogonal optical paths, as noted. The chip is held vertically during operation. We use the spectrometer as the detector which will be discussed in the section of spectrometer. The Anode we used is 4mm wide strip of MetGlas foil (Magnetic Alloy 2826 from Metglas Inc). The Cathode we used is saturated salt solution (Need To be Determined). The Glass we used is 506 mm thick, #7740 Pyrex=. The Optical filter we used is commercial dichroic filter made on a 2.5 mm thick quartz substrate.

Interface between spectrometer and microcontroller

The spectrometer will transfer data to microcontroller by RS-232 handshaking communication. This handshaking communication is established by cross over connection of TX and RX pins of the spectrometer and microcontroller. As the RS-232 has different voltage level from the microcontroller, a MAX3232, in figure 1 and figure 2, is used to rectify the voltage level and convert the RS-232 signal to TTL voltage level, or reverse the conversion. The rectified voltage is 3.3VSAM L21 from Atmel, is chosen to be our microcontroller. An evaluation board is used to learn the commands of communication between spectrometer and SAM L21.

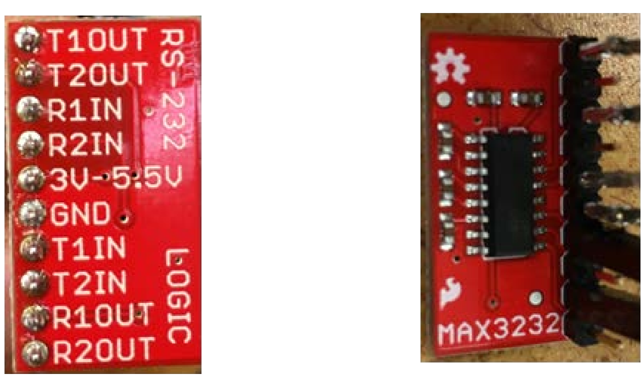


Figure 2: MAX 3232, the left is the back side, the right one is the front side

PCB

In this project, we want to grab data from the spectrometer and send those data to the smart phone through Bluetooth. So we need a microcontroller to receive data from the spectrometer and control the Bluetooth module. After doing a lot of research, we decide to choose SamL21 as our microcontroller. Because the samL21 is a Ultra low-power microcontrollers using the 32-bit ARM® Cortex® -M0+ processor at max 48MHz and up to 256KB Flash and 40KB of SRAM in a 64 pin package. It is very powerful and it can perfect match the Bluetooth module we have chosen, BTLC1000.

After we decide the microcontroller and the Bluetooth, we need to choose which kind of interface we should use. The spectrometer has the UART interface, same as the microcontroller. So we decide to build a UART serial communication between the spectrometer and the microcontroller. However, the microcontroller is on the TTL voltage level (3.3V) and the spectrometer is on the RS232 voltage level (5V). So we add an adaptor to convert the voltage level between spectrometer and the microcontroller. This adaptor is called MAX3232, it can convert the voltage from RS232 to TTL. The whole PCB need a power source to work, we decide to use a 9V battery. However, our microcontroller need a 3.3V power supply, so we need to add a voltage regulator to maintain the voltage on 3.3V. Besides that, we also have an operating LED on our printed circuit board. This operating LED can tell us if our microcontroller and the Bluetooth module works well or not. We also have a reset button on the board and a backup battery. The reset button can do the reset job by hand and the backup battery can keep the data in the memory if the regular power supply shut down.

The following graph is the schematic diagram of out printed circuit board.

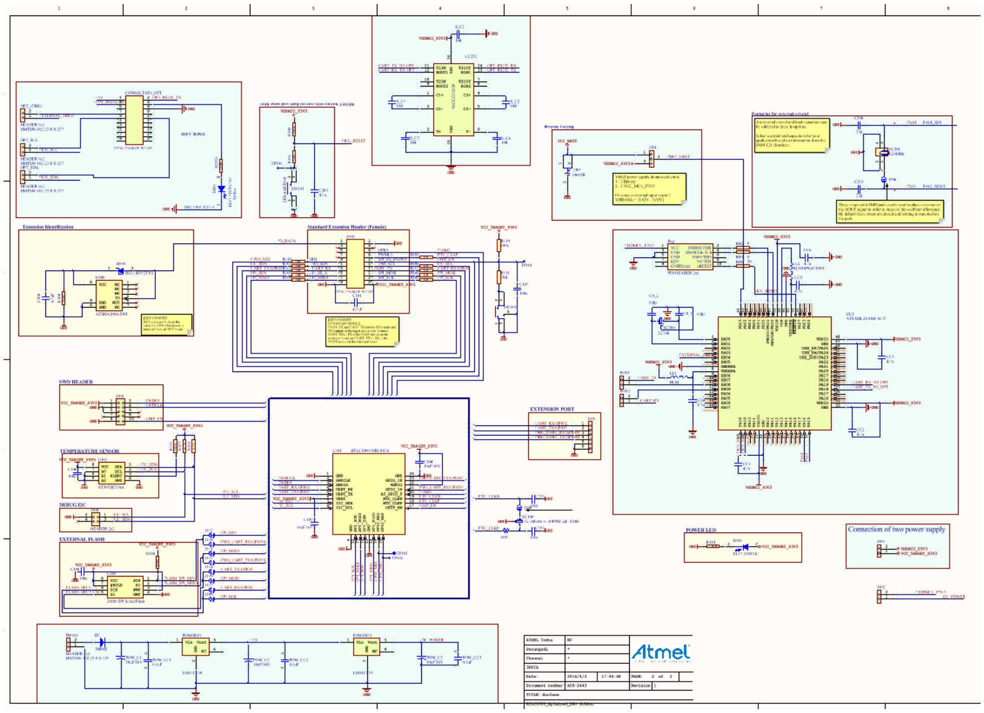


Figure 3: PCB CAD drawing

The following two pictures are the 2D view and 3D view of our printed circuit board.

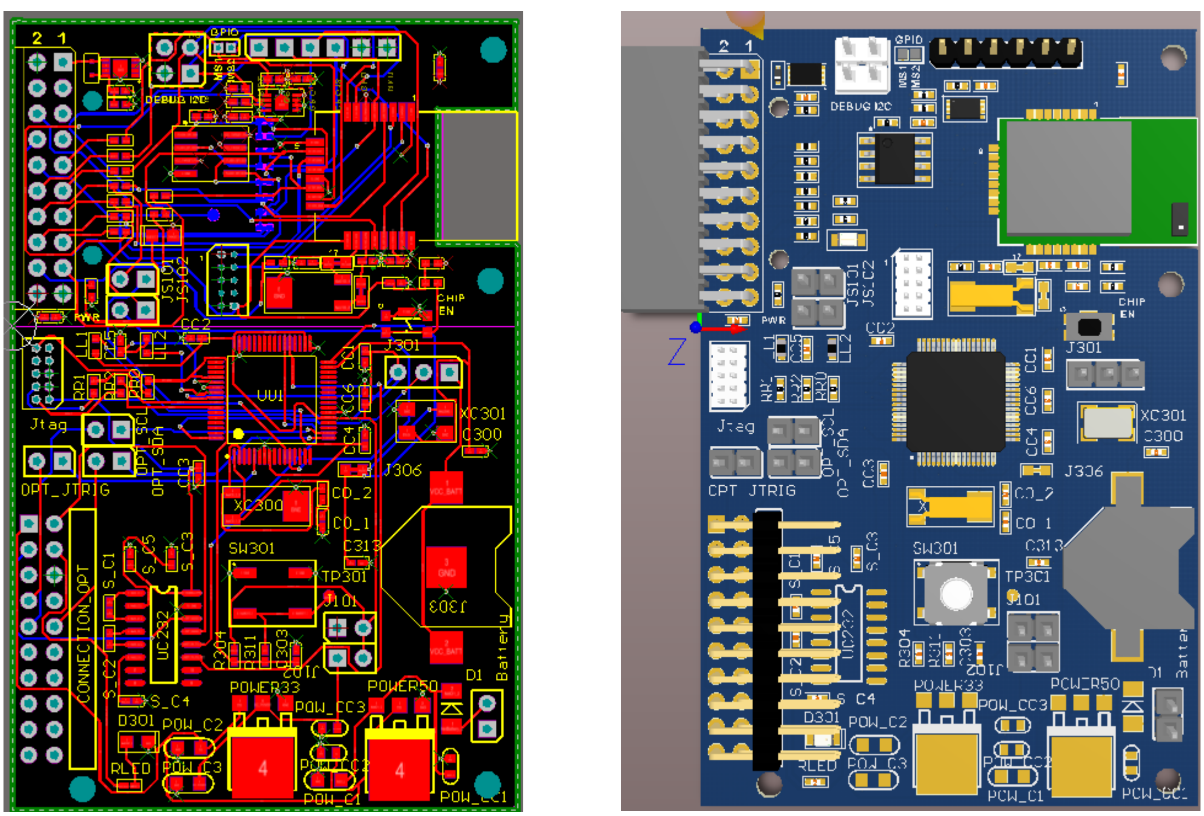


Figure 4: LEFT is the 2D view, the RIGHT one is the3D view

In order to decrease the size of our printed circuit board, we choose most of our components to be footprint 0402 surface mounted, which is super small. Although this action can save a lot of space for our whole product, it me very hard to solder those 0402 footprint components on our printed circuit board.

Bluetooth Communication

Wireless communication is needed for two roles in this project.The first role being to start the system from the Android device and the second is to transfer the generated spectrum data back to the phone. Bluetooth was chosen as the wireless communication between the microcontroller and Android device because of its known functionality for transferring data within our range of operation and because of its widespread use in almost every Android device. We decided to go with the new Bluetooth Low Energy (BLE) to meet the low power requirement for the system.

Following the Bluetooth 4.0 Specifications for BLE communication the Android device was defined as the Central Role and the microcontroller was defined as the Peripheral Role. The Android device and microcontroller both have the role of Client and Server depending on the function being performed.

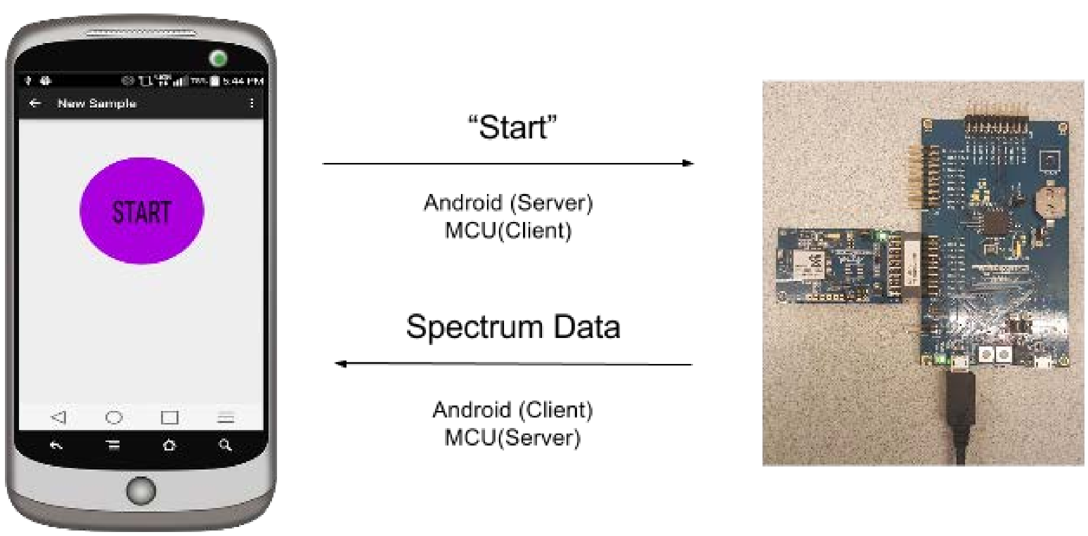


Figure 5: Android and Microcontroller Bluetooth Communication

The first role of the Bluetooth interface it to send a start signal from the Android device to the system to begin the data collection and analyzation of the water sample. After the Start button is pressed on the Android application a signal is sent to the microcontroller to notify the spectrometer to begin recording data and once that data is collected to send it back to the Android phone. Following the BLE Specification a Profile was created for this notification where the characteristic has a read and notify descriptor. When the start button is pressed it writes a value of "1" to the characteristic and notifies the Microcontroller of the change.

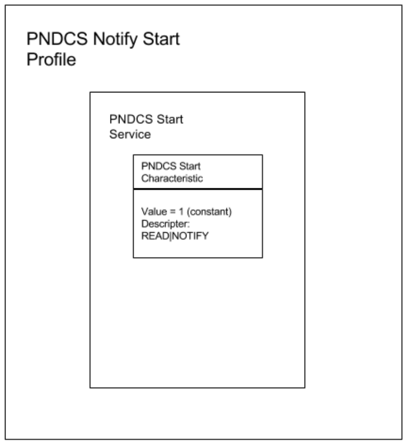


Figure 6: PNDCS Notify Start Profile

The second role of the Bluetooth communication is to send the spectrum data from the Microcontroller to the Android Device. The spectrum data is a sequence of around four thousand pixels where each x component is the wavelength and the y component is the intensity. BLE technology allows for for long writes of less than 160 bytes so to send this data over to the Android device a loop is executed sending packets of 150 bytes of pixels to the Android device which then adds those values to the graph in that callback.

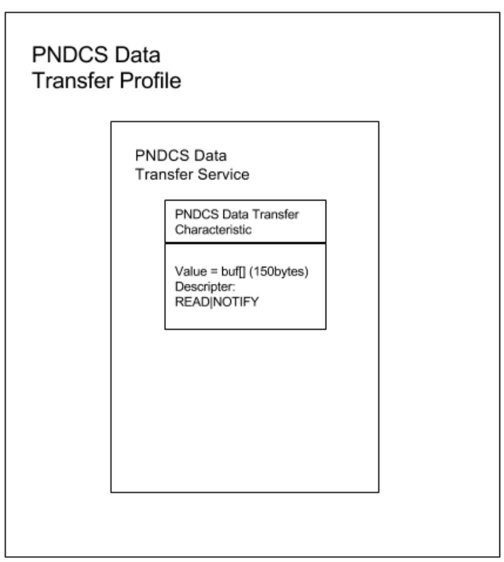


Figure 7: PNDCS Data Transfer Profile

Case

The case is designed to hold and protect devices in whole system. In our Nutrient Data collection system, most of devices are precision instruments such as BTL1000, flash microcontroller chip and Voltage Booster. In order to protect those devices and keep dust and water away. A box is necessary. Also to achieve a portable goal, the box should be as small as possible and all devices need to be set in a limited space very well.

Entire box is 12 x 12 x 12" and can be divided into two layers. The upper layer is used to place Micro-discharge device. People can put sample which they want to test on it. And the Voltage booster, Microcontroller and battery can be placed into lower layer. There are two ellipse holes on both side of the box. Wires can connect Micro-discharge device and spectrometer through those holes. Also there is a diameter 6mm hole on the top of the box. That is used to put sensor which is from spectrometer in the box.

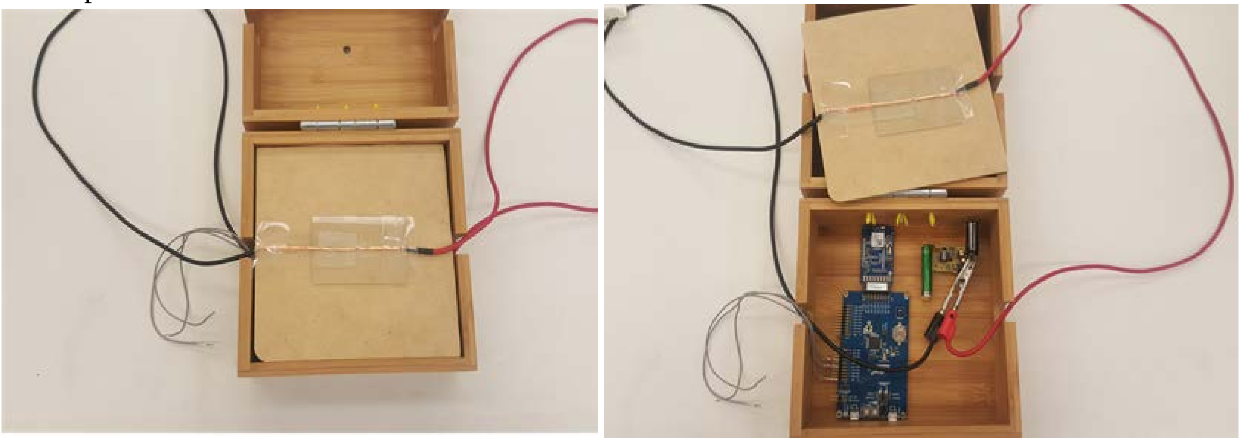


Figure 8: LEFT is the upper layer of the box, the RIGHT is the lower layer of the box

Project Timeline

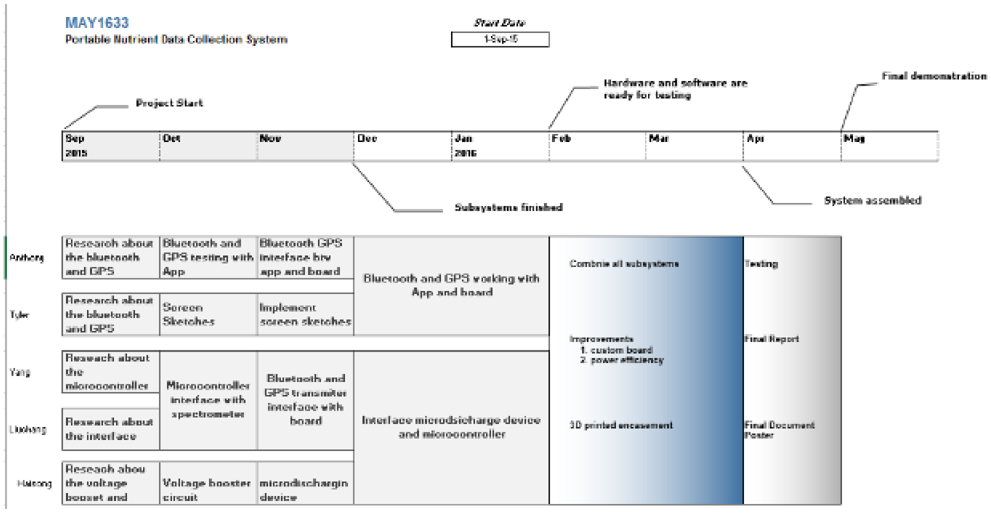


Figure 9: Gantt chart

Risk

8.1 Risk of project timeline

The biggest risk is how long the whole project will took. The system is more like research project that there are many unknown factors, such as the interface between the spectrometer and microcontroller. The current spectrometer is a wall-powered and customized spectrometer, it require extra official software to deal with the output. If the format of the data cannot be transmitted to the microcontroller successfully, it would be an issue.

8.2 Risk of power supply

The second risk would be a power supply. As the current spectrometer needs a wall plug-in to provide power, it would be hard to make it as a portable device with low power consumption. Besides, the microcontroller may also require a lot energy. To provide power for microcontroller, a phone battery may be applied but there is also the risk about back powering and burn circuit.

Implementation issues/challenges

9.1 Software

9.1.1 Bluetooth

The hardest part of implementing the Bluetooth functionality was reading the example code of the Atmel microcontroller. The Atmel ASF has a lot of example code for using the standard BLE Profiles and services but creating a custom Service and advertising that service did not have a lot of documentation. After much research a custom service example was found but allowing that service to be advertised to the central device was still not well specified in the code. Speed of the communication was also a major issue since BLE communication normally transmits 20 bytes of data per packet and most implementations have it sending after 200ms to ensure successful transmission. In test we were able to send the data as a long write of 150 bytes per packet and there is even a way to change the MTU settings to send 512 bytes per packet but it was undefined that both the microcontroller and Android device supported that change. How to format the data was also an issue because it was not well defined in the spectrometer data sheet how the pixel was formatted and without ever seeing the output from the spectrometer we were not able to decode what its format was. We attempted to send mock data from a text file over the BLE connection but the Android device was not able to find the PNDCS Data Transfer Service which is either from a bug in the microcontroller code or due to BLE current bugs in the Android 4.0 software. We would need to redefine the characteristic data for the actual spectrometer data being transferred across UART and establish a higher data transfer with MTU settings.

9.2 Hardware

9.2.1 Soldering

This is our first time dealing these 0402 foot print soldering, we have gone to the ETG and they suggested us to use the reflow oven to bake the PCB and solder components. Before we put PCB and components into the oven, we have to use the soldering paste to stick all the components on the board. Because our 0402 foot print components are too small, we have not soldered all the parts on the PCB perfectly. This makes our PCB board do not work. However, we do not have an alternative printed circuit board, so we cannot do it again and finished it successfully. To avoid these kind of mistake in the future, we should use 0804 foot print components instead of 0402 foot print components, and we should order more than one PCB board just in case.

The following diagram is the real product picture of our printed circuit board.

Figure 10: Custom PCB with battery

9.2.2 Interface of Spectrometer

To build the interface of spectrometer for the microcontroller, the physical connection needs to be established. The USB mode is our first choice, because it already built on the spectrometer and USB transmission is really fast. But after using the USB connector and installed the driver, spectrometer does not respond to the commands send from computer. The computer can recognize the spectrometer as advice. Then the DB9 connecter is used to establish the RS-232 connection. However, this time, computer cannot recognize the device. Since there is no development tool for the microcontroller inside the spectrometer, and we are not supposed to do that because the students who work on it are not very professional ebbed system programmers, we are forced to use Atmel evaluation board to communicate with spectrometer. This time, we get the response, but the Atmel Evaluation board regard the data as a bad format data. At last, we use oscilloscope to measure the output and input. It turns out, the input is correct but there is no output, probably the spectrometer block it or the evaluation board did it. Then we think there are probably certain order of setting the spectrometer and then we can get the spectrum. After using all our reachable methods, we decide to contact the technician of OceanOptics, which is the manufacture of the spectrometer, but the technician cannot give us much instruction about using code to test gathering data.

Testing

10.1 Voltage booster and micro discharger

The testing for the voltage booster is went well. We used a 1.5V battery to test the voltage booster circuit and the highest voltage can reach about 290V. The charging circuit works quit well. Then we applies the voltage on the micron discharger device, there is a flash and electronic fire come out, which according to our adviser Dr. Que, this should be a sign of a working circuit. More testing should be scheduled to test micro discharger device with spectrometer and target element samples.

10.2 Interface between Spectrometer and microcontroller

To test the interface, we first used the evaluation board to test the respond of the spectrometer. From the evaluation board side, the command is sent successfully because the return value of the function in evaluation board is correct. But there is no spectrum output. After using the return value check, we find out that the function returns to "Bad Data Format". Then we used oscilloscope to test the input and output voltages of the evaluation board and spectrometer. We observed there is voltage change when input command is sent, but there is no change of the output.

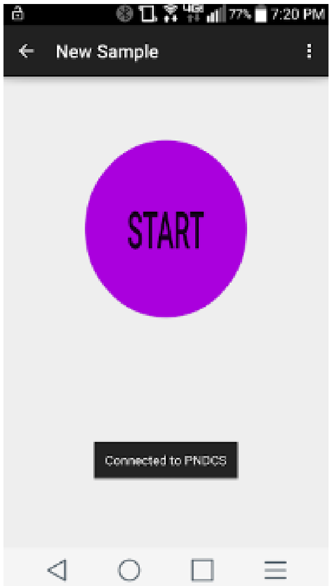
10.3 Bluetooth communication

To test the Bluetooth communication the microcontroller is connected to the host development computer and a Tera Term terminal (Serial connection, 115200 Baud Rate) is opened to watch the debug log. Similarly, the Android device is connected to the development computer and Android Studio is opened to watch the debug log of the device.

To test the pairing of the microcontroller and Android Device the microcontroller is restarted and the tester waits to see "BLE Started Advertisement" from the Tera Term terminal. The tester then connects to the device from the Settings/Bluetooth of the Android device and attempts to pair with the PNDCS device in the menu and should wait for "Pairing procedure completed successfully" from the Tera Term terminal and the device connection on the Bluetooth Screen. During testing, pairing was able to successfully complete after every trial (100+).

To test the connection to the app the tester then goes to the Nutrient Data Collection Application and click on the new sample button. Verification of connection is viewing a toast pop up saying

"Connected to PNDCS" as shown below. Similarly to pairing, connection was able to successfully complete after every trial (100+).



To test the start command is being received by the microcontroller from Bluetooth the tester should then press "START" and observe that the LED on the microcontroller illuminates. Hitting start again will turn off the LED (testing purposes). This was shown to work after 100+ trials.

To test the data transfer of the spectrum data from the microcontroller to the Android device after the "START" button is pressed the application should show a graph of the transmitted data in under 2 seconds (from requirements). This test failed because the implementation was unsuccessful.

10.4 Cellphone App

The app was given to several users to test how easy the app is to use, how aesthetically pleasing the app is, as well as testing for bugs a user may come across. Users would give feedback on the app in the form of suggestions on what to change, or to keep.

The app was also tested for connectivity to a SQLite database by storing sample data into the database, and be able to read this data. The app was also tested to see if new data was successfully stored, and the new data could be read.

Figure 11: Connection Toast

Conclusion

The system would help farmers to manage the nutrient in the fields easily, decrease the risk of over fertilizing and monitor the plant status. Implementation of this system may also save effort for research involved in elements measurement. After spend two semesters time we have learned a lot from this project.

Appendix

Appendix I: Operation Manual

1. Connect the spectrometer and the system by using a fiber with a connector SMA905
2. Check the battery for the device.
3. Turn on the power supply for the device.
4. Go to the Bluetooth menu in the Android settings. Pair the Bluetooth with the smartphone, enter 123456 for the pin. The connection should be done.
5. Run the "Nutrient Data Collection" app.
6. Hit the "Start" on the screen, and the smartphone should start the voltage booster and micro discharger (there should be some flash, which is the light source of the spectrometer)
7. Wait until the system collect data and send to the smartphone.
8. The data will be displayed on the smartphone and show which element is under testing.

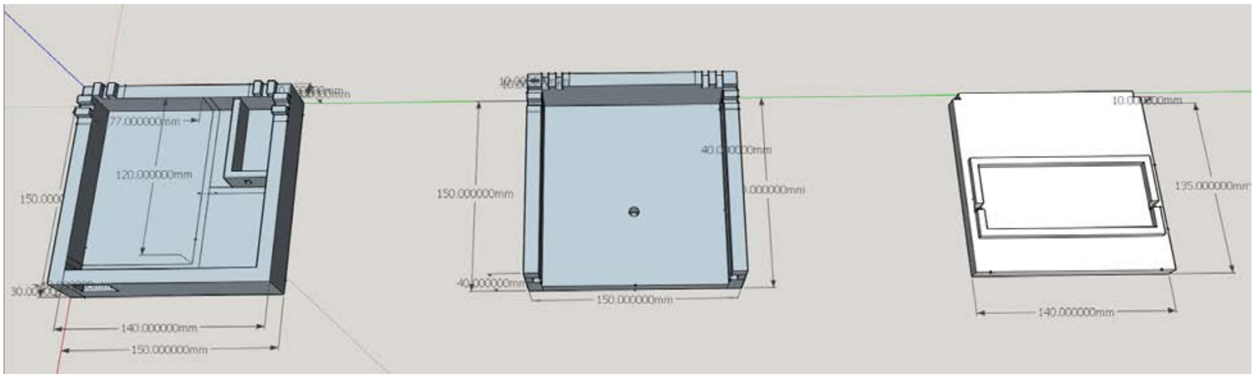
Appendix II: Alternatives

Microcontroller

Originally, we wanted to have a single chip to be able to perform the microcontroller and bluetooth functionality. The ATBTLC1000 was chosen for this purpose but we had failed to realize that this module is a microprocessing unit (MPU) instead of a microcontroller unit (MCU). With external memory this chip can be used as a standalone application processor but there is limited documentation on this procedure so we opted to use the ATBTLC1000 module as a peripheral to the SamL21 MCU that came with the evaluation board.

3D Printed Box

During design case process, one easy and accurate way is using software to build a model and print it by using 3D printer. However, this plan has been cancelled due to high price ($307). The box are currently done by hand using two wood tissue box.



Appendix III: Purchase parts

Item	Qty.	Ref.	Cost (each)	Part Desc.	Supplier
1	2	ATBTLC1000-XSTK	$ 108.26	BTLC 1000 Xplained Pro Starter Kit	Atmel
2	4	MAX3232	$ 1.82	MAX3232 transceivers	Digkey
3	1	SAM B11 Xplained Pro Evaluation Kit	$ 42.65	Evaluation board	Atmel
4	3	IC flash 2MBIT 100MHz 8SOIC	$0.59	external Flash	Digi-Key
5	2	ATSAMB11-MR210CA	$ 14.96	Bluetooth chip	Mouser
6	8	HEADER 1x2	$ 0.82	1x2 pin header, 2.54mm pitch, Pin-in-Paste THM	Digikey
7	4	6.8p Capacitor	$ 0.22	Ceramic capacitor, SMD 0402, X7R, 25V, +/-10%	Digikey
8	2	4.7u Capacitor	$ 0.14	Ceramic capacitor, SMD 0402, X5R, 6.3V, +/-20% (de33687)	Digikey
9	8	100n Capacitor	$ 0.10	Ceramic capacitor, SMD 0402, X7R, 16V, +/-10%	Digikey
10	2	10u Capacitor	$ 0.44	Ceramic capacitor, SMD 0603, X5R, 16V, 10UF ± 20%	Digikey
11	6	4.7n Capacitor	$ 0.10	Ceramic capacitor, SMD 0402, X7R, 25V, +/-10%	Digikey
12	2	22p Capacitor	$ 0.22	Ceramic capacitor, SMD 0402, NP0, 50V, +/-5%	Digikey
13	2	2x10, female pin header receptable	$ 1.67	2x10, female pin header receptable, right-angled, 2.54mm pitch, THM, Pin In Paste	Digikey
14	1	Schottky diode	$ 0.04	Schottky diode, If:200mA, Vf:0.35V, Vrrm:30V, SOD-523	Newark

15	2	LED	$ 0.26	LED, Green, Wave length=575nm, SMD 0805, ±70°	Digikey
16	1	x3 pin header	0.25	1x3 pin header, 2.54mm pitch, Pin-in-Paste THM, 1mm hole	Arrow
17	1	1N4148	0.1	Diode	digikey
18	1	Inductor	0.1	SMD RF inductor 0603. Z=470Ohm (@100MHz), Max R(dc)=0.65Ohm, Max current=1A	digikey
19	1	Inductor	0.1	SMD RF inductor 0603. Z=470Ohm (@100MHz), Max R(dc)=0.65Ohm, Max current=1A	digikey
20	2	LM1117DT-3.3/NOPB	$1.65	chip	ti
21	2	LM1117DT-5.0/NOPB	$1.65	chip	ti
22	3	capacitor	0.19	10uF/16V	digikey
23	3	capacitor	0.1		digikey
24	5	resistor	0.1	Thick film resistor, SMD 0402, 1/16W, 1%	digikey
25	12	Resister	0.1	RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, RES 0.0 OHM 1/16W 0402 SMD, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, RES 0.0 OHM 1/16W 0402 SMD, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%, Thick film resistor, SMD 0402, 1/16W, 1%	digikey
26	3	Resister	0.1	Thick film resistor, SMD 0402, 1/16W, 1%	digikey
27	2	Resister	0.1	Thick film resistor, SMD 0402, 1/16W, 1%	digikey
28	2	Resister	0.1	Thick film resistor, SMD 0402, 1/16W, 1%	digikey
29	1	Push botton	0.4	Microminiature Tact Switch for SMT	digikey
30	1	Push botton	0.35	6.2x6.2 mm SMD tact switch, same as A08-0091 but less force is needed	digikey
31	1	ATSHA204A-SWI	1.23	ATSHA204 with 1-wire interface and UDFN8 package	digikey
32	1	ATBTLC1000-MR110CA	$12.53	bluetooth chip	Atmel
33	1	IS25LD020-JNLE	0.59	2 Mbit SPI Serial Flash upto 80MHz	digikey
34	1	MAX3232SOP	$ 5.84	adapater	mouser
35	1	ATSAML21J18B-AUT	8.01	Atmel 32-bit RISC MCU 64pin	Atmel
36	2	MICRO CRYSTAL	1.25	MICRO CRYSTAL MS1V-T1K 32.768KHZ +-20PPM 7PF CRYSTAL, SMD, MET, 32.768KHZ 7.0	farnell
37	1	559-FQ5032BR-12.000	$1.17	Fox FQ5032B 12.0MHz SMD crystal 738B-12	mouser

Appendix IV: Other considerations

Future Iterations

GPS

Originally, we had specified to have GPS included in the system to allow for the data to be mapped to a certain location to make it easier for the user to know where they have had made measurements in the field. This could be an added feature to increase the quality and uniqueness of this product in the future.

Battery Indication

Since power is a major concern of this product it would make sense to use the Battery Service Profile to show the current battery level of the device on the Android application. Again this would increase the quality of the product.

Bluetooth

Bluetooth Low Power (BLE) is great for sending small, infrequent packets of data but for sending larger amounts of data it can be of the same or worse efficiency of standard Bluetooth. Standard Bluetooth can also have a higher level of throughput which would speed up the transfer process. Changing to standard Bluetooth could be effective if more data is going to be needed to transfer.

Spectrometer Alternative?

One of the main issues we had with our project was interfacing with a custom spectrometer to obtain a spectrum for the elements consistencies because of our limited access to the instrument. The size and cost of the spectrometer also limits some of the design decisions for the system. Designing an alternate way to measure the consistency of the these elements could allow for an easier interface and can allow the system to be more portable and energy efficient.

Insulating Packaging

In our project we had built a box for demonstration purposes that is relatively safe for perfect conditions. Future iterations of this project might want to look into insulating material considering the high voltage, water samples, and environment.

What we learned

Identify the highest level of risk

One of the main things we learned from this project is to identify what part of the system is crucial to its success and to address that part first and with the most manpower. For us, the communication between the spectrometer and microcontroller was a crucial part of our system that needed the most attention. We should have stressed completing this part of the project early and dedicated more of our team to it.

Communication

Communication is essential for any team and we were reminded of that in this project. Communication between each of the subsystems and how they were going to communicate with each other was crucial to our project and putting it all together. Communicating to faculty members and other members of the team when you need help early would have helped a lot in this project.

More Planning

When we designed our system we had a pretty clear idea of what each of us had to do to make this project a success but we didn't know the details of how everything was going to come together. More planning on how exactly we were going to connect each of our components and what everyone needed would have helped this project a lot. Establishing hard deadlines to accomplish our goals would have also helped so that we could allocate more resources to solving a problem if we fell behind.

Appendix V: Code

https://github.com/acschilling/Portable-Nutrient-Data-Collection-System.git