Home Hydroponics System

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***Abstract* — The goal of this project is to create a hydroponic system that can be used in the household environment. The system will be automated for easy use by individuals that don't have previous knowledge by hydroponic farming techniques. The system will use numerous sensors to measure and adjust the pH, TDS and water. Since the system can track these measurements this system can help any owner grow healthier and stronger plants. The system will interact with a website and database so that the users of the system can access the sensor measurements from either a mobile app or the website.**

***Index terms* — Microcontroller, pH Probe, Conductivity Probe, Light Sensor and LED array, Transistor Pump Control, Digital Potentiometer, WiFi Module, Water Level Sensor, Power Supply, Database, Mobile Android Application Programming, WiFi–Programming, Website Design**

I. INTRODUCTION

Hydroponic techniques have been around for thousands of years, since the Hanging Gardens of Babylon and the Floating Gardens of China. While the general theory hasn't changed very much, modern technology has enabled for plants to grow stronger, faster and healthier. Even with these improvements this hydroponic systems is able to increase the yield of each harvest and shorten the time between harvests. Even though these improvements may seem like enough the most important aspects are that it;

- Uses less water than conventional farming
- Uses less space than conventional farming
- Gives farmers more control over their plant growing cycles
- Farmer have complete control of the nutrients the plant receives
- Affordable

Because of these benefits this groups believes that hydroponic is the future of food production around the world.

II. PROJECT GOALS

The main goal of this project is creating a working prototype of a home hydroponic system that at least meets the minimal requirements needed to maintain and grow plants. In the process this group hopes to gain more experience with;

- the overall engineering process
- software design
- hardware design
- circuit design
- resource management
- working on an engineering team
- PCB design.

While the individual members in this group have a theoretical understanding of the many different aspects this task requires. Combining and executing those elements will become our greatest challenge. As each element is designed separate from the each other, the group must always remember and design that piece to fit into the project seamlessly. It is this group desire to become much more rounded and knowledgeable engineers. This project provides that opportunity.

Even though there are many benefits to hydroponics systems it still isn't the main method of growing plants currently. The main issue with hydroponics currently is the volume of energy it requires to maintain. Finding a way to cut down on this cost is a major goal for this group. Even if this group can't cut the energy for a hydroponic system to run, the group aims to create ways to cut cost outside of the circuit design. Since there have been many ingenious and creative engineers working toward making circuits and architectures more efficient, this group would like to think outside of the box and maybe find a way to cut the cost by using the available resources of the Earth. An initial thought is to use the natural sunlight for the system instead of always using lighting. As well as using supplemental lights to aid in growing of crops but just offsetting the sunlight on days that it isn't providing enough light.

III. HYDROPONIC SYSTEM DESIGN

Nutrient film technique is the system that we ended up going with in this project as it was simple to set up and is the most common setup for small area growing. This system also used a water pump to provide the plants with water and nutrients. In this system, the water is always being pumped to the roots. The difference with this type of system is that the pump provides not only the nutrients, but also the air that has been defused into the hydroponic solution by an air source and a stone. The water is generally pumped to the highest location of the grow rack and gravity draws it back down and into the containment container. This system is always bringing nutrients to the plants and is a very efficient system. In the tubes the roots are exposed to nutrients which are running down the tubes in a film technique, this means that the roots are exposed to the solution but more importantly, they are exposed to oxygen where the roots do not make it to the bottom section of the tube, in Fig.1 you can see this technique.

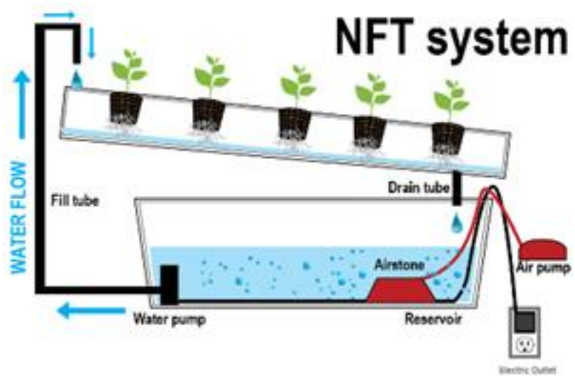

Figure 1 An example of a NFT System

IV. SYSTEM'S AUTOMATION LAYOUT

This system will use two microcontrollers, a pH sensor, a conductivity sensor (used to measure TDS of the system), a light sensor, LED array, four peristaltic pumps, digital potentiometer, WiFi module, water level sensor and a power supply system. Each of these subsystems will be explained and examined further in the following sections.

A. Microcontroller

This system uses two microcontrollers to control the entire system. The communication between these two microcontrollers we chose to use the I2C serial communication with a data and clock line attached to two analog pins on both microcontrollers. The microcontroller we chose for this system is the AtMega328P made by Atmel Industries seen in Fig.2.

This microcontroller has 32kB of self-programmable flash memory, 1kB EEPROM, and 2kB internal SRAM. It boosts 23 programmable I/O pins for communication and the package type is hole through design. Our choice of the hole through design allowed us flexibility by using a socket for mounting to our PCB and in the case of accidental short-circuit the possibility to get back up running by replacing the microcontroller. The I2C communication decision was based on that we needed our system to be able to monitor the sensors while also working in the background to update our user LCD screen and online database. In this way, we could add parallelism to our system which made it run faster and more efficiently.

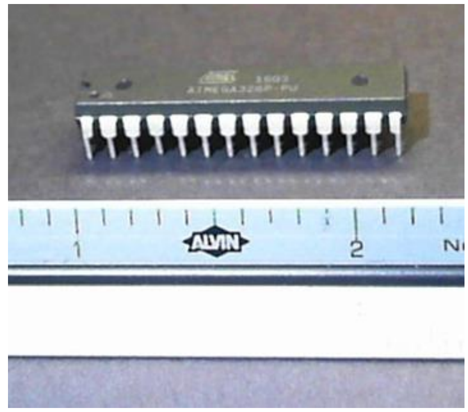

Figure 2 Atmel AtMega328P Microcontroller

B. pH Probe

In this project, we selected the Atlas Scientific pH sensor due to the reputation of this company to supply quality products and the home consumer level as seen in Fig.3. For any agricultural home hydroponics system to be successful and provide a bountiful crop, a proper pH level must be maintained as closely as possible so that the nutrients which are supplied to the roots can be absorbed at the optimum level.

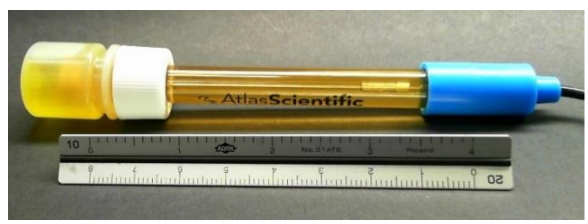

Figure 3 pH Probe

Figure 4 EZO pH Module

This kit which we ordered through Atlas Scientific came with the probe as seen is Fig.4, and the pH EZO module as seen in Fig.2. This module allowed us to choose between serial or I2C communication with the microcontroller. Not only did this allow for flexibility in our design, this module allowed us to calibrate the sensor by using three pH solutions 4.0, 7.0, 10.0, and a storage solution. This greatly increases the reliability and accuracy of the device.

This pH probe reads measurement from 1 to 14 with 1 being the most acidic and 14 being the most basic. A pH of 7 is said to be neutral. Different kinds of plants need a different range of pH values but the most common range is from 5.0 to 7.5. In our system, we will be able to control the pH from an online database or from a smart phone depending on the needs of the plants being grown. In this system, we will control the pH level to within these ranges needed by the plants by adding pH plus (a base solution), or pH minus (an acidic solution). These solutions will be delivered to the hydroponic solution using two peristaltic pumps.

Once the pH level is defined through the database our microcontroller will deliver the needed solution to the storage tank and wait the appropriate time for the solution to be fully mixed and check again if more action is required.

C. Conductivity Probe

Another very important function in our system is to measure the conductivity or T.D.S. (Total dissolved solids) in the storage solution. In our case these are the nutrients that are supplied to the roots of the plants. The sensor we chose again is another product by Atlas Scientific as seen in Fig.5.

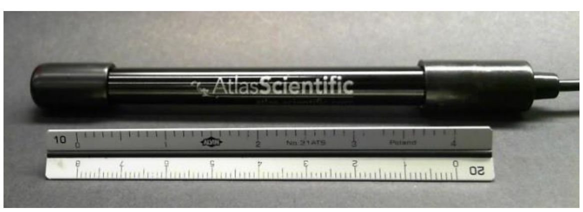

Figure 5 Conductivity Probe

Most plants need two different nutrient solutions during their life span. During early development, a fast growth nutrient is needed for fast and strong growth of branches and leaves. In their second phase a second nutrient is added to the first which promotes flowering or fruit depending on the type of plant. This sensor also came with a module which also allowed for the flexibility to communicate with the microcontroller by either serial or I2C communication as seen if Fig.6. Also, the kit we ordered also came with two known TDS solutions so that fine calibration of the sensor could be done.

Figure 6 EZO EC Module

A conductivity probe works by measuring the electrical conductivity in a solution. The more total dissolved solids that are in the solution, the higher the conductivity through the solution there will be. This voltage is turned into a value which the microcontroller can read and make changes to either nutrient solution which can be adjusted using two peristaltic pumps, one for the fast and rapid growth of stems and branches and the second for the flowering stage.

D. Light Sensor and LED array

This design incorporated the ability to adjust the lighting to reduce electricity cost and to make sure the plants received the correct amount of light to grow. As the data is collected and stored in the web based table it will give the user the ability to track what lighting produced the best harvest and then could know the exact type of plants and the time of year works best.

For plants to grow they need to receive the correct amount of lighting. The only way to know if the plants are receiving the needed light the use of a light sensor was desired. The Adafruit TSL2591 high dynamic range digital light sensor was the chosen component to meet the design specs. A main design characteristic is to be able to distinguish between artificial light and natural sunlight. During this discussion, we thought of several options and the initial phase we were thinking would require multiple sensors to distinguish the difference between light sources. According to the data sheet, “the TSL 2591 combines one broadband photodiode (visible and infrared) and one infrared-responding photodiode on a single CMOS integrated circuit” [1].

The LED array that is part of this system only produces light within the red and blue spectrum. Due to the artificial lighting only producing a specific spectrum the light sensor will detect the artificial light utilizing the visible light sensor and the infrared to detect sunlight. The sensor needs a ground, 5.0 DC voltage, clock, and a data pin to be able to implement it with the microcontroller. Once lighting sensor was mounted seven inches from the light source the coding controlled the gain of the system. The light sensor is very sensitive so the gain was set to high in the code to be able to receive proper data from the sensor. The designed system will have the ability dim the lights so the data from the light sensor will be utilized by the microcontroller to make the decision of how bright the artificial light will be set.

E. Transistor Pump Control

In making the system autonomous the design needed to be able to adjust the pH and TDS levels by utilizing data collected and the microcontroller to make the decision of the levels that were set by the user. The implementation of bipolar transistor circuits was the choice to control the peristaltic pumps.

F. Digital Potentiometer

A desired feature of the system is the ability to control how bright the lights are. The MCP4131 digital potentiometer was found to be a good choice for controlling the artificial lighting to blend with natural sunlight. The ability to control the lighting system will make sure the plants receive the correct amount of light when the sunlight is not strong enough inside of the growing area. The MCP 4131 allows the control of from -0.6 to 7.0 volts. The max current the chip can handle is 25mA. The resistance for the MCP4121 ranges from 0 to 10KΩ. A huge advantage of utilizing the MCP4131 is being able to incrementally control the brightness digitally. After testing the full system, it was determined the appropriated increment of the MCP4131 was in increment of 10. This provided smooth dimming in either direction (up or down). This gave the proper system control without overdriving the system.

G. WiFi Module

The system needed to be able to keep track of the data collected to have the best control. The agreed upon method of data storage was to send the data to a table on the created website. To send the data the best connect ability was to utilize WiFi. After much research the HUZZAH ESP8266 proved to fit the parameters of the circuit design. The ESP 8266 is designed to operate within the FCC approved 2.4 GHz frequency range. It operates with an input voltage of 5.0 volts and it provides 25dBm of power to transmit the data. The ESP will be connected to an end users WiFi modem and this chip operates with 802.11 b/g/n protocols. This module has an onboard microcontroller, 3.3 voltage regulator, logic shifter, integrated TR switch, balun, LNA, power amplifier and matching network to help eliminate the previous issues users had implementing this WiFi chip. Due to this we decided to utilize the module instead of designing the circuit within the time constraints we were faced with.

H. Water Level Sensor

For this project, we selected the 8 inch eTape from Milone Technologies as seen in Fig.7. This eTape is a solid state resistive output that varies with the level of the fluid. This allows us to not have to use the bulky float type sensors which can be unstable in a dynamic environment.

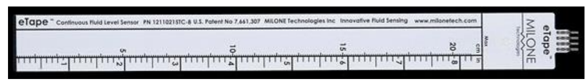

Figure 7 Eight inch eTape Liquid Sensor

This sensor has a range from 1” to 8” with a resolution of 0.01 inch. The sensor is connected to a simple voltage divider circuit which is seen in Fig.8.

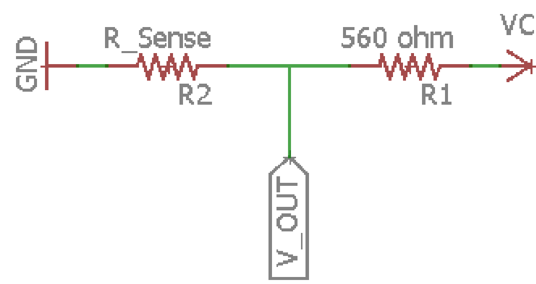

Figure 8 Voltage Divider Circuit

The resistance level seen by this devise is inversely proportional to the level of the liquid. When the water level is low the resistance is high, and when the water level is high the resistance is low as seen in Fig.9.

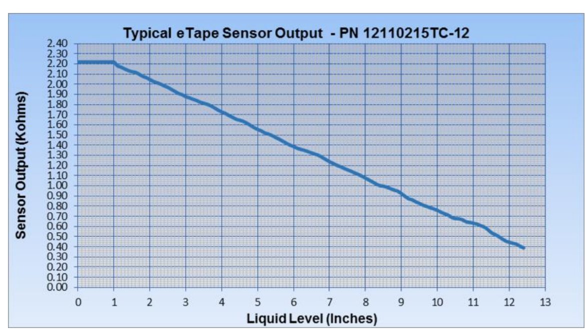

Figure 9 Resistance vs Liquid Level Sensor Output

This sensor will allow us to see when water is needed to be added to the system when it falls below a certain threshold set by the user. Another important function is if the system was to develop a leak, the water level would fall drastically alerting the user via a smartphone app. As a final precaution measure, if the fluid solution pump was to fail, the water that is in the upper part of the system would drain back to the storage reservoir showing a sudden rise in fluid level requiring urgent attention by the user.

I. Power Supply

Once the system design was agreed on the overall power needs were 12.0, 5.0, and 3.3 volts. The overall max current needs are 2.0 ampere. The power supply needs to convert 120 AC voltage to DC voltage of the system needs. The first stage was to research different transformers to match the overall system needs. The completed system needed to provide the correct amount of current so the Jameco valuepro 112512-R will take in the primary voltage of 115/230VAC at 60Hz as seen in Fig.10 and step it down to provide the secondary voltage of 24VAC with 2 amperes of current. The full bridge rectifier was designed utilizing IN4007 diodes and the results are shown in Fig.11.

Once the voltage was rectified the ripple needed to be dealt with to have a stable DC system. In calculating the capacitor value to effectively remove the ripple formulas (1-2) was utilized from [1]. With the capacitor value ripple voltage calculated at 70% the value of 4030µF was calculated. Since 4030µF is not a common value the selected 4700µF was implemented. Fig.12 shows the final desired output of the DC signal. The overall system is low power so linear voltage regulators are utilized. For Electromagnetic interference protection, the system utilized capacitors on the output of each voltage regulator.

$$C = .7\left(\frac{I}{\Delta V * 2 * f}\right) \quad (1)$$

$$\Delta V = V_{pp} * V_{regulator} + V_{dropout} \quad (2)$$

$$\Delta V = 16.9 - 12 + 2 = 2.9V$$

$$C = .7\left(\frac{2}{2.9 * 2 * 60}\right) = 4.02\ mF = 4020\ \mu F$$

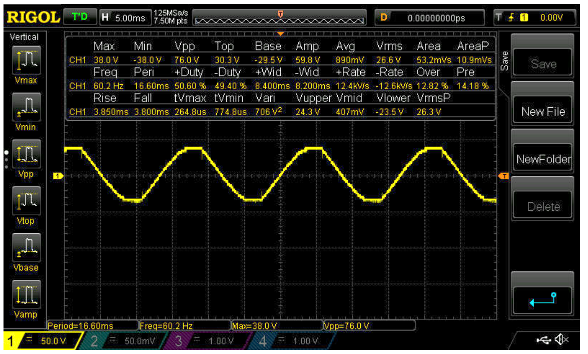

Figure 10 AC Input Voltage

Figure 11 Rectified Voltage

Figure 12 DC Voltage

V. SOFTWARE SYSTEM AND INTERFACE

Since this system was built for ease of access for user it includes uses a database, mobile app and website for the user to interact with the systems statistics. The overall software design is for the physical system to communicate with the website using the WiFi module, which then will update the database. From the database both the website and the mobile will then be update. The following sections will cover these subsystems in greater detail.

A. Mobile Android Application Programming

We wanted users to not only be able to see the readings while in the room with the system, via the LCD display, but also wanted them to be able to see their readings from anywhere there is an internet connection. This led to a decision to develop a website and phone application in tandem so that users had more options for checking their system. With the addition of a Wi-Fi module to the system, we opened our systems to the internet.

We developed a website for Home Hydroponics which allows anyone with a computer and internet connection to access their system to see reading and change settings, but what about someone on the go, that doesn't have a computer? We thought a mobile application would provide convenience for our users.

From personal experience, we knew that developing for Apple's iOS platform was a bit more restrictive. Getting applications onto the Apple's App Store is a bit more difficult and includes paying a fee of $99. Besides that, you also are required to develop iOS applications on Mac computers, something neither of our programmers own. The Google Play Store offers more options for getting your application on the store, and development can be done on Windows computers.

The application was coded with Android Studio, and was mostly written in Java. It heavily utilizes the core concepts of Object Oriented Programming, something that was instilled during coursework at UCF. The application uses HTTP to connect to a website which can then access our database and return information to the app. This three-tiered system offers security advantages as well as adding a degree of modularity to the architecture.

The companion Android application for Home Hydroponics was coded by Alex Costello. The function of the app mirrors that of the companion website. We wanted the website and application to have similar looks and functionality so that users could feel familiar with each.

The Android application allows users to add and drop systems that they want to monitor. After creating an account and logging in, the user can add different systems to their profile. Upon doing so, the user can see the most recent relevant sensor readings for each system on the home page. These readings include pH, TDS, the system's water level, and the system's light levels.

From this Home screen, the user can click a button labelled "Info" for each system. This will take the user to that system's history logs. This is a screen where the user can see all the past readings taken by the system, sorted by date. This history again includes the relevant readings of pH, TDS, the system's water level, and the system's light levels.

The application also features a navigation menu in the top right for easy access of settings. From this menu, the user can go to the Manage Equipment IDs screen, the About screen, or log out of the app. The About screen features a short biography of our Senior Design group.

The Manage Equipment IDs screen is where most of the user setup and editing will take place. Users can add systems from this screen. In addition, they can remove systems, and set the system profiles. When selected a system and hitting the Profile Settings button, the System Profile screen is shown.

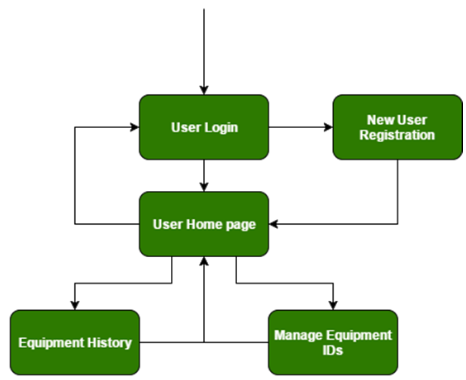

Figure 13 Mobile App Flow Chart

In the System Profile screen, the user can change the nickname of the system, in addition to setting operation parameters for the system. These parameters include pH high and pH low values, which indicate the pH range the system will maintain. Likewise, the TDS high and TDS low values can be set, which sets the range the system will keep the TDS in.

In Fig.13, you can see a generalized flow chart for the Android application.

B. WiFi – Programming

Our Wi-Fi module is the Adafruit ESP 8266 Huzzah board. It comes with NodeMCU on it that allows for the execution of LUA scripts. One of the benefits of the ESP8266 chip however is that you can also run Arduino on it.

Using Arduino, we can still change the antenna operation protocols between 802.11b, 802.11g, and even 802.11n. In addition to the Wi-Fi aspects of the ESP 8266 Huzzah board, you can also use some of the pins as GPIO pins when you use Arduino. Although we didn't end up needing them, it made Arduino that much more attractive for our application.

We set the ESP8266 up to connect to a Wi-Fi access point and transfer our sensor data over HTTP. The relevant sensor readings (pH, TDS, Light and water levels of the system) as well as the unique equipment ID are transferred to our website via an HTTP Post request. After the website enters the readings into our database, it prints out the system's profile settings. Doing this allows our response on the Wi-Fi unit to contain the most recent system settings. From this response, we can parse the relevant settings and transfer them to the microcontrollers. These settings represent the options you can set in both the website and Android application.

The way the overall system is coded is that the Master microcontroller sends readings to a slave microcontroller which then outputs the readings to the LCD display as well as sends the readings to the ESP 8266 Wi-Fi module which then uploads them to our database. Upon getting the response from the server, the ESP 8266 module then sends the response back to the Slave microcontroller, which in turn transfers it to the Master microcontroller.

In Fig.14 you can see a flow chart for the communication between the system, app and website.

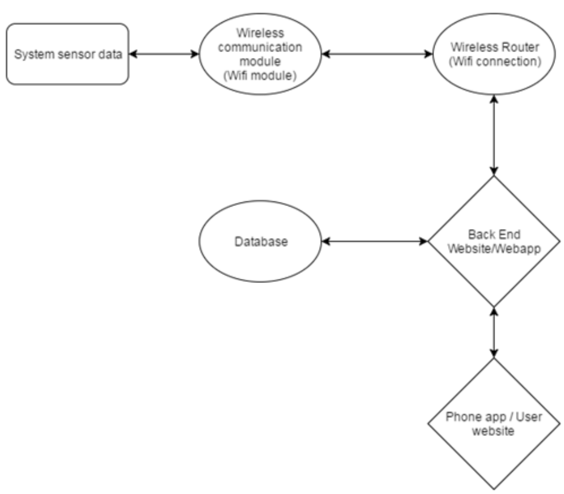

Figure 14 WiFi Programming Flow Chart

C. Website Design

The first stage in the website design was to layout the flow the user will go through to use the system, below is the flow this group decided on;

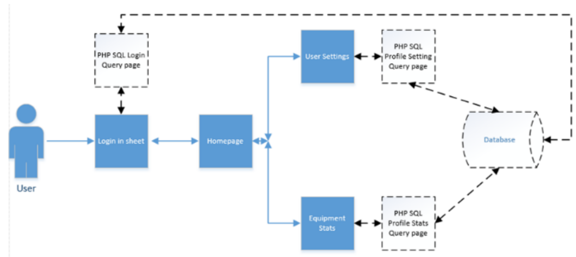

Figure 15 Website User Flow Chart

In Fig.15, the general flowchart for the website can be seen. Each visible web page that the user interacts with has a backend PHP page that will interact with the database. This design isolates the user from directly interacting the with the database and viewing other user's information.

D. Database

The database is what makes this system accessible for each of the interactive devices. The current database uses several different tables to isolate different user data. This design lets the database to be extremely robust and scalable. The database also has many checks and balances so that data can't be inserted incorrectly but either the user or the physical system.

VI. Conclusion

This hydroponic system has been a challenging and rewarding project for this group. Several problems have risen during the creation process. The misunderstandings and problems of this system were mostly cause by the lack of knowledge in how the systems interact and how to design those interactions. Over the course of both senior design I and II, this group has gained an incredible amount of knowledge and experience.

VII. ACKNOWLEDGEMENTS

The group would like to thank the numerous creators of the Adafruit library systems for which it would not be possible for this group to finish this project in time. We would also like to thank the professors at UCF for their aid.

VIII. REFERENCES

[1] Neamen, Donald A. Microelectronics: Circuit Analysis and Design. New York, NY: McGraw-Hill, 2010. Print.

IX. GROUP MEMBER BIOGRAPHIES

Joshua Casserino

Joshua Casserino is currently a Senior at the University of Central Florida with plans to graduate in the Spring of 2017 with a Bachelor of Science in Computer Engineering. Joshua Casserino is a United States Air Force veteran and with hopes of using his degree to gain his commission and return to serving in the Armed Forces.

Richard Charmbury III

Richard E Charmbury is a graduating senior in Electrical Engineering, graduating with honors this spring 2017. Upon graduation, my plans are to obtain full time employment at the space center on Merritt Island Florida, and continue with my construction company custom trim and lighting.

Alexander Costello

Alex Costello is a senior at the University of Central Florida. Alex plans on graduating in May 2017 with a Bachelor's of Computer Engineering. Alex has recently finished an internship at BarKnock, an app start-up in the UCF Business Incubator. He looks forward to future employment in the programming field, which he is passionate about. He hopes to further hone his programming skillsets and gain additional professional experience.

Ernest Inman

Ernest Inman is currently a senior at the University of Central Florida and will receive his bachelor's degree in Electrical Engineering. In the fall of 2017 he plans to enter the graduate program at the University of Central Florida to earn a Maters in Science of Electrical Engineering with the focus in RF Engineering. He currently works at Lockheed Martin as an RF engineer.