Standard Small Satellite Research Platform for Life Science Research

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***Abstract* — This project aims to lay the foundation for developing a plant habitation system for Life Sciences research to produce high-yield plants. By using interchangeable research modules that work in Low Earth Orbit, a Lunar Outpost, Lunar Orbit, on Earth, and on the Moon, the advancements and discoveries made through this development can then be implemented in all locations. This project also aims to tackle NASA KSC Technical Gap(s) throughout its multi-year development timeline. The data gathered will be from sensors that monitor the conditions of the plant as well as sensors that monitor the payload's internal conditions. None of the component parts exceed the budget and are working with the timeframe thresholds allotted. After data is collected, it is to be transmitted to a graphical user interface where it is to be displayed for analysis. This data will provide insight on ideal conditions for plant yield. The research and development conducted in this project will help humanity expand to the Moon, Mars, and beyond. Long-duration missions as such require the lack of dependency on earth-supplied packaged food, instead the cultivation of food in-situ. That not only decreases the expenses of space exploration, but increases the quality of food in space and positively impacts astronauts' health both mentally and physically.**

***Index Terms* — Automation, Life Science, Machine Learning, Plants, Sensors**

I. Introduction

Permanent settlement in space needs the lack of dependency of constant supply of prepackaged food from Earth. The ability to grow supplemental food through plant crops would allow humans to explore deep space with long-term missions. PlantPod is an independent environmental monitoring system for plants in microgravity. The system contains the plant used for the study, the payload, and the hardware design which all link to a web app that will transfer the data. The data gathered will be from sensors that monitor the plant's conditions. Using this data, the web app will display data and information that the user can login and check. The users will be able to login to compare, edit, or delete different entry points as well as add their own notes they can later go back to check on. The system is composed of off-the-shelf components as well as components that were designed and tested in-house. The reason behind this design selection is to abide by the constraints set forth by both UCF and NASA which are quite similar in nature.

Since this project is also being used for NASA's Kennedy Space Center Senior Design Program, there are hopes that by showing proof of concept, scientists are able to study and provide solutions to NASA's aerospace problems and projects. NASA has been funding senior design projects for a couple of years and they claim that the Senior Design studies have been piloted at Kennedy, with excellent results [1]. Therefore, this project will enable humanity to explore the solar system and the surrounding solar systems without dependency on Earth-supplied packaged food.

Below is the System Hardware Architecture that will be dissected in the following sections of this paper:

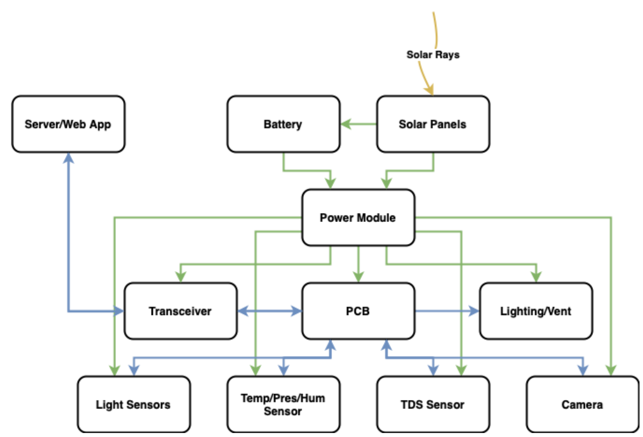


Fig. 0. System Hardware Architecture with blue arrows depicting data transmission in blue and power transmission in green.

II. System Components

The purpose of the Cubesat Project is to give manufacturers and researchers the standards for the design of picosatellites. The goal was to increase accessibility for these small payloads to space. Comprehensive component selections had to be made to maintain system reliability and satisfy several requirements. Some requirements are mandated by federal statutes including those set forth by The Federal Communications Commission (FCC) and National Oceanic and Atmospheric Administration (NOAA) on system architecture. Other requirements are set in cooperation with companies to provide a standardized platform.

A. ATmega 2560

The ATmega2560 is a low-power microcontroller that operates between 4.5 and 5.5 volts. The 2560 provides a balanced power consumption and processing speed. The 2560 is capable of 16 MIPS and operates at 16 MHz using an external crystal oscillator. The crystal-based oscillators generally offer a center frequency accuracy of 150 ppm or better. The 86 general-purpose input and output(I/O) line provide six flexible timer/counters with compare modes, PWM, four USARTs, and a byte-oriented Two-Wire serial interface. The 2560 has 16 channels integrated with a 10-bit A/D converter. This is useful because Analog signals provide a more accurate representation of changes in physical phenomena.

B. ESP8266-ESP-12E

The ESP8266 was the choice of wifi microcontroller, capable. This development board comes with a full WiFi front-end (both as client and access point) and TCP/IP stack with DNS support as well. The integrated antenna trace works on most 2.4 GHz frequencies. The optional SMT module allows integration into the arduino platform and the Adafruit Eagle library for board integration in the future. Because the scope of the project changed from communication to an adjacent computer such as the Jetson nano development board, to the separation of ground station and lack of onboard computing the wireless transfer of data was necessary. The serial communication on the ATmega 2560 can transfer data to the ESP8266. This transfer of data is requested when the ESP module requests that it wants to send data to the server.

C. ESP32 Camera Module

The ESP32 Camera microcontroller module is also used to allow camera transmission of images to the web server though the integrated wifi antenna. The addition to this module was in result to the difficulties of doing image transmission using an Arducam ov2640 camera module. The roadblock being the GUI communicates requests the camera to capture an image. The ability to autonomously capture or schedule the transmission of a Jpeg became apparent and the switch was made. The ESP32 can communicate through the serial connection and be programmed to send images wirelessly.

D. BME280

Temperature sensors are one of the most common in the industry and are used in a wide variety of applications. Surprisingly, there are no organizations that standardize the temperature range in sensors, so temperature ranges will depend on the item the user is sensing. Generally, most commercial products use temperature probes with a temperature range of -20 to 85°F. This allows the sensor to safely operate without damaging its components. Different temperature sensors offer different advantages as well. Most commercial products implement temperature probes but environmental monitoring systems and aerospace applications might use NTC Thermistors since they can handle higher temperatures and a wider range [4]. Given the budget constraints and limited availability, our current design uses the BME280.

The BME280 is an environmental sensor that offers sensing for temperature, barometric pressure, and humidity. For testing, the sensor needed to operate around an average of 62.5°F, since most flowering plants grow between 55°F and 70°F. The data retrieved from the sensors can be transmitted through a serial connection and also sent wirelessly through the wifi microcontroller.

E. Adafruit AS7341 10-Channel Light/Color Sensor

Adafruit AS7341 10-Channel Light / Color Sensor is an all in one light and color spectrum sensor. This sensor uses the light input to detect the 8 separate overlapping color bands. This is possible using 16 different sensors to detect these bands in a 3 by 2 mm footprint.

F. WS2812B LED Matrix

The WS2812B LED matrix is an LED panel with individually addressable pixels that operates at 5 volts. The panel features 64 total pixels arranged in an 8 by 8 pattern and allows chaining with multiple LED matrices. Although our current design only features one panel, we thought it was in our best interest to find a lighting system that could accommodate more LEDs, since different plants will have different lighting frequencies and needs. The panel only requires 3 connections: power, ground, and data.

G. Total Dissolved Solids (TDS)

The system will need to conserve as much water as possible to ensure that the plant can survive for the duration of the orbit. To accomplish this goal, the team can implement soil moisture sensors to monitor each plant's water levels. In industry, there are two main types of soil moisture sensors. These include sensors that measure volumetric water content or sensors that measure soil tension. Each offers its own advantages and disadvantages [5]. Volumetric water content sensors have quick measurement times, with very accurate readings.

They are generally expensive with most costing over $200 per sensor.

On the other hand, soil water tension sensors have good accuracy in most soil types. They are inexpensive at less than $50 for the more basic models but have slower response times. Both types require calibration before information can be recorded, but some can come pre calibrated. Depending on the quality of the sensor, it may need to be recalibrated manually or through code. Due to the constraints imposed by NASA's funding, the project would be unable to work with volumetric water content sensors as this would exceed the team's budget of $1600 so it would need to work with a basic soil water tension sensor to minimize costs.

III. Constraints

A. Volume

The dimensions of a standard CubeSat are 10 cm x 10 cm x 10 cm per unit with units ranging between 1U, 2U, 3U, or 6U.

B. Weight

Within the CubeSat range, the system must weigh less than 1.33 kg or 3 lbs per U.

C. Time

The system will be in space for a few months. Sensor data, water levels, and photos will need ro be measured and recorded frequently to accommodate the plant's limited time in orbit.

D. Budget

This project has received funding from the Florida Space Grant Consortium, however the team would hope to minimize costs when possible. As of right now, the team has estimated costs around $1600.

E. Testing

The testing environment that will be used to test the hardware will be the Senior Design Labs located at Harris Engineering Center, University of Central Florida, Orlando FL. The equipment that will be used is provided by University of Central Florida. The equipment includes, but not limited to, a function generator, an oscilloscope, a multimeter, a logic analyzer, etc.

IV. Software Detail

From the software perspective, a website is being developed to exhibit the plants health and growth and to allow interaction with the system without having to go to the system itself and check how the plant is doing. Data and images are being collected from the plant, stored into a database and then displayed onto the website. All together our Software side is composed of 3 different components: the website, the database, and the API.

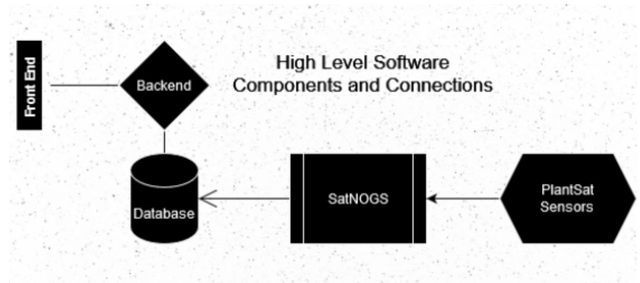


Fig. 1. Relationship between the website (frontend and backend), database (including SatNOGS), and API.

Our website allows users to log in to see their history, documents, and photographs from different dates. Users are able to compare data from the sensors into graphs depending on what sensor they want to see. They are also able to edit, delete, and change any notes they have written.

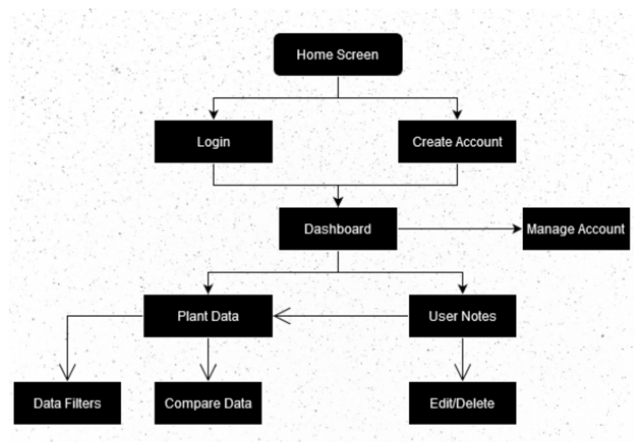


Fig. 2. Overview of the functions included in the website for users.

The website starts at a home page where the user is able to login or sign up to create a new account. During the login process, their username and password goes through an authentication process to check if they are in the user database. During the signup process, their information gets stored into the user database so they can login easily next time. In the user notes section, users are able to edit or delete any specific notes which they can find using the date. The plant data section consists of the data of the sensors and the images that were sent to the database. This is where the user can filter through the data to find a specific data entry or compare data to old data.

	id	user_id	sensor_data_id	note
	Filter	Filter	Filter	Filter
1	1	1	3	Lorem ipsum dolor sit ar
2	2	2	3	Sed ut perspiciatis unde

Fig. 3. Example of the layout of the PlantPod database.

A modified MERN stack was decided to be used, replacing MongoDB with SQLite3. MonogoDB was heavier than the project needed, therefore, it was decided to replace it with a lighter database. Since the database will only be holding a copy of the information in the SatNOGS database, it is not necessary to have the amount of features that MongoDB provides. ReactJS is being used for the frontend since it allows easy, customizable tables and graphs, which allows the end user to interpret the data the CubeSat sends back easily. For the backend, Express and NodeJS are used for both ease of use and to keep the project in the NodeJS family. The website, API, and database are being hosted on DigitalOcean, with Github as our Git control of choice for managing project versions.

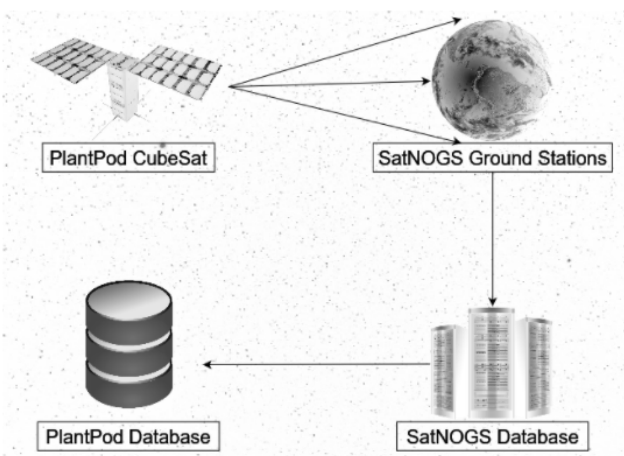


Fig. 4. Relationship between the CubeSat, SatNOGS, and the database for the PlantPod.

Since the CubeSat will be in Lunar Orbit, it will not always be in range of the transceivers for the project. To that end, it was decided to connect a network called SatNOGS, which is a series of ground stations scattered around the globe that receive data from different satellites. With this setup, the CubeSat will always be in range of at least one ground station, ensuring that there will always be access to the data streamed from the CubeSat. Once the data has been transferred to the SatNOGS' database, it can be retrieved and stored into the project's servers, allowing transformation or manipulation to take place.

V. Hardware Diagram

In keeping with the requirements of and meeting the expected demand from the sensor and mcu the linear voltage converters were designed above to provide adequate power for current demands 3.3 v and 5v and sensor testing. Initially the PCB design consisted of switching voltage regulators, after parts delay and supply chain issues it was determined that an immediate power solution was needed. This left us with little options and therefore forced us to turn to the use of less efficient and the heat rejection of linear voltage regulators.

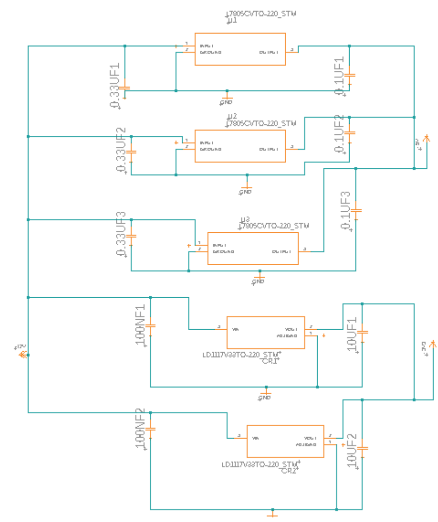


Fig. 5. shows the LD1117V33 and L7805CV linear voltage regulators, used in substitution to a switching voltage regulator because of supply issues.

The last schematic shows the various outputs and input pin headers and optional usb for all the power and signals the PCB as well as the in-circuit serial programming header (ICSP).

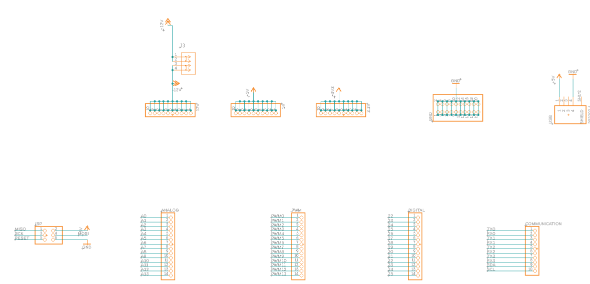


Fig. 6. Pin headers allow communication and power distribution as well as the ICSP to program the ATmel microcontroller that is integrated on our board.

PCB was originally designed with separation in mind. The current PCB uses an integrated voltage regulator and MCU for all the plants. But the desired pcb design would include all included sensors on the same board. This would mean the boards would need to be designed around the plants culture box. Each of the plants will use separate microcontrollers to allow for redundancy if one fails during the duration of the mission.

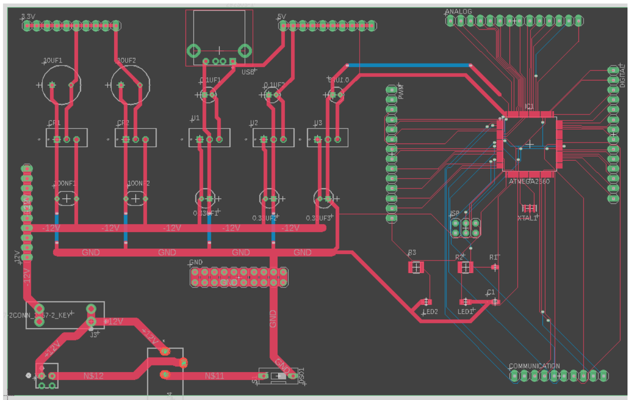


Fig. 7. Shows the current microcontroller and voltage regulator pcb that will be used.

VI. Research Plants

The plant that was originally chosen for this project was the Arabidopsis Thaliana, a small flowering plant native to Eurasia and Africa. This plant is an important model system used in many studies for identifying genes and determining their functions [2]. It has a short generation time and small size, which are both key factors in why this plant was chosen for this study. The life cycle for this plant is about six to eight weeks from germination to seed maturation. This plant was also chosen since it will be easy to identify its leaves for the Machine Learning portion of the project. The Biology department supported the team in obtaining Nicotania tobacum, a plant with very similar specifications as Arabidopsis. The team was able to test the sensors as well as the Machine Learning model on it.

VII. Machine Learning

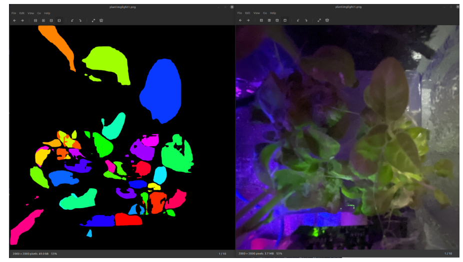


Fig. 8. Shows the pre-trained model being tested on images from the test plant.

The model that is being used is the pretrained model is the Mask R-CNN using Synthetic Arabidopsis Dataset. This dataset contains 10,000 images, 550x550 pixels. Another model was to be developed in order to train on the dataset for comparison, however the team chose not to pursue aster speaking with Dr. Massa. She showed more interest in crops that can be consumed in space rather than scientific model plants such as Arabidopsis. Nonetheless, models were still explored in order to assist the future teams continuing on this project. The information obtained is the following: YOLOv5 and Detectron2 required re-labeling of the dataset, however U-Net does not. It is a convolutional network architecture designed for image segmentation. Image segmentation comes in two forms: instance segmentation and semantic segmentation, this project is interested in instance segmentation.

VIII. Interviews Conducted

Interviews were conducted with Subject Matter Experts (SMEs) in various fields that aided the design, development, and testing of the system. The SMEs were chosen from UCF, and NASA KSC, due to the nature of the project being directly affiliated with both parties.

The team first interviewed Physics Department Chair & Pegasus Professor at UCF, Dr. Joshua Colwell. Dr. Colwell is the Director of the Center for Microgravity Research within the UCF Physics Department. He also led the development of a CubeSat that made it to orbit from UCF. Before meeting with him the team's sight was set on designing a CubeSat for the project, however, Dr. Colwell advised the team to steer away from that vision. The focus was then shifted to design a plant habitation that would be connected to a spacecraft that would provide power, etc. In addition, astronauts on board the spacecraft would interact with the device, so the device would supply them with supplementary food to meet their dietary goals.

Our project sponsor and mentor from NASA KSC, Jose Nunez, PhD, PE, PMP, is Chief, Flight Technologies Branch at NASA. Our meetings were technical in nature, we went over Systems Engineering principles and outlined goals and objectives for our system. We based our product development and project life cycle on the NASA Systems Engineering Handbook guidelines. Dr. Nunez asked hard questions that required research to discover the problems NASA needs solving. He helped us develop top level requirements for our design that determine feasibility and scope. Operation time was a big factor in the decision making process of the design. That impacted decisions such as not selecting radiation hardened components on board the spacecraft. We learned that it all stems from science. With the experiment needing only a few weeks, the team found it appropriate to use off-the-shelf parts that met the requirements for the system. The chosen parts were compared with an array of similar parts from the market and chosen based on the constraints outlined in section III as well as the Mechanical and Aerospace Engineering teams working on the rest of the system. Dr. Nunez's vision for the project outlined the original vision of the team, however it imposed a system-wide impact. With the constraints and operational scope shifting, the system had to be redesigned. So, meeting with the teams developing the MAE side of the project was crucial to the success of the mission.

The team also interfaced with Dr. Randal Allen, an Adjunct Professor at UCF's Mechanical and Aerospace Engineering Department. He also leads the Collegiate Space Foundation that incorporates the MAE Senior Design teams building the rest of the system. Interfacing with them throughout the semester provided insight on the requirements from the MAE side that provided us with the technical constraints for our payload. Dr. Allen, shared problems that their teams are facing and what they are looking to develop and test. The teams also quickly came to the realization that the core of the project is the science and that an SMEs in plants is required for the success of the mission.

Meetings were also held in the Biology Department with Dr. Chase Mason, Assistant Professor, leading the Plant Evolutionary Ecophysiology Lab at UCF. He provided detailed analysis on the plant physiology that held the essence of the science behind the project. He helped mitigate risk associated with growing a plant in microgravity. In addition, he helped guide the team to what the team should research further. Dr. Mason also helped outline a tissue culture appropriate for the cultivation of a plant such as Arabidopsis or Nicotania tobacum in a microgravity environment. In addition, he reassured the team's focus on the NASA Technical Gaps that the project aims to tackle. Dr. Chase helped mitigate risk by proposing the use of a container to house the plant on board the spacecraft. The housing would preserve the moisture from the plant, recycling it within the container. This would give the plant a few weeks of water enough to collect some data. However studies are to be conducted to ensure the feasibility of this solution. As a result, however, this approach mitigated the risk of including an irrigation system in the spacecraft. It not only saved cost, but space, power, and heat transfer.

Finally, the team interviewed Dr. Gioia Massa, Project Scientist at NASA KSC, specializing in: Space Life Sciences, Plant Science, Advanced Life Support, Controlled Environment Agriculture, Horticulture, and Crop Production. The team prepared a list of burning questions for Dr. Massa to address. She not only addressed all of the questions, but also offered the team to present at lunch for the rest of her team members and SMEs at KSC. Although this meeting will take place shortly after final presentations at UCF, the insight received from Dr. Massa to improve the design of our project was profound. Moreover, it helped the team develop the future goals for the mission so that the next team taking over knows what to focus on, how to distribute their time and efforts.

IX. Future Development

Currently the Standard Small Satellite Research Platform is a multidisciplinary multi-year project. The groundwork laid out by our group will allow for the development of a payload system designed for small satellite research of plants in space. Initial development used easily sourced components and development boards to handle a lot of the necessary functions of the entire system design. More communication is needed to ensure the payload system can communicate with the power regulation hardware onboard and the antenna array to transmit data. Since the project is in coordination with other senior design groups and is multi-year, development and communication under one team wasn't possible. This means that material on payload and hardware restrictions had to be researched and taken from other vendors which only released certain restraints including total power available to the payload. But when developing space grade hardware requires a closer look at electrical and final design restraints. Initial guidance and research didn't layo. These requirements should follow the vendor's restrictions. In general the cube satellite chassis follows the guidelines of the lunch provider and As well as further testing with reliability and hardware integration. Design restrictions in the future should be more

X. The Team

Nicolas El Tenn is a computer engineering student who is seeking a career in the space industry.

Personal Statement:

My previous experiences with NASA have given me insight into what it takes to research and develop space-grade technology. I have had first person experience at Kennedy Space Center where they study plant habitation systems amongst other things. There, I visited Veggie where I was exposed to their plant habitation system design. So, we are aiming to meet all the requirements for our design as we abide by NASA's solicitation. My academic background is in Computer Engineering, so I hope to contribute to this project from both the hardware and software side.

My interest in this project stems from my fascination with space at an early age. I believe in a future where humanity becomes interplanetary, expanding the scope and scale of our imprint on the Universe. For that, we must develop the technology that will allow us to live elsewhere besides Earth. However, at the core, we are still Earth beings. So, taking a part of Earth with us ensures we stay connected to our mother plant as we travel deeper into space. This organic touch on space exploration allows us to live for prolonged periods of time in space without the dependency on Earth-supplied packaged food. As a result, developing a plant habitation system for microgravity is crucial to our future in space. This vision also aligns well with that of NASA as we prepare to explore from the Moon to Mars and beyond.

Raquel Guzman is a 22-year old graduating computer engineering student who is taking a job with Lockheed Martin to work for their rotary and mission systems.

Personal Statement:

I personally wanted to be involved in this project because of my interest in space. I believe that space is the next frontier and efforts to continue exploration should be supported. Right now astronauts mainly eat prepackaged meals and have constant resupply missions. As humanity continues to explore and travel deeper into space, constant resupply missions will become impossible and the need to bring plants to keep astronauts healthy is vital. The plant pod would be helping these efforts and allow for humans to travel and survive for extended periods of time in deep space.

For the past three years I have been working for the Stephen W. Hawking Center for Microgravity Research and have worked on microgravity experiments. While there I have worked on ground-based experiments, which never travel on flights but give great insights on how certain projects will interact in microgravity. Others were flight-based experiments that needed space grade materials, and traveled on parabolic flights. Regardless of experiment type, each one has required intensive investigation and research to properly develop and design, as well as testing plans to ensure the hardware and software components worked properly. I hope to apply the knowledge I have gained from working there throughout senior design, but ultimately contribute to humanity's efforts in space exploration.

Noah Heikes is a software engineering student driven to study Cyber Security by pursuing a higher education at UCF.

Space has always been the next big step in humanity's future. Whether in the next hundred years or the next ten, humankind's path forward as a species will always be off of this planet. But the technology level needed to truly begin colonizing space is yet to be achieved. Research on the effects space has on humans, how to create a sustainable atmosphere, how gravity works, and more still needs to be accomplished before humanity can move forward.

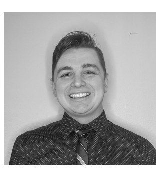
With that in mind, the first step towards colonizing other planets and exploring space is a stable food source. Without food (and air and water, but that's a problem for another project), humans can't survive anywhere at all. I want to have a hand in building the technology that will help humans to survive outside of Earth's atmosphere. If this project is able to help further the goal of making long term space travel possible, then I want to contribute as much as I can.

Shivani Kumar is 21-year old graduating Software Engineering student who is taking a job with DigitalOcean to work for their App Platform team.

Personal Statement:

I've been in love with space from a very young age. Many people around me are afraid to talk, explore, or even learn about space. Although that is understandable since the majority of it is unknown, the curiosity in me only wants to learn more about it. Space has always been an area that interests me, but I have never been able to work on a project that combines my computer science skills with my space knowledge. Now that I have been presented with this opportunity to work on an incredible project with team members that have the same interest in space as me, I've been looking forward to implementing my knowledge and learning more from them as well.

Space is the next big thing. In a couple million years, the Sun is going to consume Earth and the human race will die off. The only way to prevent this is to start exploring space and the planets that lay within our galaxy. We, as humans, have been given the freedom to pursue this plan and I think it's very important that we jump at this opportunity. The more we explore, the more knowledge we gain, and that knowledge will help us figure out how we can evolve and start a new life in a new place. If I can help out humanity even in the slightest way by being able to expand the knowledge of growing food in space, mankind will change entirely and space will become our new home. As humans explore deeper into space, constantly packaging food for astronauts will not be ideal nor will it keep the astronauts healthy. Not only will humanity evolve with this technology, but so will our future in space.



Matthew Philpott is a 24-year old graduating electrical engineering student who is pursuing a career in digital design of FPGA or VLSI design.

Personal Statement:

Growing up on the Space Coast, the view of a rocket launch was just two steps from my front door. Because this reason space has always felt accessible. With that along with sci fi movies and tv shows dreams were inspired to make space accessible to the average man. The access to space will allow for many things including the reduction in cost for average goods because humans will have access to different planetary bodies and natural resources. As well as allow for the human race to become more than a type one civilization.

I am interested in Plant-Pod because when I imagine a future, I see a civilization that is not limited by the gravity of earth. Space is this next frontier, with that comes similar challenges the unknown will bring. From the beginning of humanity plants and humans have lived in coexistence. This means millions of years ago humans needed plants to survive, and will need to continue this symbiosis in order to make space as well as bodies in space a permanent habitable place for humans. This is why Plant-Pods studies can teach us how to determine plants yield, and hopefully maximize it. This goes along with my long-term goal in life is to explain to my family or friends how I had a lasting effect on meeting my expectations for that type of future.

XIII. Conclusion

Throughout this year, the University of Central Florida Senior Design Team 30 has worked diligently on this project, making sure to stay on track with the deadlines that were set for the project. This project aims to set the foundation for developing an independent plant habitation system for Life Sciences research to produce high-yield plants in microgravity. By using interchangeable research modules that work in Low Earth Orbit, a Lunar Outpost, Lunar Orbit, on Earth, and on the Moon, the advancements and discoveries made through this development can then be implemented in all locations. This project also aims to tackle NASA KSC Technical Gap(s) throughout its multi-year development timeline. Using this type of technology, humanity will be able to explore the solar system and surrounding solar systems without having to depend on Earth-supplied food. This will not only aid humanity to expand but also astronauts to have fresh food, which will benefit their overall health and psychological health.

Since technology is advancing faster every year, this project will be worked on for multiple years to come and hopefully improved to the point where plants will be able to grow efficiently and with high yield. The team hopes that this research will contribute to the technical advancement of life science research in microgravity environments to provide new alternatives for sustainable farming for future generations. The team also hopes that soon enough, humanity will learn how to live in space and expand to different parts of the galaxy.

The team is united under one vision outlined below:

"We believe in a future where humanity becomes interplanetary, deepening our understanding of our Universe and ourselves within it. To realize our vision, we are designing a closed plant habitation system for microgravity. We hope that our project enables humanity to explore our solar system from the Moon to Mars and beyond without the dependency on Earth-supplied packaged food."

XI. Acknowledgement

The authors wish to acknowledge the assistance and support of Dr. Samuel Richie, Dr. Mark Heinrich, Dr. Jose Nunez, and Dr. Lei Wei; University of Central Florida and NASA KSC.

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