MESA SURP RESEARCH PROPSAL

# Automation and Control of Hydroponic Systems

Marshall Amey, Kathya Alfaro, Isaac Olson, Madeline Wrzesinski

San Antonio College

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## Abstract

The goal of this research project is to design, build, and test a low-cost system for remotely monitoring and controlling critical parameters of the nutrient solution in a containerized hydroponic garden. Optimizing the production of hydroponic shipping container systems for cost efficiency and ease of operation could revitalize the health of our communities through access and participation in new urban gardens that operate year-round. By creating the simplest technology that optimizes plant yield at the lowest cost, more research can be conducted to study its potential to benefit world hunger and environmental sustainability. The project involves using Arduino hardware and sensors to measure pH and conductivity values of the nutrient solution, temperature and humidity of the environment at different locations, $O_2$ and $CO_2$ levels in water and air, and the intensity of our lighting system. The finished system will be able to report all of these values via the Internet, where they can be viewed and changed remotely.


*Keywords: hydroponics, gardening, automation, agriculture.*

## Automation and Control of Hydroponic Systems

The goal of this research project is to design, build, and test a low-cost system for remotely monitoring and controlling critical parameters of the nutrient solution in a containerized hydroponic garden. The first objective is to use Arduino hardware and sensors to measure pH and conductivity values of the nutrient solution, temperature and humidity of the environment at different locations, $O_2$ in the water, $CO_2$ in the air, and the intensity and spectrum of our lighting system. Second, the finished system should be able to report all of these values via the Internet, where they can be viewed remotely. The final objective is to automate control of pH and conductivity values so that they can be regulated without human intervention. Once construction of the shipping container is complete, temperature, humidity, and $CO_2$ levels inside of the system can be regulated remotely as well.

## Literature Review

The human population is growing rapidly and will reach approximately 9 billion in the next 30 years (Touliatos, 2016). In order to meet the growing demand for food, there will need to be a 70% increase in agricultural production (Corvalan et al. 2005; Tilman et al. 2011). Because the earth's resources are already wearing thin, it is important to find ways to produce food that do not involve further land degradation, depletion of soil, and loss of biodiversity.

In collaboration with the Texas State University ReEnergize Renewable Energy Research & Education Partnership, San Antonio College students have been designing and constructing a hydroponic system inside a shipping container. The goal is to develop an improved and cost-efficient containerized hydroponic system incorporating leafy greens that can test horizontal and vertical hydroponic tubing systems and experiment with low-energy grow light systems that draw upon solar energy (ReEnergize, n.d.).

Growing leafy greens and herbs inside shipping containers has become a new and exciting niche in the agricultural industry. Already, companies like Growtainer, Freight Farms, and Vertical Harvest Hydroponics have been making important strides in advancing new agro-technology. Last November, Kimbal Musk, brother of Elon Musk, launched an urban farming program in Brooklyn called Square Roots (Garfield and Jacobs, 2017). This program intends to help young entrepreneurs develop vertical farming startups using hydroponic systems in shipping containers. The majority of these companies use a vertical growing system to maximize their plant yield and each shipping container can produce between 25,000 to 50,000 heads of leafy greens per year (Barth, 2015; Garfield, 2017; MacFarland, 2015). They have also championed the use of LEDs as a light source, and all elements within their container systems can be measured and changed remotely. Some systems even come with smartphone apps that meet this purpose.

In trying to determine an estimated cost, a variety of information was considered. Nicholas Heredia (2014) was able to construct a small, hydroponic garden of lettuce for under $300 as a student at California Polytechnic State University. This small system was only able to grow 20 plants at a time. On the other end of the spectrum, purchasing a fully operational shipping container from Freight Farms would cost $76,000 plus $13,000 per year in operational costs (MacFarland, 2015). Although the cost is significantly higher, one farmer can grow up to 4500 plants per container at a time and the technology to manage the system has already been created and installed. The system that will be developed for this research project will need to be much simpler and less costly than those currently available. A preliminary search on eBay shows that the cheapest shipping containers can be purchased for about $1500. Insulated and refrigerated shipping containers are available for $5000-$10,000. Using these figures as a guide, it seems plausible that a comparable system could be built for \$20,000-\$30,000, if you consider cost of LED lighting and construction. Ideally, this new system could be built at a price 60-75% less than those that are commercially available.

Current and past members of the ReEnergize project have performed research and experiments on a motorized vehicle to be placed inside the shipping container in order to take sensor readings (Ward, 2016). They built and tested two different, robotic vehicles that could be programmed to move via line sensor technology. A hoisting mechanism on top of the vehicle was meant to allow sensors to reach different vertical heights where additional readings could be taken. In light of our goal to produce plants simply and cost efficiently, it seems more appropriate to place multiple, stationary sensors inside the container that will take readings at different parts of the container than to build a movable robot. The robot may require future owners of the system to have a higher degree of technical knowledge in the event of a malfunction.

The popularity of Arduino's open source hardware has allowed many designers, students, and makers to easily create the same kinds of technology as the new agro-tech companies previously mentioned. Arduino is a flexible, programmable hardware platform with a fairly standard onboard microcontroller that can interact with the world around it by using its programmable inputs and outputs (Arduino, 2017). It also has a USB port and controller for easily communicating with a computer and can be equipped with Wi-Fi technology and programmed remotely. The core language used in the Arduino development environment is the C programming language. By using the Arduino and an array of sensors to detect pH and conductivity levels, as well as temperature, humidity, light intensity, dissolved $O_2$ in the water, and $CO_2$ in the air, we can produce the same type of systems as these pioneering companies.

## Hypothesis

As of now, efforts to take advantage of this new technology have been geared towards the for-profit, agricultural sector. However, in the non-profit sector and in academic research there has been less effort to work on this specific opportunity and study its potential to benefit world hunger and environmental sustainability. Business models like Habitat for Humanity are successful because of financial support from individuals and organizations, volunteer support at building sites, and no-profit, interest free mortgages (Habitat, 2017). A similar model can be employed for food gardens. It is our belief that optimizing the production of hydroponic shipping container systems for cost efficiency and ease of operation could revitalize the health of our communities through access and participation in new urban gardens that operate year-round. By creating the simplest technology, that produces the largest plant yield at the lowest cost, we can recreate the gardens of humanity's habitat.

## Methods

In order to perform pH and conductivity measurements of the nutrient solutions, a small bin of water will be prepared with the appropriate level of nutrient mixture used to grow the plants. The solution will be measured with pH and conductivity sensors. The sensors can be connected as analog inputs to the Arduino microcontroller. After an accurate reading has been established, a system will be built to control pH levels in the event that they fall outside of the acceptable range (5.8 - 6.2). Five pump systems will then be constructed. Two pumps will deliver pH UP and DOWN solutions to raise or lower the pH levels in the reservoir respectively. Another two pumps will deliver the nutrient solution for the plants. The final system will pump air through the solution to ensure proper mixing. The four peristaltic pumps will be controlled using the digital outputs on the Arduino. A program will be written to deliver a specific amount of pH UP solution when the sensor detects a pH value of less than 5.8 in the bin. Likewise, the system will deliver pH DOWN solution when a pH value of more than 6.2 is detected in the bin. Repeated experiments will determine the specific amounts that need to be delivered to return pH to an acceptable level.

In the first set of experiments, a nutrient solution with a pH level of 6.0 will be prepared. pH UP solution will be added manually to raise the pH level in the bin to 6.2. The amount of pH solution added will be recorded, the system will be programmed to deliver an equal amount of pH DOWN solution and a new measurement will be taken after 2 minutes to allow the air pump to mix the solution. If the pH level returns to 6.0, the experiment will be repeated, except that the pH level in the bin will be manually raised to 6.3. After 5 trials, data from the experiments will determine a function that can be used to program the system to deliver the optimal amount of solution. This set of experiments will also be repeated using pH DOWN to manually lower the pH level in the bin.

The next set of experiments involve raising and lowering the conductivity manually in order to elicit the appropriate response from the third and fourth pump systems. After the system (Figure 3) have been verified to operate correctly and accurately, it will be integrated with the current grow ebb and flow hydroponic system (Figures 1 & 2). At this point, the final set of experiments can begin. These involve growing plants under a variety of different pH and conductivity levels in order to establish the optimal values for plant yield. Complete data from these experiments cannot be obtained feasibly for this project due to the constraints of time and will not be included in our final results. It will, however, be included in fall research efforts.

Temperature, humidity, and $CO_2$ measurements can also be taken with sensors and connected to the Arduino. We will monitor values in different parts of the hydroponic system, including temperature of the nutrient solution, the environment surrounding the plants, and the area near the light source. Humidity and $CO_2$ readings near the plants will also be taken. Since the hydroponic system is not yet fully constructed and the constraints of our growing environment prevent us from controlling the temperature and humidity at this point, we will not perform any experiments to change these values remotely. In the future, this may be accomplished by connecting the system to the thermostat and/or humidifier inside the shipping container. Because of the amount of memory necessary to run the required amount of sensors, 3 Arduino Mega microcontrollers will be used. They will allow each member of the group to practice writing code using the Arduino IDE platform. Secondly, it will provide us with enough equipment to take readings in multiple locations. This includes the seedling/germination container, the hydroponic prototype system in the lab, and the inside of the shipping container once construction begins. Third, there are only enough analog input pins for 3 sensors on the Arduino Uno, whereas the Arduino Mega could control up to 8. For present purposes, dividing the Arduinos between the different areas of the project is more suitable until the time that we integrate everything into the final design of the shipping container. The Arduino microcontrollers may prove to be inadequate for our needs in the future, but more information is still needed.

Data will be collected through the Arduino and ThingSpeak website where sensor readings can easily be saved and printed. In the case of pH and conductivity measurements, data will be sufficient when induced changes of levels within the nutrient solution are automatically corrected by the appropriate Arduino program. Construction of the system will occur during the first 2 weeks. The following 4 weeks will be dedicated to pH and conductivity experimentation and controlling the nutrient environment. In the final 4 weeks, we will monitor and collect data, connect the system remotely via WiFi, and prepare materials for a final presentation.

## Results

Keeping the technology of this system simple will be the easiest part of this experiment as the majority of the team members have limited knowledge of electronics and programming. Construction will be geared toward those who possess a similar knowledge or less. Data to be measured includes man hours required to manually control the system vs using an automated system, as well as graphs showing variation of pH and conductivity levels in each system over time. Another important factor related to the project is the price involved. The cost of this system will be compared against various alternatives to assess the viability of producing our own system versus using other available automated systems. With a baseline of reliable, accurate data about the hydroponic growing environment, the team can begin to make changes to the system that encourage higher plant yield and/or reduce operation and set-up costs. The results of this research will allow future teams to begin taking control of all aspects of plant growth and conduct more reliable research geared toward maximizing the effectiveness of these new systems.

## Discussion

Investing in hydroponic shipping containers has numerous benefits. A high yield of crops can be produced with only a minimal footprint. If solar power is used to operate the system, it can greatly increase its sustainability and long-term affordability. Automating the growing process makes producing healthy food easy and accessible to a greater number of people. A good system only needs up to 10 gallons of water per day and access to an electric power supply. This will allow the system we create to be used in many of our country's food deserts and can supply an abundance of healthy food to poor and urban communities.

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## Appendix

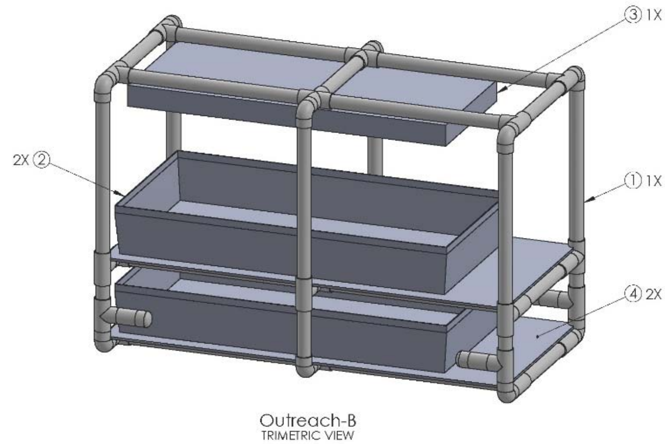
Table A. Proposed Budget

| Quantity | Item | Vendor | Product Number | Unit Price | Total Price |
|---|---|---|---|---|---|
| 4 | Peristaltic Liquid Pump with Silicone Tubing | http://www.adafruit.com | PID: 1150 | $ 24.95 | $ 99.80 |
| 1 | OMEGAFLEX® Polypropylene Tubing - 100ft | http://www.omega.com/pptst/TYPP.htn | TYPP-1418-100 | $ 20.50 | $ 20.50 |
| 2 | Dual H-Bridge Motor Driver for DC or Steppers - 600mA - L293D | http://www.adafruit.com | PID: 807 | $ 2.95 | $ 5.90 |
| 3 | 9 VDC 1000mA regulated switching power adapter | http://www.adafruit.com | PID: 63 | $ 6.95 | $ 20.85 |
| 3 | WiFi Module - ESP8266 | https://www.sparkfun.com/products/13 | WRL-13678 ROHS | $ 6.95 | $ 20.85 |
| 3 | 4-channel I2C-safe Bi-directional Logic Level Converter - BSS138 | https://www.adafruit.com/product/757 | PID: 757 | $ 3.95 | $ 11.85 |
| 2 | LCD Shield Kit w/ 16x2 Character Display | http://www.adafruit.com | PID: 772 | $ 19.95 | $ 39.90 |
| 4 | Delta 1 Datatainer Chemical Storage Bottle 128-oz (One Gallon) | https://www.bhphotovideo.com/c/prod | MFR # 11140 | $ 7.95 | $ 31.80 |
| 1 | Hook-up wire spool set – 22awg solid core – 6x25’ | http://www.adafruit.com | ID: 1311 | $ 15.95 | $ 15.95 |
| 1 | JBtek 8 Channel DC 5V Relay Module for Arduino | https://www.amazon.com/JBtek-Channe | B00KTELP3I | $ 8.98 | $ 8.98 |
| 1 | Elegoo 120pcs Multicolored Dupont Wire | https://www.amazon.com/Elegoo-120p | EL-CP-004 | $ 8.86 | $ 8.86 |
| 1 | Weller SP40L Marksman Iron (40 Watt) | Intertex Electronics | SP40L | $ 19.49 | $ 19.49 |
| 1 | Easy Braid Q-B-5 Quick Braid Solder Wick 0.050" W X 5' L Gold QB5 | Intertex Electronics | Q-B-5 | $ 2.87 | $ 2.87 |
| 1 | Dewalt Ceramic Glue Gun | Home Depot | Store SKU #100215 | $ 29.97 | $ 29.97 |
| 1 | Solder wire – SAC305 RoHS Lead Free .5m/.02” dia. 50g | Intertex Electronics | PH-50-30521 | $ 16.80 | $ 16.80 |
| 3 | USB Cable standard A-B 3’/1m | http://www.adafruit.com | ID: 62; | $ 3.95 | $ 3.95 |
| 1 | Stanley 10 in. Dual Temp Glue Sticks (12 Pack) | Home Depot | Model# GS25DT | $ 6.87 | $ 6.87 |
| 1 | Velleman K-RES-E3 Set Of 480 Resistors | Intertex Electronics | K-RES-E3 | $ 7.95 | $ 7.95 |
| 1 | Velleman VTD2 Extra Powerful Desoldering Pump | Intertex Electronics | VELL-VTD2 | $ 8.99 | $ 8.99 |
| 5 | P-Channel MOSFET 60V 27A | https://www.sparkfun.com/products/10 | COM-10349 | $ 0.95 | $ 4.75 |
| 1 | 1N4001 Diode - 10 pack | http://www.adafruit.com | PRODUCT ID: 755 | $ 1.50 | $ 1.50 |
| 1 | General Hydroponics MaxiGro for Gardening, 2.2-Pound | https://www.amazon.com/General-Hydi | B00NQANQAC | $ 14.58 | $ 14.58 |
| 1 | pH UP and DOWN Solution | https://www.atlas-scientific.com | Part # CHEM-pH-UI | $ 23.00 | $ 23.00 |
| 2 | Nutrient Solution | Brite Ideas | | $ 100.00 | $ 200.00 |
| 1 | BrassCraft 1/2-in x 3/4-in Barbed Barb x Garden Hose Adapter Fitting | Lowe's | Item # 645836 | $ 7.98 | $ 7.98 |
| 2 | BrassCraft 1/2-in x 1/2-in Barbed Barb x MIP Adapter Fitting | Lowe's | Item # 645668 | $ 4.19 | $ 8.38 |
| 1 | Active Aqua Air Pump, 2 Outlets, 3W, 7.8 L/min | https://www.amazon.com/Active-Aqua- | B002TCC46U | $ 16.24 | $ 16.24 |
| 1 | Active Aqua ASCL Air Stone Cylinder, Large | https://www.amazon.com/Active-ASCL-! | B00564IT5S | $ 6.84 | $ 6.84 |
| 1 | Sleek Airline Tubing in Black | https://www.amazon.com/Lees-Sleek-Ai | B001D4XTUU | $ 5.24 | $ 5.24 |
| 1 | 18-Pcs Aquarium suction cups for 3/16 airline tubing holder(black) | https://www.amazon.com/18-Pcs-Aquai | B01N0F8S36 | $ 8.29 | $ 8.29 |
| 1 | Gravity: UART Infrared CO2 Sensor (0-50000ppm) | https://www.dfrobot.com/product-156! | SKU:SEN0220 | $ 93.00 | $ 93.00 |
| 1 | DFRobot DFR0066 SHT1x Humidity and Temperature Sensor | Intertex Electronics | DFR0066 | $ 19.95 | $ 19.95 |
| 1 | BioTek Marine PAR Sensor with 15 ft USB Cable | http://www.drsfostersmith.com/produc | CD-92904 | $ 195.00 | $ 195.00 |
| 5 | 4' x 4' tube fluorescent grow light | Brite Ideas | | $ 203.00 | $ 1,015.00 |
| | | | | | **$ 2,001.88** |

****Before making any purchases, please make sure to use an approved vendor. SAC is a tax-exempt entity and we do not pay tax. If a vendor is not approved, they will need to fill out a vendor application. If needed, teams can provide a tax-exempt form.***

Total projected cost of the project: ____________________________________________________

Figure 1.  Ebb & Flow Hydroponic Prototype System (Trimetric View)




| PARTS LIST FOR Outreach-B | | | |
|---|---|---|---|
| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
| 1 | frame_B | FRAME SUB ASSEMBLY | 1 |
| 2 | 24X48X7 TRAY | GROW TRAY | 2 |
| 3 | 19.5X46X3 LIGHT | GROW LIGHT | 1 |
| 4 | Base | 1/4" PLYWOOD | 2 |

Figure 2. Ebb & Flow Hydroponic Prototype System

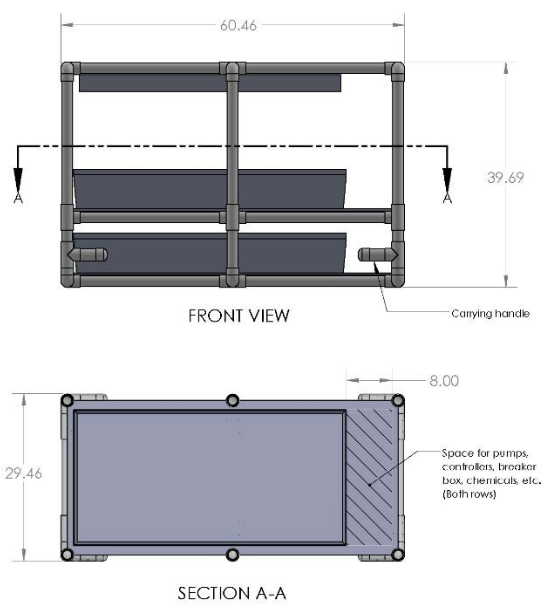
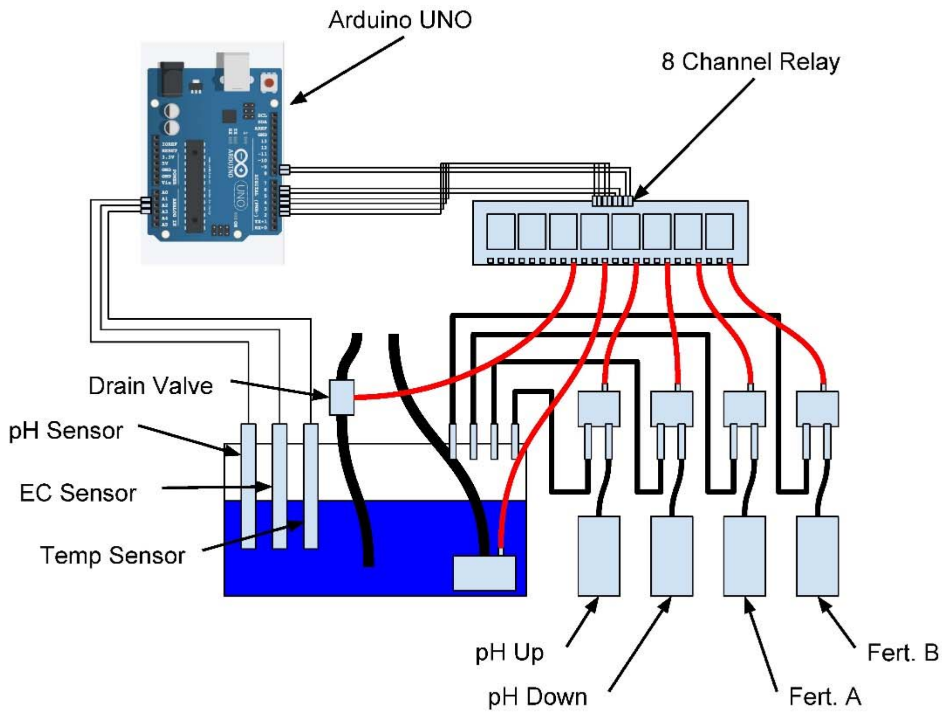


Figure 3. Automated Nutrient Delivery System



**Work Plan and Tentative Schedule**

| Week | | Weekly Objectives | Due at week's end |
|---|---|---|---|
| Wk 1: | June 5 –10 | Complete design and begin construction | Finished design plan |
| Wk 2: | June 12-17 | Begin construction of pH test system | Completed four pump system |
| Wk 3: | June 19-24 | Work on coding/programming of nutrient delivery system | Completed pH UP control program |
| Wk 4: | June 26-30 | Work on coding/programming of nutrient delivery system | Completed ph DOWN and nutrient control programs |
| Wk 5: | July 3-8<br>* Campus closed July 4. | Experiments with nutrient delivery system | Complete data chart showing successful control of pH levels. |
| Wk 6: | July 10-15 | Write program to monitor temperature, humidity and $CO_2$ levels. | Complete data chart showing sensor values over time. |
| Wk 7: | July 17-22 | Integrate test system into hydroponic system.<br>Wrap up final experiments.<br>Write program to view data remotely. | Fully integrated hydroponic system |
| Wk 8: | July 24-29 | Testing programs for usability and errors | Be able to view incoming data from the internet. |
| Wk 9: | July 31-Aug 5 | Prepare presentation materials and report | All data organized |
| Wk 10: | Aug. 7-12 | Prepare presentation materials and report | Complete presentation and report |
| Aug. 15 - Deadline | | Poster, PowerPoint, report due to Faculty Advisor and Dee Dixon. | |
| September 20/21 | | Research Symposium/Poster Session. Location TBA | |

**Mandatory Team Meetings**

| Name of Meeting | Day/s of Week | Frequency | | | Time | Location |
|---|---|---|---|---|---|---|
| | | 1X/WK | 2X/WK | 3X/WK | | |
| Advisor | Mondays | X | | | 10:00am | Annex Lab |
| Project Team | M, W, F | | | X | 10:00am | Annex Lab |

**Team Information**

| Advisor | Department | Office | Email address | Office phone | Cellphone |
|---|---|---|---|---|---|
| Alfred Alaniz | Engineering | CAC 204 | Ldixon4@alamo.edu | 486-0598 | 789-4416 |

**Students**

| Team Members | Banner ID | Major | Graduation | E-mail | Cell Phone | Role |
|---|---|---|---|---|---|---|
| Kathya Alfaro | 901144836 | ENGR | 05/17 | kalfaro14@student.alamo.edu | 201-875-0737 | Team member |
| Marshall Amey | 901148369 | BIOL | 05/17 | Mamey2@student.alamo.edu | 210-259-7513 | Team Lead |
| Madeline Wrzesinski | 901010420 | ENGR | 12/17 | Mwrzesinski@student.alamo.edu | 210-627-3706 | Team member |
| Isaac Olson | 901230538 | ENGR | 12/18 | iolson@student.alamo.edu | 425-330-9135 | Team member |

**Team Member Experience**

| Team Member | Related Experience | Year | Advisor |
|---|---|---|---|
| Kathya Alfaro | | Sophomore | Claudia Calvario |
| Marshall Amey | Basic Arduino Programming, CSCS 1336, Hydroponics Project Participant | Sophomore | Casey Tamez |
| Madeline Wrzesinski | ENGR 1201<br>ENGR 2304<br>ENGL 2311<br>PHYS 2426 | Sophomore | Javier Vargas |
| Isaac Olson | *10+ yrs working as Mechanical Designer in Aerospace, Automotive, and Oil & Gas industries<br>*ENGR 2304<br>*PHYS 2425<br>*CHEM1411 | Sophomore | Shawn Melendes |