

Fresh Bytes

A Senior Project

presented to

The Faculty of Liberal Arts and Engineering Studies
California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Liberal Arts and Engineering Studies

by

Jack Bowen

December, 2014

Table of Contents

Primer.....	3
Introduction.....	4
Hydroponics and Aquaponics.....	7
Project Description.....	8
Technology Review.....	9
Technology Overview/ Implementation.....	9
Analysis and Verification of Success.....	26
Future Work/ Next Steps.....	28
Conclusion.....	30
References.....	32

Report Primer and Choice of Language

The following report describes the design and construction of electronics. Accordingly, this section will introduce some of the necessary concepts for those with non-technical backgrounds to understand the project description and implementation. We begin by defining two major concepts when dealing with electricity: voltage and current. To define these, we will use the analogy of a pipe through which water flows. The current is the amount of water flowing through the pipe. The greater the current, the more water flows through a particular section for a given period of time. The unit of measurement for current is Amperes. Voltage is the difference in height between two points of the pipe. Point A might be 10 feet off the ground while point B is only five. Voltage is always measured with one point relative to another. Much like how water would flow downwards from A to B, current flows from areas of higher voltage to those of lower voltage. The unit of measurement for voltage is volts. The final concept we will introduce is resistance. Resistance is opposition to current flow. All electrical components have at least a small amount of resistance. When current flows through a component with resistance, a voltage drop occurs. The side of the component through which current flowed into will have a higher voltage while the side it flows out of will have a lower one. The unit of measurement for resistance is ohms. These are all an oversimplification but will serve their purpose just fine as a reference for any of the description of the implementation that seems confusing (for a more detailed discussion, please see: Beste, 2014).

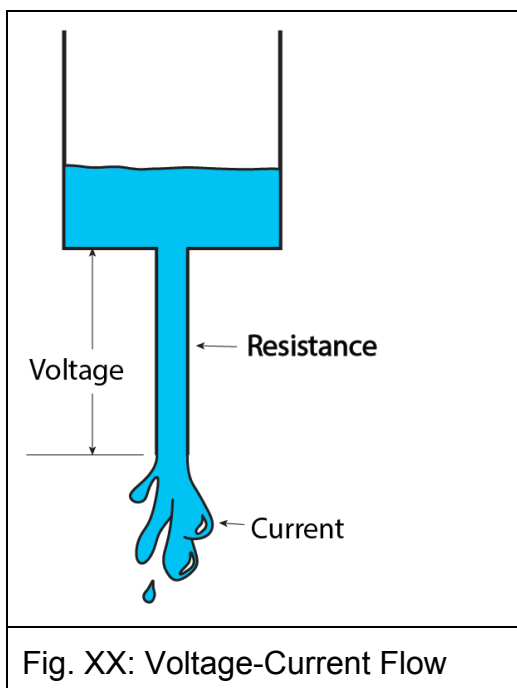


Fig. XX: Voltage-Current Flow

In terms of what perspective this report is written in, it changes depending on the subject matter. All of the non-technical aspects of this report are written in the third person unless explicitly stating a personal opinion. All technical parts, the implementation, are written in the first person using the pronoun “we.” This is due to the fact that all of the technical materials I researched throughout the course of this project, from textbooks to online tutorials, used “we” when illustrating concepts. I would like to continue this precedent in case any do-it-yourselfer wishes to use this report in future research.

All code, schematics, and instructions related to this project are open source and available at: <https://github.com/jackbowen/BloomWall>.

Introduction / problem to be addressed in senior project

For the past 70 years, industrial agriculture has conducted business with a foolishly unsustainable but profitable stoicism in the face of changing ecopolitical conditions. Rather than operating in a reactionary manner, responding to changing climatic and political conditions, industrial agriculture has habitually post-rationalized a shift away from sustainable practices, instead choosing to transition toward a more abstracted, patentable, and profitable notion of ecology (c.f. Horrigan, Lawrence, and Walker, 2002).

It is becoming clear that when sustainability and food safety are prioritized over the potential for monopoly, there emerges a need for distributed, small-scale methods of production. In 1940, the United States food system produced 23 calories of food energy for every calorie of fossil fuel consumed. Now “it takes ten calories of fossil energy to produce a single calorie of modern supermarket food” (McKibben, 2010, 200). 19-29% of greenhouse gas emissions are due to agriculture and a large majority of those emissions produced occur in post-production, during transportation and packaging (Vermeulen, Campbell, and Ingram, 2012, 195). The problems related to a heavily centralized, globalized notion of agriculture are compounded when the political landscape is taken into account. Most Arab countries import over half of what they eat and as a result they suck in food inflation when world prices rise. In 2007-08, they spiked, with some staple crops doubling in price. In Egypt local food prices rose 37% in 2008-10. “The food-price spike was the final nail in the coffin for regimes that were failing to deliver on their side of the social contract,” says Jane Harrigan of London’s School of Oriental and African Studies (Economist, 2012).

Consumers are responding to this. Farmers’ markets and community supported agriculture programs are popping up all over the place. The farm to table movement is gaining traction both at home and in upscale restaurants (cf. USDA, 2014). Still, there are limitations to what can be produced nearby and palates often have a wider set of desires than local climates can produce. It is my belief that we are at the onset of a transitional phase in supplementing our conventionally available local offerings. I believe that we will transition away from imported produce, wherever possible, in favor of locally grown produce that makes use of ecosystemic practices, relying on a holistic approach to produce food in an area that would otherwise be unable to support it. I am tempted to say that this would also be a more a more technological approach but upon consideration the alternative methods I am proposing are much lower tech than the GPS driven columbines and pesticide spraying drones that are becoming prevalent.

This expected change is a sentiment echoed throughout many of the farmers, designers, and consumers necessary to support it. The design community, however, has tendency to sensationalize this transition, monumentalizing what should be a humble concept. One designer's proposal for a vertical farm, as seen below, espouses all of the ideas I disagree with in regards to this transition. It has little regard for economic feasibility, destined to stay a utopian pipe-dream. It's inefficient, valuing phantasmagoric aesthetics over density and efficiency. It's gargantuan structure, dwarfing the Chrysler building in the foreground, has such an enormous amount of embodied energy, the energy required to produce all the materials it is comprised of and then construct it, is so great that it can't possibly balance out over its lifespan. Essentially, it's using "green" as a design trend to manifest narcissism.

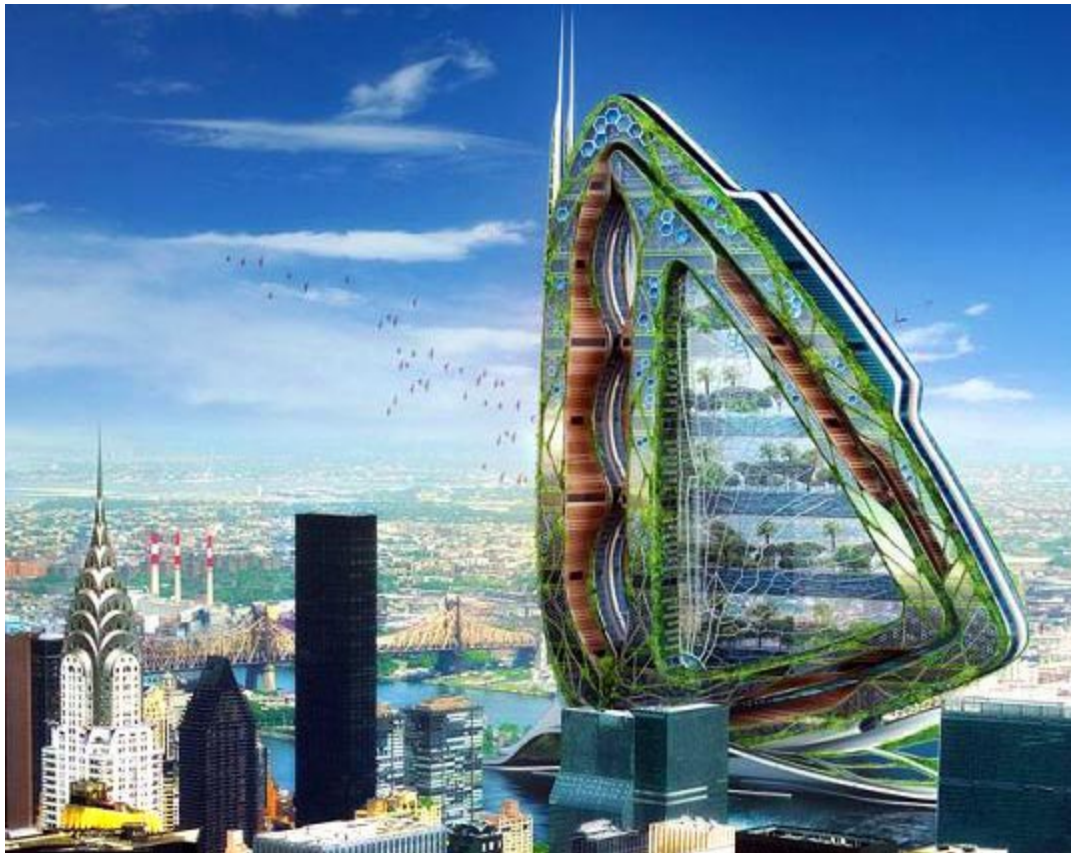


Fig. 01: Vincent Callebaut's "Dragonfly" proposal

In contradiction to this narrative, I am proposing a transition that is evolutionary, not revolutionary. The consumers must be the catalyst for this transition Industrial agriculture will not adapt to consumer preferences unless out of economic necessity.

Similarly, designers are at the mercy of what is actually plausible to bring to market. For this reason, my project focuses on assisting consumers in this transition.

Hydroponics and Aquaponics

The desire to eat local has caused many consumers to transition into producers, supplementing their purchasing with food grown at home. Many of these producers are doing this either hydroponically or aquaponically. Hydroponics is a method of growing in which plants roots are grown in a soilless environment, with their roots exposed directly to water that has been mixed with a nutrient solution. Aquaponics follows this same methodology but swaps out the nutrient solution for fish waste. Bacteria break down the waste into nutrients the roots can absorb, filtering the water that returns to the fish tank (Davis, 2012). In the diagram below, you can see the hydroponic method has a tank full of the nutrient-enriched water that the plants need. To convert it to an aquaponic system, you would need to simply place fish in the mineral solution tank and introduce some sort of biological filter. This filter can be anything from simply placing the plants in clay pellets to filling a small tank with sea shells. All you need is an environment where the nitrogen fixing microbes can grow. For the remainder of this paper, both techniques will be referred to under the umbrella of hydroponics as aquaponics is a subset of the former.

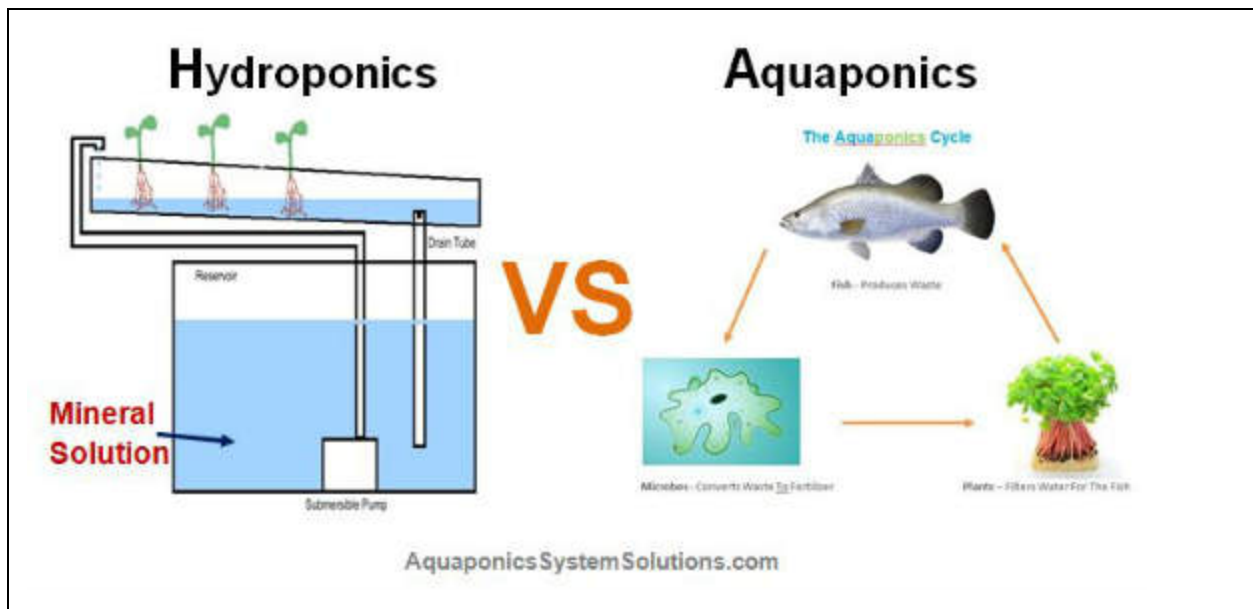


Fig. 2: Aquaponics vs Hydroponics

The importance of these systems are becoming increasingly clear to me on a local level. California is currently experiencing a terrible drought and irrigation claims 70% of

our water consumption (Torsten, 2009, 364). Because hydroponic systems are closed loops, they don't lose nearly as much water to evaporation or inefficient delivery systems. Traditional gardening requires 20 times the water use of a recirculating system (Baptista, 2014). Also, because the root systems don't have to stretch as far to reach water and nutrients, they are more compact This allows denser planting than traditional agriculture.

Project Description

While the benefits of hydroponics may be clear to see, the maintenance required to support these systems may be less intuitive than traditional gardening. What would normally be pre-mixed potting soil is now either a syrup-like concoction that the user has to mix into their water supply or it is the effluent of a group of fish that must be carefully balanced with the amount of plants that can absorb it. The water may be too hot or too cold for the plants, either triggering them to shut down or even killing them. The pH of the water can also affect the plants' growth, stifling it if the solution is too basic or acidic. Together, these factors can form a barrier to entry, making hydroponics appear prohibitively complex to get started with.

Fresh Bytes attempts to lower this barrier to entry by automating or monitoring these various factors, assisting the user wherever possible. The core of this system is a small box. Various sensors, a water pump, and lights may all be plugged into this box. Inside this box, a small microcomputer records all of the data, performs any analysis necessary, affects the system it is monitoring to reach more desirable results, and contacts its owners if any changes are necessary. It is designed so that it can easily be placed in existing gardens.

This senior project is part of a larger project I am working so it is important to distinguish what parts of that project are included in my actual senior project. My senior project focuses on elements that I would feel less confident about completing outside the setting of Cal Poly. The components included in my senior project are the hardware necessary to monitor these elements and the software that drives it. I will be constructing a small hydroponic garden as a testing apparatus but it is simply to test the functionality of the hardware.

Technology Review

The Growerbot emerged from an Arduino project called the Garduino. It is a single probe designed for monitoring soil-based gardens. It contains sensors for sunlight, soil moisture, and humidity. It differs from my project in that my project is optimized for growing in water-based environments and contains the necessary hardware to accompany it. The Growerbot is packaged in a small case, so I think it may serve as a nice precedent when considering how to shrink certain aspects of my project.



Kijani Grows is an aquaponic control system. Kijani Grows focuses on the mechanical aspects of hydroponic systems while mine focuses on the hidden ones. His system prioritizes fluid flow and the like while mine focuses on qualities that can't be observed with the naked eye, like pH. Outside the scope of my senior project, I like that Kijani Grows is heavily involved in community development with educational programs at schools nearby their headquarters in Oakland.

Technology Overview / Implementation

In order to test the system as we incrementally increase its functionality, we must first begin by constructing a small hydroponic garden. The chosen method is a vertical aeroponic tower based off of the research being done at Disney's EPCOT with the assistance of NASA. The tower, as shown below, contains multiple levels whose porosity allows for a steady drip of nutrients to contact the roots. This all pools into a tank at the bottom where it is then pumped back up to the top level.

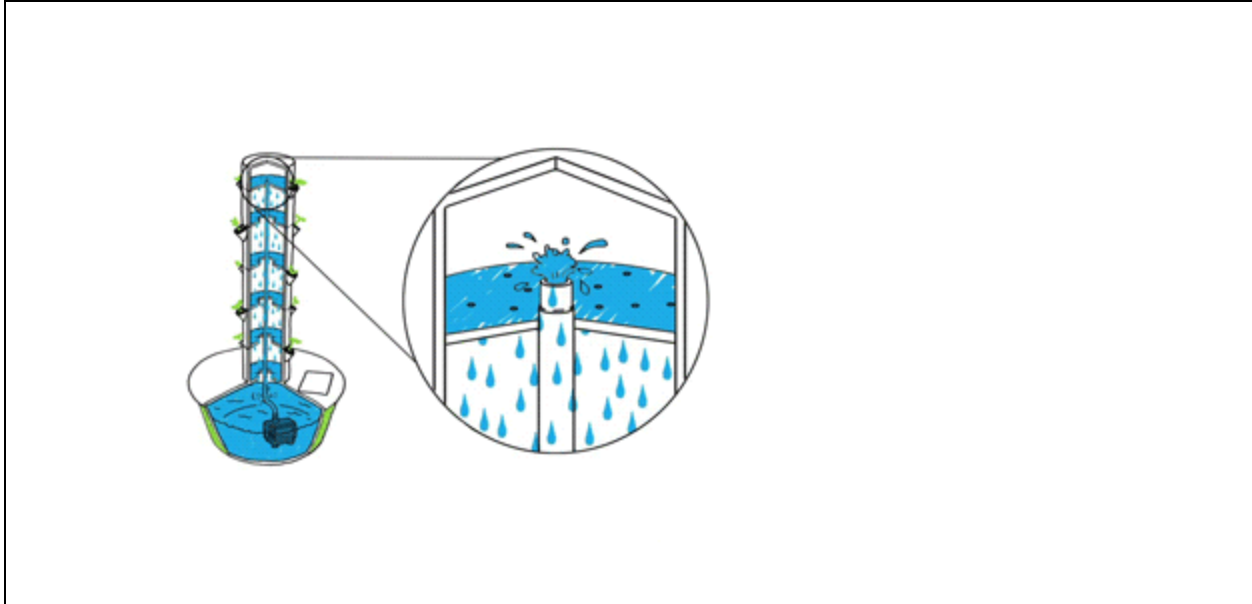


Fig. 05: Disney's Tower Garden

We order two of these stacking levels from Tower Garden and build a makeshift top out of an appropriately sized bucket. We drill holes in the bucket in the same pattern as the levels and then connect the three together with a steel rod. This stack is placed on top of a larger bucket with a hole that is bored to be the same diameter as the stack.

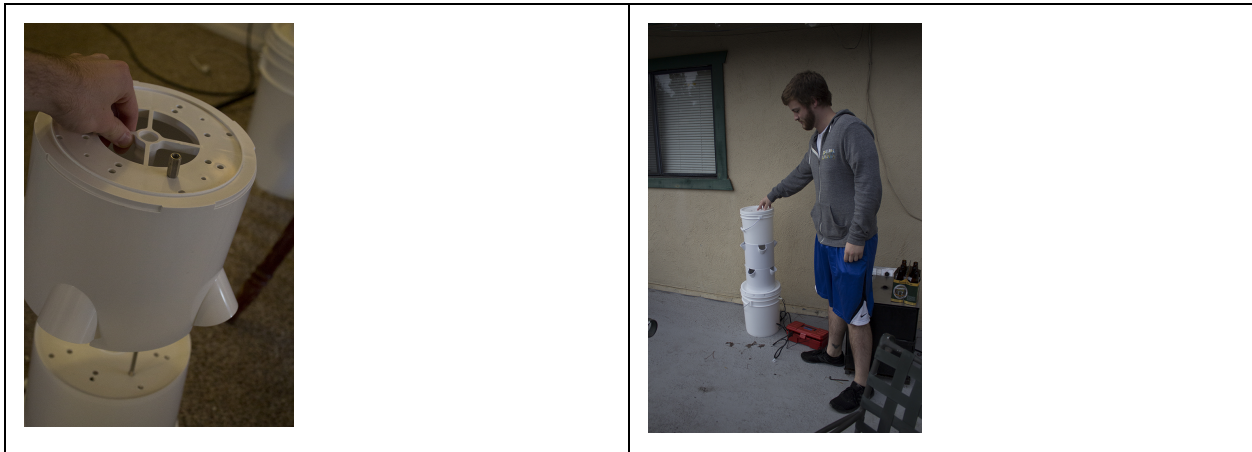


Fig. 06: Connecting the Levels

Fig. 07: Assembled Tower

Computation

In an effort to reach a larger DIY community, we house all of the necessary automation and computation of Fresh Bytes in a distinct module that is able to easily retrofit into existing hydroponic and aquaponic setups. A Raspberry Pi microcomputer functions as the computational backbone for the automation system. We select it due to its small

size, affordability, and pre-existing community. Other microcomputers of similar size, power, and price are available but the Raspberry Pi has the most extensive community, enabling savvy owners to easily hack and modify their system. The Raspberry Pi functions as both a microcontroller and a web server; automating the system's functions while allowing it to talk to other web-connected devices. Node.js a "platform built on Chrome's JavaScript runtime for easily building fast, scalable network applications. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient, perfect for data-intensive real-time applications that run across distributed devices" (Joyent, 2012). Essentially, this means that the same code that functions as the web server also has the logic to operate the electronics associated with the system. The Raspberry Pi relies on small programs written in the scripting language Python to talk to the connected electronics. The Node.js backend simply executes these programs if it needs to measure how much light is available or turn on a pump. The following table outlines each component related to the automation and the function it serves.

Artificial grow lights	An outlet to connect artificial lights that supplement the natural light the plants receive
Photometer	Measures the amount of sunlight a plant receives in order to determine whether or not to supplement the plants with artificial light
Aquarium pump	Circulates water through the system
Water level sensor	Senses when the system is low on water
Nutrient sensor	Measures the density of nutrient solution within the water
Thermometer	Ensures the water does not get too hot for the plants' roots
pH sensor	Ensures the acidity of the water is right for optimal plant growth

EEProm

The main component to design is circuit board that plugs into the Raspberry Pi and contains all the sockets to plug in the various sensors. This board, henceforth referred by Raspberry Pi's preferred language as the HAT (Hardware Attached on Top) will

simply plug in to the input/output and power ports on the top of the Raspberry Pi. Because there is a desire to have this technology easily retrofitted to whatever users currently own, and many users will already possess a Raspberry Pi, there is a desire to have the HAT plug in to boards and just start working right away. Although most Raspberry Pi users will likely be computer savvy, it is too much to expect them to clone a Github repository (a version control system where all the up-to-date code is stored) and initialize it on their end. Instead, we supply each HAT with some Electrically Erasable Programmable Read-Only Memory, or just EEPROM, that will contain all the software and drivers necessary to use Fresh Bytes. Below, we can see the schematic, the abstract representation of all the electrical connections, with the EEPROM memory added. The lower symbol represents all the connections coming from the Raspberry Pi while the one above it represents the EEPROM itself.

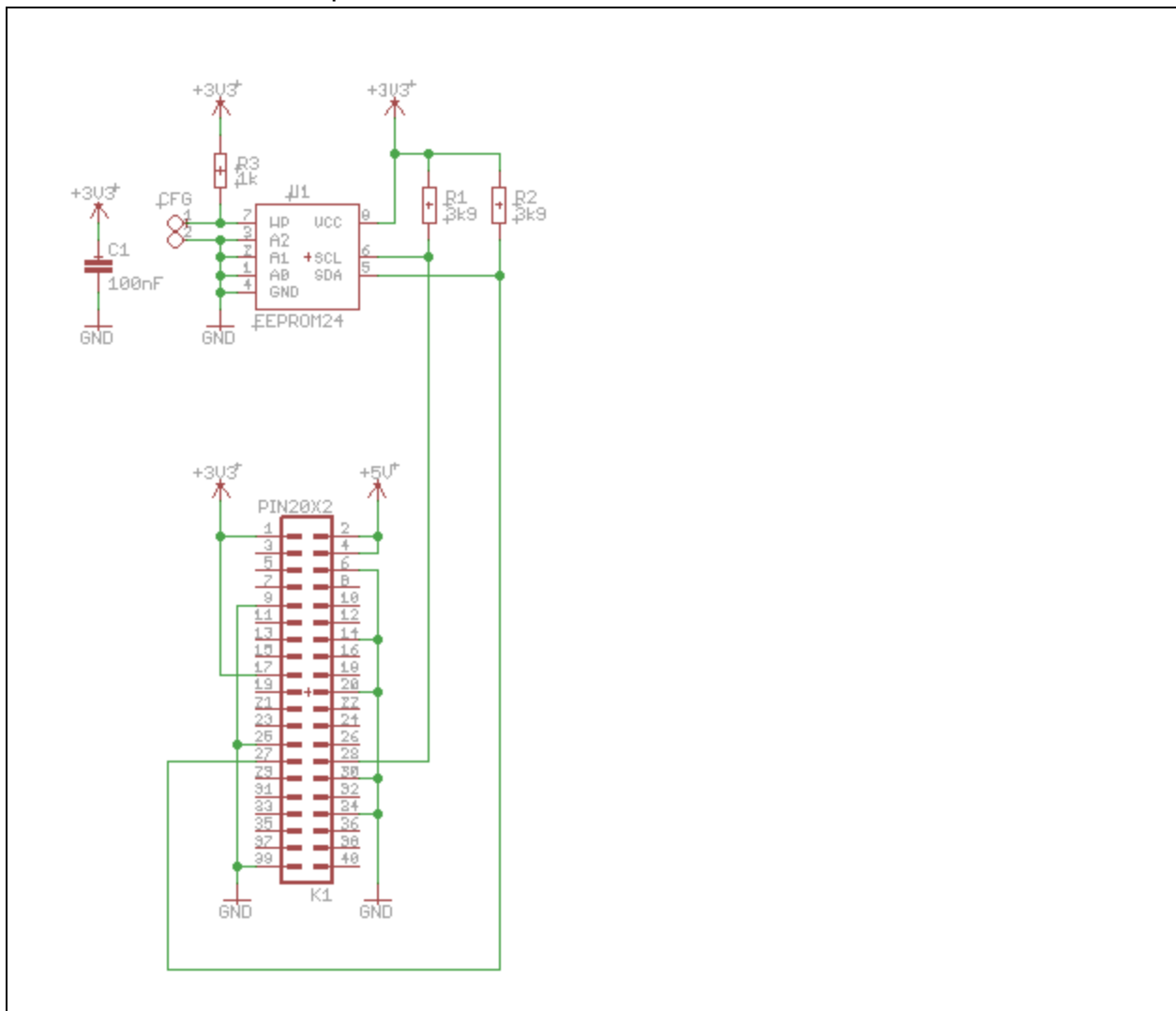


Fig. 08: HAT with EEPROM Schematic

Thermometer

The temperature probe is probably the simplest sensor so it is a good one to start with. The sensor itself is a DS18B20 waterproof digital temperature sensor. It's a digital sensor, more on what that means in a minute, so it is able to easily interface with the Raspberry Pi. The diagram below shows how it is connected to the Raspberry Pi.

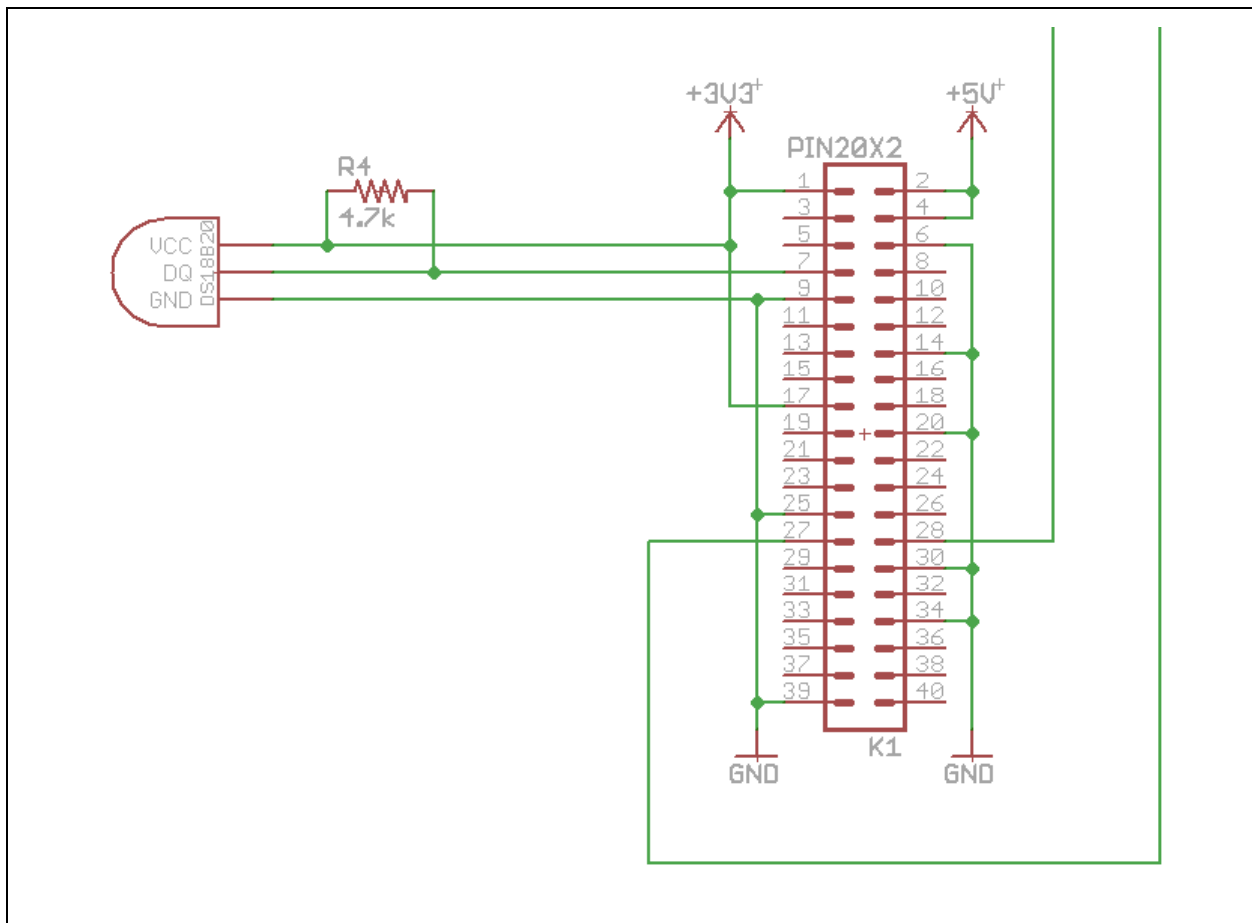


Fig. 09: Temperature Sensor Schematic

The temperature sensor sends readings via serial. The 47 k Ω resistor functions as a pull-up for the data line and keeps the data transfer stable (Monk, 2013) .

So what happens to the data once it is collected? The first thing that occurs is a check to see if the water is the correct temperature. The temperature of the water should be 65 to 80 degrees Fahrenheit (18 to 26 degrees Celsius). If it falls outside of this range, a notification is sent to the owner warning them to take corrective action. After this, the data is saved to a MySQL database stored on the Pi.

MySQL is a relational database that is simple to use and will function well for the relatively small amount of data this project deals with. The Pi's operating system along with all ROM is stored on an 8 GB microSD card. If left unchecked, the data collected through the various sensors would eventually outgrow the memory limitations of the Pi. Accordingly, some form of data decay must be introduced. In this manner, the SQL database will have many discrete measurements for recent events while measurements made in the past will decay into averages. The following table depicts how the temperature data will be stored.

Date of measurement	Data stored
Within the last week	The temperature taken every 5 minutes
Within the last 30 days	The temperature taken every 15 minutes
Within the last year	The average temperature of each hour
1 year ago or more	Daily high, daily low, daily average

pH Sensor

Many of the sensors used in Fresh Bytes are offered in both digital and analog varieties. Analog sensors, like the kind we use to measure our pH, can return an infinite amount of values based on their inputs. An example of this would be a temperature sensor whose resistance is a function of temperature, also known as a thermistor. While it may have a maximum resistance, there are infinite values in the range between 0 ohms and its maximum value. A digital temperature sensor would have a minimum and maximum temperature it could sense. It would also have a certain precision. Together, these factors create a finite set of values that the sensor could return. A digital thermometer with a precision of 0.1 degrees Celsius will never send a signal indicating 43.235 degrees because it is not one of those finite values. The Raspberry Pi can only understand digital signals. There are possible workarounds, such as using a capacitor to measure how long a resistor takes to fill it up, but these methods aren't accurate enough for any engineering grade sensing.

Instead, the next component we add to our system will be an analog to digital converter chip. This will allow the Raspberry Pi to accurately record data from any analog sensors necessary. The chip we are going to use, the MCP3008, is chosen because of its low cost, high number of inputs, and is easily sourced. We give the chip a reference voltage, 5V in our case, and a reference ground (GND), 0V. The MCP3008 has 8 input pins

which we can plug our analog sensors into. They are connected to this 5V and GND, allowing current to flow through them. The chip reads the voltage returning to the input pin, a value between 0 and 5 for us, and converts that to an analog value between 0 and 1023 that is sent via serial communication back to our Raspberry Pi. The schematic below shows how we connect it to the Raspberry Pi.

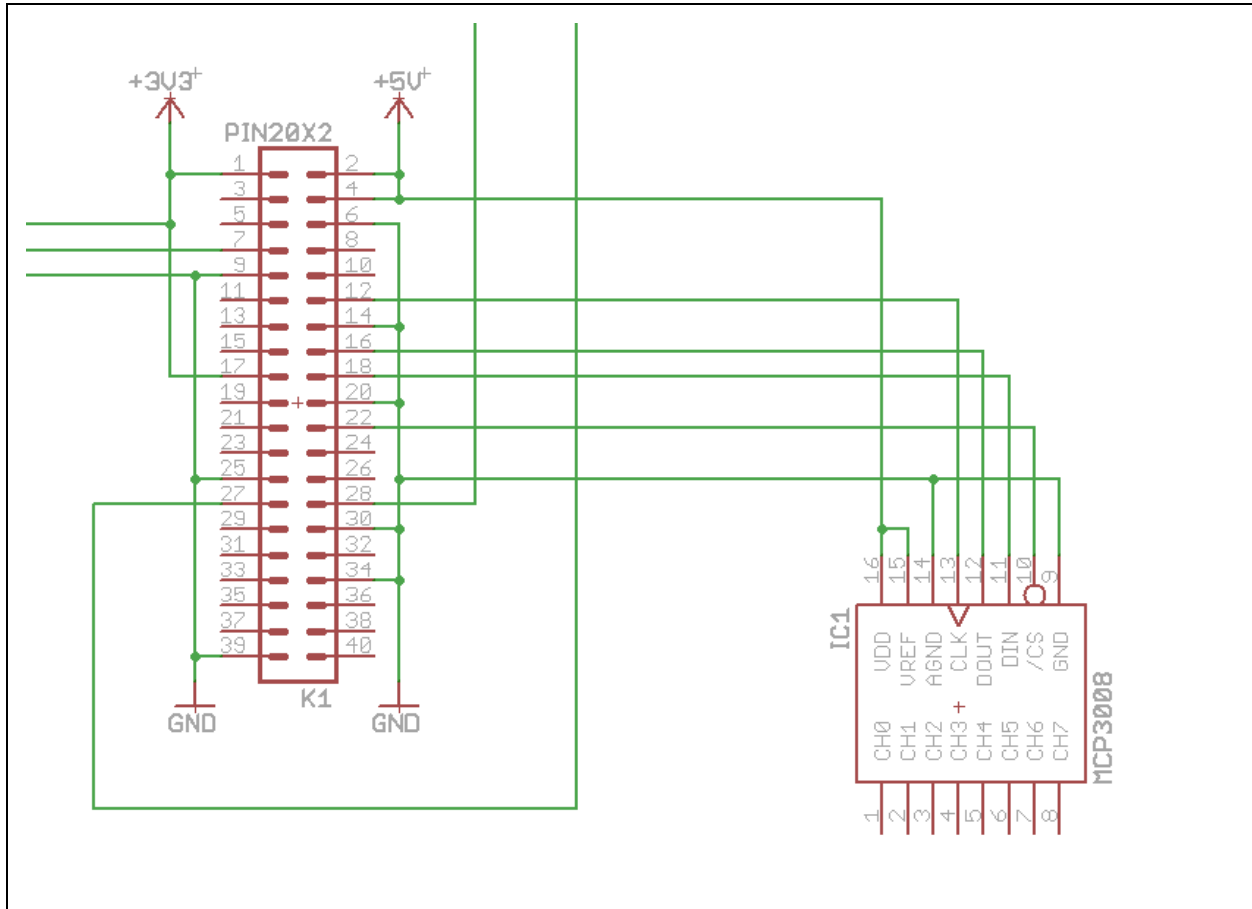


Fig. 10: MCP3008 Analog to Digital Converter Chip Schematic

The actual sensor we are going to use is a pH probe by RobotMesh. This sensor boasts a pretty great accuracy/ cost ratio. It's one quarter or less than of the cost of most available pH probes and within +/- 2% of expensive probes when properly calibrated. It comes with all of the necessary components on a small circuit board so we simply need to add a connector to our schematic that will connect to the breakout board.

We start by trying to calibrate the sensor against a solution with a known pH of 3.3. The sensor is accurate about 90% of the time. However, a small fraction of the time, it reads a value of either 0 or about twice what it should. To mitigate this, we read 50 values,

spaced 20 milliseconds apart, into a list. We then sort the list from highest to lowest and average the 30 readings that appear in the middle of the list. This removes any outliers.

PAR Meter

There are multiple ways to measure the incoming light that the plants receive. Many DIY projects simply use a photoresistor which is a resistor whose resistance depends on the amount of light the sensor is exposed to. DIYers measure the voltage drop across these photoresistors, also known as a photocells, to determine a rough estimate of the light available at the location of the resistor. While inexpensive, the values determined from this method are not precise enough for anything outside of a hobbyist's pursuit. A digital lux meter, while still relatively inexpensive (the price tends to stay around \$5.95 on adafruit.com), measures lumens. Lumens are simply the amount of visible light emitted from a source. When growing plants, we're not interested in raw brightness as much as we are the concentrations of certain wavelengths of light that stimulate photosynthesis. This spectral range, also known as a wave band, is from about 400 to 700 nm and roughly corresponds with the spectrum visible to human eyes. Plants rely on various pigments to capture the energy available in sunlight in order to use in photosynthesis. Chlorophyll, the most abundant pigment, absorbs red and blue light while reflecting green, giving plants their color.

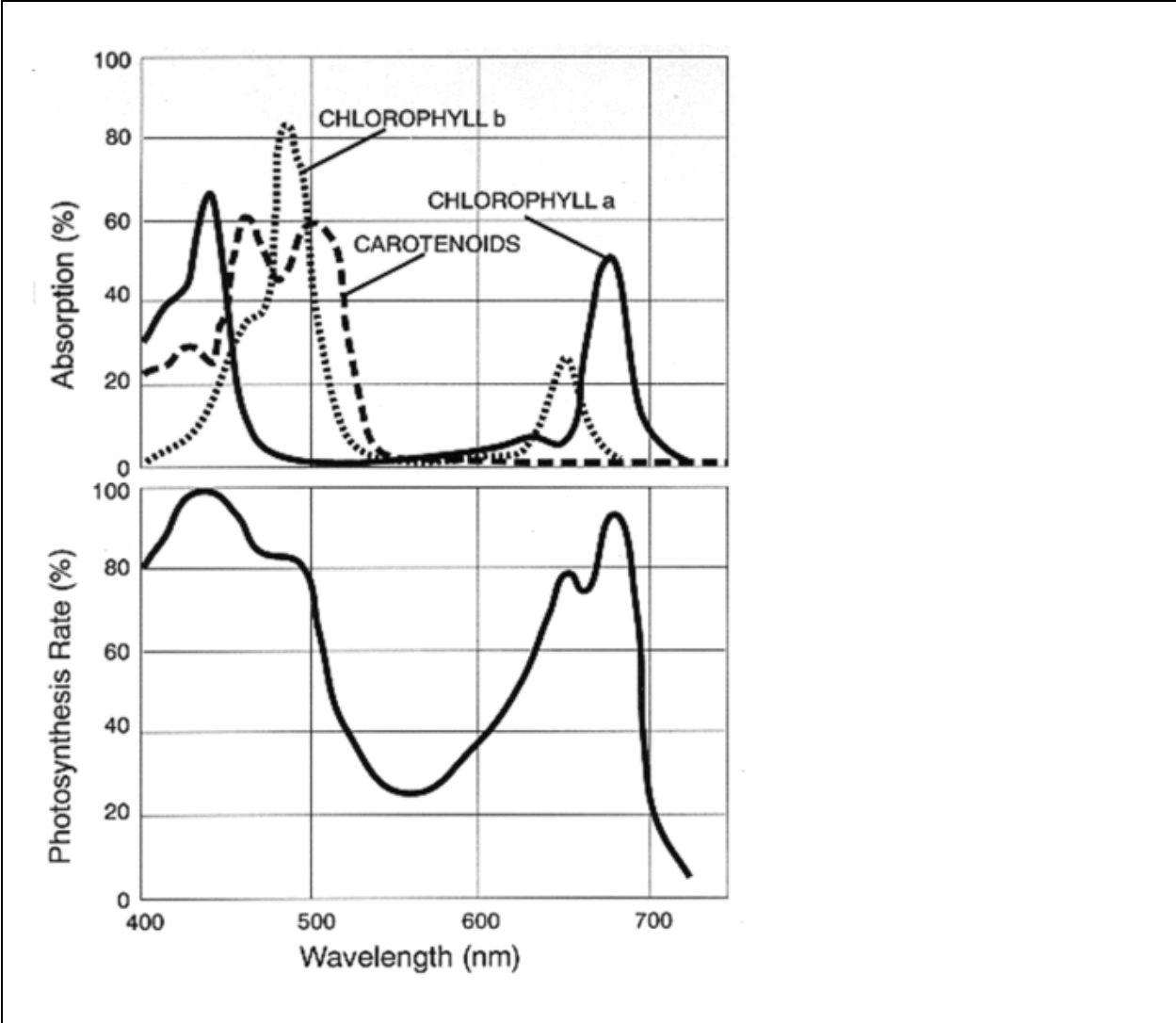


Fig. 11: Photosynthesis Rate compared to Wavelength of Light

As depicted in the figure above, the photosynthesis rate has local maximums at ~450 nm and ~675 nm. A sensor known as a PAR meter can detect these specific wavelengths but all the sensors available are currently hovering around \$300 and rely on proprietary control systems .

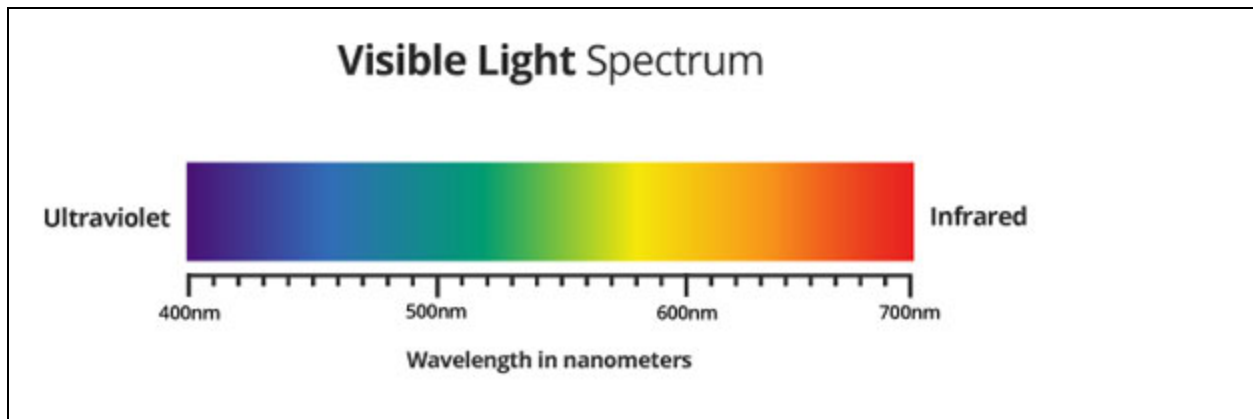


Fig. 12: Visible Light Spectrum

An alternative to these systems is an LED photometer. These photometers work as PAR meters, measuring the amount of incoming light at various wavelengths by relying on a discovery known as Mims Effect. In 1973, Forrest M Mims discovered that much like a motor can function as a generator when run the opposite way, LEDs absorb a narrow band of light associated with the color they produce and produce a small amount of current (Justo and Gertz, 2013, 51).

In order to create an LED photometer, we must first label the wavelengths of light our LEDs pick up. To do this, a device must be created that can emit various wavelengths of light. We measure the voltage generated at each wavelength and the maximum measured voltage will occur at the wavelength our LED is sensitive to. An RGB LED is an LED that can emit various colors. Instead of a single anode and cathode, the RGB LED used in this project has a common cathode with three individual anodes related to the amount of red, green, and blue light the LED emits. To map wavelengths to their proper RGB values, we use an algorithm derived from the diagram below (Bruton, 2014).

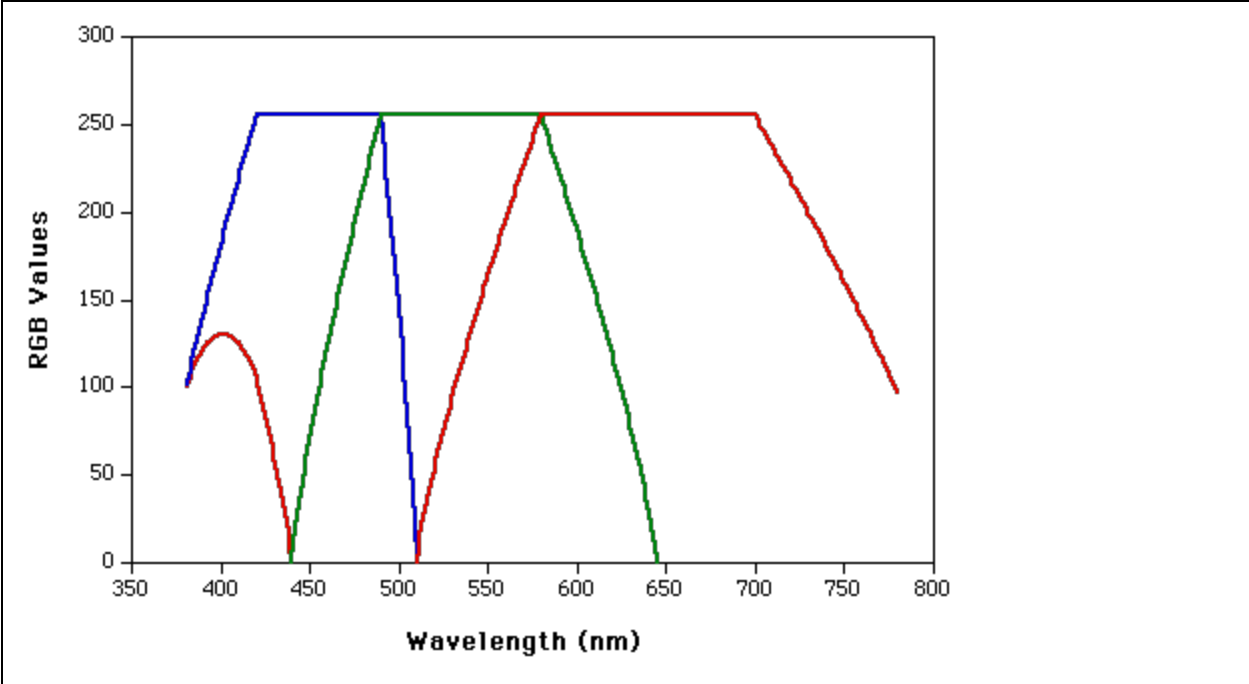


Fig. 13: Wavelength vs. RGB Value

We place the RGB LED in a tube across from the LED we are trying to measure. We then cycle the RGB LED from 350 to 700 nm in 1 nm steps and record the voltage at each wavelength. This process is repeated five times for each of the 3 LEDs.

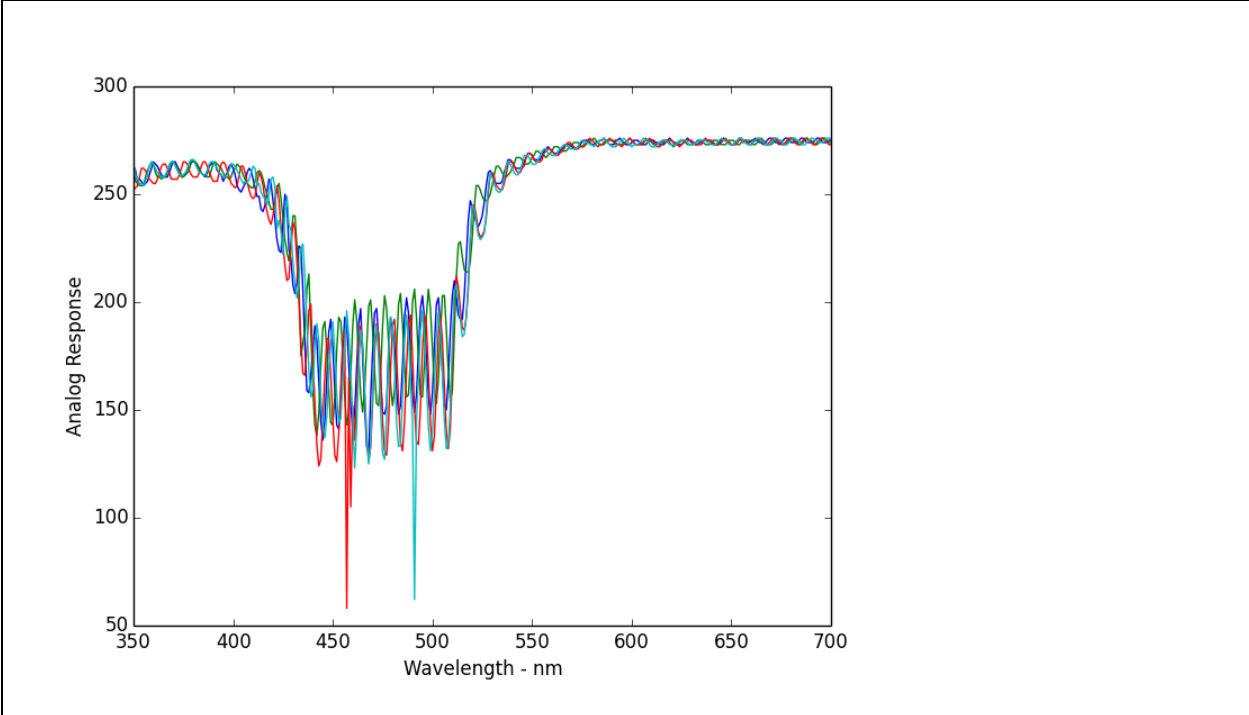


Fig. 14: Voltage Response of red LED

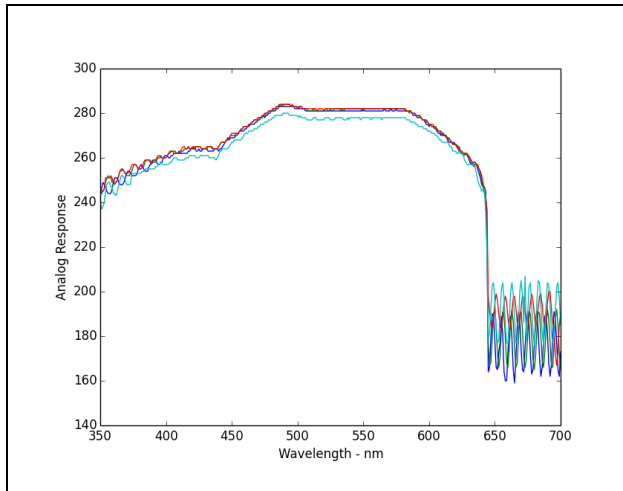


Fig. 15: Voltage response of green LED

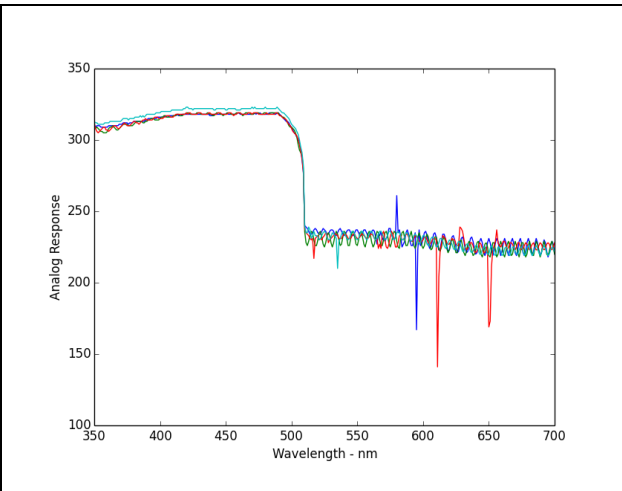


Fig. 16: Voltage response of blue LED

Red:	583 nm
Green:	487 nm
Blue:	421 nm

From this, we can see the peak absorption of each LED. The voltage across each LED is inconsistent though, even for a set wavelength. Our response is sinusoidal over time. Instead, we can use a photodiode. The diode, like the LED, produces a current based on the wavelengths of light it absorbs. The diode is a smaller version of the solar cells used in solar energy set-ups. We simply need to find one whose absorption matches that which we are looking for. Once we have our photodiode, we connect it like the photo and diagram below. Unlike, previous sensors, this circuit will be placed somewhere independently of the main board. Thus, it is a separate schematic and board.

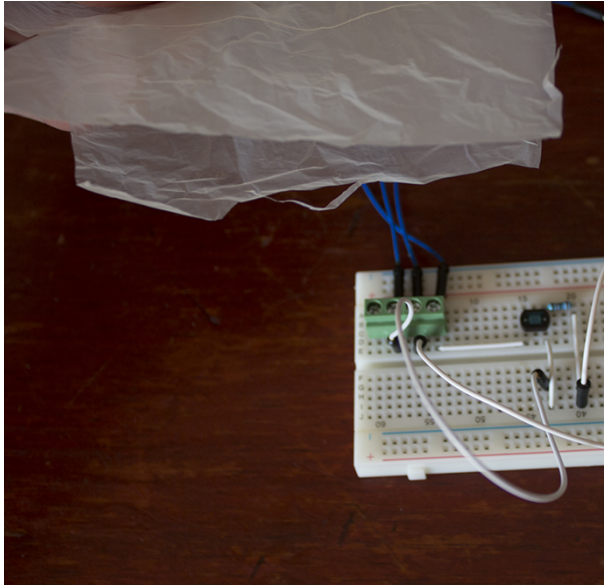


Fig. 17: Prototype PAR Meter

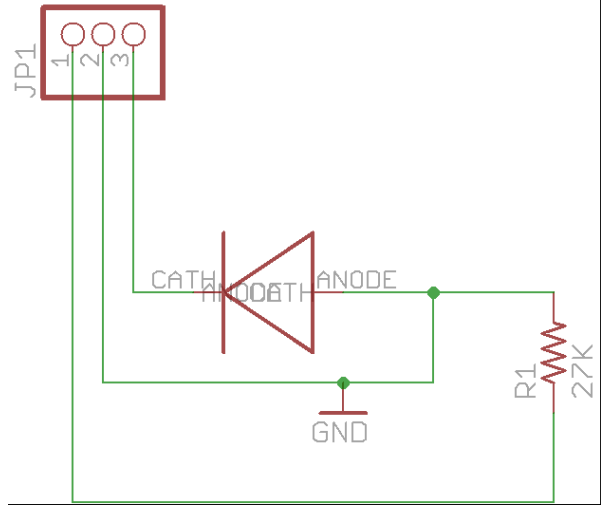


Fig. 18: PAR Meter Schematic

Because this PAR meter is a stand-alone board. We can now design the printed circuit board that it will use.

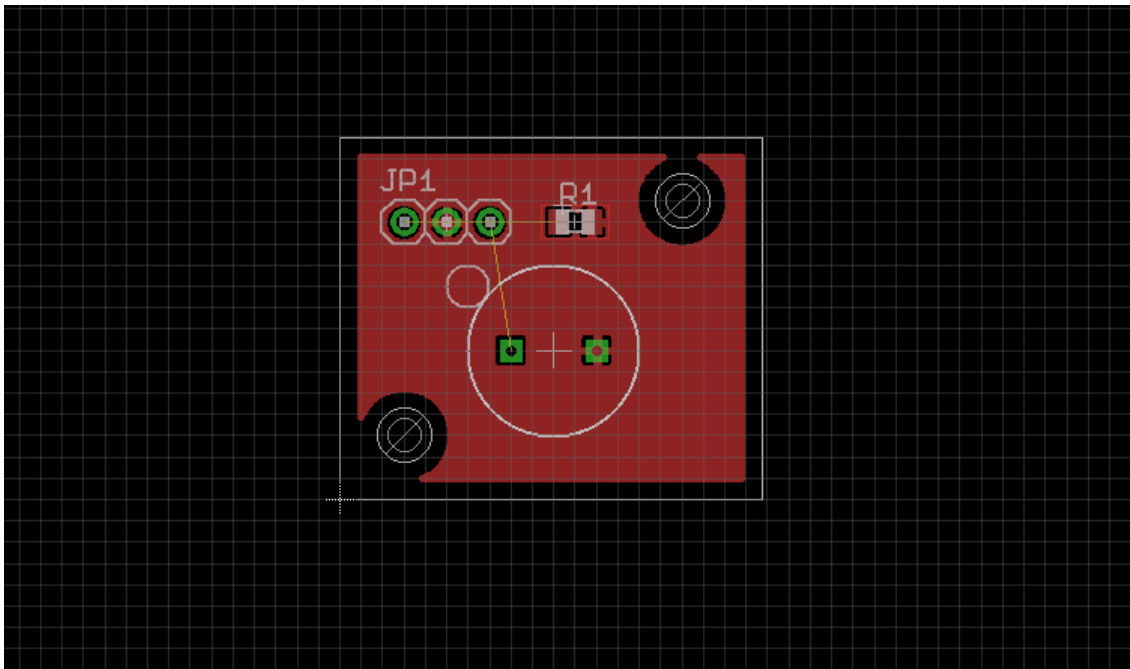


Fig. 19: PAR Meter PCB

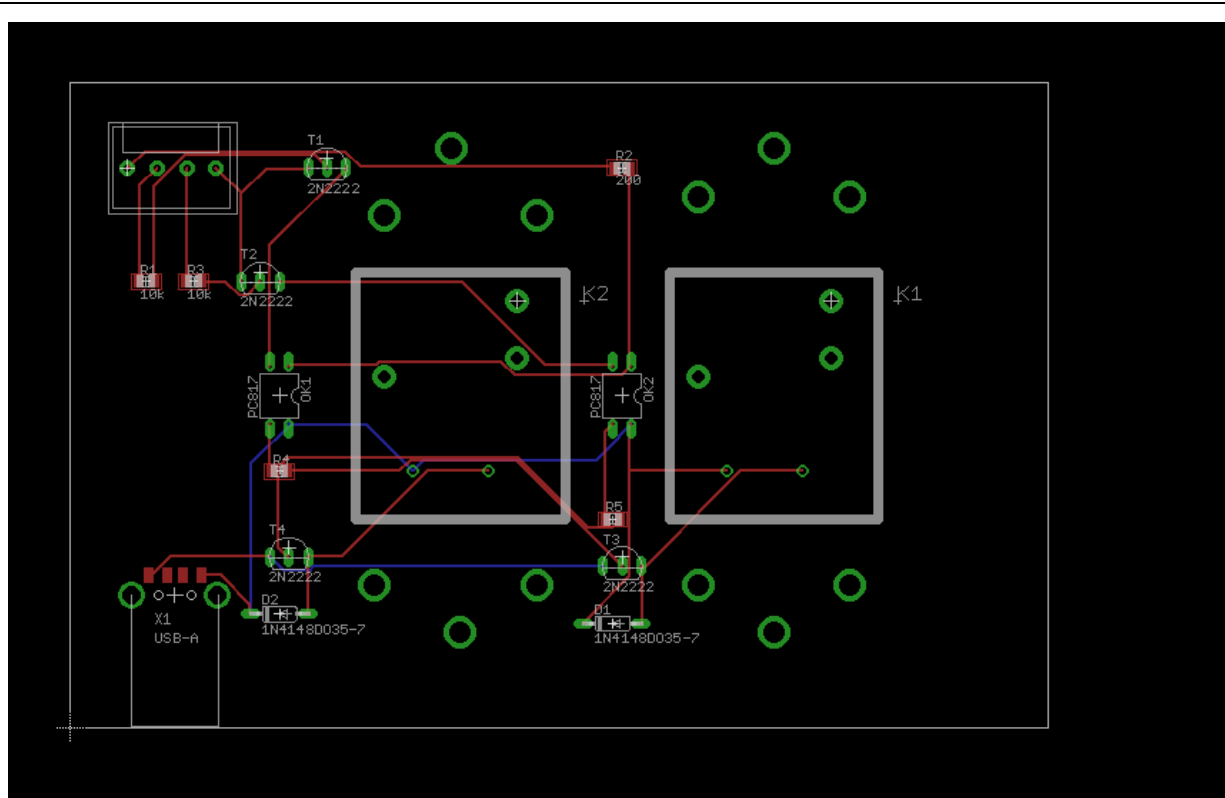


Fig. 21: Relay Board PCB Design

Nutrient Sensor

The measure of dissolved solids, nutrients in our case, is measured most commonly in parts per million when discussing hydroponics. Whether it is a solution that we manually add to the water or simply the effluent from fish, we must ensure that is within a range that is healthy for our plants. To measure this, we test the electrical conductivity of the water. This is the only sensor where an affordable alternative is not viable. Many DIY versions of this sensor exist but they are too inaccurate and fragile for our use. Our sensor must be deployed continuously and with all of the DIY offerings I found in my research, all suffered the same problem of diminished accuracy over time. Salt builds up on the electrode in these versions, obscuring the true conductivity.

The sensor we will use is the Conductivity K1.0 kit from Atlas Scientific. This communicates via the RS-232 serial interface. It will draw power from the 5V rail that is supplying our temperature probe so all that needs to be done is to connect the probe to the RX and TX pins of the Raspberry Pi.

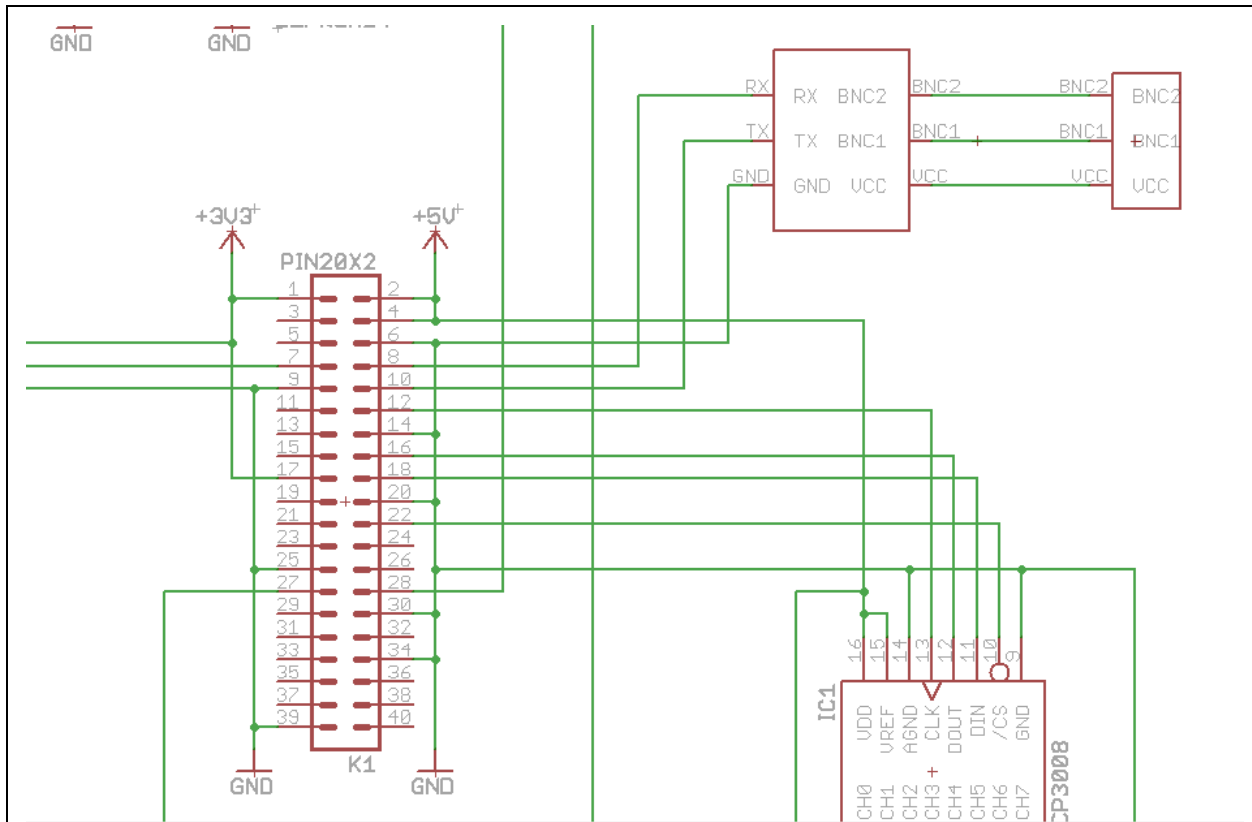


Fig. 22: Atlas Scientific EC Probe Schematic

Now that the probe is connected, it must be calibrated against a series of solutions with known conductivities. The probe itself measures conductivity in microSiemens but a quick calculation will later convert this to PPM. A python script, `calibrateEC.py`, guides the user in performing the various calibrations with the supplied solutions.

Water Level Sensor

There is no water level sensor. There doesn't have to be. All that is necessary is to place the pH probe and EC probe at different heights within the tank where one sensor is above the necessary level and one below it. Let's place the EC probe above the minimum level for explanation's sake. The probe will read 0.0 in plain air because the EC of air is less than the detectable range of the sensor. When the EC sensor reads 0 but the pH probe is still returning valid values, the software determines the water level is too low and alerts the user.

Putting it Together

Now that we have all of our necessary componentry placed on our schematic, we can use it to generate our HAT. We must work to fit our components into a board size that

properly fits on top of a Raspberry Pi. Generating our final and most complex PCB, we get the following.

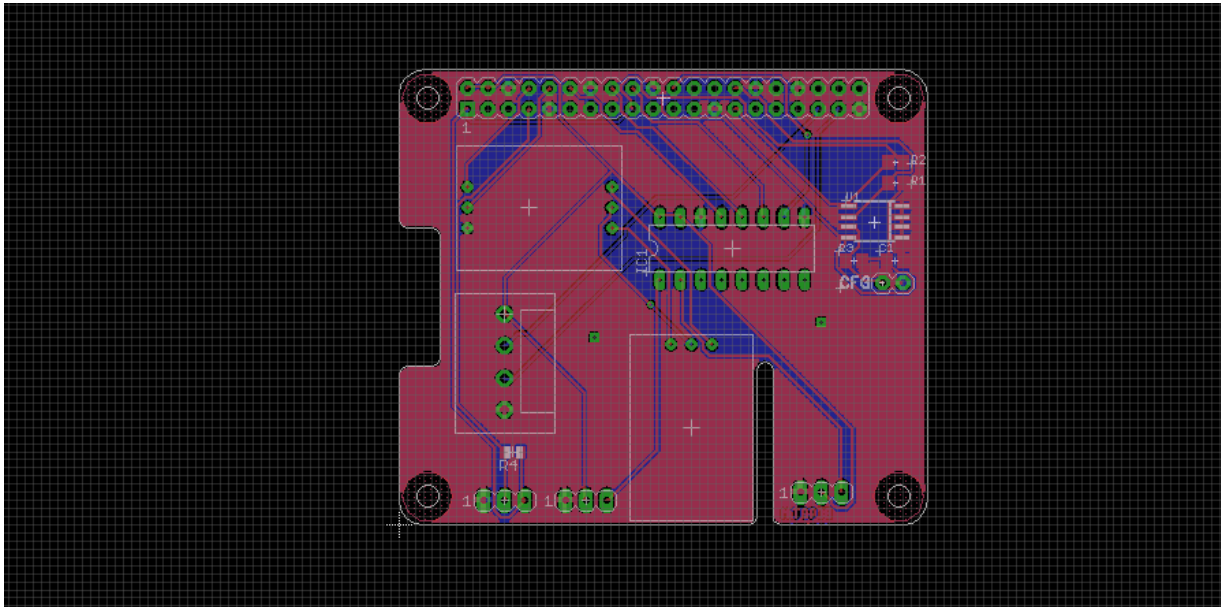


Fig. 23: Raspberry Pi HAT

A rough prototype of the board above gives us the following.

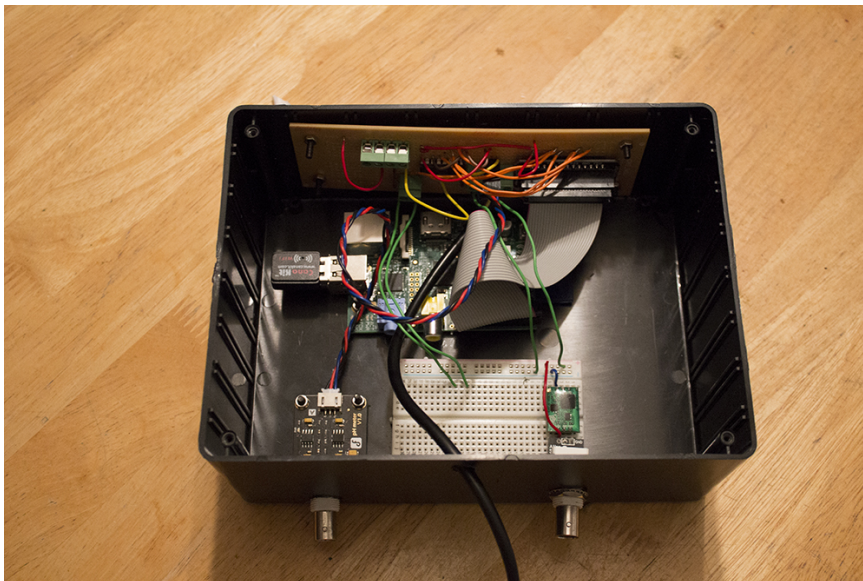


Fig. 24: Prototype

Analysis and Verification of Project Success

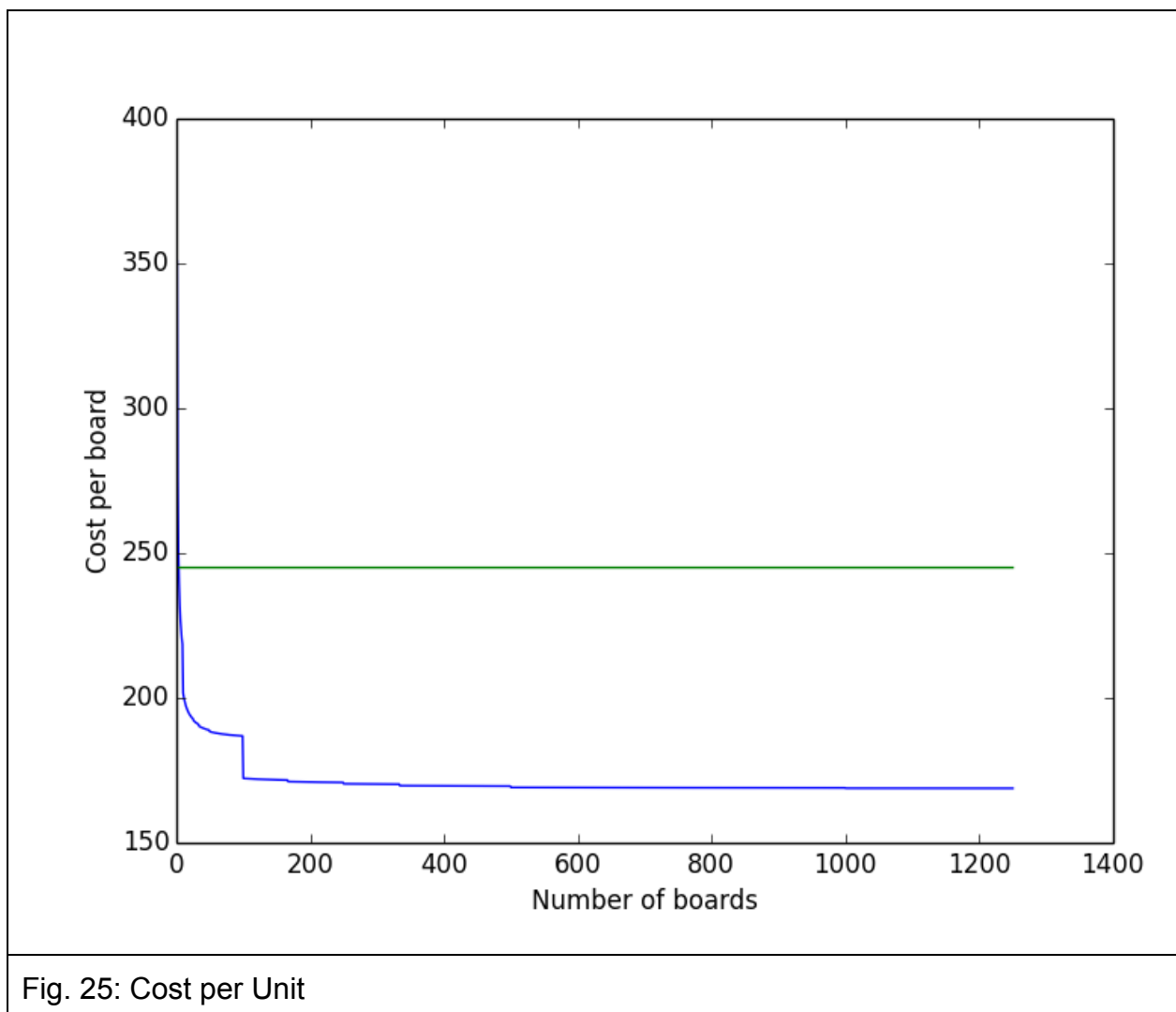
Fresh Bytes had 3 criteria for success; whether or not all the sensors were completed; if they were within 10% accuracy of either lab-grade equipment or known values, and if the system could be assembled and shipped for less than it would cost a hobbyist to do it themselves. Together, these formed the more difficult aspects of the larger project that I'm working on. I am not as confident in my hardware design abilities or economic analysis as I am my programming and design skills. Stressing these aspects in an academically rigorous setting will push my project further along than if I were to do it entirely independently.

Sensor Name:	Accuracy:	Testing at home:
Temperature	+/- 2.2 %	Compare against thermometer
pH	+/- 6.0 %	Compare against pH strips
PPM	+/- 0.8 %	Compare against certain amounts of salt mixed in water
Water level	0 %	Look
Pump flow	N/A	Look
Lighting control	N/A	Look
PAR Meter	+/- 5.1%	Compare against values under standard conditions

The pH probe was compared against those used in the chemistry labs at school. Users at home may compare it against the color-changing pH strips readily available at home improvement stores. The EC/ PPM sensor was calibrated against a series of solutions with known conductivities. Users at home may mix recipes quantities of water and salt to produce a solution with a known PPM. The PAR meter was calibrated and verified against one borrowed from the College of Agriculture on campus. Users at home would have to calibrate their sensor against known values, such as the sun producing a PAR

reading of 2000 while a fluorescent bulb produces one of about 600 when placed 2 feet away. The rest of the sensors were binary so accuracy was not a factor to be measured. They could be verified by simply looking at the system to ensure that they were working properly.

Gathering the price info for each component at various quantities and using EagleCad to generate a board manufacturing quote, a python script was written to estimate the cost per unit under various sizes of production. The green line represents the cost for a hobbyist to construct a similar system themselves. The system starts to become pretty viable at around 100 units.



Future Work / Next Steps

Currently available hydroponic planters are not optimized for indoor, personal, and diversified production. Instead they are optimized for commercial scale production. They are predominantly designed for outdoor or greenhouse based growing, both of which would be an unrealistic expectation of what end users will have access to. Of the systems optimized for indoor production, most are incredibly unsightly, space inefficient, and cater heavily toward single crop cultivation instead of a diversified food production. Designed for personal use, I wish to create a planter will be easily integrated into users' homes. The major design constraints that will guide this project are that it must be unintrusive, easily assembled, thoughtlessly maintained, and successfully transported without losing any plants. Now that the majority of the global population dwells in cities where living quarters are often tight, the system must slim enough to be retrofitted into small spaces without becoming an obnoxious artifact (Obaid, 2007, 1). It will accomplish this through deploying the plants via a vertical gardening system. The system must also be easily constructed with a minimal amount of effort, expertise, and tools. Upon receiving the kit, construction will be intuitive with pictographic driven instructions, along the lines of Ikea. The system must also be impermanent and transportable. This is to ameliorate the issues that arise with people renting their homes and repeatedly moving from place to place. There must be a method to keep the roots wet during transportation, either through a grow medium that retains water or through a reserve battery to continue watering the roots. System processes that require human intervention, such as requiring a water tank to be refilled, may be sent as a notification to the producer through a text, email, or app.



Fig. 26: App Mockup

The planter must be vertical in an attempt to maximize space. It will accommodate twenty plants at a time. This number was reached after looking at existing systems such as the Tower Garden and many DIY hydroponic and aquaponic systems. This production size allows a user to effectively supplement their meals with homegrown fruits and vegetables without the burden of having to constantly outpace production for fear of over-ripening and rot. Assuming that an owner has access to and working knowledge of a power drill and stud finder in order to mount the system on a wall would be an overestimation of the handiness of many users and destroy the simplicity of use that this system strives for. Thus, it is necessary that this system offer a tools free method for deploying it. In this case, a stand will be offered. Assuming an owner has the proper expertise to mount the system on a wall, it must be lightweight enough to be mounted using simple drywall screws. Horizontal hydroponic systems generally use a growing media such as shale or hydroton, which are pellets of expanded clay aggregate. The growing media provides structural support for the plants to root themselves in, and retains the nutrient enriched water so that the plants may continuously absorb the water and nutrients even if there is not constant input. While these media have their merits in horizontal systems, they are far too heavy for a system mounted on a wall, especially one with minimal bracing.

I'm going to construct my system using aeroponics, a system in which plants are grown in an air or mist environment with the roots constantly being exposed to oxygen

I would like to compare the energy of the food produced to the energy required to create and run the system. This is essentially a measure of whether or not the system is the eco-friendlier alternative to industrial agriculture that it claims to be. The energy required to produce the system, henceforth referred to as embodied energy, will be a function of not only the materials the system is comprised of, but also the techniques employed to create the system as well as the packaging and distribution of the system. To understand the impact of production, the embodied energy of each raw material will be calculated using the Inventory of Carbon and Energy (ICE) prepared by the University of Bath (Embodied Energy and Carbon - The ICE Database). These base levels of energy required and CO₂ emitted will then be added to by any processes that are employed by the local production that I employ, such as machining or injection molding. The packaging of the product will be calculated via the ICE described above and its shipping impact will be calculated by the Environmental Protection Agency's SmartWay database which updates each major freight company's environmental impact weekly. Finally, there will be a measurement of the energy required for the system to run. This will be compared against the net impact of each calorie produced in the food present at a

traditional supermarket. There will be an examination of the typical American diet and the net impact of it. A curve will be generated that plots the embodied energy and maintenance energy of this system per calorie against the energy tied up in each calorie of industrial food. At a certain point, the energy per calorie of the aquaponic system should dip beneath that of industrial agriculture and remain beneath it. I would be happy if this crossover point happened within six to twelve months

Whether or not users will adopt this system is limited by its aesthetic beauty. Few people will be keen to implement a sparse connection of tubes and wires that resembles a dystopian manifestation of pragmatism. That being said, I am going to take this system as an opportunity to explore potential semiotic and phenomenological effects of design on consumer behavior. I would like the system to emanate a subdued feeling of sublimity in the artistic and architectural meaning in which beauty is paired with minute sense of horror, resulting in an exhilarating reaction. The sensation is akin to how one feels when confronted with the view of a picturesque but dominating mountain range. Locating this balance between Pottery Barn and NASA is what will allow this project to achieve its additional goal; opening up a discussion about diets and methods of agricultural production. The system's aesthetics must be innocuous enough to widely adopted but subversive enough to become a point of conversation.

Conclusion

I was able to design and prototype a system that was up to my standards throughout the course of this project. I greatly improved my confidence when it comes to tackling engineering problems that I'm unfamiliar with. Moving forward, I would like to explore the possibility of using this project as a springboard to start a small business based around ecosystemic technologies. The hardware designed might be a bit much for testing whether or not I could run this small business. Instead, I intend to market and produce the photometer to test the waters. Once I feel comfortable locating manufacturers, dealing with inventory, and dealing with customers, I may refine this project a bit more so that I could make a Kickstarter out of it.

A big thank you to Jane Lehr, Michael Haungs, Karen Donaldson, Tim Schoepp, Gary Perks, and Scott Steinmaus. Without their assistance and their guidance, I'm not sure how much of this project would have been completed.



Fig. 27: Working Prototype

References

- "Agricultural Marketing Service - Farmers Market Growth." *Agricultural Marketing Service - Farmers Market Growth*. United States Department of Agriculture, 14 Aug. 2014. Web. 12 Dec. 2014.
- Baptista, Perry. "Water Use Efficiency in Hydroponics and Aquaponics." *Bright Agrotech*. Bright Agrotech, 04 June 2014. Web. 04 Dec 2014.
- Beste, Bill D. "Basic Electricity." *Basic Electricity*. Reprise, 08 Feb. 2014. Web. 12 Dec. 2014.
- Blanc, Patrick, and Véronique Lalot. *The Vertical Garden: From Nature to the City*. New York: W.W. Norton, 2008. Print.
- Bruton, Dan, Dr. "Approximate RGB Values for Visible Wavelengths." Stephen S. Austin State University, 04 Dec 2014. Web.
- Davis, Colle, and Phyllis Davis. "What's the Difference Between Hydroponics vs Aquaponics?" *Portable Farms*. N.p., 14 Mar. 2014. Web. 12 Dec. 2014.
- "Embodied Energy and Carbon - The ICE Database." Embodied Energy and Carbon - The ICE Database Circular Ecology, 2014. Web. 30 Apr 2014.
- Horrigan, Leo, Robert S. Lawrence, and Polly Walker. "How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture." *Environmental Health Perspectives*(2002): 445-56. *National Center for Biotechnology Information*. Web.
- Justo, Patrick Di, and Emily Gertz *Atmospheric Monitoring with Arduino: Building Simple Devices to Collect Data about the Environment* Farnham: O'Reilly, 2013 Print
- "Latest Publications." Urbanization: A Majority in Cities: Population & Development : UNFPA United Nations Population Fund, n.d. Web. 26 May 2014.
- "Let Them Eat Baklava." *The Economist*. The Economist Newspaper, 17 Mar 2012. Web. 03 Dec 2014.
- McKibben, Bill. *Eaarth*. New York: Time /Henry Holt, 2010. Print.

Monk, Simon. "Adafruit's Raspberry Pi Lesson 11 DS18B20 Temperature Sensing." *Adafruit* Np, 28 Jan 2013. Web. 05 Dec 2014.

"Node.js." Nodejs. Joyent Inc, 2014 Web. 26 Aug 2014.

Obaid, Thoraya A. *UNFPA State of World Population, 2007: Unleashing the Potential of Urban Growth*. New York: United Nations Population Fund, 2007. Print.

Torsten, E.I. Wik, et al. "Integrated dynamic aquaculture and wastewater treatment modeling for recirculating aquaculture systems." *Aquaculture*. 287. 2009.

Vermeulen, Sonja J, Bruce M Campbell, and John Si Ingram. "Climate Change and Food Systems." *Annual Review of Environment and Resources*. 371. (2012): 195-222
Print

"Water Usage in Recirculating Aquaculture/ Aquaponic Systems." *Simply Hydroponics*. Food and Water Watch, 2009. Web. 03 Dec 2014.