FINAL DESIGN DOCUMENT

PROJECT NAME

AutoFarmOS

DOCUMENT DATE

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DESIGN TEAM (TEAM #7)

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1. Project Overview

Synopsis

AutoFarmOS is the software used to control the sensors and actuators for the Terrafarm farming module.

Description

This project is being undertaken to satisfy the embedded software needs of the farming module for the start-up company, Terrafarm. The start-up is currently working to establish a minimal viable product to prove the viability of their idea and our team hopes to support this goal by developing an operating system and drivers for the module. The Autofarm product aims to solve many agricultural and environmental issues. According to Terrafarm,

> *"Autofarm is intended to completely disrupt the food supply chain by introducing 21st century information technology to agricultural production. This will eliminate substantial food waste, reduce environmental degradation, improve produce freshness and nutritional content, increase food security and accessibility, slow the process of climate change, and make cities more sustainable and self-sufficient."*

By working with Autofarm, we hope to help push the world towards greener forms of agriculture. Additionally, we as a team are excited about the opportunity to explore new development territory by working with embedded systems and by undertaking a large, multi-team project. The end result for our project is a minimum viable embedded software system that can be combined with other software components to form a comprehensive software suite that can be extended for use in Autofarm commercial units.

2. Project Design

Product Overview

The product, as designed by the start-up company Terrafarm, has two main components: a farming module and a software suite. The farming module is a small-scale, refrigerator-sized vertical farm that will, by the product description, “autonomously grow fresh, nutritious produce for food businesses such as grocery stores and restaurants.” The software suite has three primary functions: handle data from the farming module, control growing conditions in the farming module, and provide an interface for users to interact with the module. Together, the hardware and software components form a system that yields high quality produce while also giving produce-dependent businesses more control over how their produce is grown and handled.

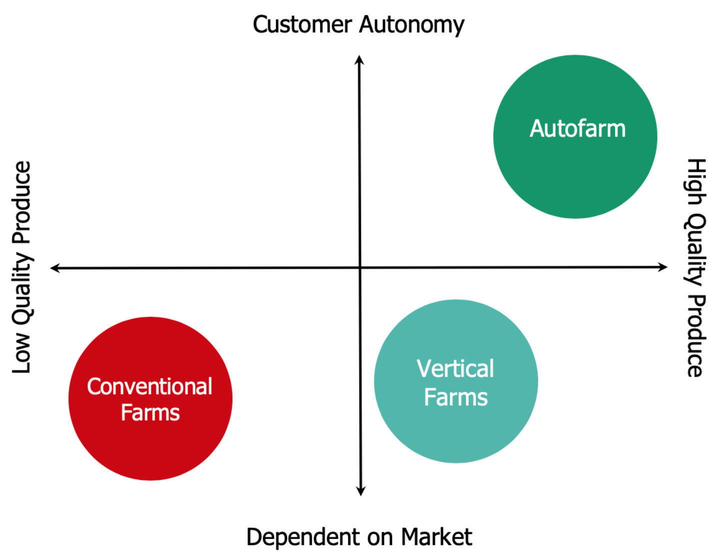


Figure 1: Autofarm Market Analysis Graph

The product design team is composed of the start-up company itself, which serves as the product owner, the mechanical engineering team, which is responsible for designing the hardware unit, and three software teams, which are responsible for user interface, data analytics, and embedded systems, respectively. The user interface team is working to develop a website (that may later be extended to a mobile application) to allow users to interact with the farming module by viewing data and sending commands. The data analytics team is designing a machine learning program that will use sensor data to ultimately determine settings and inputs for better plant growth. Our team, the embedded systems team, is developing the software that will read sensor data and control actuators, by sending information to the server and receiving commands from the server, respectively. All of the software teams will work together to establish proper interfacing methods for the separate software components.

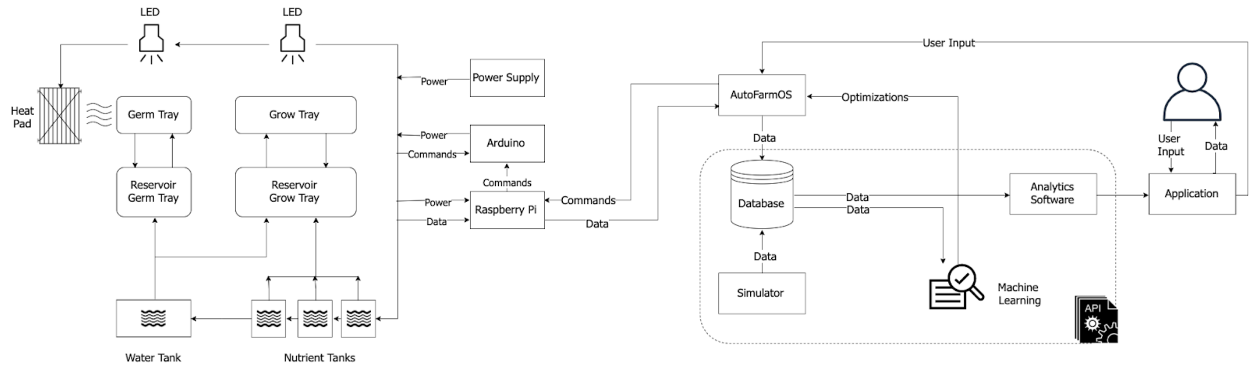


Figure 2: Product Overview Scheme

Hardware Design

The hardware involved in our project will consist of two systems. Both parts will be using a Raspberry Pi 4 as the backbone of the embedded system. Part one will include the sensors connected to arduinos which then report to the Raspberry Pi 4. Part two will control the pumps, pressure valves, and any other mechanical systems that need a controller. We chose to separate the functionality of these two systems for two reasons. The first reason being the amount of ports available to us. Having two Pi's will allow us to organize the internal wiring ergonomically. Secondly, we wanted to have a failsafe in case one of the two systems goes down. Being as our project is based off of the growth of plants, it may be awhile before anyone would notice that something has gone awry. If one system were to go down for any reason we would be able to use the second Pi as a failsafe to let the server know this unit is malfunctioning.

The first system will be configured as a star topology connecting all of the sensors we need to a Raspberry Pi 4. The sensors will first communicate through an arduino and the arduinos will be wired over USB or I2C (depending on the sensor) to the Raspberry Pi. The Pi will be the main computer for our project. It will handle many of the information passing tasks: collection, organization, and uploading to the server. The model of Raspberry Pi we have chosen included 4GB of memory allowing us ample computing power to do the collection of data while using it to communicate to the server or user.

The types of sensors we will be using will measure PPM (Parts Per Million), pH, temperature, humidity, and light wavelength. To measure the temperature and humidity we will be using a hygrometer that is water resistant to withstand the residual condensation from the misters that water the plants. It will be connected to an arduino in a waterproof case using wiring safe for use in wet environments. To measure PPM and pH we will have two separate probes that will be used in the water tanks to evaluate whether or not adjustments need to be made to the water. Lastly to measure the wavelength of light that our LED's are emitting we use a PAR (Photosynthetically Active Radiation) which will use an arduino uno to report back to the sensor Pi.

The second system we will be implementing is a control system for the tanks, misters, thermal pad, and LEDs. The LEDs we will be using are called Cob LEDs which will allow us to configure them in use for growing. A thermal pad will control the heating of the germination tray (a special part of the hydroponics unit that will be tailored for seed germination). Lastly, we will control the rate at which the water system disperses water.

Our task will be to implement an embedded system to react to the readings in our sensors and the parameters given to us by the server. We will implement this functionality using arduinos nanos/relays to adjust the heat of the thermal pad, the wavelength given off by the LED bulbs, the frequency of the misters and to alert to a low tank water level. The requirements of the control system will change as we see progress from the other teams. Our goal is to make a robust design that will allow for changes later on.

In conclusion, our sensor system will gather data relating to the wellbeing of the plants and their environment. We will then adjust our control systems to match the predefined configuration given to us from the server and the current readings from our sensor network. We will then send our data to the AutoFarmOS server.

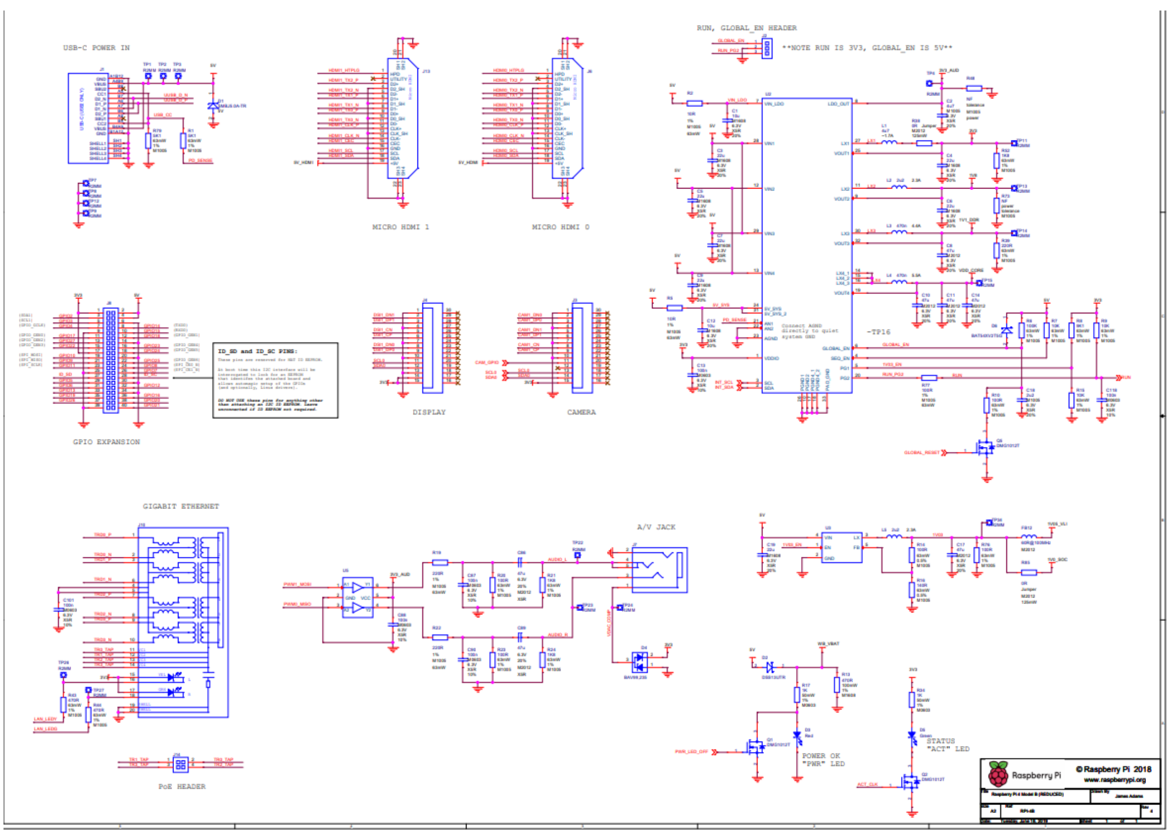


Figure 3: Raspberry Pi Diagram

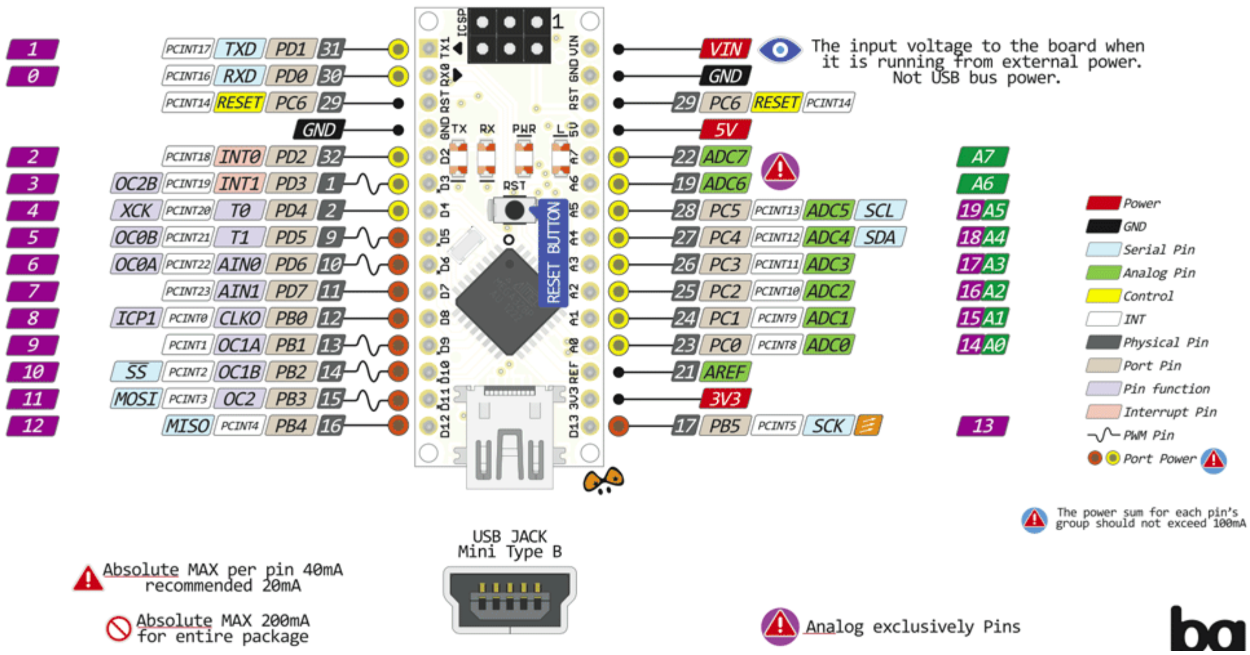


Figure 3.5: Arduino Nano Diagram

Embedded Software

The software for this project will be fairly simple, consisting primarily of a base operating system for the module, drivers that will connect hardware and software, and API wrappers used to communicate with external software components. The base operating system will be Raspbian, an open-source OS selected by our team based on hardware compatibility. The drivers, which will either be provided by the sensor manufacturers or written by our team, will have two main functions: to get data from the sensors, such as information about growth conditions, and to send commands to the actuators, which will control the LEDs and the watering of plants. The API wrappers will allow the other software components, potentially written in other languages, to interact with the sensors and actuators of the module.

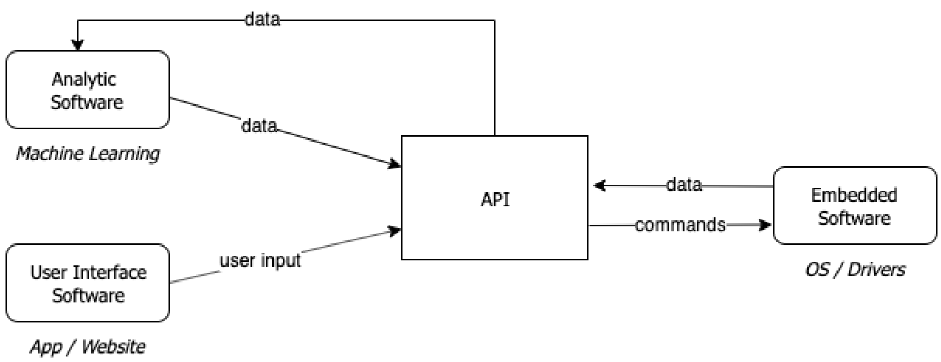


Figure 4: Basic Software Interface Map

Testing software will also be a significant part of our development. Due to the fact that the development of the user interface software, analytic software, and embedded software are all being done separately, we will have to develop tests that simulate the receiving of data on the server and the sending of commands from the server. This is necessary to ensure that the embedded software is as functional as possible when it is brought together with the other software components of the overall product.

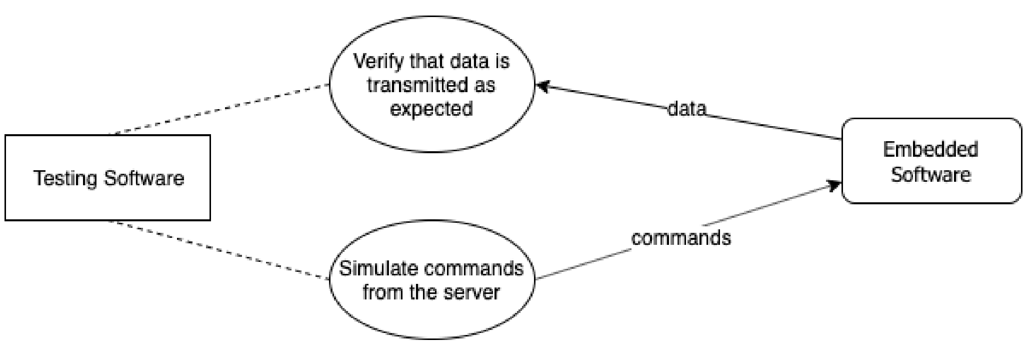


Figure 5: Basic Testing Software Map

Software Constraints

One of the main software constraints for this project is deciding how the hardware system will communicate with the server. We have decided to make this connection over the Internet, as an alternative to bluetooth or other connection protocols. The main concern with regards to connection is the potential loss of Internet connection, which we have opted to handle with either a local text file cache of sensor data or a lightweight SQL database stored on the Raspberry Pi.

Another constraint is how we will handle physical problems with the farming module. For example, we need to implement a way of notifying users of low levels of water or nutrients and we need to outline a protocol in case a user allows the module to run completely out of water or nutrients. These constraints will be handled on the tail of our project by working directly with the Terrafarm team.

There are also software constraints that are specific to our team and the development process. First, our team possesses a limited knowledge of embedded software, which we have started and will continue to overcome with significant amounts of research along with assistance from a faculty mentor. Second, the Terrafarm farming module has a commercial future. Planning, research, and communication with the product owner is critical since the software developed could potentially be sold commercially in the future. In addition, thorough documentation is critical if the Terrafarm team plans to take over the maintenance and support of the software after the term of this project is completed.

Integration

The connection between the sensors and actuators and the module's operating system is the drivers. With regards to sensors, the drivers are responsible for reading in the data, analyzing it, formatting it, and sending it to the server. For the actuators, the drivers are responsible for receiving signals from the server, interpreting those signals, and sending them to the actuators. As mentioned above, the drivers will either be provided by the manufacturer of the sensors or be developed by our team and this will likely vary from sensor to sensor. The most important factor here is the compatibility of the drivers with the operating system. The provided drivers or the driver development process for each hardware component (i.e. sensor or actuator) were considered heavily during part selection as an optimization of hardware and software codesign. Optimal part selection has encouraged the fastest possible development cycle and, because we are working with a start-up company, speed is critical.

3. Project Logistics

Milestones

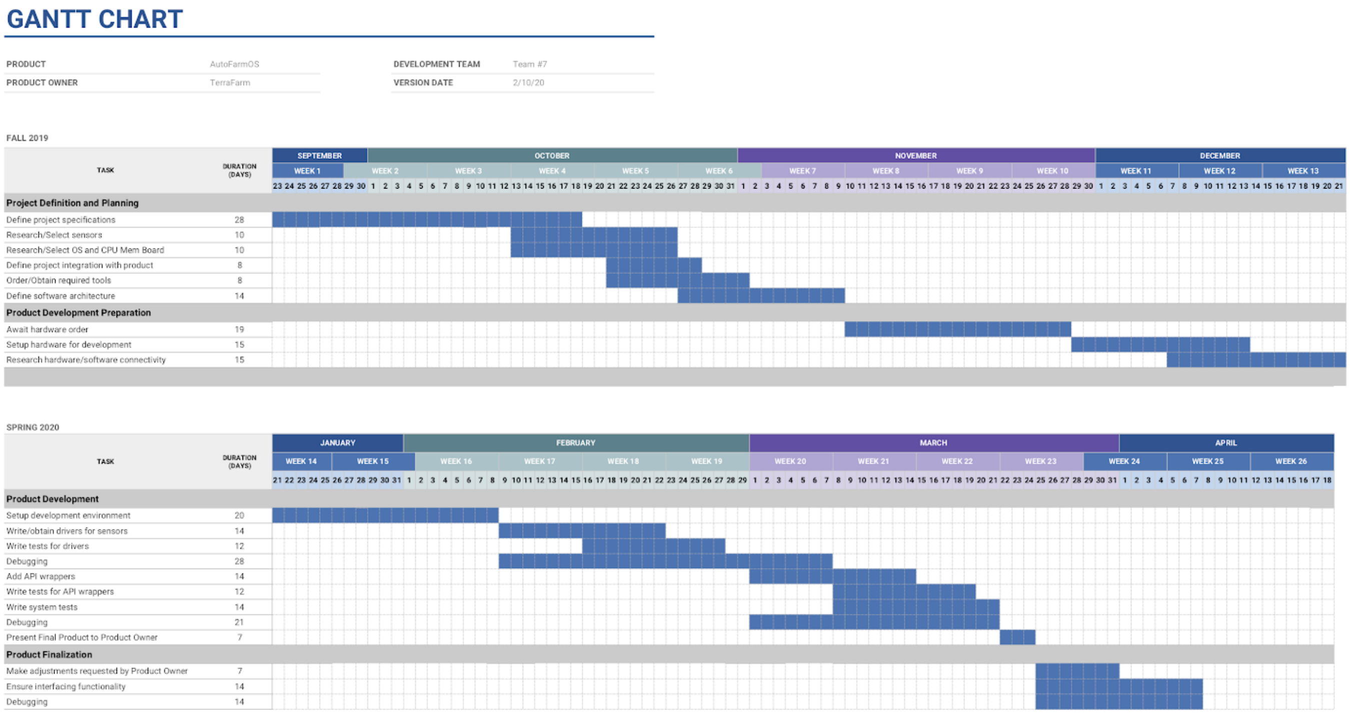
Milestone	Tasks	Date
1 - Project Definition & Planning		
1.1	Project specifications defined	10/18/2019
1.2	Hardware specifications defined	10/22/2019
1.3	Integration with overall product defined	10/28/2019
1.4	Required tools ordered	11/01/2019
1.5	Required tools obtained	11/28/2019
2 - Development		
2.1	Hardware setups completed for development purposes (one for each team member)	12/13/2019
2.2	Basic HW/SW connectivity established	11/21/2019
2.3	Drivers for sensors completed	02/22/2020
2.4	OS prototype completed	03/07/2020
2.5	API wrappers completed	03/14/2020
3 - Testing / Diagnostics		
3.1	Tests for drivers completed	03/07/2020
3.2	Tests for wrappers completed	03/21/2020
3.3	System tests completed	03/24/2020
4 - Finalization		
4.1	Alpha Prototype completed; Presented to Product Owner	03/24/2020
4.2	Interfacing with external software components confirmed	04/07/2020
4.3	Modified Alpha Prototype completed	04/11/2020

Work Plan

- Matt Cherry
  - Chief Responsibility: OS Selection
  - Additional Responsibilities: Sensor Selection, Driver Development
  - Sensor Assignment: LED/PAR
- Ethan Lefert
  - Chief Responsibility: Sensor Selection
  - Additional Responsibilities: Driver Development
  - Sensor Assignment: Hygrometer
- Zach Freund
  - Chief Responsibility: Driver Development
  - Additional Responsibilities: Testing
  - Sensor Assignment: PPM
- Kyle Curry
  - Chief Responsibility: Testing / Diagnostics
  - Additional Responsibilities: Driver Development
  - Sensor Assignment: pH
- Kristi Daigh
  - Chief Responsibility: Product Management
  - Additional Responsibilities: Driver Development, Testing
  - Sensor Assignment: Tank Gauge

Schedule

Gantt chart is shown below and also linked for better readability.



Budget

Resource	Vendor	Date Needed	Estimated Cost
Raspberry Pi 4 Model B Kit (x5)	CanaKit(Amazon)	11/1/2019	$500.00
SHT20 I2C Temperature & Humidity Sensor (Waterproof Probe)	DFRobot	11/1/2019	$22.50
Apogee FullSQ-500-SS: Full-Spectrum Quantum Sensor	Apogee	11/1/2019	$378.00
Conductivity Probe K 1.0	Atlas Scientific	11/1/2019	$139.00
Gravity: Analog pH Sensor / Meter Pro Kit For Arduino	DFRobot	11/1/2019	$56.90
Gravity: Non-contact Digital Water / Liquid Level Sensor For Arduino	DFRobot	11/1/2019	$10.00
Gravity: Water Flow Sensor (1/2") For Arduino	DFRobot	11/1/2019	$10.00
DFRduino UNO R3 - Arduino Compatible	DFRobot	11/1/2019	$15.00
Arduino Uno (x4)	Arduino	11/1/2019	$60.00
AmazonBasics USB 2.0 Printer Cable (x4)	Amazon	11/1/2019	$20.00

Ethical and Intellectual Property Issues

Ethical Issues:

One ethical issue we may face in regards to our project is the security of controlling the farming module. Since the user will be able to control the module through an app or website, we have to authenticate that only permitted users have control. If someone else were to gain control of the machine, they could destroy the crop currently being grown resulting in a loss of time and money for the owner.

An ethical issue that our project is addressing is over farming. There are also issues of topsoil erosion and overuse of pesticides and fertilizers leading to soil pollution. The concern is that eventually we won't be able to keep up with demand due to damaging the growing conditions. The hope is that the TerraFarm farming module can help reduce the environmental effects of current farming methods.

Intellectual Property Issues:

One issue we have is related to how to handle our portion of the project once we have finished our work. As we are developing the operating system for a start-up, the company will most likely want to take ownership of the intellectual property, assuming it functions properly and meets their expectations. If this proves to be the case, our team will have the option of selling the software to TerraFarm which would involve a purchase of the intellectual property.

Another issue we may face is the use of certain drivers for controlling the sensors and actuators. We have to be sure that we are allowed to use the drivers that we choose. We don't want to use any drivers that aren't open source. When we pick out what we want to use, we also need to be sure that we use the drivers in a means that are permitted by the original creator. As we are purchasing various parts for the farming module, these will include drivers that will help us avoid these problems.

Change Log

From the final project proposal, we haven't had to change many aspects of our project. One change we have is that the first prototype for the farming unit is not going to have a heating mechanism since lettuce is the first food we will be growing and doesn't require a specific temperature. However, we will still have to include code to handle reading data from the heat sensor and passing it onto the database so that it's available for future use.