Plant Automated Sustainable System (PASS)

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***Abstract* — Reducing the human supervision needed for plant cultivation may be implemented by a control system that measures the state of the plant per closed loop feedback. The system evaluates the state of each variable important to the viability of the plant and sends the acquired data to the microcontroller to determine if a response is needed. If so, the user is notified via a wireless device and a certain system is activated to return the variable to the necessary state. Primarily intended for domestic use, this device demonstrates the feasibility regarding the automation of plant cultivation.**

Index Terms — Autonomous, control system, irrigation, grow light, Nernst Equation, pH, PhoneGap, solar tracker.

I. Introduction

Plant cultivation often demands a great deal of attention and labor on the behalf of the grower. Optimal conditions for ensuring the viability of plants are maintained by the grower. Reducing such oversight may be accomplished by a control system that governs the state of the plant. The Plant Automated Sustainable System (PASS) is a design that acts to achieve this goal. Such a system would receive feedback from the plants environment and would serve to compensate for any external disturbance that would undermine the growth of the plant. Acquisition of data used for feedback involves a distribution of sensors and the data collected from the sensors are sent to a microcontroller unit (MCU) to determine if any system within the device must be activated to offset the change in growing conditions. Realizing such a system entails identifying which growth conditions are vital to a plants survival and implementing a subsystem to maintain such conditions. These thresholds are different between each type of plant and the MCU must maintain these values in order to preserve the plant's overall health. The user can interact with the PASS through an application targeted for a mobile platform, such as a tablet or smart phone. This software component contains a friendly interface to display the status of the plant and the system. In order to power the PASS, a subsystem composing of a series of solar cells maintain the charge of a battery. A solar tracker was also implemented to increase the energy collection efficiency by ensuring the solar panels are facing direct sun exposure. This report will address the approaches and implementation of the design of the PASS. The next series of sections will describe the system constraints before moving onto specific details of the design.

II. Goals and Objectives

The objectives involved in this project are related to automating plant care in a sustainable fashion. Many factors were that contributed to this objective were considered. The system must be economical; fabrication should use quality components with minimal cost. It should be modular in that, components such as the pump and sensors can be replaced with ease. This is especially important in terms of servicing and repairing the device. The primary objectives for this device are sustainability and autonomy.

This system automated component of this device requires sensors to detect conditions from the environment and send that data to the MCU. The MCU then uses this information to determine if devices, such as the pump or grow light, should be activated. For this reason, both sensor and MCU precision is critical for this project. A user with either an Android or iOS device should obtain the status of the plant reliably. The status is in the form of data generated that defines the conditions of the plant's current environment.

Sustainability is another primary goal for this project and attaining this involves selecting components that consume the least amount of energy as possible. The devices that consume the most power are the pump and grow light, so their operating values were selected with this requirement in mind. The device must acquire and deliver power reliably, safely and efficiently. The solar panels and tracking device must operate within the parameters outlined in the specifications. The rechargeable battery should be stable in addition to storing an acceptable amount of energy. The power system must correctly alternate between utilizing solar power and the battery as a source.

III. Requirements and Specifications

This system's requirements collectively with the goals and objectives define the approaches to the design. In Table I, each specification is listed with a description, comments, and a priority level. The priority is broken up into three possibilities including essential or desirable. These levels helped distinguish the importance of each requirement to ease the decision process during the implementation of the design.

TABLE I
DESIGN REQUIREMENTS

Description	Comments	Priority
Total system weight shall be less than 20 lbs	Maintain portability	Essential
There shall be a rated 12V, 10W solar panel		Essential
Enclosure dimensions: 10"L x 12"W x 10"H	Units in inches	Essential
Enclosure weight shall be less than 12 lbs	Units in pounds	Essential
There shall be a 12V battery with max dimensions: 4.5"L x 3"W x 4"H	Units in inches	Essential
Power cables 16 AWG oil resistant and rated for outdoor use.	12 AWG cable may be needed for extended length	Essential
The water pump shall have a max flow rate of 100 GPH	Minimal pump rate thru 1/8" tubing GPH = gallons per hour	Desirable
The water tank shall supply less than 2 gallons	A small reservoir with options to refill and empty	Desirable
The sensor measurements will be within 10% accuracy		Desirable

The methods and explanations in attaining these constraints are outlined in the proceeding text.

IV. SYSTEM OVERVIEW

The PASS has a composite enclosure assembly, which includes electrical systems that communicate to each other via the microcontroller. These systems are the plant, irrigation, communication, and power distribution system. The plant system includes the sensors that monitor the plant's environment and the grow light. The different sensors are the moisture, pH, temperature, and light sensor. The moisture sensor controls when the plant is watered as well as when the pH can be measured. The light sensor controls when the grow light is activated. While the pH and temperature sensors notify the microcontroller when the plant is in dangerous conditions. The irrigation system contains the water pump and the two water level sensors. The water level sensors will be placed at the bottom and the top of the water tank. The bottom water level sensor prevents the pump from operating when the tank is low; this is to prevent the pump from malfunctioning. The water level sensor at the top will notify the user if the tank is full. The communication system includes the Bluetooth module and the user interface application. The user interface application is located on a mobile device and communicates with the microcontroller via the Bluetooth module. The application can collect data from the sensors, turn on the water pump and light, and provide feedback if the conditions are acceptable. The power system includes the battery, which is charged by a solar tracking system with a commercial power backup. The solar tracking system includes a charge controller, a solar panel, and the tracking device to maximize efficiency. To accomplish adaptability, there is a switch to convert to commercial power.

V. HARDWARE DESIGN

The PASS is composed of many different systems in order to achieve the aforementioned goals and requirements. There are two major components, the main device and the solar tracker. The main enclosure base consists of the MCU circuit board, potted plant, and all the components used to maintain the plant condition. The enclosure will be portable, durable and easy to maintain. The device is analogous to a control system; it regulates the current ambient condition of the plant's environment and takes action to maintain the current state when environmental factors change. This section describes the design and function of the subsystems.

A. Microcontroller

Today's options for microcontroller units (MCU) are large and vast, so careful research and investigation was completed to select one. The PASS can be categorized as a small sensor network feedback system and a control unit such as a microcontroller is key for this type of system. The requirements for the MCU include the need for a set of low power modes, series of analog and digital I/O, multiple clock system with real-time clock (RTC) capability, set of serial communication interfaces, and an interrupt compatible software library. A decision was made after a few comparisons between the top embedded systems manufacturers such as Microchip, Atmel, and Texas Instruments (TI) to name a few.

The choice was the MSP430 microcontroller family due to the flexibility, numerous model options, and implied support from the company and community. The MSP430F5342 was the eventual choice to use in the PASS. It contains 128KB of Flash and 10KB of SRAM. It also has low power consumption, multiple timer interfaces, four serial communication ports, seven external ports to the 12-bit analog-to-digital converter (ADC), and 38 I/O pins. These features fit the requirements of the PASS as well as provide flexibility with the development and integration of the design.

The MCU software was designed as an interrupt driven algorithm in order to maintain a responsive system to support the health of the plant. This is achieved by taking actions to the system's environment by analyzing the measurements attained from the sensors. Further details of the software design can be found in the Software Design section.

One of the main hardware components to allow turning on/off the peripheral devices from the microcontroller is the 4N25 opto-coupler from Fairchild Semiconductor Inc. These devices consist of a light-emitting diode (LED) and a phototransistor on a 6 pin dual-inline package (DIP). A microcontroller digital I/O pin is connected to the anode of the LED, which emits light with a digital one [1]. This causes the phototransistor's base current to cause a collector current to flow and thus the other circuit will be switched on [1]. This allows for the safe control of each peripheral device since there is no electrical connection between the higher voltage devices (5V, 9V, 12V) and the lower voltage MCU (3.3V).

Overall, the microcontroller not only acts as a data logger, but also the main orchestrator for the PASS.

B. Wireless Communication

A communication design is necessary for the system to notify the user of the overall state of their plant and the various PASS sensors. In order to minimize complexity for the user and to cater to the majority, the decision was made to utilize Bluetooth technology for the communication design. In an optimal environment, the user will link their mobile device, a cell phone or tablet, to the PASS system and receive updates as per user request after the initial connection. An application forms the link between the user's mobile device and the Bluetooth module of the PASS. Further details of the software implementation of the user interface (UI) are provided in the Software Detail section of this report.

The selection of the Bluetooth module of this device considered the fact that modern popular mobile platforms are split between two Bluetooth technologies, Bluetooth Classic and Bluetooth Low Energy (BLE). The PASS is designed to cater towards both technologies by using a dual-mode chip, the PAN1326 from Panasonic.

The PAN1326 is controlled directly by the MSP430 via the universal asynchronous receive/transmit (UART) communication interface. The microcontroller is the master and the PAN1326 is the slave. The MSP430 is programmed to respond to requests from the PAN1326 in order to maintain a responsive user interface. The Bluetooth stack is provided by TI and resides on the MSP430 and a serial port profile is used as the communication protocol. In summary, a Bluetooth link is implemented to maintain a one-to-one connection between the PASS and the user's mobile device with the PASS UI application.

C. pH Measurement

Nutrient uptake and pathogen regulation of plants are each governed by the pH value of the soil. Most plants have a relativity broad pH range of 5.5 to 8.The feasibility of accurately acquiring a pH reading was contingent on many factors, which included expense, sensitivity and tolerance. To understand how these define the performance of the actual pH device, a cursory description of pH is necessary. pH is "hydrogen potential", defined by the presence of ions in a solution. These ions contact the probe; the quantity of ions is proportional to a voltage the pH meter will yield, i.e., pH is commensurate with voltage. However, it should be noted that the acquired signal is analog and the displayed reading is digital. Consequently, the ADC of the microprocessor is implicated in the generation of a pH reading. Complicating this matter was that most pH meters available on the market were bundled with ancillary components such as an LCD, ADC and other circuitry.

Some companies sold only the probes, but these were very sensitive and therefore, cost prohibitive. Forgoing this option, the group resorted to alternative methods and purchased the standard meter, which included the ancillary components, with the intention of dismantling the device, disconnecting and using only the probe. The native LCD, ADC, etc. were discarded. The upshot to this method was the biasing circuitry and the connection to the MCU was based solely on the design choices of the group.

A notable challenge encountered with this design option was correlating pH and voltage. This was largely an iterative process, however comparing two pH values and using the Nernst Equation gave a pH to voltage correlation. The Nernst equation is an electrochemical equation that governs the correspondence between voltage and pH. It provides a generic correlation between voltage and pH. The device that the company offers may deviate slightly from this formulation but not significantly.

D. Grow Light

Due diligence involved in selecting the needed grow light was important for the plants viability. What is not apparent is that plants need a specific type of light. Such light is defined by the plants absorption spectrum, which contains the spectral components amenable to the growth of the plant. The absorption spectrum is a function of the plants photoactive pigments. Different spectral components influence the plant differently during specific growth stages, effecting horizontal and vertical growth of the plant. Much of this spectrum lies outside human perception, which is why the lumen, the unit that governs light quantity, does not relate to plants. The lumen is defined from the luminosity function, which is based on human perception. The design of the lighting system is predicated various factors such as power considerations, heat generation and efficiency. Ideally, the system must be waterproof and inexpensive. Many growing applications use High Intensity Discharge or Sodium Vapor lamps as these modalities generate copious light with a conducive grow spectrum. Also, the distribution of light is broad and fairly uniform. However, this light is accompanied by excessive heat dissipation, which also bolsters the inefficiency of the bulb. Such heat is to be avoided, as it may damage the plant.

LEDs, with their unique merits, are becoming more prevalent in plant cultivation. In the past LEDs were limited, providing narrow coverage and a limited spectrum. Currently these issues are ameliorated by advances made in LED fabrication and consequently are no longer an issue. In addition to generating a negligible amount of heat, LEDs represent a cost effective solution. These bulbs consume very little power and are normally rated for 12 Volts. The bulb the group selected provides generous amount of light at 6 watts, 12 volts. Since the power system functions with DC the use of a rectifier is unneeded since LEDs are DC devices.

Constant light inhibits plant growth and is in fact inimical to the plants survival. For this reason, plants are photoperiodic; most require light during the day. One feature this system offers is to supply light during periods it should receive light. A phototransistor is implemented into the system, when the sensor detects light below a certain threshold determined by a value in the ADC, the grow light activates. As these conditions would also cause the grow light to activate at night as well, this is undesirable, since the plant is periodic. Conditions must be programmed into the controller to ensure that the grow light does not activate at night. So program will follow a function of the periodicity of the plant. The real time clock on board the MSP430 keeps the time and is read by the program to ensure that the grow light does not activate at night.

It is also important that the light detecting phototransistor is placed above the grow light, so the artificial light does not interfere with it. The grow light is placed in an Edison 26 (E26) base. The base has a neutral, hot and ground wire, which will be soldered onto the terminal block of the power distribution board. The three will run from the base through a shaft that extends a foot above the enclosure.

E. Moisture Measurement

Water control and is key to maintaining a healthy plant so a moisture sensor produced by Vegitronix was included in this design. Its function is to measure the moisture in the soil to notify the microcontroller of when the PH can be measured as well as when the plant needs watering. The sensor measures the dielectric constant of the soil between transmission lines; this keeps it from corroding over time. Corrosion can cause a lack of sensitivity to salt levels in the water as well as errors in the conductivity measurements. The sensor requires a supply voltage between 3.3V to 20 VDC. The output has 2% accuracy, with an output range of 0-3VDC depending on the soil's moisture content. The operational temperature is between -40 to 85ºC and -40 to 185ºF.

F. Temperature Measurement

The temperature sensor is also produced by Vegitronix, and will measure the outside temperature around the plant to notify the user if the temperature is reaching dangerous levels for the particular plant. The sensor requires a 3.3 to 20VDC input and less than 3mA on the power pin to take a measurement. The output requires 2 seconds before it has a stable measurement, with an impedance of 10Kohms. The output will be from 0-3V depending on the temperature between 40ºC to 85ºC with 0.5ºC accuracy. The output voltage is in a linear relationship to the outside temperature, as shown in (1).

$$\text{Temperature in } {}^\circ\text{C} = V_{OUT} \times 41.67 - 40. \tag{1}$$

G. Irrigation System

The irrigation system includes two water level sensors and a water pump. This system controls the water going into the plant enclosure. Level switch sensors from GEMS Sensors and Controls are used for water level sensors in the PASS. The level sensor is a single-pole, single throw switch that has 2 pins and it is either open or closed. One sensor will be placed at the top of the water tank in order to tell when the tank is about overflow, the other sensor will be at the bottom of the tank and thus be able to identify when the tank is empty. This is necessary, as the pump is not allowed to run dry. The pump is submersible and has low power consumption, at 0.2A at 7.5VDC.

H. Enclosure Assembly

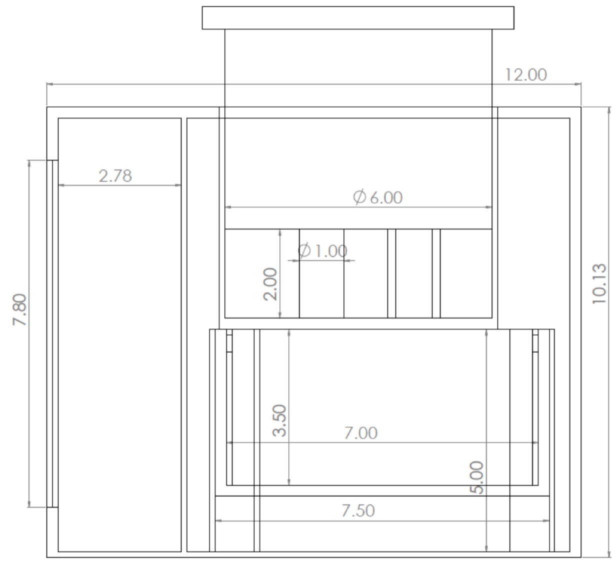
As previously mentioned an enclosure design is necessary to encompass all the electrical devices with the potted plant. The weight, size, center of gravity, and durability were key parameters to the overall configuration. The enclosure was deemed to be light and balanced while also being durable in order to provide the user with the option for indoor and outdoor use of the PASS system.

The material selection was the primary consideration that addressed most of these requirements. Taking into account the desire for a selection that was economical and ease in fabrication, the options narrowed to a few compositions such as aluminum, acrylic, polycarbonate, and some other plastics. At the end, acrylic was selected as the material of choice for the enclosure.

Acrylic is a type of plastic material that is widely used in a variety of products. It fits the goals and requirements of the project with regards to the weight, size, and durability constraints. Acrylic is also resistant to water, dirt, and other conditions, which are potential to the environment of the PASS. This plastic is also widely available and common tools such as scoring knifes, jigsaws, miter saws, and drills can be used to modify it. Plastic welding cement along with plastic caulk was used to bind sheets together and provide a watertight seal.

The enclosure was first designed using SolidWorks, a computer-aided design (CAD) software, in order to determine the material needs and fabrication approaches. A snapshot of the simulated design can be seen in Diagram I. The enclosure is built around supporting a pot of 6-inch diameter. A top-open water tank is directly below the cylinder, which supports the potted plant. An internal wall is used to separate the water, dirt, and other potential hazards from an electronics compartment. This partition (shown on the left) has shelves, which contain all

DIAGRAM I
ENCLOSURE MODEL (SIDE VIEW)



the primary electronics of the PASS such as the MCU, battery, and 12V rectifier to name a few. An external door is provided to allow for easy access to the electronic components. All of this is made from the 1/8-inch thickness acrylic sheets. The material was ordered to be clear in order to allow ease to showcase all of the internal parts of the system. Overall, the enclosure was carefully designed and fabricated around the requirements and goals of the PASS.

VI. SOFTWARE DESIGN

The PASS software components are organized into two main parts, the microcontroller software and the mobile application for the user interface. This simplifies the development and the management of the programming efforts. The following section will cover both of these software modules in detail.

A. MCU Software

The microcontroller software is an important piece to give the PASS the ability to take care of the user's plant. This component has two main operational modes, the autonomous and controller mode. The autonomous mode is a free running behavior that will take care of the plant while the user is preoccupied with other things. The controller mode allows the user to send commands to the PASS via the user interface in order to manually control the device's features and to check its status. Overall, the microcontroller software follows a cooperative multitasking design pattern. This consists of a simple control loop with a series of interrupts that determine the next sub-process to execute. The main advantage to this design is the modular style, which eases the process of adding new tasks to the control loop. Testing and close analysis is required for a cooperative multitasking to ensure proper timing and minimize process starvation. The software is also optimized to maximize power efficiency by activating the low-power modes while the peripheral devices are not active.

One of the main software activities will be polling the sensors in order to record the collected data and to react to the environment. Sequence diagrams were created in order to clearly define the sub-processes. An example of one of these is the following scenario: the moisture sensor is polled first and then one of the corresponding actions is taken. If the soil is damp, then it is valid to test the pH of the soil if it has not been checked for an extended amount of time. If it is dehydrated, then the irrigation system is activated in order to water the plant. If the soil is drenched, then the user will be notified to prevent overwatering of the plant. Each of the sub-processes to poll the sensors occurs on a periodic occasion during all times of the day.

B. User Interface Application

The user interface (UI) application is a software piece that is meant to act as the link between the user and the PASS. It was developed for use with a mobile commercial-off-the-shelf (COTS) device such as a smart phone or tablet. This device must support Bluetooth communication and the PASS can link to both Bluetooth classic and Bluetooth Low Energy (BLE). In order to cater to multiple platforms, the application was developed by using PhoneGap, a software development kit (SDK). This provides the ability to program for multiple platforms by using only one code base. Normally an application would be developed for each device, such as one code base for Android-based and another one for iOS devices [2]. A PhoneGap application is a web application. It is developed in Javascript, HyperText Markup Language (HTML), and Cascading Style Sheets (CSS). This code is built and complied along with the corresponding build target native SDK to produce a hybrid application: half web-based and the other half a native application [2].

The UI is a page-based application that consists of a menu design to provide the user with a friendly and simple interface. During initial use, the user will have options to setup the wireless connectivity with the PASS and enter information about their plant and it's environment. The main menu of the application will have choices to traverse to a few different pages, such as the initial setup, controller menu, settings screen, and other options. The controller provides the direct interaction with the PASS by giving the user choices to activate the subsystems and view the measured readouts. The settings menu allows for the user to make changes to the UI application, such as wireless connectivity setup, time format, and others. The mobile application of the PASS provides the main interaction to the underlying control system.

VII. Power Design

The aim of this device is to utilize natural resources effectively and efficiently. The primary concerns associated with the power system are energy acquisition, energy storage and energy regulation. Both domestic power and Photovoltaic Cells are incorporated into the design. Since plants need sunlight to thrive, the device will consequently be exposed to a great deal of sunlight. This provides an opportunity to utilize the sunlight to energize the device in a sustainable manner during the day. In terms of storing energy, the sunlight may also charge a battery that will also power the device. Therefore, the power supply system is primarily comprised of a solar array and battery. Back-up commercial power supply single phase 120 VAC source has been integrated in the system in the unusual event that the battery requires an extensive and overcast or dusk conditions are present. Regulating the release of energy both from the PV Cell and the battery requires specialized circuitry. During the day under sunny conditions, the photovoltaic cell (PV cell) is to supply power to components within the device such as the controller, water pump and grow light. Also during this time, the PV cell is to charge the battery. Many conditions must be implemented via a power control network to avoid any hazardous possibilities that may arise.

A. Solar Cell, PV Controller and Tracking device

Designing a Photovoltaic array system should approach the robust level of a residential system but obviously at a smaller scale. The 30 watt Polycrystalline PV array will meet this requirement in comparison to a 100 watt roof mounted assembly for home use. The array weighs eight pounds and its maximum power voltage is 17.3 volts with a maximum power current rating at 1.77 amps. Alternative power and conservation of energy is the primary concept of this design approach.

Solar radiation describes the energy that is sent to the earth from the sun. The concepts of solar radiation are critical since this is the energy being transferred on a typical Photovoltaic system. There are two general categories of solar radiation and these are direct radiation and diffused radiation. The amount of solar radiation is dependent on regional atmospheric conditions. On a clear sunny day, radiation levels are close to maximum, and on cloudy days this level is reduced or diffused. Direct radiation will make the greatest contribution to a solar array and result in the greatest effect of desired power transfer. This is the fundamental reason for the PV tracker design, which will position the PV array normal to the sun.

The photovoltaic controller will govern switching and the activation of either the battery or cell as the current supply source. Defining what conditions activate either supply source is essential to the design of the power source. When sunlight is available, the solar cell will act as a source charging the battery and potentially energizing a component of the device if needed. Likewise, under minimal light the battery must energize the device since the solar cell would be incapable of doing so. Distinguishing which conditions are needed to activate either power source is the function of the PV Controller.

The operation and design theory of the PV controller is to establish a battery voltage level threshold and to determine if the battery needs to be charged. Protection devices are in the design to prevent improper battery connection, which will render the battery unserviceable or cause damage to the controller or both. An Schottky diode is used in the circuit and thus will prevent stored energy / current from the battery flowing back to the solar array at night. The Solar array will act as a load if a power source is connected during dusk conditions, which is an undesirable condition.

A solar tracking device will be used as a movable platform for essentially 2D tracking, and can provide approximately 50% more power than a fixed array configuration. However a full view of the horizon is needed in order for this design to be effective. The fundamental components are the wooden platform base, ancillary MCU, bipolar stepper motor, and motor driver.

Brief specifications for the NEMA 17 bipolar stepper motor are the following:

Phases 2; Steps/Revolution 200; Step Accuracy ±5%

Shaft Load 20,000 Hours at 1000 RPM; IP Rating 40

A DC stepper motor will operate at 2,000 RPM or less in comparison to brushless motors, which will run at higher speeds. Since this device is tracking the sun, a high RPM requirement is not needed for this application. Another big advantage to using a stepper motor is that it can be driven above the rated current draw since this device is not normally operating at 100% duty cycle. A typical application using this device will run at about 25% duty cycle. The operation modes for the stepper motor are single, double, interleave, and micro-step. The micro-step will be used in this design to allow for fine tuning adjustments.

B. Battery

By obtaining its energy from the sunlight collected by the solar cell during the day, the battery is intended to supply energy when available light is under a certain threshold. Because the device consists of only four energized components, the most power intensive is the pump, the battery's function will be ancillary since these components may be powered by the solar cell during the day. In the absence of sunlight, the battery may assist in activating the pump, which requires a great deal of power. During occasions of minimal sunlight, with the exception of nighttime, the energy in the battery will also activate the grow light. Selecting a battery relied on certain criteria; storage capacity, discharge rate, size and lifetime. Preventing the battery from discharging back into the solar array is accomplished by the use of a Schottky Diode, 555 Timer and a MOSFET.

C. Voltage Regulation and Filter Network

Low profile form factor with a 12 volt input connection via the solar array will be the scope of the initial power supply design effort. Some important 115 VAC line requirements are listed below:

*Maximum input level is 135 VAC (rms).
*Minimum input level is 105 VAC (rms).

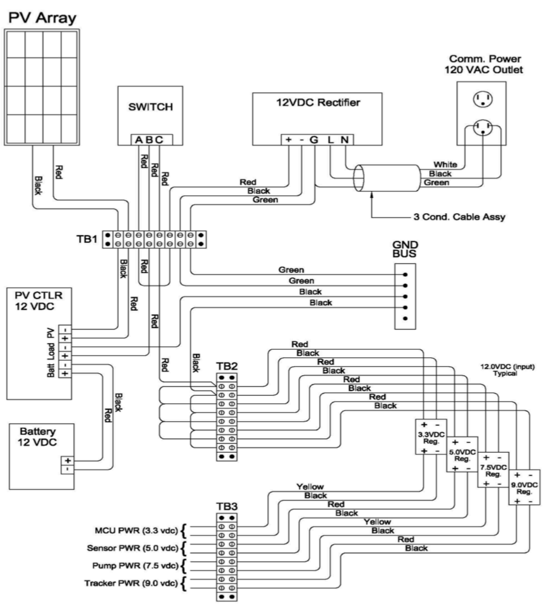
For in-rush current limiting, the maximum current when the power is initialized is up to three line cycles and will be limited to a level that is lower than the surge rating of the input power cord. The final design will use a 18 AWG 3 conductor cable assembly. A repetitive on/off cycling of the AC input voltage should not cause damage to the power supply or blow the fuse. If a problem does occur with this initial test, there is a manufacturing defect or a design flaw. Before administering this test, consider the load in use before executing this initial power cycling test. An optional dummy load/ load resistor should be used for this test.

The filter network was designed to mitigate or even prevent any undesired voltage spikes generated in the power system. The filter network contains bypass capacitors, which will reroute undesired signals to ground. Such undesired voltage is noise transmitted through long wires or power supply ripple voltage.

Energizing the microcontroller entails the implementation of an interface network between the controller and the power supply. Operating the microcontroller requires a voltage that is significantly smaller than the value supplied by the power system. This is very common among digital products as one is reminded of the AC adapters, which contain a transformer, rectifier and filter to achieve compatibility with the digital device. 12VDC power source from the battery to regulated 3.3VDC for the microcontroller.

The fundamental power sources identified in Diagram II are the PV array, 120 VAC outlet and the 12 VDC battery.

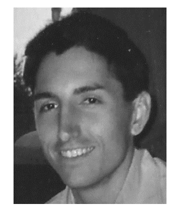
DIAGRAM II
PASS POWER SCHEMATIC



The three terminal blocks (TB1 thru TB3) listed are used form ease of component replacement and efficient troubleshooting in case of power faults. The switch selects either commercial power (position A) or battery power (position B) out to port C of the switch. This output is routed through TB1 and then to TB2 where the applied 12 VDC is distributed to the four individual regulators, which will provide the 3.3VDC thru 9.0VDC. The output from the battery is received via the PC controller module. The battery is being charged by the PV array via the PV controller through the power distribution network specifically through TB1. If continuous overcast conditions are present and the battery is below the proper voltage threshold, the selection of commercial power will keep the overall system in operation. As mentioned previously the system should be connected to an outlet in order to receive proper grounding. A grounding rod could be used and connected to port G of the rectifier but was deemed impractical for this scale of the design. Overall, the power design provides the PASS with an efficient, renewable energy source.

THE ENGINEERS

Devin Erickson is a 23-year old Computer Engineering student with interests in an array of engineering and science topics.



Jason Fitzgerald completed a seven-month Co-op assignment at Monsanto in St. Louis as an Automation Engineer. An Electrical Engineering Major, he has a strong interest in Control Systems and intends to work in industry upon graduation.

Kelley Ice is a 22-year old Electrical Engineering student who has accepted a job with Ford Motor Company in Dearborn MI, as a Ford College Graduate in their product development rotational program.

Vincent Kondracki is a 53-year old Electrical Engineering student with 33+ years of Electrical experience. Employment history, presently with Harris Corporation and initial electrical experience was provided by U.S. Army aviation with an electronic warfare systems specialty.

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