# eMpower solar powered mobile device charger with remote control

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***Abstract* — The eMpower solar powered mobile device charger is a system that provides a billable way for remote station to provide charging services for mobile devices. eMpower can tolerate a wide input power voltage range to allow direct connection to solar panels. User account information is uploaded to the unit via a cellular link. The "Master Unit" stores user's account information locally. User interface is provided by a keypad and LCD. The Master Unit communicates with multiple "Port Control Boards" to enable and disable individual charging ports, allowing for expansion based on individual site needs. Charging ports are provided in accordance to the USB charging standard.**

***Index Terms* — Microcontrollers, rail to rail amplifiers, land mobile radio cellular systems, universal serial bus, GSM, Master-Slave.**

## I. Introduction

The eMpower solar powered mobile device charger is dependent on the excess power from a solar array that provides the power to a water pump. These Solar water pumps are a product of a nonprofit called Water Missions International who asks us to create a unit to utilize this Power. They got the idea from the creation of an initial system that was used to charges phones from this excess power. The initial charging system consisted of a wired power strip that was placed in parallel with the pump and plugged in to cell phone chargers that were used to charge up the clients cell phones. This system can be seen in figure 1. Surprisingly, his set up worked and his business has been quite successful, charging dozens of phones per day. The charging business is so successful that it is actually bringing in more income than the water sales. The eMpower device introduces a safer setup as well as introduces more features that will allow Water Missions International to control the device remotely and set up accounts as needed for device charging.

Given the specifications from Water Missions International, the team proceeded to design a device that satisfied the specifications which include:

1) Charging attached devices with a supply voltage range of 12 – 30 VDC.

2) Provides 10 USB ports and 2 cigarette lighter socket ports.

3) Has provisions for a secondary battery input for backup power.

4) Use an integrated Quad band GPRS device to communicate with the eMpower device.

Using a buck and fly back converter, the primary power input is converted to the necessary voltages that will be needed throughout the device. The charge port module will route and switch the required 5 and 12 VDC to the individual ports to charge the mobile devices. The charge port module will also communicate the status of each port to the central processor. The central processor will communicate via SMS to Water Missions updates and logs, as well as determine which port the user will use. The central processor will also turn on and off each port as necessary and log the time each account uses. It will also send the command to turn off a port when the time on the account is exhausted.

The unit is specified to have a pre-determined number of ports per master unit. A slave unit will also be designed in order to allow for the expansion of charging capabilities.

Fig. 1. Previous system used for charging in mobile devices from a pump's power system, located in a remote village in Haiti.

The central processor will detect the presence of the slave unit or units and employ the use of the added ports in the decision making scheme for additional users to charge their phones.

## II. Motivation

According to the World Health Organization, an estimated 780 million people lack access to safe drinking water in 2010, and that number is rapidly growing. It appears that a lack of funding and motivation of getting filtration systems and pumps installed in areas of need is the reason why so many people remain deprived of this essential need. The real problem is that an estimated 30% of all hand pumps installed in sub-Saharan Africa over the past two decades have failed prematurely and water points in some areas such as the Chikwawa and Phalombe districts of Malawi are less than 50% functional.

We initially contacted Water Missions International to see if they had any available projects that we could work on. They proposed that we help create a solution to their problem by creating a mobile phone device charging system that can be remotely monitored and controlled over a GSM and GPRS network. This device will be applicable to not only Water Missions Internationals project but to various other projects throughout the world where there are devices that produce an excess of power for their needs. Our goal is to design a safe, scalable product that has expandable features that can be deployed with Water Missions International's and many other renewable energy project sites.

Water Missions International is a nonprofit organization who must fundraise every dollar that is spent, affordability of these units while meeting the requirements is very important. While looking at the possible solutions, being cost-effective and creative is highly encouraged during the solution creation process. We also needed to be sensitive to the resources of the country it will be utilized for and it must be easy for the average layman to use.

The result of this project being able to create revenue for Water Missions or any other organization is a real motivator on the sustainability of the project. This will allow people that do not have access to a power source to use the eMPower system at a nominal fee. In addition this fee will make sure that the project can endure for many years and for the expansion of other units just like it. This was important due to the increasing numbers of projects that are sitting dormant in other countries due to their lack of ability to be sustainable. This device will be able to be attached to any device that is set up to get sustainable power like a wind turbine, solar array, or any other project that produces power. That means that the eMpower will make use of any lost power from other systems that isn't put to use.

## III. System Components

The following in Fig. 2 is a picture of the overall design of the eMpower unit. The ten ports in the front of unit are the USB ports and the two on the top are the two 12 volt ports. It also includes a keypad and LCD to interface the device as well as indicator lights to let the client know the status of their port. The keypad is used to let the client interface their accounts as well the initialization of the charging of their phones. The LCD includes a visual display of the menu and options to the client. In addition a connector is included to connect additional units that can expand the amount of ports the eMpower unit provide power to. This will be used in situations where there are more clients then the device can service.

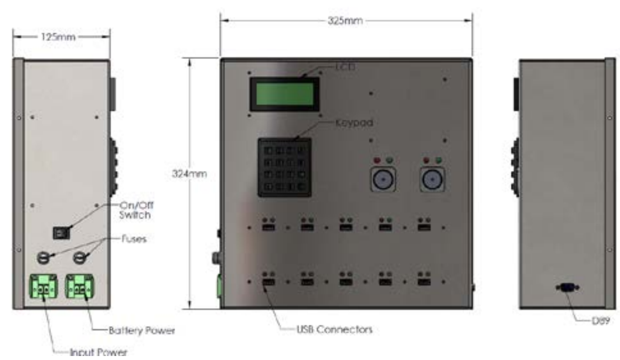


Fig. 2. CAD drawing of eMpower master unit.

The block diagram in figure 3 shows the different parts of the eMpower unit . They consist of the master control board which communicates with the port control board for the setup of ports. In addition it keeps track of clients accounts updates them and communicates with the keypad, LCD and the GPRS. The Port Control board also communicates with master control board to validate the turning of a port on or off. It also controls the indicator LED's on the ports and if any additional units are daisy chained to the main unit. The last unit is the power supply board that regulates the power that goes to each of the boards and determines if the additional power supply is needed due to a power loss.

## IV. Master Control Board

The master control board uses the ATMega 2560 microcontroller that is used on the Arduino Mega board. The Arduino Mega provides a good starting point for the design of the primary control unit However; unnecessary features such as the Arduino Mega 2560's on board ATMega 16U2 microcontroller which is programmed as a

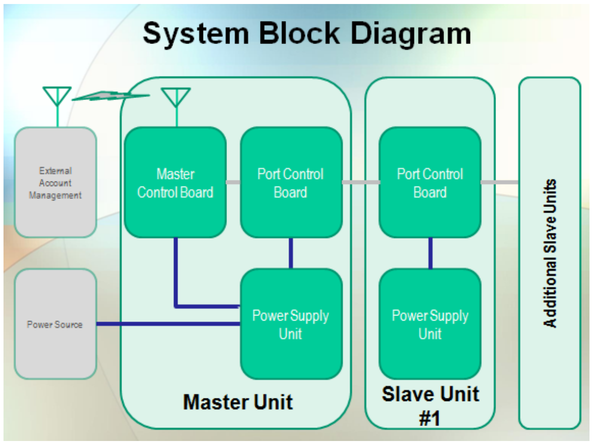


Fig. 3. Block diagram illistrating the subsystem layout of the eMpower system

USB-to-serial converter has been deleted. Originally the Arduino boot loader was going to be utilized in order to allow uploading sketches through the serial interface. However in order to save flash memory the ATMega 2560 are programmed with Arduino sketches via the ICPS pins which uses a SPI interface [1]. Programming it through the ICPS pins was done using the Atmel AVRISP mkII. The primary reason is that it will save 8 KB of flash memory that would normally be allocated for the Arduino boot loader on the microcontroller [2]. The Pin layout conforms to the needs of the peripherals such as the keypad, LCD and GPRS. With 4 UARTs, 54 digital I/O pins and 16 analog I/O pins there were not be a shortage of pins for the eMpowers needs [3]. The extra digital pins will provide for further expansion of the communication system in the future. For this reason the master board has additional headers broken out to allow for this expansion, as seen in Fig. 4 and Fig. 5.

The functions of the master board are to control the initialization of ports for the clients and validate that the port is turned on by use of I2C with the port control board. We utilized the use of status strings that let the port control know to turn a port on or off. If the string contains a one then the port is to be turned on and if it is a zero then that port is to be turned off. I2C proved to be invaluable due to its seamless communication ability with other microcontrollers. Early on we realized that it implements a listener that will interrupt the board it is communicating with which helped with the flow of information in the unit [4]. The port control then sends back a string to confirm the port has been plugged on, and the phone is being charged. This in turn initiates a counter to track the usage on the account until the client unplugs where at that time the port control lets the master unit know by use of the same string. At this time the account is updated on the SD card and the port is freed up for future use [5]. The SD card contains the client's account information which consists of their name, minutes left, and minutes used up to date. The file name consists of their four digit pin for validation reasons. The SD card can be updated by use of SMS and the GPRS [6][7].

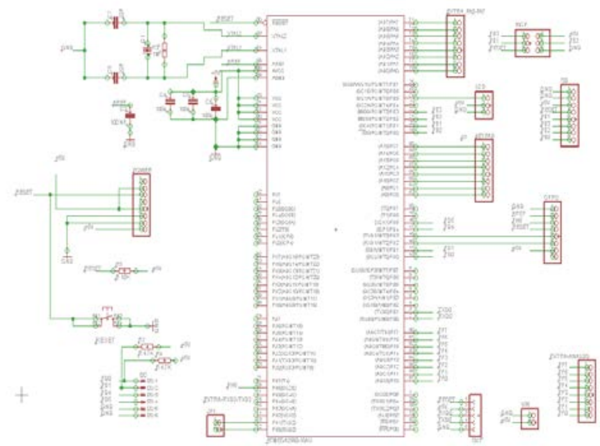

Fig. 4. Block diagram illistrating the subsystem layout of the eMpower system

The GPRS is used to establish communication with the device by use of SMS [8]. The text message contains a command of what is to be done like "update" followed by a delimiter of a comma then the account to change then the minutes to add. The GPRS is also utilized to send text messages to clients as accounts are set up and when status updates are needed for the owner of the device [9]. A unique feature of the GPRS is that it can buffer text messages and it will also only allow certain phone numbers to send it a text which adds to the security of the system. This way a client will not be able to access the unit by just sending the same update text that the owner will sent it from their home base wherever that may be [10].

The master control unit is constantly monitoring the keypad for any user input. The keypad is a simple 4x4 keypad that uses the LCD as a visual display to the client. The LCD is a basic 20x4 display which allow for a four line menu. It includes a backlight that will help when the device is located in areas where the ambient light makes it difficult to read the screen [11]. It is used for navigation through the menus on the device and for the client to choose to charge a port or just check on the number of minutes left on their account.

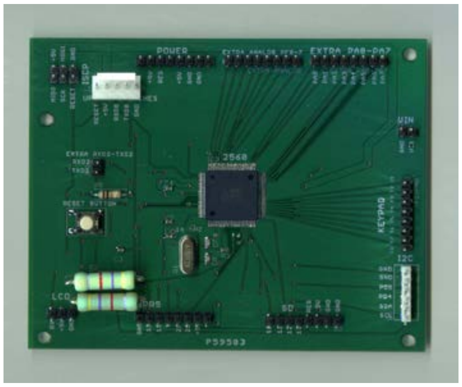

Fig. 5. Master Control board PCB, measuring 5”x 4”.

## V. Port Control Board

The Port Control Board is the interface between the Master Control Unit and the user’s mobile device. This board is responsible for switching ports on and off based on the Master Control board’s direction. It is also responsible for the controlling of LEDs associated with each port to indicate port status, regulate port output, sense mobile device current use status, and report port status to the master unit when requested.

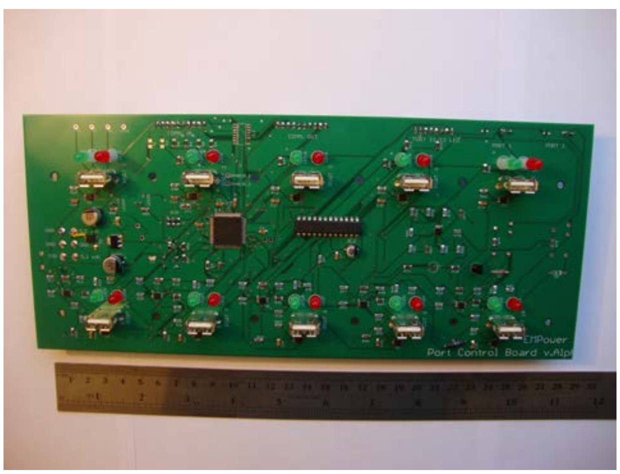

Fig. 6. Port Control Board PCB. Measures 11.5” x 7”.

### *A. Address Bus*

The Port Control Board includes circuitry to detect the value of a 4-bit addressing bus to be used as the units I2C address. The board will also increase the value of the bus and pass it to any subsequent slave unit’s address bus input. This will automatically sequence the address of up to 16 Port Control Boards, eliminating the need for reprogramming as the system is reconfigured, i.e. additional units are added. This is accomplished using one 4-bit adder per board. The incoming address bus lines are connected to 4 inputs on the microcontroller which are programmed to be used to define the slave I2C address on power up. This bus is also attached to one of the 4-bit inputs on a MOS 4-bit full adder. The other input is hardwired to a value of 1. The output is then passed to any subsequent unit’s address bit input. A schematic of this implementation is seen in Fig. 7.

### *B. Charging Ports*

Each Port Control Board has 10 USB ports which the users will plug their device to be charged into. The USB charging standard has been adapted to several different implementations by the mobile device manufactures. These various versions and implementations require different electrical signatures on the two data lines, or handshaking scheme, to inform the mobile device of the available power as well as to confirm compatibility. The three most common handshaking schemes are:

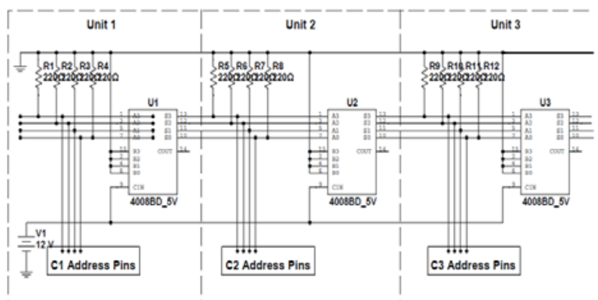


Fig. 7. Schematic of slave unit addressing bus to automatically sequence the address of slave units without user programming

1) Divider DCP
   - Used by Apple devices
   - 2.7 vdc/2.0 vdc or 2.0 vdc/2.7vdc on D+/D- lines
2) USB 2.0 BC1.2 DCP
   - Most common (Motorola, HTC, Sony)
   - <200 ohm short D+/D-
3) 1.2 vdc/1.2vdc
   - Used by some Samsung devices
   - 1.2 vdc/1.2vdc on D+/D-

Implementing only one of the schemes can cause devices utilizing another handshaking scheme to charge at a slow rate or not at all.

Texas Interments has developed an integrated circuit that will manage the USB ports. The TPS2511 is a USB dedicated charging port controller (DCP) and current limiting power switch. An auto-detects feature monitors USB data line voltage, and automatically provides the correct handshaking scheme. Conveniently, the TPS2511 provides enable pin that will allow the microcontroller to directly turn each port on and off.

*C. Port Use Sensing*

The charging status of each port is required in order for the Master Unit to end the respective user's charging session. This is accomplished by incorporating a current sensing, or shunt, resistor in series with the supply line to each port. The voltage drop access the shunt resistor is input to a comparator for sensing. Hysteresis was implemented to reduce the tendency of unintended rapid switching when a user plugs into or unplugs from a port [12]. A diagram of the circuit is given in Fig. 8. A rail-to-rail comparator was utilized to allow high side sensing with a common reference voltage and supply voltage.

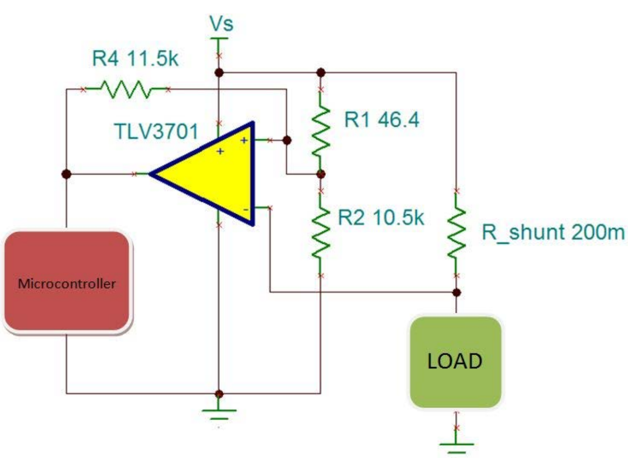


Fig. 8. Schematic of current sensing circuit, with hysteresis

## VI. Power Supply Board

The Power Supply Board provides the necessary power to the device. It can receive a primary input voltage ranging from 12VDC to 32VDC, as well as a secondary input voltage ranging from 10VDC to 24VDC. Each input is switched and fused before being routed to the input receptacle in the power supply board. The diode circuit in the following Fig. 9 determines the presence of primary power or secondary power.

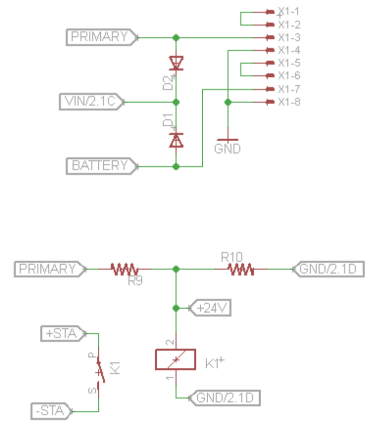


Fig. 9. Diode Selector Circuit and Status Relay of Power Supply Unit.

When primary power is available the status relay is energized and provides the status to the port control board, enabling the charging of all ports. When primary power is lost and secondary power is available, the relay is de-energized providing the status to the port control board in order to disable the charging of all ports. When the unit is utilizing running on secondary power, all charge ports are disabled in order to conserve battery energy.

Subsequent circuits in the unit require several voltages in order to operate. The charge port control board requires a 5.3VDC at 15A in order to deliver the appropriate voltage and current to each USB port as well as its controlling circuits. This board also requires 12VDC at 4A in order to provide the necessary voltage and current to the cigarette lighter ports. The Main control board requires 5VDC at 4A in order to energize its circuits and provide power to the LCD. Due to the multiple number of output voltages at different currents, it was decided to design a power supply with separate PWM controllers, one per voltage.

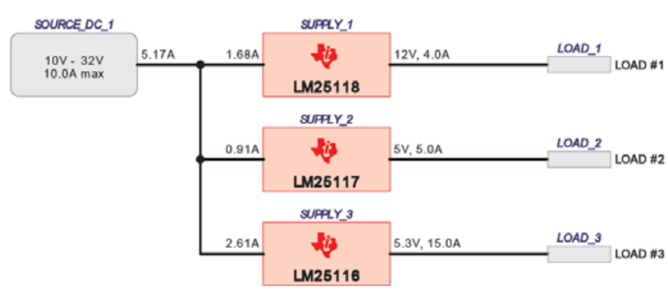


Fig. 10. Power Supply Block Diagram , *Courtesy of Texas Instruments.*

As seen in Fig 10, "SUPPLY1" provides 12VDC for the cigarette charge ports using the LM25118 PWM controller. The LM25118 is a wide range buck boost controller, which is necessary in situations when the input voltage is lower than or equal to 12VDC. The LM 25117 and LM25116 simply buck the input voltage and allow for a wide input voltage range.

An additional component to the device is the slave unit as seen in Fig. 11 below. The slave units only needs to contain (10) USB port charging ports and do not need to include the car lighter socket ports as in the master unit. Due to the nature and purpose of this device, it is important to take into account not only the locations for the eMpower devices, but also the abilities of the administrative personal that will oversee the day to day operations of the units. It is for this very reason that the slave units need to have the ability to employ a plug-and-play topology. This is also true for many devices that we use today in popular electronic systems. When the slave unit is connected, the master unit shall have the ability to recognize the presence of a slave unit and employ the added ports. It will employ the use of a decision making algorithm when assigning charge ports for each user.

In a previous section, the communication protocol was researched and decided upon. The I2C protocol was chosen due to its many advantages in the context of the device, one of them being the allowance of the protocol to enable the configuration of a plug-and-play set up for the master/slave configuration [13]. The inclusion of the adders in the address assignment of the charge port control module was introduced in order for the system to autonomously address each slave unit and communicate with the central control module without the need for administrator to assign addresses to each slave unit [14]. This feature greatly enhances the eMpower device to operate without the need of highly skilled personnel.

The slave units' only function is that of an expansion of the master unit. This function eliminates the need for a communications module or a central control module. This will also cut back on the cost of the upgrade of a system that can charge 12 ports to a system that can charge 22 ports. However, it is important to note that in order for the unit to be a true plug-and-play addition to the master device, it must receive a separate power input. This was decided in order to allow each slave unit to convert its own input power and not rely on previous units. A catastrophic failure of a previous slave unit will not disable the operation of any slave units after it, thus providing a parallel function of the system. This feature further enhances the overall design of the eMpower system by allowing slave units a pseudo stand-alone configuration.

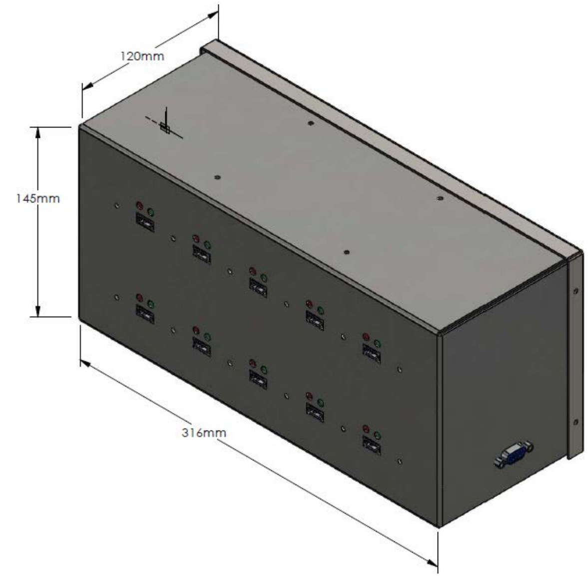


Fig. 11. CAD drawing of eMpower slave unit

The slave unit only needs to contain a power regulation module and a charge port module. The elimination of unnecessary modules also decreases the cost of the slave unit, which is in keeping with the necessity of Water Missions to keep the units at a minimum cost. Each slave unit also retains the capability of an ON/OFF feature, as well as indicator LED's for each port to inform the users when a port has been enabled (green LED) or disabled (red LED).

## VII. Robustness and Safety

The robustness of the system is imperative due the nature of it providing and managing a service that has financial implications to its users. The system has a high uptime ratio in order for the user to justify the expense of using the service. High quality components with a long history of application and verified performance have be used in the implementation of the design. Manufacture example application circuits have be referenced where possible to reduce unexpected results in the field and reference designs have consulted when available.

User safety was regarded as the primary design consideration. This system will be located in remote villages where the equipment may be exposed to the elements. Users are not expected to identify hazards or safety concerns and must not be allowed contact with hazardous parts. The specific users of this system will have little to no experience with electricity and may not have the same regard for the potential danger of an unmaintained or damaged electrical system as would a user from a society where electrical devices are used on a daily basis. Grounding, lightning protection, moisture protection, and isolation will be properly implemented. The device will be implemented in foreign countries such as South Africa. In regards to safety, ANSI/ISA S82.01 and ICASA's (Independent Communications Authority of South Africa) "Regulations in Respect of Technical Standards for Electronic Communications Equipment" will be followed as the final design will be used daily by the general population. Electric shock is not the only aspect of electrical equipment safety design.

Fire hazards and burns result when equipment is not designed correctly, overloaded, malfunctioning, or is not provided with proper heat dissipation. Thought has been given to the mechanical design of the unit. Injury or damage resulting from contact with sharp edges or corners of the unit, movable parts, or being improperly secured or mounted should be avoided at all times. Likely faults, power surges, and foreseeable misuse should all be considered.

## IIX. Serviceability

Serviceability was considered in the design process to permit the operators to be able to safely and reliably troubleshoot, repair, and expand the system. The specification provided by Water Missions International requires that the unit be fitted with LEDs to indicate when the unit has sufficient power. In the event that the unit shuts down, this will provide the operator with an indication of whether proper power is simply not being supplied by the power source, or if a malfunction has occurred and the unit its self is in need of service.

Additionally, the provided specification calls for a system power switch that will be incorporated in the system, which the operator may utilize to power down the unit. The unit may be powered down in order to:

1) Safely service the unit
2) Reset the unit in the event of a malfunction
3) Eliminate load on the power supply system
4) Power off unit when not in service

Particular consideration to safety should be given in the design of how the unit will be serviced. Since the unit will have a power supply of up to 30 volts the system was designed so that the switch shuts off power on the high potential voltage side of the circuit in order to reduce or eliminate the risk of electrical shock. Any conductors within the enclosure that have the capability of electrical shock have been properly insolated and protected to prevent accidental contact. Capacitors that can have a discharge time greater than several seconds have been protected against accidental shorting or contact. The switch should also completely eliminate all loads to the primary power supply, in order to provide the maximum amount of power to the water pump system in times of high demand.

While not detailed in the provided specification, the system should be designed in a way that it can be safely and easily serviced by the average individual that will be in charge of daily management and upkeep the unit. The remote nature of the sites where these units will be installed can hinder timely response of experienced support personnel. We assume the primary servicer is proficient in the use of basic hand tools and has some experience with several common types of electrical connectors. We assume no electronic troubleshooting skills. In order to simplify the serviceability of the system in the event of component malfunction, the units various subsystems should be designed and constructed into several separate components, hereafter referred to "boards". The various boards are:

1) Main Board (1 per site)
2) Power Supply Board (1per unit)
3) Port Control board (1 per Unit)

If more charging ports are required at a later time, or if a unit is in need of replacement, the master unit will automatically detect and configure expansion units each time it powers up. This will eliminate the need of any onsite software configuration or addressing as the system is expanded. The power regulator boards and charging port boards that are found in all units should be standardized and interchangeable. All parts should be labeled with dates and some sort of identification, such as a part number, so that if any components of the system are redesigned at a later time, correct replacement parts can be obtained without confusion.

Basic troubleshooting procedures and self-diagnostic tests should be provided to the servicer to aid in assessing system malfunctions. Certain diagnostic tests are required to have the ability to be performed remotely via the cellular communications system as described in the administrative menu description portion of this document.

## IX. Conclusion

One of our greatest goals of this project was to create something that could be used by not just one company, but for a device that could be used by anyone that is willing to help those who need it. This device will allow for a person or organization to monitor their device and maintain its client's accounts from around the world. It will provide a service to those in need, that is affordable yet those nominal fees will maintain the device and add to its expansion throughout other areas that have a need.

We wrote the software and designed the unit to be open source so it can be improved upon and used where it is needed the most. It gives us great pleasure that a worldly organization is already interested in implementing the design and we hope that others will expand upon it and share those designs with others with like interests.


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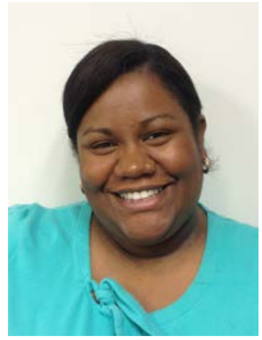

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**Bernard Eugene Feeser Jr**., a senior student of the computer engineering department at University of Central Florida. Has accepted a position with the government pursuing a career in computer engineering and following his passion of serving his country. He is a member of IEEE, Eta Kappa Nu, and a Veteran.

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