The Smart Digital Voltmeter

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***Abstract* — The digital voltmeter has been a key tool for electricians, engineers, and everyday users for decades. Though there have been improvements over the years, data logging still presented an inconvenience to users as measured values must be manually recorded. The Smart Digital Voltmeter aims to remedy this issue by allowing users to connect their smartphone to our meter via Bluetooth which will log data in real time. Using an ATmega328P-PU microcontroller, the project will measure AC and DC voltages, display three to four measurement parameters on an LCD while simultaneously transmitting the data to be plotted and recorded on the application. This paper will describe the input and user protection circuitry, the measurement technology, and the smartphone application design.**

***Index Terms* — Voltmeters, microcontrollers, bluetooth, power dissipation, analog-digital conversion**

I. Introduction

Traditional digital voltmeters allow users to measure voltage using two conductive probes and read the data on an LCD or LED display with high accuracy. These meters do not affect the circuitry under inspection because of the large input impedance between the measurement probes, upwards of 10MΩ. The Smart Digital Voltmeter accomplishes this same technology with the added convenience of wireless transmission of data to be stored and analyzed once the probes have been removed and the data has been recorded.

This project utilizes the 10-bit analog to digital converter (ADC) that is built into the microcontroller. The ADC converts the measured voltage to a digital value between 0 and 1023 in which the code then converts this value back to an analog value to be displayed. For voltages above the ADC's reference voltage of 1V, the analog signal passes through a voltage divider before being fed into the microcontroller. The user selects the range with one of four switches in which the voltage is expected to be. If the voltage is not within the selected range, the display will prompt the user to select another range.

In the design process for this project, several aspects had to be kept in mind such as user and product safety, accurate measurements, and usability. As this project will potentially be used to measure large voltages, the first and foremost issue that needed to be addressed was the circuitry that would protect users from large voltage spikes, current inrush, power dissipation, and exploding components. Fluke, a well-known manufacturer of high end digital measurement technologies, presented a document on the dangers of measurement and the safety technology used to prevent these dangers titled "ABCs of Multimeter Safety." These guidelines served as the basis for the input protection of the project.

When it comes to the measurement circuitry, the voltage dividers and resistor values were chosen based on several factors such as the resolution and accuracy requirements, the size of the microcontroller's ADC, and the range that the product needed to be able to measure accurately. The meter is able to measure four ranges: millivolts, 1-10V, 10-100V, and 100V-1000V.

The final section of the design process comprised of wirelessly transmitting the measured data to the smartphone application via Bluetooth. The application needed to display both AC and DC values, along with plotting and updating the waveform in near real time. This functionality separates the Smart Digital Voltmeter from any other technology that is presently available.

II. System Design

The voltmeter can be broken down into four basic systems: input protection, measurement circuitry, wireless transmission, and application design. To best describe the design and operation of these systems, they will be analyzed separately. In each section, the strategic hardware design and software implications will be presented.

A. Analog vs Digital Voltmeter

The digital voltmeter is different from all kinds of analog voltmeters because it is the only voltmeter that obtains a measurement digitally rather than an analog reading. In other words, a digital multimeter directly indicates a measurement value rather than relying on deflection. Digital voltmeters are excellent instruments because they completely eliminate error due to parallax [1]. Parallax is when a user attempts to read the pointer on a scale. With digital voltmeters, any two users will not have two results that differ by more than 0.01%. Similar to analog and digital clocks, digital voltmeters have a high-speed reading advantage. The user simply takes one quick look and instantly reads the recorded measurement on the digital voltmeter rather than looking at a pointer and deciding which marker it is pointing to the closest. Additionally, high speed readings of digital voltmeters can be stored in memory for further analysis. This speeds up the recording process because none of the analog voltmeters have this capability. Digital voltmeters have other advantages such as being versatile and accurate, compact and cheap, having low power requirements, increased portability, and the ability to measure both AC and DC voltages. Analog voltmeters do not go without their respective advantages as well. Analog meters are most handy when comparing certain voltages. When a user measures a voltage from a circuit, and wants to see the voltage's magnitude in relation to a different circuit, the user can instantly see the needle's position in both cases. A physical needle in this case is very useful in determining voltages of two different circuits in comparison to one another very quickly. Likely the biggest advantage of of analog voltmeters over digital voltmeters, is that analog voltmeters have a needle. Due to this needle, the user can see much easier when a voltage reading alternates between multiple values, unlike a digital voltmeter which goes haywire.

B. Input Protection

Before selecting the safety measurements for the voltmeter, all of the possible hazardous phenomenon that could occur when using the product must be identified. The most obvious threat are high voltage transients. According to Fluke's "ABCs of Multimeter Safety," voltage spikes can be generated from motors, capacitors, and power conversion equipment such as variable speed drives [2]. Additionally, lightning strikes on substations, power plants, and most commonly transmission lines can also cause high voltage transients. These transients can even occur on low-voltage power circuits and can reach values as high as many thousands of volts. In a case like this, the voltage rating alone is not enough information to tell the user how well the measurement device was designed to not break from these high transient impulses. This is where the user depends on safety margins already built into the voltmeter. Before selecting a range of input protection components, many possible different forms of input protection were considered.

One device used for overload protection in voltmeters is fuses. A fuse is a very thin wire that melts or vaporizes when current passing through it exceeds a particular fuse rating. Fuses are available with current ratings from 1/500 Amps to hundreds of amps. The thin wire can made from aluminum, tin-coated copper, or nickel. Most fuses in electronic equipment are cylindrical in shape and are glass or ceramic with a metal cap at each end. The current rating and voltage are written on one of these two metal end caps. Fuses are placed near the start of the circuit on a measurement device such as a voltmeter in order to monitor the current going into the meter. If the current entering the probes of the voltmeter is too high for the circuitry inside the meter to handle, the fuse will melt and prevent further damage to the device. Although fuses are not very necessary because the high input impedance of a voltmeter already limits most of the current that can pass into the meter, fuses serve as an extra protection against overcurrent. Overcurrent can cause electric components to overheat and cause a fire. It is beneficial to incorporate a fuse into the voltmeter design because if worst case scenario occurs, it is cheaper to replace a fuse rather than purchase a new meter. Adding a fuse into a voltmeter also helps count for the user making a mistake and connecting the meter's probes where they should not be touching. If lightning were to strike on equipment with a fuse, the user may open the device and, upon examining the parts, see that only the fuse was damaged rather than the power supply or other components.

A second possible preventative measure for input circuitry protection is varistors. Similar to how a fuse offers over-current protection, the varistor provides over-voltage protection. Varistors do this by utilizing voltage clamping, similar to a zener diode. That is, a varistor will trap extra voltage if the input voltage becomes too high, thus protecting the delicate circuit components of the voltmeter. The word varistor itself is an acronym, combining the words "variable" and "resistor." This means that the resistance of a varistor is dependant on the amount of voltage flowing through it because the varistor changes its resistance value automatically with the change in voltage across it. The main function of varistors in input circuit protection is to combat transient surges. If lighting strikes near or onto a circuit which is being measured by a voltmeter, transients will travel through the circuit and can reach voltages up to several thousand volts. As a preventative measure, varistors are placed in parallel with the delicate circuitry inside of the voltmeter. By doing this, under normal measurement readings, the varistors act as high impedances and force most of that important current into the circuit of the meter. However, in the case of a transient surge, the high input voltage results in the varistors behaving as short circuits, thus forcing most of this current to travel to ground instead of damaging the significant and delicate electronic circuits and components.

A third possible preventative measure for input circuitry protection is the zener diode. A zener diode also acts like a voltage clamp, similar to the varistor. However, a reverse biased Si small-signal diode breaks down at approximately 100 volts. This is much lower than a varistor. Additionally, once a zener diode breaks down, it usually does so permanently. The zener diode breaks and acts as a short circuit with zero voltage across the diode. They can no longer return to their normal working state like varistors. Therefore, zener diodes may require additional maintenance compared to varistors. Another difference between a zener diode and a varistor is that a varistor is connected in parallel to an input voltage, while a zener diode connects in series to the input voltage. As a result, if a zener diode were to break down during the event of a transient surge, then the bulk of the transient voltage will go into the delicate circuitry and further damage the voltmeter.

A fourth possible preventative measure for input circuitry protection is a thermistor. A thermistor is a combination of the words "thermal" and "resistor." Although all resistors are slightly affected by temperature, their temperature coefficient is quite minimal compared to the special high coefficient in thermistors. Thermistors can have negative temperature coefficients (NTC) or positive temperature coefficients (PTC). In NTC thermistors, the resistance of the thermistor decreases as the temperature increases. NTC is most popular for having a quick response, being reliable, robust, and have a low price. Conversely, PTC thermistors experience an increase in resistance as temperature increases. PTC type thermistors are prefered when a sudden change in resistance at a certain temperature is required. Positive temperature coefficient thermistors have a type of temperature controlled switch that allows for its resistance to instantly increase. They are most commonly used in self-regulating heating elements and self-resetting overcurrent protection. PTC thermistors are a good choice for input protection in a voltmeter circuit design because it can help lower the input current if it reaches a dangerously high value.

A fifth possible preventative measure for input circuitry protection is the wirewound resistor. A wirewound resistor is a passive electrical component that limits current. It is basically a resistor that has a wire with a high resistivity wrapped around an insulating core in order to provide resistance. Wire wound resistor values can be very precise because its resistance value is dependent on the resistivity of the wire, the cross section, and the length, all of which can be accurately controlled by the designer. However, wire wound resistors can influence the current flow in an alternating current circuit, negatively impacting the results. This is because of the natural capacitance and inductance of the wire wound resistor. As a result, wire wound resistors are not ideal for high frequency operation within a circuit.

C. Microcontroller/Power Supply

During the design process of this project, several technologies were considered for the brain of the meter. Modern digital multimeters use chipsets which are specifically designed for the product they will be used in. These chips have several functions and upwards of 70 I/O pins for full functionality and product growth. As The Smart Digital Voltmeter needs only four analog inputs and 7 digital I/O ports, a microcontroller was chosen for the project. The microcontroller allows the function of the meter to be altered during testing that was necessary due to time constraint on research and development. After considering several options, the team chose to use the ATmega328P-PU which is the microcontroller used in several Arduino platforms. Due to its widespread popularity, the resources for Arduino project development are abundant online which was the final factor for choosing this technology.

The ATmega328P-PU operates on 5V logic levels and must therefore have a 5V regulated supply. To meet the battery life requirements for this project, several battery types were considered. As the microcontroller does not pull a large current, and the external circuitry is designed to draw as little current as possible, the team decided to use a standard 9V battery. This would provide sufficient power for the life of the meter before needing replacement.

D. Voltage Measurement

In order to measure a large range of voltages, the meter must utilize a voltage divider following the protective circuitry. The ADC can only measure values within its reference voltage. In order to increase the resolution of the meter for better accuracy, the reference voltage of the ADC was chosen to be 1V. While this does increase the resolution, in turn it decreases the measureable range. To remedy this issue, the meter is equipped with four switches for each range that implement a voltage divider network that uses 10MΩ of nominal input impedance. The nominal input impedance is the "R1" value in the voltage divider equation shown below.

$$V_{out} = V_{in} \times [R2 / (R1 + R2)]$$

Each range contains a different value of "R2" in which the voltage Vout will be fed into the ADC to drop a voltage between 0 and 1V. For the microcontroller to produce an accurate measurement, each resistor values are stored as variables in the code and used to compute the measured voltage. Additionally, the code must recognize which range the user is operating in for accurate computation along with warning the user in the case that multiple ranges are selected.

The following figure shows the voltage ranges, their R1 and R2 values, as well as the output voltage that eventually connects to the microcontroller:

Vin Range (Volts)	R1 (Ohms)	R2 (Ohms)	Vout (Volts)
1.00 - 9.99	10000000	1111111	0.099999991
10.0 - 99.9	10000000	101010	0.099999901
100 - 1000	10000000	10010	0.0999999001

Fig. 1. Numerical resistance values for voltage divider network. R1 describes the nominal input resistance.

E. Wireless Transmission

The entire voltmeter system will incorporate a wireless transmission system. This system will act as the link between the voltmeter circuit and the smartphone application. The type of wireless technology that is going to be implemented for transmission in the system will be Bluetooth technology. The module that shall be implement in the system is the HC-05 module.

Once the voltage has been measured by the voltmeter from an external source, it will be converted from an analog signal to a digital signal by the ADC. From there the data in the form of a digital signal will get transmitted from the voltmeter memory to the smartphone application using the HC-05 Bluetooth module. The reason is very simple , the module acts as a serial port for transmission of data. It is analogous to connecting with wires or USB cable, except this time, we are not using any wires but wireless transmission technology . Once the the module has been paired, it will be responsible for transmitting the voltage that is being measured, it will send it to the smartphone application where the data will be further processed by the voltmeter application into meaningful data that is beneficial to the user.

F. Smartphone Application

The smartphone application will be compatible with mobile Android devices versions 6.0 and below. This smartphone application will utilize the mobile device's built in bluetooth capabilities as well as internal storage to display and store files that can be accessed later or sent to remote locations using an existing network. The smartphone application will first prompt the user to turn on bluetooth on the mobile device if it is not enabled already. Once connected to the Smart Voltmeter hardware, the voltmeter will wirelessly transmit data based on the ranges and voltage type chosen previously by the user. If direct current (DC) is selected, then only numerical values will be presented to the user with basic analytical data such as the minimum voltage, maximum voltage, and average voltage. If the user selects alternating current (AC) then the user is given the choice of either a numerical view displaying similar data as the DC view or a graphical representation of the data received from the smart voltmeter, given an oscilloscope like functionality to the mobile application. This graphical representation can be captured using the devices built in screen capture functionality and be sent remotely as the text files of data with the numerical values can be. The android application will comply with the basic requirements for the android google play store in order to be available for download across multiple platforms and to a wider group of potential users.

III. Hardware/Software Description

The hardware and circuitry design for this project is best broken down into the three sections as described previously.

A. Analog vs Digital Voltmeter

For the purpose of the project, a digital voltmeter design was prefered rather than any type of analog voltmeter design. Voltmeter input impedance is the biggest difference between analog and digital voltmeters. Because most digital voltmeters have 50 times more impedance than analog voltmeters, digital meters are more accurate when measuring voltage in high resistance circuits. It is important to select a digital voltmeter for the design to minimize this "loading effect." The loading effect a voltmeter has on a circuit is determined by the total resistance of the measured circuit in relation to the impedance of the voltmeter. The higher the input impedance of a voltmeter when compared to the circuit that is measured, the more accurate the measurements will be. As a result, to maximize the accuracy of voltage readings, a digital voltmeter is encouraged instead of an analog design. Another disadvantage of the analog voltmeters is that they are generally more bulky than the digital meters. This disadvantage results from the required long needle, scale, and coil that must be placed into an analog meter. Because the group is interested in creating a more portable and compact voltmeter, the digital voltmeter is prefered over analog due to this convenient and lightweight quality. Last but not least, one of the most significant perks of using a digital voltmeter over an analog version is the digital display. The display of a digital voltmeter is very easy to read because it shows one simple value after setting the voltmeter to the correct range. In an analog meter display, there is a scale with a pointer which shows the measured value. Not only is it difficult to discern between the many different markings on the scale, but the scale does not provide accurate voltage readings to several decimal points like the digital voltmeter does. In addition, analog meter displays are difficult to read because the user is required to close one eye and try to determine the most accurate marker that the pointer is aiming to. After considering the many differences between analog and digital voltmeters in regards to convenience, portability, and accuracy, a digital voltmeter design proved to be the better option especially when equipping the project with short-range wireless Bluetooth capabilities.

B. Input Protection Circuitry

For the purpose of this voltmeter, three types of input protection circuitry were used due to the fact that the meter is designed to perform mainly indoors and on smaller circuitry to medium sized circuitry. The input probe will first connect to a thermistor that will be connected in series with a wirewound resistor. The other end of the WW resistor is connected to a node. One path of the node leads to the remaining circuitry, and the second path leads to three varistors in series that will protect the circuitry from the first path in case of a transient.

C. Measurement Components

The nominal input resistance of the meter is comprised of four resistors(3.3MΩ, one 2MΩ, one 1MΩ) and a 500kΩ trim potentiometer. The trim pot was added so that a precise nominal input resistance could be achieved for maximum accuracy. Each of the four SPST range switches connect their respective R2 values to the nominal input when selected, otherwise the range is connected to ground. This guarantees that the ADC will output a discrete 0 when the range is not selected. The other side of the R2 values are connected together to ground, which is fed back to the negative measurement probe. Figure 1 under section IV shows the voltage divider network values as they apply to this project.

D. Wireless Transmission

The module that shall be implement in the voltmeter system is the HC-05 module. This bluetooth module that we are using works well and is compatible with the Atmega328 chip, in that they both operate at the same power of 3.3V to 5V. This is extremely important for our needs because the voltmeter is going to be mobile, lightweight and not overheat.

The HC-05 includes a radio, a memory chips, a 26 MHz crystal, an antenna and a RF matching network. This enables fast transmission of serial data for short distances of around 10 meters or 30 feet.

The module is connected to the board through its RX, TX, GND and VCC pins operating at 5V. The HC-05 can be set to either master or slave. This means that the module has two modes of operation. The first one is where we can send AT commands to it to reconfigure and reset the settings and Data mode, where it transmits and receives data to another bluetooth module (in this case smartphone application). This means that the communication and transmission can go back and forth between the voltmeter board and the smartphone application. The default is the “data mode” which is configured at baud rate of 9600bps, 8 bits, stop bit of, and parity (total of 10 bits).

To reconfigure the settings such as baud rate, this can be done in the serial command for the microcontroller and adjusted accordingly. For example, in order to configure the bluetooth as master and pair it with the smartphone, we can send commands that changes the mode. To configure to slave mode, the HC-05 module has to be set through the serial command prompt.

We need to be able to receive the voltage measurement that we measured, have those measurements converted from analog to digital and transmit the data packets (bauds) to the smartphone application as soon as possible and also send information such as commands to the voltmeter from the smartphone through the bluetooth application. HC-05 is the best solution for this.

The module is going to programmed specifically to our needs. The programs (also called sketches) will be implemented using “C++-like” language that can run on the atmega328 chip. The program will read in the converted voltage analog signal at a rate of 9600 baud rate from pins 9 and 10. The digital data read in the will then be used to perform the necessary calculations such , voltage peak, RMS, Vmax,vmin, vout. Once the calculation are done, the data will be displayed on the voltmeter LED screen to show the user what is being read by the voltmeter. The calculations and other data is then transmitted to the smartphone through the bluetooth module HC-05 to give an in depth display of the measurements.

E. Microcontroller and Power Supply

The ATmega328P-PU is the brains behind The Smart Digital Voltmeter. It operates on 5V logic levels and therefore must have a 5V regulated supply to VCC. The meter is powered by a 9V battery which is regulated by a 7805T voltage regulator and two 10uF capacitors. The microcontroller is driven by a 16MHz crystal oscillator with two 22pF capacitors. The final components for operation are the push button that connects the reset pin of the microcontroller to ground, and the 10kΩ pullup resistor that keeps the device out of reset. In order to obtain the 1V external reference voltage for the ADC, the project makes use of another voltage divider that divides the 5V VCC.

IV. Standards and Constraints

The Smart Digital Voltmeter shall follow the standards of the "international Electronical Commission (IEC)". We shall use the IEC 61010-1 standard because it offers a higher level of safety and the low-voltage (<1000V) requirement we will be using; it is also the test equipment needed for the highest levels of protection for our portable device. The hardware standard(s) that we will mainly be concerned with are the "measuring categories". The categories deal with voltage operation that the devices need to work on. We use what is known test instrument. It is rating system used to find the ability to withstand a voltage spike, which are applied through a specified level of resistance. The ratings are broken down into categories - CAT I, II, III, and IV.

Measurement Category	Working Voltage (DC or AC-rms to ground)	Peak Impulse Transient (20 repetitions)	Test Source (Ohms = V/A)
CAT I	1000 V	4000 V	30 ohms source
CAT II	600 V	4000 V	12 ohms source
CAT II	1000 V	6000 V	12 ohms source
CAT III	600 V	6000 V	2 ohms source
CAT III	1000 V	8000 V	2 ohms source
CAT IV	600 V	8000 V	2 ohms source

Fig. 2. CAT ratings and their specifications.

Creepage and clearance - in addition to being tested to an actual overvoltage transient value, multimeters are required by IEC 1010 to have minimum "creepage" and "clearance" distances between internal components and circuit nodes. Creepage measures distance across a surface. Clearance measures distances through the air. The higher the category and working voltage level, the greater the internal spacing requirements.

Overload Protection - is another factor that has to be considered on top of CAT III, it is simply a protection circuit that clamps high voltage to an acceptable level. Another addition is the thermal protection circuit that detects an overvoltage condition, it protects the meter until the condition is removed and then automatically returns to normal operation the most common benefit is to protect the voltmeter from overloads when it is in Ohms mode

Bluetooth® is a technology that describes communication between devices using short range radio frequency (RF) technology that operates at 2.4GHz. This technology is capable of transmitting voice and data at low power. This is why we are using it in our project, because we want to transmit the readings of the voltmeter to an Android application wirelessly.

V. Microcontroller Code

The microcontroller performs several functions for this project. To visualize the system as a whole, a flowchart is shown below.

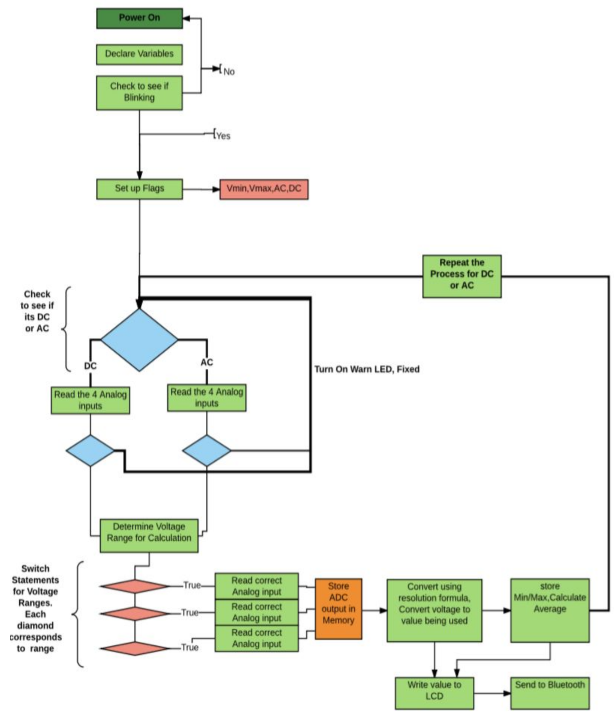

Fig. 3. Block diagram of microcontroller functions.

The first and foremost function is voltage measurement. The microcontroller first checks the AC/DC selection flag to determine which mode the meter will be measuring in. It then polls the ADC outputs and determines which range has been selected. In the DC loop, the program reads the ADC output and computes the voltage being read by knowing the ADC reference voltage, resolution, and R1 and R2 values. Additionally, the program computes maximum, minimum, and average values by polling the ADC output and recording the number of samples taken.

AC measurement posed a difficult problem for this project. As the ADC cannot read values below zero volts, the negative half of the input signal produces a zero on the output of the ADC. To determine the frequency of the signal, the code rapidly samples the ADC output and locates the strings of zeros produced from the negative cycle. Using a complicated sorting algorithm and by knowing the sampling rate, the frequency is determined. Simultaneously, the code checks for the largest ADC output during the positive cycle to determine the peak value. This value is constantly updated to produce the most accurate results. Lastly, the program computes the RMS value of the AC signal based on the peak value.

Once the values have been computed, the program writes the measurements to the LCD and simultaneously sends the data to the Bluetooth module. The Bluetooth module transmits the data to the smartphone application where the data is converted to readable characters and displayed.

Background processes of the microcontroller code include a low-power mode which places the device in a sleeping state when no range has been selected for an extended period of time. Additionally, the code contains safety checks that inform the user if voltages larger than the selected range are measured.

VI. Application Code

The android application displays data between separate activities and allows the user to access real time information of the circuitry they measuring. This application will only be functional on android devices at the time of final implementation and presentation, however the application is compatible with most mobile devices including the newer android devices using API 24 (Android 6.0 Marshmallow) and lower.The application also follows the guidelines presented by Google's Play Store in order to meet basic application distribution standards.

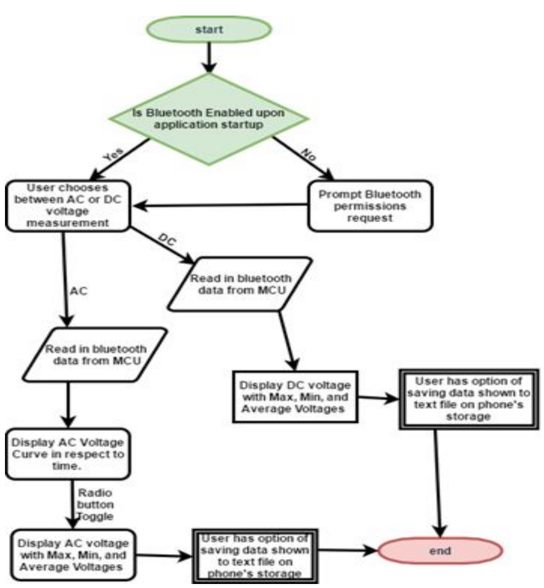

Fig. 4. Flowchart of application functions.

As shown by the above flowchart, the application will start at a home screen granting the user initial options. The user will first access the bluetooth menu via the button on the home screen. This bluetooth menu will toggle the bluetooth state on the mobile device as well as allow the device to be discoverable by other nearby bluetooth devices. This same activity will list the bluetooth devices within the vicinity and allow the user to pair to the appropriate device. If a passcode is required upon pairing request the application will prompt the user for this information within the same bluetooth menu. After the appropriate credentials are entered, the connection is complete and the user can use the home button to return to the home screen. At this point the user has two options, to display either the AC or the DC voltage measurements. The DC measurement option allows the user to see the current voltage as well as maximum, minimum, and average voltages. This information will be presented in near real time and updated continuously as long as a bluetooth connection exists. The user will also have an option of saving this data into a text file for later use and review or sharing to other remote locations in the present condition. This text file will be stored on the phone's internal storage. The AC option offers similar functionality, however the user is also presented with a graphical representation of the voltage information, making the application operate similar to an oscilloscope in function. The AC measurement option defaults to the graph view which will also be updating in near real time and the user may use the mobile device's built in screen capturing function to store an image file into it's storage. The AC measurement activity also has radio buttons that can be toggled to show the same data as the DC measurements, i.e the current voltage along with the maximum, minimum, and average voltages. This view also allows the user to save the data presented in a text file if the user so desires. The actual code is comprised of 5 separate java files to introduce the functionality within the android APK and 5 different xml files for the graphical representation of the application. Each java file is self contained with a reference to one other activity, generally done by a button click which launches the new destination activity. The "Bluetooth Activity" java file facilitates the bluetooth communications as well as managing the input stream from the arduino bluetooth module. The other java files are mostly managing the representation of data such as refreshing text views on the numerical data view or updating the graphical representation of the voltage data.

VII. Board Design

The entire system of electrical components fits on a 3.924-inch by 2.287-inch dual layer printed circuit board. A 2-layer board was selected because of its significantly reduced cost when compared with boards that contain a much greater number of layers. Furthermore, the design is simple enough that a two-layer board is sufficient to safely connect all onboard components. Nearly all of the components fit onto this compact board with the exception of the 9-Volt battery and the LCD display. For the battery, wires will be soldered onto the board and connected externally via wires to a 9-Volt battery holder. This external battery pack as well as the PCB will both be mounted onto a small, thin piece of plywood to serve as a base for the smart digital voltmeter. The LCD display is nearly as big as the PCB itself; therefore, the LCD display will be mounted near the bottom of the PCB and extend below the bottom edge of the PCB. The top of the LCD display will be held in place by inserting the male pins of the LCD into a set of female pins that will be soldered onto the printed circuit board. The bottom of the LCD will be connected to the plywood via a set of screws. This setup will allow the replacement of the LCD display if it were to be damaged. A set of 6 potentiometers are mounted in a row near the right side of the PCB so that the user may calibrate the voltmeter and optimize its accuracy when measuring voltages in the four different ranges (millivolts, 1-10V, 10-100V, and 100-1000V). A set of 6 manual, user-activated switches is placed in a row above the LCD display. One switch turns on the power from the 9-Volt battery source, one switch determines whether the measured input voltage is in AC or DC, and the remaining four switches allow for the user to select between the four available voltage ranges. An HC-05 Bluetooth module is mounted onto the PCB to allow data transfer of voltage measurements to be transmitted wirelessly to a phone application.

Because this was the group's first encounter with PCB design, an online tutorial was used to learn the in's and out's of PCB design. A brilliant 3-part tutorial video by Jeremy Blum was found on YouTube that contained step by step instructions on how to use Eagle software in order to generate a schematic design, generate a printed circuit board layout, and how to order a PCB [3].

VIII. Conclusion

The Smart Digital Voltmeter is a unique technology that combines the usefulness of a traditional digital voltmeter with the convenience of automatic data logging and waveform display. Making use of analog-digital conversion, voltage dividers, wireless transmission and sorting algorithms, product development relied on nearly all aspects of electrical and computer engineering. Additionally, new technologies such as varistors and thermistors were learned through the course of this project. The project was developed using the electrical and computer design techniques the team learned throughout the ECE program and personal study.

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