***Original Research Article***

Development of IoT Smart Voltmeter for Real time Voltage Monitoring

**ABSTRACT**

A voltmeter capable of accurately measuring and providing remote monitoring for both AC and DC voltage is crucial in modern application, especially with the growing demand for IoT based devices. Real-time voltage measurement poses challenges, particularly in ensuring reliability and efficiency. This thesis addressed these challenges by designing and constructing a wireless voltmeter incorporating an ESP32 microcontroller for wireless communication, a 7805-voltage regulator for stable power supply and PCB17 opto-coupler for electrical isolation and safety. The circuit design was simulated using Proteus software to verify its functionality and performance prior to physical implementation. The completed system successfully measured AC voltages in the range 2-250V and DC voltages between 3 -25V, achieving a minimal error margin after calibration. Voltage readings were wirelessly transmitted to the Blynk IoT platform, enabling seamless real-time monitoring via a mobile application. The system’s accuracy and reliability were validated through extensive testing, demonstrating its effectiveness as practical solution for modern voltage measurement.

***Keywords:*** *Design,Microcontroller,Remote,Development, Wireless, AC (alternating current) and DC (Direct Current) Voltage, measurement, IoT(internet of things)*

**INTRODUCTION**

Measurement provides a standard for everyday things and processes. Without the ability to measure, it would be difficult for scientists to conduct experiments or form theories. It is essential in farming, engineering, construction, manufacturing, commerce, and numerous other occupations and activities, hence plays a very important role in our lives. Measurement plays a crucial role in numerous scientific and engineering disciplines, enabling us to quantify and understand the physical properties of various phenomena. When conducting experiment(s) on electrical or electronics system it is essential to measure the fundamental electronic properties like resistance, voltage, and current, capacitance and inductance using appropriate measuring equipment, (Banerjee, 2016).

Electronic systems are made of circuits that contain a sequence of electronic components that are connected by wires to a power source, such as battery or main electricity. Electronic systems also involve the generation, transmission, processing, and storage of electronic signals or data. These signals can represent information, such as audio, video, or digital data, and are typically in the form of electrical voltages or currents. The measurement of electronic signals is a critical aspect of working with electronic circuits and systems. It involves the quantitative analysis and characterization of various electrical parameters to understand the behavior and performance of electronic components, circuits, and systems. Some common electronic signals that are measured include voltage, current, resistance, frequency, and time, (Maini, 2007).

Electronic systems have two categories, which are analog and digital electronics systems. The analog system is a continuous-valued system which changes its output value linearly as the input value varies. An analog voltmeter is an example of a scale and pointer. A digital electronic system is one in which both the input and output values are discrete or quantized. This means that the values can only take on specific distinct values. In digital electronics signals are represented by binary digits (0 and 1), which are the only two output levels it may produce based on the input’s range of values. Bits, a term derived from “Binary Digit,” are the names given to these discrete values, (Malaric, 2011).

The bits are used to perform many arithmetic and logical operations. The '0' and ‘1’values are otherwise known as logic levels or logic states. The 0 level is called the low level while the 1 level is called the high level. With this bit, it's easier for computers and specialized electronic instruments to process data and gives out the required output because it is only dealing with discrete values, (Atul, 2009).

However, most electrical quantities are measured with a device called a meter. Among the most fundamental measurements is the determination of voltage, a key parameter in electrical and electronic systems. Voltage is measured with a voltmeter. Voltmeters are sometimes connected into a circuit to provide continuous monitoring of an electrical quantity. Voltmeters are devices specifically designed for voltage measurement, and have evolved significantly over the years, transitioning from analog to digital formats to provide greater precision, accuracy, and ease of use, (Eren, 2005)

A voltmeter is an electrical instrument used to measure the voltage, or electric potential difference, between two points in an electrical circuit. In every aspect of electrical engineering, from power systems to the voltage inside VLSI (Very large-scale integration) chips, voltage is a fundamental quantity. Voltmeter is connected in parallel to the part of the circuit where the voltage needs to be measured. By connecting the voltmeter in parallel, it creates a parallel branch with a very high resistance, which ensures that the current flowing through the voltmeter is minimal and doesn't significantly affect the circuit being measured. This allows the voltmeter to measure the voltage accurately without disturbing the circuit's operation. (Bauer, 2011)

When the voltmeter is properly connected, it displays the voltage difference between the two points in the circuit, usually in volts (V). The operating range and precision of a voltmeter can vary depending on the specific application and the requirements of the electrical circuit being measured. For example, in power systems, where high voltages are involved, voltmeters capable of measuring kilovolts (kV) may be required. On the other hand, in more sensitive applications such as measuring voltages inside VLSI (Very Large-Scale Integration) chips or nerve cells, the voltage levels are much lower and may be in the millivolt (mV) or microvolt (μV) range. (Malhotra *et al*, 2015)

In this particular design, the voltmeter is optimized for measuring voltages within the range 0 - 25V for DC (Direct current) voltage and 2- 250V for AC (alternating current) voltage, which is a common range for many electronic devices and circuits. It has a precision of 10mV, meaning that the smallest distinguishable change in voltage it can detect is 10mV. This level of precision allows for accurate measurement and monitoring of voltage levels within the specified range. It's important to note that when using a voltmeter, it should be set to an appropriate voltage range that matches the expected voltage in the circuit being measured. Otherwise, using an incorrect range can damage the voltmeter or yield inaccurate readings, Voltmeters can be analog or digital, with digital voltmeters providing numerical readings, while analog voltmeters use a pointer or needle to indicate the voltage on a scale.

Analog voltmeters require a direct physical connection to the circuit under measurement, typically by using probes or test leads. They provide a continuous, analog display of the voltage, which allows for precise readings and the observation of voltage fluctuations. However, they may have limitations in terms of accuracy, sensitivity, and the ability to measure rapidly changing or high-frequency voltages. It's worth noting that digital voltmeters have largely replaced analog voltmeters in many applications due to their higher accuracy, wider measurement range, and additional features. Digital voltmeters use analog-to-digital converters to convert the voltage into digital form, which is then displayed numerically on a digital screen, (Md. Imran, 2014).

A voltmeter can measure both AC and DC voltages. The measurement capability of a voltmeter depends on its design and specifications. Some voltmeters can specifically measure AC voltages, while some can measure DC voltages. However, some voltmeters are designed as dual-range voltmeters, capable of measuring both AC and DC voltages. They provide separate scales for AC and DC measurements, allowing the user to select the appropriate range for the type of voltage being measured. (Aora, 2014)

In recent times, the advent of wireless communication technologies has revolutionized the field of instrumentation by introducing wireless sensing and monitoring capabilities. This has led to the development of wireless sensors and transmitters that can transmit measurement data to a central monitoring system without the need for physical connections. Integrating wireless communication into voltmeters offers the potential for increased convenience, mobility, and flexibility in voltage measurement applications, (Gay, 2021)

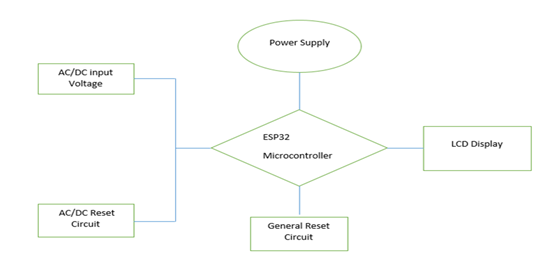
This thesis aims to explore the development of IoT digital voltmeter to provide accurate voltage measurements wirelessly. By leveraging advancements in wireless communication technologies and digital signal processing techniques, this thesis seeks to contribute to the development of innovative solutions in the field of measurement instrumentation. The successful implementation of a wireless voltmeter will enable improved efficiency, flexibility, and convenience in voltage measurement applications, paving the way for advancements in various sectors that rely on precise voltage measurements. The objectives of the design includes;To Develop an IoT voltmeter, write a firmware for microcontroller to establish remote monitoring and data transmission, implement wireless communication protocol (Wifi/GPRS), create a user friendly mobile Application for data visualization, and ensure high precision and accuracy in voltage measurement with an error margin of less than 1%. The scope of this thesis is limited to the design, simulation and construction of a digital voltmeter with an IoT cloud interface. It is specifically configured to measure AC and DC voltage without the capability to measure current or resistance. This restricts its application to scenarios where voltage measurement is required. The circuit design includes a voltage interface, battery management and temperature monitoring interface which can be viewed from both the LCD display and through the Blynk IoT cloud platform.

**material and methods**

The following materials were used in the development of IoT smart Digital Voltmeter; ESP32Dev Microcontroller, Voltage regulator sensor (7805), Opto-coupler, BC547 Transistors, Thermistor, LCD (Liquid crystal display), Piezo-Buzzer, 18650 Lithium-ion battery, TP4056 Battery charging module, DPDT Push button, Resistors, LED (Light emitting diode), Capacitors, Connecting wires, soldering iron, Metal alloy (63/37 Sn-Pb), Blynk IoT app, Proteus app.

**Hardware Design**

Design of hardware circuit is composed of six parts: AC/DC input voltage, AC/DC reset circuit, and General reset circuit, and Power supply unit, Control unit (ESP32 Microcontroller), LCD display. The block diagram of the circuit design is as shown in Figure 1 below.



**Figure 1** Block Diagram of the Circuit Design

**Power supply section**: The power supply section is responsible for managing power for the entire device. This is the charging section of the device, it accepts a minimum to Maximum voltage of 5-5.1V to charge the battery of the device. In this section, the charging and distribution of voltage was configured. When the device is switched on, power moves in through the four diodes (IN4007) for rectification. The device's battery is rechargeable, so the four diodes provide the rectification for charging the battery. The power then moves to voltage regulator U2 (7805), which is used to regulate a 9V built-in battery. However, since 9V cannot pass U2 (7805), it has to be regulated from 9V to 5V to give an acceptable voltage. And this is what powers the LCD and the microcontroller.

**AC/DC Reset Circuit**: A push button/switch is used to toggle between AC/DC modes, preparing the device for the correct type of voltage reading. When the switch is pushed down, the connections move to the DC terminal and when pushed up it switches from DC to AC. The push switch is connected to the microcontroller through pin 11 and pin 5.

**General Reset Circuit:** This unit consists of Double pole, double throw push button. This is where you toggle between interface for voltage measurement, Temperature interface and Battery percentage interface.

**2.2.4 Control Unit:** The ESP32Dev module serves as the central control unit managing all operations based on an embedded algorithm. It’s powered through pin 3v3 (pin 1), which receives 5V supply. Usually, the power supply comes from the 9V rechargeable battery, which is regulated by the voltage regulator U2-7805 to the 5V to match the required input for various components. Once, the power for battery charging enters the device, it’s first rectified by the four IN4007 diodes, before passing it to the voltage regulator for regulation. The regulated 5V passes to the VDD of the LCD and powers it on.

When voltage signals from the measurement probe enters the Opto-coupler PCB17, it conditions it to allow only safe voltage levels to pass through. If the voltage is within acceptable range, it is sent from output 4 of the Optocoupler to pin 3v3 of the microcontroller. If it’s out of range, the voltage is diverted to the ground through output 3. Resistor R7 steps down voltage levels to ensure compatibility with the microcontroller. The inbuilt ADC converts analog voltage signals from the probe to digital data. It’s then passed to the LCD through pin 36 for data communication. The ESP32Dev’s Wi-Fi and GPRS capabilities allow real-time data transmission to a cloud-based configuration accessible through the Blynk IoT app for end users.

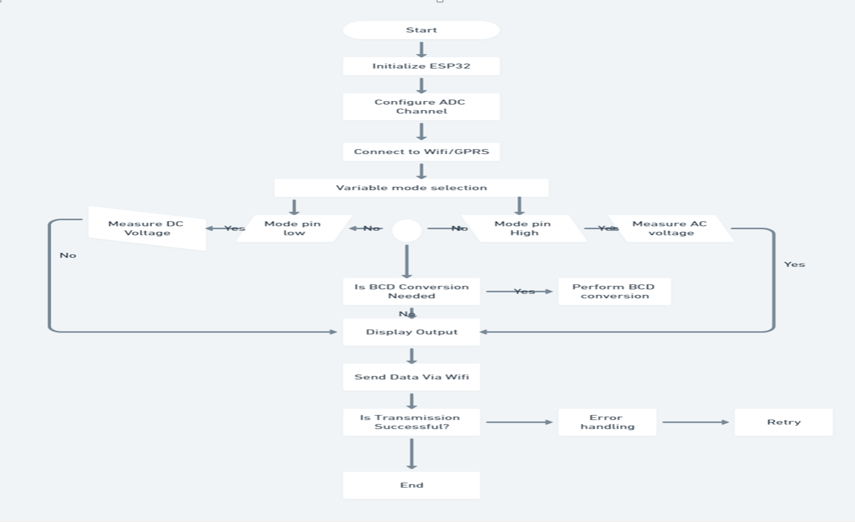
**LCD Display:** The voltage values processed by the microcontroller are sent to the LCD for display through pins 36 and 33 on the microcontroller. The two pins are connected to the data pins SCL of the LCD, handling the transmission of voltage values to be displayed. The LCD requires 5V power supply, which is regulated by the U2 7805 voltage regulator. The 7805 regulator ensures a consistent 5V output to power the LCD, preventing fluctuations that could affect display stability. Pin 38 to the VSS of the LCD is connected to the ground, while VDD is connected to the 5V output from the 7805 regulator. Pin 27 from the microcontroller is connected to the base of a BC547 transistor to a resistor. The BC547 acts as a switch in the setup. When the microcontroller sends a signal to pin 27, it triggers the BC547 transistor creating a closed circuit. The closed circuit activates the Buzzer (Buzz), which emits a beep to indicate that the device is powered on. Simultaneously, the LCD lights up, confirming that the device is active and ready for measurement display. The measured voltage can also be viewed through Blynk IoT app.

**Program Design:**

Before transitioning to hardware, a simulation model of the voltmeter was created using Proteus software. This simulation phase enabled the design and testing of a circuit that emulates real-world electronic components and systems, providing accurate representation of the intended hardware.

The circuit was designed to replicate the voltmeter functionality in a simulated environment. The embedded code for the voltmeter was written in C++ within Arduino sketch. Since the ESP32 microcontroller’s online interface functionality could not be directly simulated in Proteus, the code was structured with careful consideration of the voltmeter’s operational requirements.

The code relies on Binary Coded Decimal (BCD) format to handle digital-to-analog conversions essential for the voltmeter’s accuracy and precision. BCD simplifies handling voltage values by converting binary representations into decimal format, aiding in accurate digital representation and display. This process is described through a flowchart given below.

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**Figure 2** Flow Chart of the Program Design

**Real time voltage monitoring using Blynk IoT Mobile application interface**

The ESP32 reads and processes the digital voltage values, then transmits them to the Blynk cloud server via Wi-Fi. This is achieved by assigning the Blynk IoT virtual pins to the voltage data output from the microcontroller’s ADC. By aligning virtual pins with the ADC output, The ESP32effectively communicates voltage data to the Blynk platform.

To facilitate communication between the ESP32 and Blynk, the Blynk library is installed in the Arduino IDE. This library includes functions to establish the Wi-Fi connection, format the voltage data, and transmit it to the Blynk cloud where it’s stored and visualized on the Blynk app.

Custom code is written in Arduino IDE to collect voltage readings, process them and send them to the Blynk cloud. This code integrates the Blynk library to handle data transmission between the ESP32 and the Blynk app, ensuring continuous updates in real time.

During setup, the voltage readings from the ESP32 were compared with the values displayed on the Blynk app to ensure synchronization. Both the local voltmeter readings and the Blynk displayed values were confirmed to be accurate and in sync, verifying the reliability of the data transmission. A password and user name are usually assigned to the hotspot of the mobile phone where the Blynk app is installed and used for the remote data reading.

This integration allows real-time voltage monitoring on the Blynk app, providing an efficient and convenient IoT solutions for remote access to the voltage data.

**results and discussion**

**Simulation and Error analysis**

The designed voltmeter was simulated and debugged of error before transferring it into a hardware. The simulation results are somewhat consistent with the hardware results, with small variations due to rounding up and potential calibration issues. The absolute error values between the simulated and measured results of the IoT voltmeter range from 0.0004 to 0.0046. This indicates that the hardware measurements result of the designed voltmeter are very close to simulation results with minor deviations. The biggest error 0.0046 occurs at the highest voltage 10.20 suggesting a slight precision loss at higher voltages. It was also compared with the standard voltmeter in the market. For DC voltage, Standard voltmeter in the market has higher values, except for the first voltage, and in the AC voltage measurement except for the last voltage reading. However, the designed hardware voltmeter demonstrates a high level of accuracy, making it reliable for most applications. The table below shows the simulated IoT voltmeter, Measured (hardware) voltmeter and standard voltmeter in the market.

Table 1. Measured voltmeter, Simulated IoT Voltmeter and Standard voltmeter.

|  |  |  |  |
| --- | --- | --- | --- |
| Measured Iot Voltmeter Reading (V) | Simulated Iot Voltmeter Reading (V) | Standard Voltmeter Reading (V) | Actual Voltage Value (V) |
| 3.27 | 3.2704 | 3.26 | 3.00 |
| 4.40 | 4.4017 | 4.84 | 4.50 |
| 6.20 | 6.2037 | 6.48 | 6.00 |
| 7.41 | 7.4113 | 7.80 | 7.50 |
| 9.20 | 9.2024 | 9.81 | 9.00 |
| 10.20 | 10.2046 | 10.89 | 10.50 |

DC Voltage Readings

|  |  |  |  |
| --- | --- | --- | --- |
| Measured Iot Voltmeter Reading (V) | Simulated IoT Voltage Reading (V) | Standard Voltmeter Reading (V) | Actual Voltage Value  (V) |
| 2.30 | 2.3147 | 2.00 | 2.00 |
| 4.30 | 4.3087 | 4.05 | 4.00 |
| 6.23 | 6.2336 | 6.10 | 6.00 |
| 8.23 | 8.2371 | 8.15 | 8.00 |
| 10.20 | 10.2061 | 10.20 | 10.00 |
| 12.21 | 12.2122 | 12.23 | 12.00 |

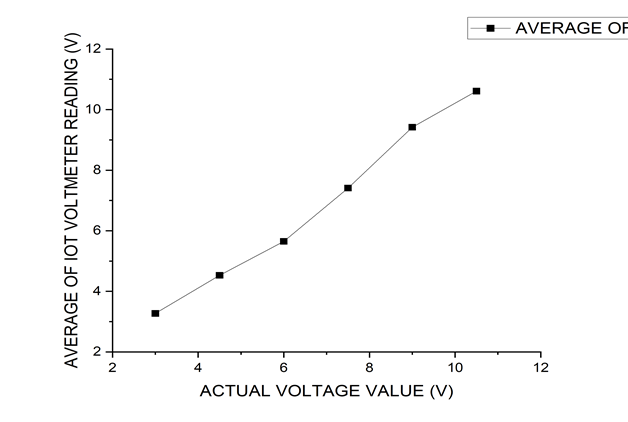
AC Voltage Readings

**Quantization error represents the variation between the digitalized output voltage and the real analog input voltage**.

The Accuracy of the ADC’s digital output is within of the actual analog input voltage. This means that the digital representation might not exactly match the true analog voltage but will be within 1 step of it. For this prticular Voltmeter Design, the quantization error for the first reading of the DC voltage measurement is 12.207mV or 0.012027V, while the quantization error for the first AC voltage reading is .

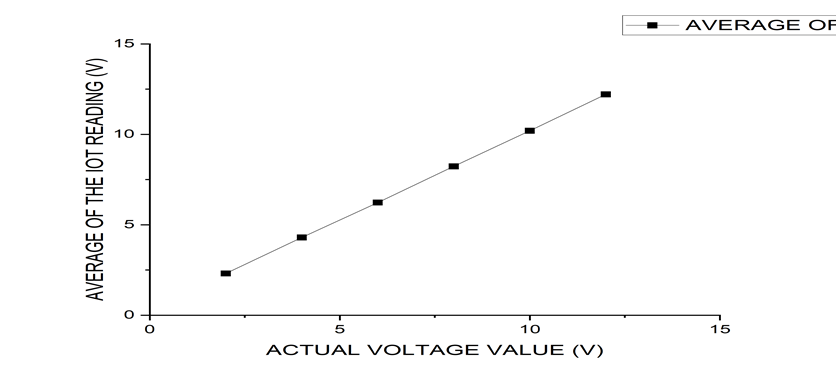
The linearity error for DC Voltage reading is 1.05%, which suggest that the voltmeter measurement deviates from a perfect linear response by a maximum of 1.05% of the full-scale range of the actual value. This can be seen from the figure below.

**Figure 3:** Graph of average voltage value of measured IoT Voltmeter against actual Voltage value for DC



While the linearity error for AC voltage is 0.0378%. This can be seen in the figure below.

**Figure 4:** Graph of average voltage value of measured IoT Voltmeter against actual Voltage value for AC



The full-scale error for DC voltage reading is 1.2%, which shows that the measurement error across the entire range is up to 1.2% of the full-scale, while the full-scale error for AC voltage is 0.125%.

The efficiency of the DC voltage reading is 95.23%, while the efficiency for AC voltage reading is 99.98%.

**Conclusion**

This thesis has successfully presented a functional IoT based digital voltmeter capable of accurately measuring and transmitting AC and DC voltage wirelessly within a specified range. The stand out features includes a variable output voltage range of 3–25V for DC voltage and 2–250V for AC voltage, wireless capability for remote monitoring. Opto-coupler and voltage regulator for safety measures. The test carried out proved that the thesis is stable, accurate and precise. It can also successfully transmit data wirelessly to a cloud-based platform.

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