

# Design and Development of a Universal Digital Microvolt Meter for Real-Time Sensor Measurements

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## Abstract

Many laboratory-prepared sensors and transducers operate by modulating parameters in terms of voltage or current. However, conventional laboratory voltmeters and current meters often lack the sensitivity required to measure such low electric quantities accurately, while commercially available instruments can be prohibitively expensive. Thus, a microvolt meter becomes indispensable for effective signal conditioning of sensors and transducers. This manuscript introduces the development and simulation of a Universal Digital Microvolt Meter (UDMVM) tailored specifically for sensor signal measurements. The UDMVM is designed to offer a dependable and precise solution for measuring microvolt-level voltages in sensor applications. Constructed around the widely available operational amplifier AD620, known for its high input impedance, the microvolt meter circuit ensures accurate readings. For digitalization and display, the Arduino nano open-source microcontroller platform is employed. The developed system undergoes testing in a set of experiments, including utilizing an LED as a light detector and employing a piezoelectric sensor and triboelectric sensor for pressure measurement. Moreover, the compact size and rechargeable power supply of the developed system make it suitable for integration with sensors, effectively functioning as a sensor module. Additionally, the system facilitates real-time data storage on a PC via a USB port, enhancing its usability and practicality.

**Keywords:** Universal microvolt sensing, sensor signal measurement, universal digital signal condition

## 1. INTRODUCTION

Sensors play a key role in various applications, requiring special measuring tools that can handle low voltages. Antosia et.al describe the design a prototype Voltmeter using ADS1115 (i.e. ADC with 16-bit resolution) and Arduino Nano, which can be applied in DC resistance measurement [1]. Djermanova et.al designed an Arduino-based portable LCR meter that used an AD5933 impedance converter to measure reactance [2]. Antosia et.al. used voltage divider method to the to measure direct current (DC) voltage [1]. This paper describes the development of an experimental system for measuring electrical quantities and protection against over and under voltage situations in a single-phase power supply. The system is based on an Arduino Nano microcontroller board [3]. In this paper, measurements of electrical quantities were made with an Arduino Nano microcontroller and were also confirmed with measurements made with a universal voltmeter. The main objective of this paper is to create an intelligent electronic system based on a light dependent resistor (LDR) sensor. A very interesting, but also very useful part of this scientific research is the measurement of electrical quantities with high precision, as intelligent machines

know and can achieve, and one such in this case is the microcontroller Arduino Nano [4].

The primary goal of UDMVM is to provide a universal solution for measuring sensor signals that is flexible according to different sensor types. The integration of Arduino Nano, AD620 operational amplifier, and OLED display offers a cost-effective and versatile solution for accurately measuring microvolt-level voltages across diverse sensor applications. The paper discusses the design considerations, hardware setup, software development, calibration techniques, and experimental validation of the proposed universal microvolt sensing system. Furthermore, potential applications namely LED as a light detector and employing a piezoelectric sensor and triboelectric sensor for pressure measurement are also explored.

## 2. SYSTEM ARCHITECTURE

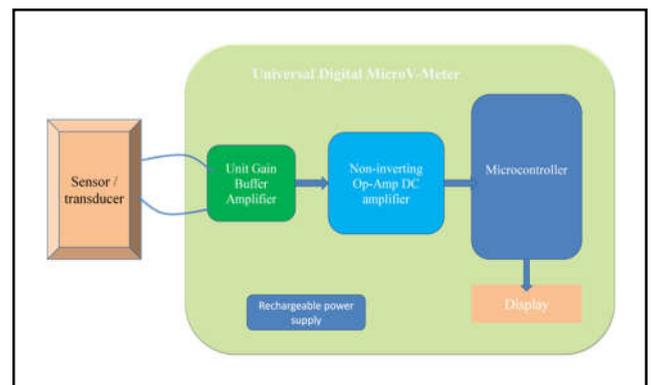


Fig. 1. Basic Architecture of Universal Digital MicroVolt-Meter

Figure 1 shows Architecture of Universal Digital MicroVolt-Meter. The UDMVM consists of three main components: the AD620 microvolt to millivolt converter, an Arduino microcontroller, and an OLED display. The AD620 serves as the front-end amplifier, providing gain and filtering to amplify microvolt-level signals. The amplified signals are then digitized by the Arduino microcontroller using its built-in analog to digital converter (ADC). The measured values are displayed in real-time on the OLED display, providing users with immediate feedback.

### 2.1 CIRCUIT DESIGN

The AD620 was chosen for its high input impedance, low noise and wide bandwidth, making it suitable for amplifying signals from weak sensors [5]. The AD620 microvolt to millivolt converter circuit is configured to provide adjustable gain settings to accommodate a wide range of input voltages. A gain of AD620 amplifier is adjusted to 1000.

The Arduino microcontroller interfaces with the AD620 through its analog input pin namely "A0", and the measured

values are processed and displayed on the OLED screen. The entire circuit is powered by a rechargeable 9v DC battery supply.

The UDMVM includes a sensor interface that connects to a AD620-based amplifier circuit. This interface includes several sensors to ensure compatibility with various signal sources. Arduino Nano microcontroller that processes the amplified signal from the sensor. The Arduino Nano has a 10-bit ADC, which is critical for accurate voltage measurements [6]. The amplified signal is processed by an analog-to-digital converter (ADC), which enables accurate digitization. The voltage can still be seen on the OLED screen [7]. The circuit connection is shown in Figure 2.

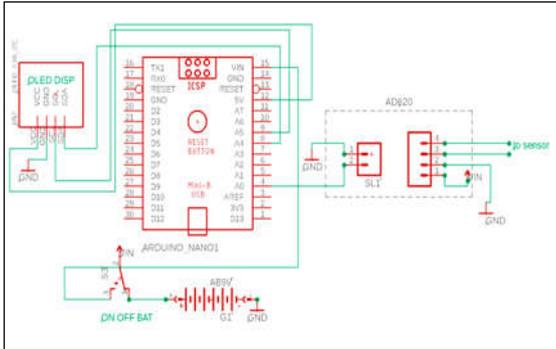


Fig.2. Circuit diagram Universal Microvolt Sensing system

## 2.2 SOFTWARE IMPLEMENTATION

The Arduino firmware is developed using the Arduino IDE and written in C/C++ programming language. The firmware includes functions for initializing the ADC, reading analog input signals, applying calibration factors, and formatting data for display on the OLED screen. Additionally, error handling and user interface features are implemented to enhance usability and reliability. The firmware is uploaded to the Arduino microcontroller via USB for easy reprogramming and updates. Arduino Nano R3 programmed in Embedded-C language in Arduino Integrated Development Environment (IDE). Details of the flowchart can be seen in Figure 3.

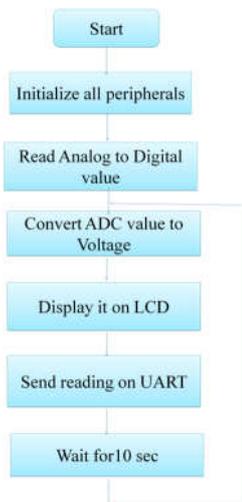


Fig.3. Arduino Nano programming flow chart for the system.

## 3. PROTOTYPING WITH 3D PRINTER

A custom case is created for the Universal Digital Microvolt Meter (UDMVM) using a 3D printer flash adventure 3 and TinkerCAD software is a straightforward and affordable option. With TinkerCAD's easy-to-use interface, designing a case to fit the UDMVM's components is simple and customizable. Using a 3D printer, designs can be turned into physical prototypes quickly. This allows for precise fitting of components and the addition of extra features like mounting brackets or cable management channels. Plus, because TinkerCAD is open-source, it encourages collaboration and creativity among users. Overall, using TinkerCAD and a 3D printer provides a practical way to create a custom case for the UDMVM, making it easier to protect and customize the device. Figure 4 shows the custom design of the 3D printed equipment container using Autodesk Tinker CAD (Pearce, 2012).

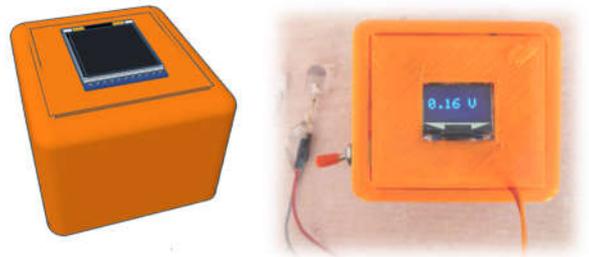


Fig.4. 3D printed prototype of UDMVM system

## 4. RESULTS AND DISCUSSION

The performance of the UDMVM is evaluated using calibrated voltage sources. Measurements are taken across a wide range of voltages, from microvolts to millivolts, and compared against reference values. The UDMVM demonstrates high accuracy and repeatability, with minimal errors and deviations. Real-time display on the OLED screen allows users to monitor changes in input signals instantly. The testing phase of the Universal Digital Microvolt Meter (UDMVM) is crucial for evaluating its performance and confirming its functionality across diverse applications. In this discussion, we'll delve into experiments utilizing a diode as a light detector and a piezoelectric sensor and triboelectric sensor for pressure measurement. Furthermore, the system is linked to a PC via a USB port, allowing real-time monitoring of readings using the "Serial Monitor" tool provided by the Arduino IDE. Figure 5 to Figure 7 illustrates the real-time results obtained during the device testing phase.

### 4.1 UTILIZING AN LED AS A LIGHT DETECTOR

One of the experiments involves utilizing an LED as a light detector to demonstrate the versatility of the UDMVM in measuring different types of signals. LEDs can act as photodiodes, converting incident light into electrical signals. By connecting the LED to the input of the UDMVM, we can measure the voltage generated by the LED in response to varying light intensities.

During the testing phase, the UDMVM is exposed to a light source with varying intensities.

The results shown in Figure 5 depict a white LED used as a light detector. It is evident from the graph that the amplified output voltage from the LED ranges from 0V to 3V. This indicates that the output from the LED falls within the range of 0 to 0.003V, since the gain of the amplifier is adjusted to 1000.

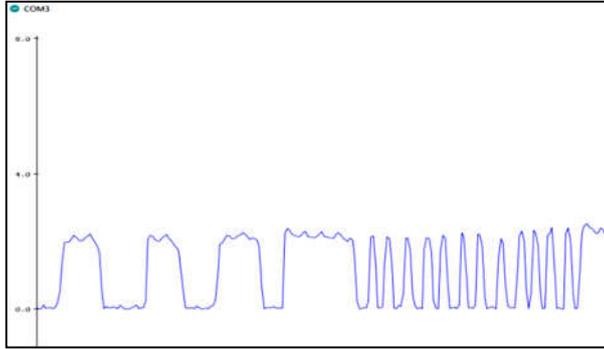


Fig.5. Universal Microvolt Sensing testing in a set of experiments: White LED as a light detector.

Figure 6 illustrates the real-time output recorded for an RGB LED used as a light detector. The amplified output voltage from the LED varies between 0.8V to 3.8V. This implies that the output from the LED ranges from 0.0008V to 0.0038V, considering the gain of the amplifier adjusted to 1000.

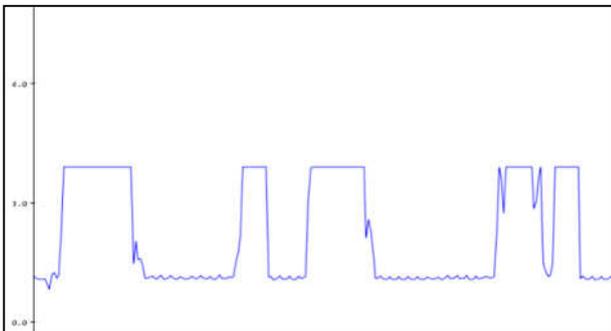


Fig.6. Universal Microvolt Sensing testing in a set of experiments: RGB LED as a light detector.

Figure 7 demonstrates real-time output recorded for a Zener diode used as a light detector. The amplified output voltage from the LED varies between 0.8V to 2.6V. Thus, the output from the LED is within the range of 0.0008V to 0.0026V, considering the gain of the amplifier is adjusted to 1000.

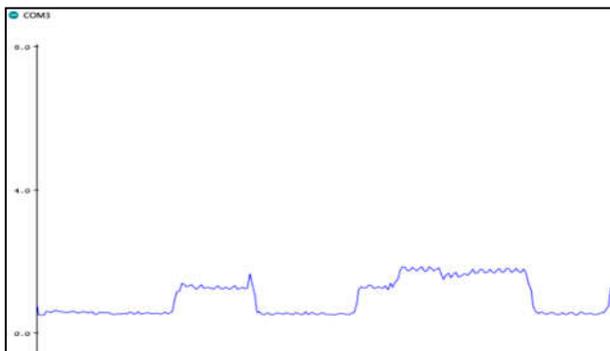


Fig.7. Universal Microvolt Sensing testing in a set of experiments: Zener diode as a light detector

The results of this experiment demonstrate the UDMVM 's capability to accurately measure microvolt-level signals generated by the LED under different lighting conditions. The real-time display on the OLED screen allows users to monitor changes in light intensity instantaneously, making the UDMVM suitable for applications such as light sensing, photovoltaic characterization, and optical communication.

#### 4.2 EMPLOYING A PIEZOELECTRIC SENSOR FOR PRESSURE MEASUREMENT

Another experiment involves employing a piezoelectric sensor for pressure measurement to demonstrate the UDMVM 's utility in biomedical applications. Piezoelectric sensors generate voltage signals in response to mechanical deformation, making them suitable for measuring pressure, force, and touch.

In this experiment, the piezoelectric sensor is placed between two conductive plates, and varying pressure is applied to simulate body pressure. The voltage output of the piezoelectric sensor is then connected to the input of the UDMVM for measurement. Different pressure levels are applied, ranging from gentle touch to firm pressure.

Figure 8 indicates the low-amplitude piezoelectric output measured using the UDMVM, where the sensor generates small but consistent voltage pulses 0.05–0.30 V in response to mechanical excitation, while remaining close to 0 V during the resting state.

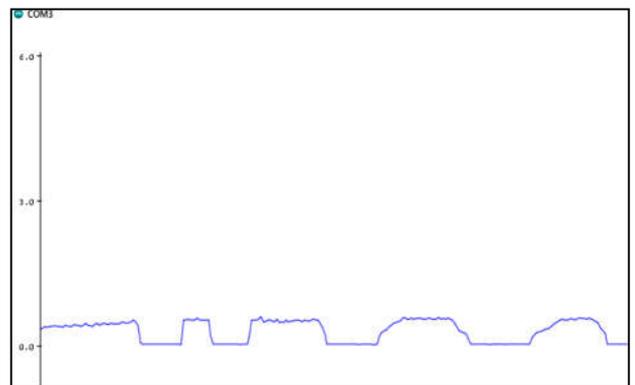


Fig.8. Universal Microvolt Sensing testing in a set of experiments: Piezoelectric Sensor.

The UDMVM accurately measures the voltage signals generated by the piezoelectric sensor, which correspond to the applied pressure levels. The real-time display on the OLED screen allows users to visualize the pressure variations and monitor the sensor's response. This experiment demonstrates the UDMVM's capability to accurately measure microvolt-level signals from piezoelectric sensors, making it suitable for applications such as biomedical sensing, touch interfaces, and force feedback systems.

#### 4.3 EMPLOYING A TRIBOELECTRIC SENSOR FOR PRESSURE MEASUREMENT

The experiment uses a triboelectric sensor to assess the Universal Digital Micro-Voltage Meter (UDMVM) for measuring extremely low and transient signals relevant to biomedical applications. Triboelectric sensors generate charge when two materials with different electron affinities contact and separate [8,9], producing voltage signals highly sensitive to touch, pressure, and motion [10].

In this study, the sensor is made using Kapton and aluminum foil, which exhibit strong charge transfer due to their wide separation in the triboelectric series [11,12]. When pressure is applied, the surfaces interact mechanically and generate triboelectric charges, resulting in voltage variations based on the degree of contact and separation [13].

The sensor output is fed directly into the UDMVM's high-impedance input, enabling accurate detection of microvolt- to millivolt-level short-duration pulses typical of triboelectric devices [14]. Various pressure levels, from gentle touch to firm pressing, simulate realistic pressure scenarios used in wearable and biomedical sensing [15,16].

The UDMVM successfully records these low and dynamic voltage signals, with amplitude and polarity reflecting both pressure intensity and contact separation speed [17], demonstrating its suitability for capturing transient biomechanical interactions.

Fig. 9 shows that the triboelectric sensor produces clear micro-voltage pulses in the range of 0.01–0.5 V. The waveform displays consistent peaks during mechanical interaction and a stable baseline when force is applied. A single peak at the end confirms the sensor's sensitivity to even small disturbances. Overall, the results indicate stable and repeatable voltage responses from the triboelectric sensor.

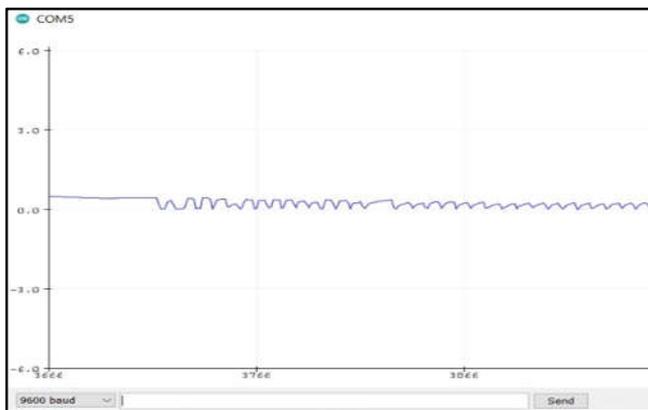


Fig.9. Universal Microvolt Sensing testing in a set of experiments: Triboelectric Sensor.

Overall, the experiment clearly demonstrates that the UDMVM can reliably measure microvolt-level and fast-changing signals generated by triboelectric sensors. These findings validate its use in biomedical monitoring, touch-based interfaces, motion tracking, wearable electronics, and force-feedback systems, where precise measurement of small mechanical-to-electrical conversions is critical [12,16]. The results further support the potential of UDMVM as a versatile, low-noise measurement tool for next-generation flexible and wearable sensor technologies.

## 5. CONCLUSION

In summary, the Universal Digital Microvolt Meter (UDMVM) presents a compact, precise, and user-friendly solution for microvolt-level measurements. Through careful testing, including experiments with light detection and pressure measurement, the UDMVM has demonstrated its reliability and versatility. Its integration with a PC for real-time monitoring adds convenience and usability. Overall, the UDMVM is a valuable tool with broad applications in research, engineering, and education, capable of further advancements in precision measurement instrumentation.

## ACKNOWLEDGMENT

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