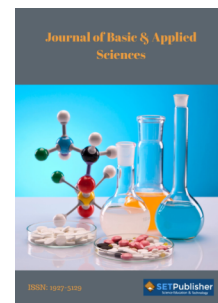




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## Development and Testing of a Low-Cost Solar-powered Disdrometer for Rainfall Characterization

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### Abstract:

This research explores the development, construction, and validation of a cost-effective, solar-powered disdrometer designed to enhance the study of rainfall parameters. Disdrometers are essential tools for quantifying rainfall characteristics, such as drop size distribution and intensity, which are critical for understanding precipitation microphysics and improving weather radar and satellite rainfall estimation. However, the high cost of commercial disdrometers limits their accessibility, particularly in resource-constrained regions. To address this challenge, a low-cost disdrometer was developed using widely available and affordable components, without compromising performance. The device integrates a piezoelectric sensor for raindrop detection, an amplification system, and a microcontroller for data processing. The system is powered by solar energy, further reducing operational costs and enabling remote deployment. Field tests conducted in a tropical region demonstrated that the disdrometer reliably captures rainfall parameters comparable to those obtained by commercial systems, making it a valuable resource for atmospheric research, hydrology, and meteorology, particularly in resource-limited settings. The study concludes that this solar-powered disdrometer offers a feasible, efficient, and sustainable solution for rainfall characterization.

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## 1. INTRODUCTION

Rainfall is a fundamental component of the Earth's hydrological cycle, playing a crucial role in various environmental processes. Understanding rainfall characteristics, such as drop size distribution (DSD) and intensity, is vital for applications ranging from flood prediction and agricultural planning to climate modeling and microwave communication attenuation [1,2]. These parameters are typically measured using disdrometers, specialized instruments that record the size and velocity of raindrops.

Disdrometers are essential instruments for studying rainfall microphysics, such as droplet size distribution DSD and rainfall intensity, which are critical for applications ranging from weather forecasting to hydrological studies meteorology and microwave communication attenuation modeling. By detecting and analyzing the DSD of hydrometeors like rain, snow, and hail, disdrometers contribute to a better understanding of various meteorological phenomena. Modern disdrometers, equipped with advanced capabilities, can distinguish between different types of precipitation with high accuracy, enabling more precise weather measurements and enhancing the study of precipitation microphysics [3].

However, despite their importance, the high cost of commercial disdrometers has limited their widespread adoption, particularly in resource-constrained regions and for small-scale research endeavors [4]. Commercial models such as the OTT Parsivel and Joss-Waldvogel systems are renowned for their precision but are expensive and complex, making them less accessible in developing countries like Nigeria [5]. As a result, there is a growing interest in developing low-cost alternatives that maintain reliability and

accuracy while being affordable and easy to deploy [4]. Previous research on development of low-cost disdrometer shows good prospect in comparison to commercial disdrometer [6,7].

This research aims to contribute to this effort by presenting the design, development, and evaluation of a cost-effective disdrometer for rainfall parameter analysis. The goal is to provide an affordable and reliable alternative for meteorologists, hydrologists, and communication engineers interested in understanding rainfall characteristics. By leveraging widely available components and open-source electronics platforms like Arduino, this study seeks to democratize access to essential rainfall measurement tools, particularly in regions where commercial systems are prohibitively expensive.

## 2. SYSTEM DESIGN AND DEVELOPMENT

The development of the low-cost disdrometer involved several key phases: design conceptualization, component selection, fabrication, and testing. The initial design phase focused on identifying the essential features required for accurate rainfall parameter measurement while minimising cost. This involved a comprehensive review of existing disdrometer designs, considering factors such as sensor technology, data processing algorithms, and structural integrity. Figure 1 shows the block diagram of the disdrometer. It describes the basic design and functioning of the instrument. This diagram is made up of seven blocks representing the major component units assembled to develop the disdrometer, and these include the sensing unit, amplifier, ADC (Analog to Digital Converter), MCU (Microcontroller Unit), RTC (Real Time Clock), logging unit, and power source.

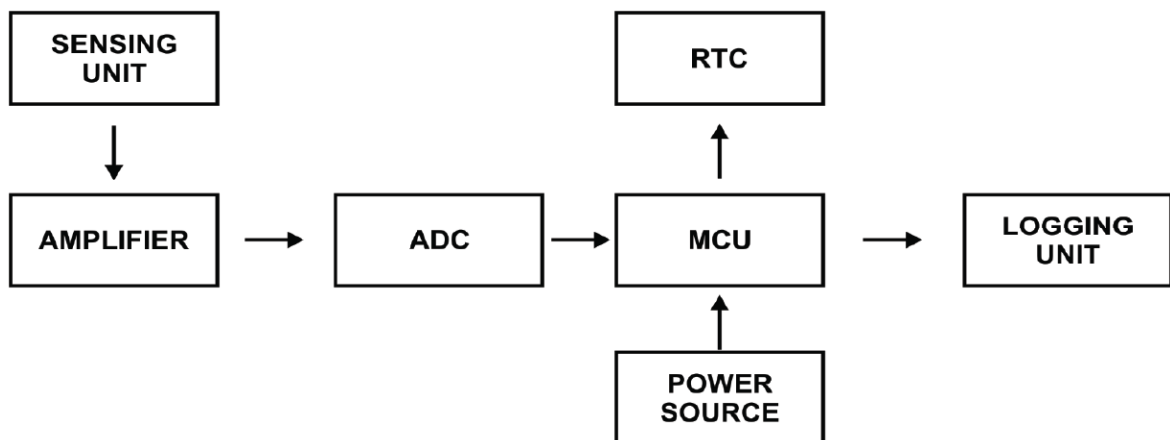


Figure1: Block Diagram of the Disdrometer.

The developed low-cost disdrometer is categorized into two main sections: hardware and software. The hardware section includes the sensor unit, an amplification unit, a filtering section, and the microcontroller unit, while the software section involves programming and circuit simulation using the Arduino Integrated Development Environment (IDE) and Proteus software.

The sensing unit consists of a piezoelectric disk coupled with a conical-shaped hat. A piezo-buzzer transducer is utilized to capture the mechanical energy generated by the impact of raindrops. The piezoelectric sensor is ideal for measuring the size of raindrops due to its ability to generate a voltage signal when pressure is applied to its surface, such as during a raindrop impact. The conical-shaped hat is designed to protect the sensor from environmental degradation, such as corrosion, while ensuring accurate measurements.

When raindrops hit the surface of the piezoelectric sensor, an electrical signal is generated. This signal is initially low in magnitude and requires amplification. The output from the sensor is fed into an operational amplifier, which boosts the voltage to a level suitable for further processing. A filtering section is also incorporated to eliminate noise and unwanted signals, ensuring that only the relevant impact signals are processed.

The amplified signal from the sensor is transmitted to the Arduino UNO ATmega328 microcontroller, which acts as the core processing unit of the system. The microcontroller utilizes an Analog-to-Digital Converter

(ADC) to convert the incoming analog signal into a digital format. The processed digital data, which is proportional to the raindrop impact size and rate, is then displayed on a Liquid Crystal Display (LCD). Additionally, the data is recorded onto a Secure Digital (SD) card for storage and subsequent analysis.

The microcontroller is programmed using the Arduino IDE, which allows for the compilation, testing, and debugging of the device's functionality. The system is designed to maintain a minimum voltage threshold of 0.08 V in the absence of precipitation, ensuring that false detections are minimized. When raindrops impact the sensor, the voltage increases, correlating with the size and intensity of the rainfall, allowing for accurate measurements of the drop size distribution and rainfall intensity. Figure 2 shows the schematic diagram of the disdrometer

The low-cost disdrometer developed is an impact disdrometer. The impact type is used to obtain observations of the drop-size spectra of rainfall. When a given raindrop hits the piezoelectric sensor, it converts the mechanical impact of the drop into an electrical signal, or pulse. With the calibration, the size of each pulse is interpreted as the diameter of the raindrop being observed. The RTC takes the time reading of the measure, and then the information is stored in the SD card for future reference. Following fabrication, the developed disdrometer underwent rigorous testing to evaluate its performance across a range of rainfall conditions. Laboratory experiments were conducted to assess the instrument's sensitivity, accuracy, and reliability in measuring drop size distribution and intensity. Additionally, field tests were

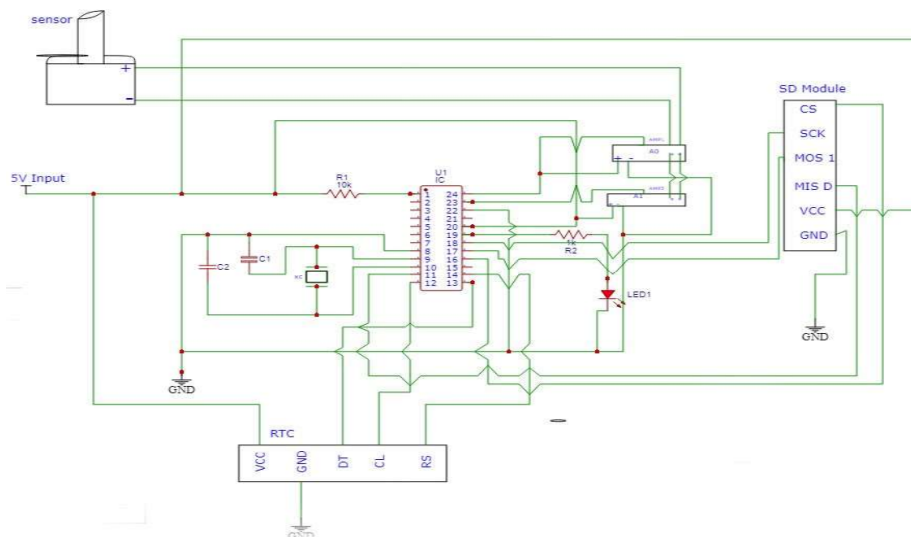


Figure 2: Circuit diagram of Low-Cost Disdrometer.

conducted to validate the disdrometer's functionality under real-world conditions.

### 3. TESTING AND PERFORMANCE EVALUATION

The testing of the disdrometer was conducted at the Department of Physics, Adekunle Ajasin University, Akungba Akoko. This location was strategically selected due to its accessibility and the prevalence of varied rainfall patterns, including light, moderate, and heavy rainfall intensities, which are critical for evaluating the instrument's response under different conditions. These diverse rainfall patterns provided an ideal natural environment for calibrating and validating the disdrometer. The raw data collected by the disdrometer included the time of each raindrop's detection and the corresponding signal amplitude from the sensor. This data was processed using a matlab script to compute droplet size distribution, rainfall intensity, and other relevant parameters. The rainfall measured were classified into categories, Table 1 shows the classification of rainfall based on drop diameter and rainfall rate

### 4. RESULTS

Parameters observed during the experiment to characterize precipitation are the raindrop size which is quantified using a piezoelectric sensor to detect individual raindrop impacts and rainfall intensity, evaluated based on the frequency and magnitude of the rainfall. Figure 3 show the dropsize of a rainfall event for a duration of about thirty minutes. The disdrometer measures the range of raindrop sizes, from small to large, and gives insight into the characteristics of the rain,. Initially, the plot shows small drops with diameters of less than 1 mm, indicating light rainfall at the beginning of the event. These small drops are typically associated with less intense rainfall, where the rain is scattered and the drops have not yet grown significantly due to the atmospheric conditions [8]. As the event progresses, the plot shows a transition toward larger raindrops, which signifies an increase in the intensity of rainfall. Larger drops (greater than 1 mm in diameter) are indicative of heavier rainfall, as they form when the smaller droplets coalesce and grow due to higher moisture content in the atmosphere or stronger updrafts within the storm [9]. This change from small to large drops aligns with the observed

Table 1: Classification of Raindrops Based on Drop Size and Rainfall Rate

Rainfall Category	Raindrop Size(mm)	Rainfall Rate(mm/h)	Description
Light Rain	Less than 0.5	Less than 2.5	Gentle, mist-like rain with minimal impact.
Moderate Rain	0.5 – 2	2.5 – 10	Steady rain with noticeable wetting and minor surface disruptions.
Heavy Rain	Greater than 2	Greater than 10	Large, rapidly falling drops, leading to pooling, localized flooding, or both.

### Plot of drop diameter against time

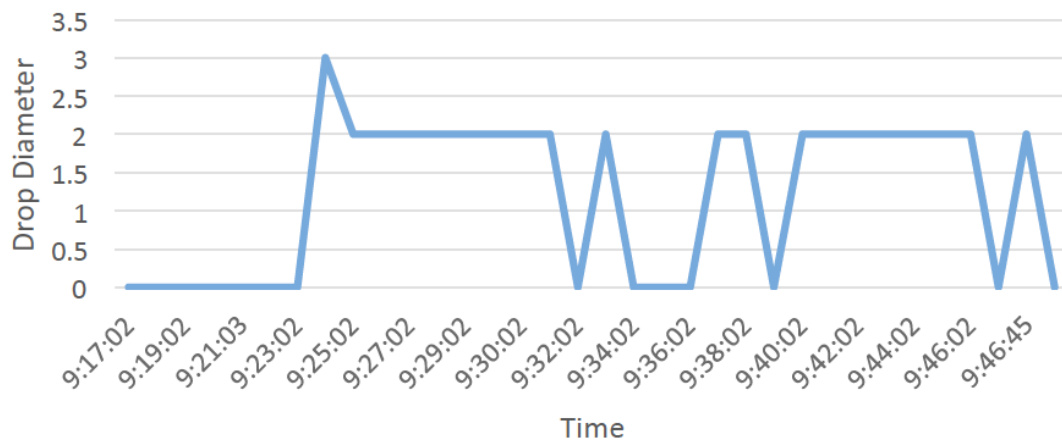


Figure 3: Graph Showing Drop Diameter against Time.

intensification of the rainfall in the latter stages of the event. Moreover, the plot reveals an interval break in the rainfall, which can be seen by a temporary reduction in the drop size distribution. This gap in rainfall might suggest a brief pause in the precipitation or a decrease in the intensity, possibly due to local weather dynamics like a reduction in atmospheric instability or changes in wind patterns [10]. After this break, the occurrence of larger drops resuming further confirms the variability in rainfall intensity, indicating that the event was characterized by varying rainfall rates.

The rainfall rate was assessed by evaluating the frequency and magnitude of raindrop impacts, offering a comprehensive understanding of the rainfall's overall strength and behavior. Rainfall rate is calculated based on the number of raindrops hitting the sensor per unit of time, which reflects both the intensity and volume of rainfall over a given period. Figure 4 shows the relationship between rain rate and drop size, with values ranging from about 2 mm/hr to 40 mm/hr, highlighting different precipitation characteristics. At the lower end of the range (around 2 mm/hr), the rainfall is relatively light, which corresponds to a predominance of small drops (typically less than 1 mm in diameter). These smaller drops are associated with light rain events, where the frequency of impacts is lower but the drop size remains small. As the rain rate increases toward 40 mm/hr, the drop size also increases, which is indicative of more intense rainfall. Larger drops, often

greater than 1 mm in diameter, fall at a higher rate, suggesting stronger precipitation associated with more substantial atmospheric moisture and stronger convective processes [9,11]. This correlation between rain rate and drop size is typical of tropical rainfall events, where rapid changes in intensity are observed due to the dynamic nature of the atmosphere. Figure 4 also reveals that as the rain rate increases, the distribution of drop sizes becomes wider, with more frequent occurrences of larger drops. This behavior is often observed in convective storms, where updrafts promote the growth of raindrops by colliding smaller droplets, resulting in larger and more frequent impacts on the sensor [10].

#### 4.1. Comparative Analysis

The measured raindrop size distribution was compared with modeled raindrop distributions for both moderate and heavy rainfall events. For moderate rainfall, the raindrop sizes ranged from 0.5 mm to 2 mm in diameter, while for heavy rainfall, the drop sizes were greater than 2 mm. Figures 5a and 5b show the observed raindrop size distributions for both moderate and heavy rainfall events, with the moderate rainfall showing a high correlation coefficient of 0.97 and the heavy rainfall showing a lower correlation coefficient of 0.8. The high correlation for moderate rainfall suggests that the measured is closet to the model's prediction for the distribution of smaller raindrops, while the lower correlation for heavy rainfall points to the increased

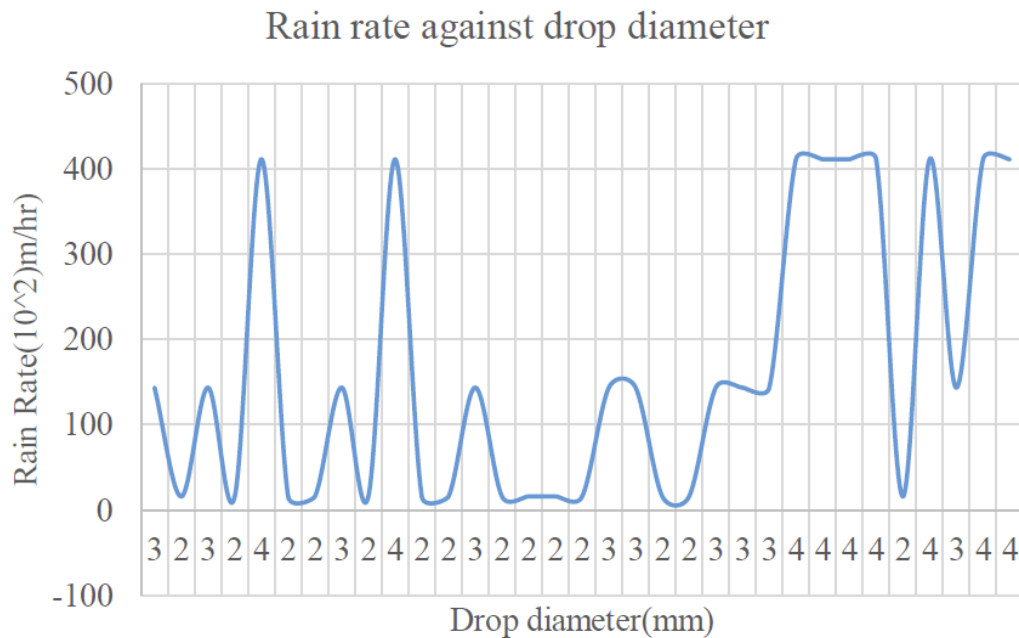
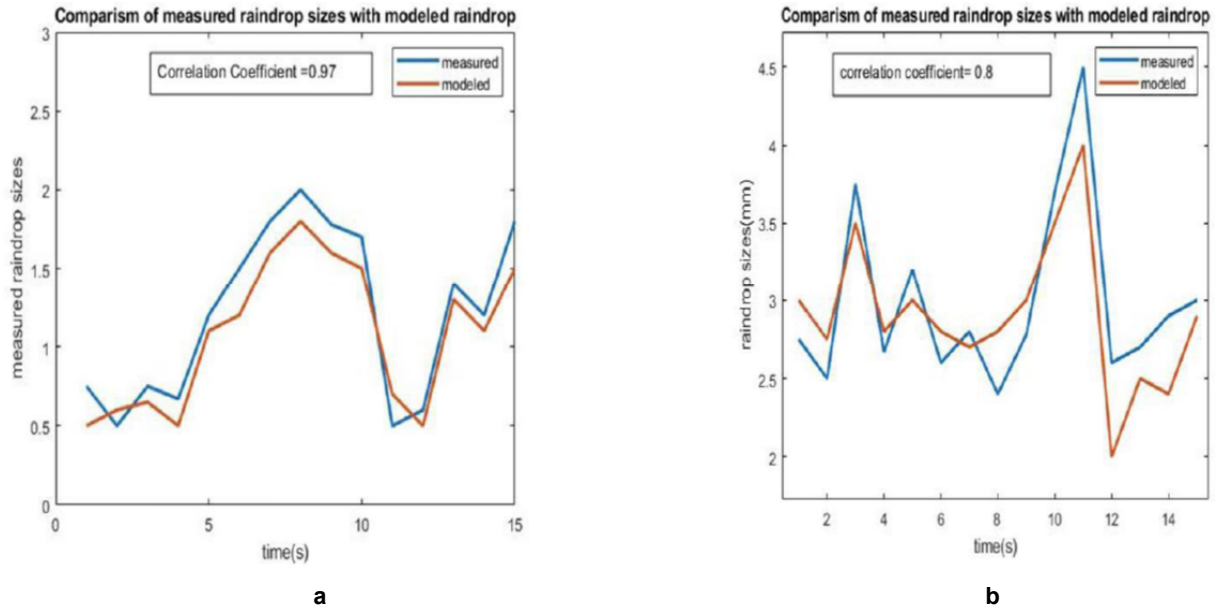


Figure 4: Graph showing result for rain rate.



**Figure 5:** Comparison of measured and modeled raindrop sizes for (a) moderate rainfall type, (b) heavy rainfall type.

complexity of modeling larger drops, which are influenced by more dynamic atmospheric conditions and interactions between droplets.

## CONCLUSION

This study demonstrated the feasibility of developing a low-cost disdrometer for rainfall characterization using widely available components. The device successfully captured key rainfall parameters such as droplet size distribution and rainfall intensity, with performance comparable to commercial systems under most conditions.

The total cost of the locally made disdrometer was approximately \$50, significantly lower than commercial systems, which can range from \$5,000 to \$20,000. and the low-cost disdrometer demonstrated reliable performance in most conditions, however some limitations were observed such as its sensitivity to small droplets (<0.5 mm) thus data during light rain fall conditions was not obtainable. It is also crucial to consider potential sources of error such as wind effects, splash effects, and calibration inaccuracies. Strong winds can distort velocity measurements, while secondary drops from splash effects may lead to skewed drop counts. Additionally, improper calibration should be done to ensure the reliability of the data, regular quality control analysis should be performed, Implementing these measures will enhance the accuracy and performance of the disdrometer for local applications.

However while there are areas for improvement, particularly in the sensitivity to light rain and weatherproofing, the low-cost disdrometer offers a promising alternative for researchers in resource-limited regions by significantly improve the accessibility of rainfall data for various applications, including weather forecasting, hydrology, and radio frequency communication studies, particularly in tropical and subtropical regions.

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