Development of a low cost disdrometer using piezo-buzzer as a sensing device

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Abstract. Using approaches ranging from manual rain gauges to rain drop counting to satellite-based precipitation, numerous research investigations have been conducted to better understand rainfall. The work reported here focuses on the construction of a low-cost Disdrometer that uses a piezo-buzzer as the sensing unit to measure and log rain rate in real-time for drop sizes ranging from 0.5 mm to 5.5 mm. The sensor unit, microcontroller, logging section, DS3231 (RTC), display unit, and power supply unit make up the instrument. For calibration of the Disdrometer, two methods were employed namely: an experimental calibration setup and field instruments. To validate the performance of the developed Disdrometer, the Micro Rain Radar (MRR) and Davis weather instruments were used. The developed Disdrometer reproduced very well the rain rate and rain drop sizes measured by Micro Rain Radar (MRR).

Keywords: Rain drops, rain gauges, operational amplifier, sensing unit, calibration, Disdrometer.

1. Introduction

Rainfall is a dynamic process that changes in form and intensity throughout time. Because water is such a valuable resource, several studies have been conducted to better understand rain. Sensing and measuring rain kind and amount aids man in developing a physical and dynamic description of rain, allowing him to get a better understanding of the environment and prepare for potential environmental disasters such as drought, flooding, and earthquakes. However, due to the nature and variety of precipitation, understanding and modeling its physical properties and behavior is difficult. The total volume of rain, rainfall rate, and drop size distribution are the parameters that explain the type of rainfall. [1]. The investigation of these parameters aids in the development of a physical and dynamic description of rain, as well as a better understanding of its impact, intensity, and energy [2]. Since the 17th century, measurement of rainfall in a scientific sense has been conducted. Rainfall measurement has been done scientifically since the 17th century. Mechanical recording gauges, electrical rain gauges, and drop-counting gauges are some examples of measurement approaches [3]. Consequently, this work exploits existing technology for the development of a low-cost piezo-buzzer Disdrometer for measuring rain drops for research purposes.

2. Review of Relevant Literature

[4] provided one of the oldest reports of raindrop measurement, in which the diameter of the spots generated by drips falling on sheets of slate was measured, but no attempt was made to link these "slate" dimensions to actual drop diameters. Following the presentation of Lowe's article, the discussion was also published, and it was revealed that a scheme to measure drips falling on chemically prepared paper had previously been proposed. However, until [5] used it to measure the size of droplets in tropical rain, this method was not extensively employed. Raindrops
were permitted to fall freely on the surface of the dye-impregnated filter paper [6], and raindrop velocity was measured. During the same years that Laws and Parsons were doing their research on raindrop sizes, cloud and precipitation physics grew in importance. During the same years that Laws and Parsons were doing their research on raindrop sizes, cloud and precipitation physics grew in importance. The diameter of a raindrop, D, is a distinguishing feature in many applications which is still being studied [7-10]. The two most statistically viable relationships for differentiating a rain event are the relationship between D and the corresponding rain rate (RR) [7], as well as the whole drop size distribution (DSD) of the rainfall. [11] proposed that the significance of D in the total RR is not only limited by the number of raindrops but also by their variation and composition within a storm, which varies from region to region [12].

2.1 The Piezoelectric Transducer

On application of pressure, piezoelectric device outputs voltage. According to Newton's second rule of motion, when motion is imparted, seismic mass loads the piezoelectric material. The direction of the applied force determines the polarity of the charge.

\[ \text{Charge, } Q = d \times F \ (\text{Coulomb}) \]
\[ d - \text{Crystals' charge sensitivity} \]
\[ F - \text{Force exerted, where } A - \text{Crystal Area, } E – \text{Young’s Modulus and } t - \text{Crystal Thickness} \]

\[ E = \frac{\text{stress}}{\text{strain}} = \left( \frac{F}{A} \right) \frac{1}{\Delta t/t} \]

3. Research Method

3.1 Design principle

To accomplish the goal of this work, the device's electronic circuit was examined, constructed, and assembled using easily accessible components and each piece was connected. The created Disdrometer is divided into two major sections: hardware and software. The arduino Integrated Development Environment (IDE) and proteus software as a circuit simulator are included in the software section, while the hardware interface contains a sensor unit, an amplification unit, a filtering section, and the microcontroller unit.

3.1.1 Sensing Unit

A piezoelectric disk and a conical-shaped hat make up the device sensing unit. The gadget employs a piezo-buzzer transducer to gather energy generated by raindrop impact, with the sensory apparatus consisting of a piezoelectric sensor amplifier for transduction. It generated an output voltage proportional to the impact of the raindrops. The sensing element's output was supplied into the operational amplifier, which amplified the low input voltage to produce a high output value. The analogue signal is transformed to a digital signal in the microcontroller via the Analogue to Digital Converter (ADC), and the measured values are shown on the Liquid Crystal Display (LCD). The piezoelectric disk has a diameter which fits perfectly for the measurement of raindrop sizes, while the hat which serves as a protector to prevent corrosion guard. Piezo-buzzer was used based on its ability to generate voltage signal on application of pressure on its surface. When rain drops hit the sampling area of the sensor, an electrical signal is generated which is filtered, amplified, and then converted into digital signal by the ADC for the microcontroller to process. The produced voltage is then fed to the amplification unit. The sensing unit produces voltage in proportion to the rate of impact of the drop sizes. When no precipitation particle was detected, the set minimum threshold of 0.08 in the instrument is maintained. The Arduino UNO ATmega328 microcontroller is at the heart of the core unit, which has been utilized by numerous writers for a variety of projects. The Arduino Integrated Development Environment (IDE) software was used to program, compile, test the device circuit for analyzing the amplified analog input signal from the sensing unit, the data is displayed and recorded on a Secure Digital (SD) card as represented in the block diagram below (Figure 1).
4. Results
A performance test was carried out for its calibration utilizing a comparison of rain rate and drop size distribution measurements with MRR and Davis625 weather stations. The obtained results from the two instruments are herein presented. The characteristic equations obtained is $y = 1.0069x - 0.0146$ (Figure 2). The designed Disdrometer was placed at various locations around the field to monitor rain drop sizes and rates. It was observed that the developed instrument’s measurements compared favourably to that of MRR and Davis 625 weather station. Table 1 show the measurement obtained from a tower setup for a 3 mm burette tip used for rain drop simulation. A 3 mm burette tip was selected because it is the average burette tip size in the arrays of tips used for rain drop size simulation since lower burette tips kept drifting away before reaching the ground due to air resistance and drag force at terminal velocity. To achieve maximum impact, it was first placed at a height of 3 m directly above the surface of the intended sensor. Thereafter, the height was varied to 4 m, 6 m, and 8 m. It was observed that smaller drops couldn’t hit the surface of the designed sensor due to air resistance. In Table 1, the burette size (3 mm) along with the equivalent output voltage (mV) generated by the designed sensor (Piezoelectric disk) upon impact were recorded. The mean value was computed and a value of 0.056657224 was obtained. The value obtained was computed into the program as correction factor for drops lower than 3 mm.

Table 1: Experimental 3 mm Burette Size Measurement

| Burette tip size (mm) | Voltage output (mV) |
|-----------------------|---------------------|
| 3.00                  | 53.16               |
| 3.00                  | 52.89               |
| 3.00                  | 53.67               |
| 3.00                  | 53.06               |
| 3.00                  | 53.45               |
| 3.00                  | 52.39               |
| 3.00                  | 51.99               |
| 3.00                  | 53.05               |
| 3.00                  | 52.89               |

Mean value 52.95

Conversion factor (mm/mV) 0.056657224
Table 2 shows the rain rate measurement comparison between the developed Disdrometer and Davis 625 Weather Station. The rain rate measured in mm/hr was repeatedly measured and absolute deviations in measurement from the instruments were calculated so that the developed Disdrometer could be re-calibrated. The inconsistent deviation in the measured rain rate of the two instruments was due to inability to totally eliminate external interferences (environmental noise) at drop diameters lower than 1 mm. As seen in Table 2, the highest deviation recorded by the logger was 0.5; hence, a correction factor was generated in the software by using the sensitivity value of the analog-to-digital converter (0.1875) coupled with a 100 Ω resistor in parallel with the sensor. To minimize the interferences further, a resistor of 1Ω with tolerance of 0.1 % may be connected to the piezo-buzzer output [13]. A resistor of such characteristics was unavailable at the time of this research work.

Table 2: Comparison of the rain rate data obtained from the developed Disdrometer and Davis 625 Weather station

| S/N | Davis 625 Weather Station | Developed Device Rain | Absolute Deviation |
|-----|----------------------------|-----------------------|--------------------|
|     | Rain Rate (mm/hr)          | Rate (mm/hr) Measurement |
| 1   | 3.00                       | 3.13                  | 0.13               |
| 2   | 2.43                       | 2.56                  | 0.13               |
| 3   | 2.06                       | 2.16                  | 0.16               |
| 4   | 2.01                       | 2.24                  | 0.23               |
| 5   | 1.89                       | 2.10                  | 0.10               |
| 6   | 1.40                       | 1.56                  | 0.08               |
| 7   | 0.59                       | 1.03                  | 0.22               |
| 8   | 0.31                       | 0.33                  | 0.01               |
| 9   | 0.20                       | 0.31                  | 0.05               |
| 10  | 0.19                       | 0.20                  | 0.01               |

Figure 2 shows the graph of correlation of the developed instrument and Davis 625 weather station. The data obtained for the month of October showed drop diameters less than 4 mm as seen on the graph with dotted lines representing the Davis 625 weather station and circles representing the developed Disdrometer. Clusters were observed at drops less than 1.0 mm for the developed Disdrometer due to the sensitivity of the grove piezo amplifier not being able to simultaneously measure both high and low rain drop sizes when the potentiometer is turned anticlockwise. When this was observed, the sensitivity was first tuned appropriately to its positioned as described by the manufacturer. This was later corrected in the program by multiplying the output reading from the sensor with the sensitivity value of the analog-to-digital converter used coupled with a 100 Ω resistor connected in parallel with the output of the piezoelectric sensor. Figure 3 shows the correlation graph of the developed disdrometer and davis 625 weather station after computation and sensitivity correction.

Figure 2: Correlation Graph of the Developed Disdrometer and Davis 625 Weather Station
Figures 4, 5 show the log-normal curves for the drop size distribution against drop diameters of the developed Disdrometer and MRR for the month of July, 2019 respectively. The composition of raindrop diameters as a function of volumetric diameters per unit volume of space is usually expressed as a rain event. Because DSD covers differences in the components of raindrop sizes, it's a good place to start a developed Disdrometer with an integration time of 1 second of data processing was used to compute the lognormal variation as seen in Figures below. The values shown on the vertical axis indicate the tallies of the raindrops recorded, while those on the horizontal axis indicate the drop diameters recorded. The values presented are in their log forms. A deviation in data obtained was visible in drop diameters higher than 2 mm and lower than 3 mm due to similarities in output reading which resulted in data normalization in the developed Disdrometer. The maximum tally recorded in the developed Disdrometer was a bit higher than 100 since the integration time of 1 second was used and the sensitivity of the piezoelectric transducer was not fast enough to capture at a much faster rate. Figure 4 shows a close tally of measurements between 0.1 mm and 1.7 mm on the 9th of July, 2019; while discrepancies were observed between 0.3 mm and 1.3 mm on the 11-07-19 as the sensitivity of the piezo amplifier was decreased further to eliminate noise.

On the 13th of July, 2019, a much better measurements were taken due to adjustment in the timing sequence of the program. The log of the data obtained was calculated to obtain a relationship between the developed and the Davis 625 weather station. It was observed that the developed instrument performed favourably as the standard instrument with a deviation of 0.20 in output.
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Figure 5: DSD Curve for the developed Disdrometer and Micro Rain Radar (MRR) for 11th of July, 2019.

5. Conclusion
This research has produced an efficient low cost Disdrometer which operates smoothly on a solar powered system, utilized a digital display (suitable for field measurement), and an integrated data logging system suitable for future research purposes. The developed instrument is inexpensive, easy to maintain, service, and repair when faulty. The Disdrometer's calibration revealed a definite relationship between a drop's signal energy and its size. The performance evaluation shows that its continuous measurement can be used to analyze rain parameters such as DSD and RR which can be useful for prediction of soil erosion, microwave communication, traffic control, and many more.

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