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Development and Performance Evaluation of a Portable Rainfall Logger for Small-Scale Farming Applications

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ABSTRACT
Understanding the rainfall pattern of a location can assist farmers in selecting appropriate crop types and optimizing planting schedules. A portable rain gauge logger was designed and constructed for use on small farms to monitor rainfall patterns. The system employs a locally fabricated tipping bucket mechanism, an ATmega328P microcontroller, and an SD card module for real-time data logging. To time stamp the logged data an RTC chip was incorporated. The instant value is also displayed on LCD. The primary objective was to provide farmers with an affordable and reliable solution for capturing rainfall data to optimize planting and irrigation decisions. The fabricated rain gauge was tested against a standard reference rain gauge, and the performance evaluation revealed a percentage error of 11.47%. This level of accuracy demonstrates the potential of the designed device for practical agricultural applications, particularly in resource-constrained environments. The portable rain logger offers a viable tool to empower farmers with localized meteorological data, thereby aiding strategic farm management and enhancing crop yields.

Keywords: Rain gauge, irrigation, logger, tipping bucket, agriculture

I. INTRODUCTION

Climate change is inevitable, especially with humanity's insatiable quest for an improved "quality of life" (IPCC, 2021; NASA, 2022). This unquenchable taste has drastically accelerated the rate at which our globe warms (UNEP, 2022). Rainfall is one of the key parameters of climate, especially from an agricultural perspective (World Bank, 2020). There is a direct relationship between rainfall and agriculture, as it is responsible for most of the water used by plants either directly or indirectly (FAO, 2019). This is the reason all countries of the world are concerned about the effects of climate variability on agriculture (Pendilo, 2017; Lobell et al., 2008).

Crop production largely depends on the regularity and pattern of rainfall in a place. The knowledge of the rain profile of a location could guide and help farmers in selecting suitable types of crops and scheduling planting activities (Hatfield & Prueger, 2015). Kyei-Mensah et al. (2019) reported that the net potential effect of severe changes in rainfall pattern in Ghana is the disruption in crop production, which he believed has increased food insecurity, joblessness, and poverty (Sultan & Gaetani, 2016). Ajetomobi (2016) observed that both temperature and precipitation extremes can result in wide fluctuations of Nigeria's crop production, which could make crop prices unstable, and thus negatively impact Nigeria's agricultural sector as well as food consumers (Ajetomobi & Abiodun, 2010).

In fact, Akinboade (2012), the Director General of the Nigerian Meteorological Agency, identified extreme weather conditions as one of the reasons for Nigeria's underdevelopment (NIMET, 2015). Kyei-Mensah et al. (2019) also claimed that rainfall variability affects the production of traditional crops, increases crop disease incidents, and causes drastic reductions in soil fertility (Zhao et al., 2017). Rain is usually seen as beneficial to crops and fields, but there is an "ideal" amount of rainfall during any given growing season for most crops (Gornall et al., 2010).

Additionally, analysis of recent rainfall conditions in West Africa suggests long-term changes in rainfall patterns within the semiarid and sub-humid zones (Nicholson, 2013). Also, the mean number of rainy days has significantly reduced throughout the different seasons in West Africa (Dunning et al., 2018). Rainfall is also a

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good indicator for predicting common crop diseases, as it can affect the spread of pathogens and pests (Chakraborty & Newton, 2011). Rain can spread pathogens, pests, and other diseases to plants, leading to massive diseased crops. This could affect yield or cause the entire field to become unusable (Rosenzweig et al., 2014).

Knowing when to water, preventing disease and mold, and ensuring the soil is kept at the right moisture level are all components of the overall goal of crops and their farmers: to achieve the highest crop yield possible (Wheeler & von Braun, 2013). The right amount of rainfall can balance out these factors, which can lead to healthier, larger crops that can be harvested more fully. This helps farmers know what is best for their crops without having to manually estimate or make an educated guess. With better data being fed live from their own crops, farmers can make the best possible decisions for planting, watering, and pest control (Lobell et al., 2011).

In this paper, a portable precipitation logger is presented. The logger is intended to assist farmers in keeping the rainfall profile of their land, thereby providing them with information on rain patterns to strategize planting activities. It is designed for use in farms to enable a farmer to maintain a record of rainfall in a particular area. The gadget records the amount of rainfall and the time/date of rainfall, and the record can be retrieved for analysis.

II. METHODOLOGY

Design and Construction of Tipping Bucket Rain Gauge

For the rain (precipitation) measurement, a tipping bucket rain gauge was designed and constructed. The blocks diagram of the device is presented in Figure 1. The tipping bucket serves as the sensor of the rain amount. The amount of rain collected (tipping count) is converted to electrical pulses using an encoder. The counts are fed into a microcontroller that logs the data in a memory. An LCD is used to display some vital information. Appropriately rated power supply is designed to power all the sections.

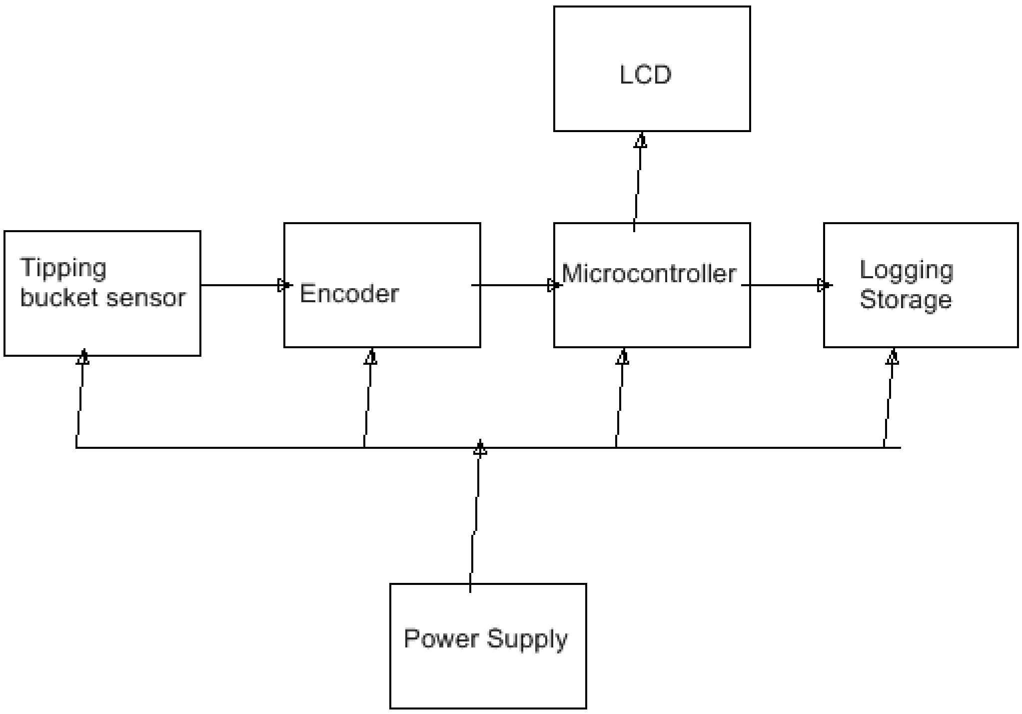

Fig 1. Block diagram of the system

The tipping bucket rain gauge consists essentially of a funnel that collects and channels the precipitation into a small see-saw-like container. The container is designed in such a manner that it tips after it has gathered a pre-set amount of water. The seesaw shaped container is shown in Plate 1.

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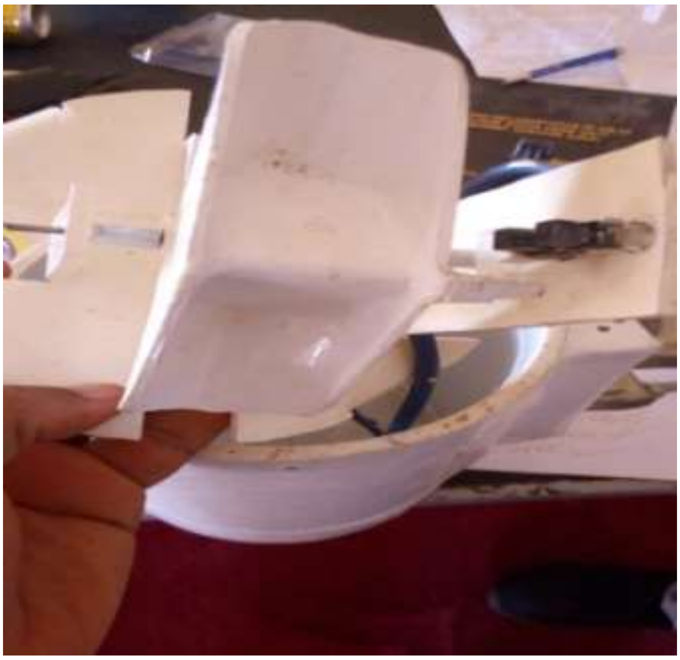

Plate 1: See-shape of tipping bucket

It is fabricated such that from the outset one receptacle is tilted relative to the other, placing the two receptacles at different elevations. The receptacle at the higher elevation fills up with precipitation, and when filled up, its weight is enough to force it to tilt, moving into a lower elevation, discharging its content, and at the same time causing the opposing receptacle to move to a higher elevation to accumulate precipitation. The amount of precipitation dumped by the alternate tipping actions of the receptacles can be evaluated if the number of tips is known.

The tips were converted to electrical impulses using a scheme similar to that implemented for the anemometer. To achieve this, a spindle was attached to the receptacles in such that whenever it tips the spindle interrupts beams of light transmitted by a LED in an optical encoder circuit as shown in Figure 1.

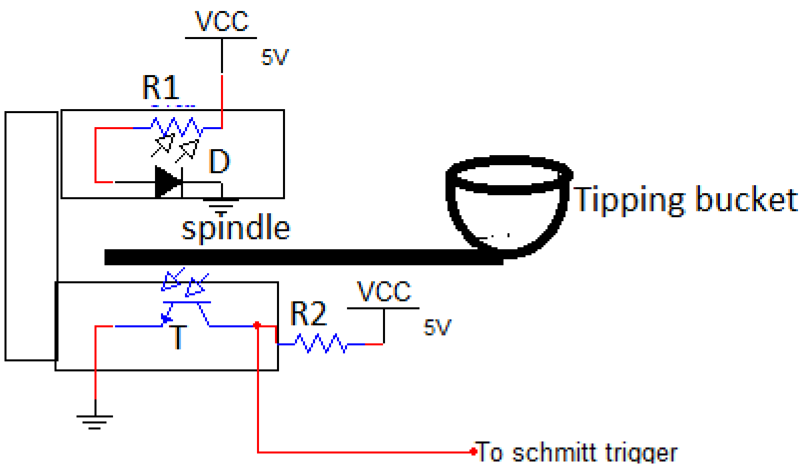

Figure 1: Circuit diagram of the tipping bucket encoder

To interface the number of tips with the microcontroller a digital logic train propagated at a speed proportional to the frequency of tipping was achieved by including an optical interrupter. The circuit of optical interrupter normally depends on the detection or interception of the continuity or discontinuity of light between two points. In this design LED was used to serve as the source of light to be detected by a phototransistor circuit to indicate changes in logic states. The anemometer was coupled to a plastic arm that either blocked or allowed the light generated by the source to impinge on the detector. As the shaft rotates, the arm caused interruptions of the light beam, causing a pulse waveform to be generated at the output of the phototransistor.

An internal photo detector senses the alternating light beams and the encoder's electronics convert the pattern into an electrical signal that is then passed on to an external system. To protect the forward-biased diode in the optical assembly, a resistor R1 was connected. As a current limiter a resistance value of 100 Ohms was considered adequate.

The photo-detector used is phototransistor. A 1k resistor is used as the load resistor. The transistor conducts if light generated by the LED shines on its base, pulling its collector to logic 0. On the other hand whenever the tipping arm blocks the LED, the transistor is cut off, and the collector potential rises to a voltage level dictated by the supply voltage. The consequence of this is the generation of a pulse train whose frequency is directly proportional to the number of tipping and by extension to amount of rainfall.

The IR LED current was fixed at 100 mA at a forward voltage of 1.1 V. The decision was based on the suggestion that when an LED diode is operated on a continuous mode the current should not exceed 200 mA and 1 A when pulsed (Ryer,1998)

The supply voltage, V_L, to the LED is 5 V so that:

$$R_1 = \frac{\text{VL} - \text{Forward diode voltage}}{\text{IR LED Current}}$$

$$R_1 = \frac{5-1.1}{0.1} = 39\ \Omega$$

For the collector resistance of the receiving phototransistor, the value was evaluated by allowing for a drop of 1 V as the Knee voltage and 10 mA for the collector current. Therefore,

$$R_2 = \frac{5\text{ V} - 1\text{ V}}{10\text{ mA}} = 400\ \Omega$$

The microcontroller used requires voltage inputs that are fast edges on the high and low transitions. To sharpen the edges of the pulses generated, a Schmitt trigger circuit was incorporated. The Schmitt converted the varying signal voltage into one of two possible binary states, depending on whether the voltage is above or below a preset threshold value.

The Schmitt trigger IC used is the 74HC14 CMOS device. The 74HC14 is ran on +5v, with thresholds of typically 2.4 V and 1.8 V (Texas Instruments, 2019). The pin configuration and logic symbol of the 74HC14 Schmitt trigger is as shown in Figure 3.8. Pins 14 and 7 serves as the + supply and ground terminals respectively.

The conditioned output was connected to I/O bit 3 of PORT B on the Atmega1284 microcontroller.

Calibration of the Tipping Bucket Rain Gauge

To calibrate the fabricated rain gauge, a reference type was used. The two gauges and fabricated) were placed in the open in a way that they measure the same amount of rainfall. The experiment was performed at the Electrical Department of Umaru Ali Shinkafi Polytechnic, Sokoto, Nigeria on the 12^{th} of August 2016. The number of tips by the two was recorded in Table 1 as T_r and T_f. Each tip of the reference gauge corresponds to 0.2794 mm quantity of rainfall.

Since the two gauges were placed close to each other and the counts taken at the same time it was assumed that the amount of rain measured by the two gauges should be approximately equal. The amount of rain measured by the reference rain gauge can be evaluated as the product of the number of its tips (t_r) and 0.2794 mm. By the same thinking the amount of rain measured by the fabricated meter can be evaluated as the product of the number of its tips (t_f) and a constant say C. Since both rain gauges recorded the same amount of rain it then follows that:

$0.2794 t_r = C\ t_f$.

Substituting for the values of t_f and t_r from Table 1 constant C was evaluated as:

0.2794 x 3258 = 1926 x C

So that C = 0. 47263 mm.

This means each tip of the fabricated gauge is equivalent to 0.47263 mm. Every second the main program of the microcontroller reads the number of tips in the rain gauge register, multiply it by the constant 0.46263 mm and saved as the rain for that second.

Table 1: The result of the number of tips by rain gauges

Type of rain gauge	Number of tips for the given water quantity
Reference	3258
Fabricated	1926

Following the fabrication of the rain gauge sensors, it was interfaced with the microcontroller to enable signal conditioning necessary for logging and presentation. This was done based on the electrical signalling capabilities of the sensor so fabricated. The rainfall sensor produces discrete output pulses that were directly measured using the hardware interrupt features of the Atmega1284p microcontroller.

To evaluate the performance of the fabricated rain gauge, a reference (TPJ-32, ZhejiangTop Cloud-Agri Technology) and the fabricated rain gauges were placed side by side in the rain to measure the rain fall for some time. The rain fall measured by the two were recorded. The heart of the system is the AVR microcontroller. The 40pin dip is used to control the activities of all other sections. Atmega1284p microcontroller was selected due to its good features of being cheap and readily available in the market it also has high performance low power consumption 8 bit operation with 130 powerful instructions. In terms of peripherals it has two 8-bit Timer/counters with separate pre-scalers and compare modes, one 16 – bit/counter with separate prescaler, compare mode, and capture mode, four – PWM channels and 8 – channel, 10 - bit ADC internally, programmable serial USART and master/slave SPI serial interface. It has On-chip Analogue comparator.

The microcontroller datasheet recommends two separate voltage lines for the IC, one for the Digital signal circuit and the other for analogue signal. The ADC requires analogue voltage and it is suggested that the value should not differ from the V_{cc} by + O. 3V. Since V_{cc} = 5V, it was connected to the analogue voltage terminals of the IC. A capacitor of 100 nF was connected between the analogue supply terminals of the chip to ensure analogue noise cancelling in the circuit.

Pins 12 and 13 of the microcontroller serves as the crystal input and output of an inverting amplifier and it is configured as an On-chip oscillator. A crystal of value 32.768 KHZ was used as the oscillator. The data was configured to be logged in an SD card.

For long-term historical storage of environmental data, a rugged and high-capacity storage medium was required. Based on the requirement for easy interfacing with a PC system, a Secure Digital (SD) card was used. The Secure Digital Card is a FLASH-based memory card. The SD Card communication is based on an advanced nine-pin interface (Clock, Command, 4 x Data and 3 x Power lines) designed to operate in a low voltage range.

The SD Card includes an on-card intelligent controller which manages interface protocols, security algorithms for copyright protection, data storage and retrieval, as well as error Correction Code (ECC) algorithms, defect handling and diagnostics, power management and clock control. The high-capacity card was interfaced via PORTB of the Atmega1284p as it features the hardware SPI communication interface. The microcontroller was set up as the master device, the card being the slave device. This interface provided the access required to create, modify, or delete files on the SD card. To minimize power consumption when the card is not being accessed, and to enhance robustness against electrical faults, the card was power applied, with power connected to the card only when being accessed. The voltage requirement of the device is 3.3V. This was derived from the DC supply using a linear series voltage regulator designed around a LM317 adjustable voltage regulator.

It is necessary to present the status of the monitoring system to a user, and a liquid crystal display (LCD) comes handy in this respect. There are many different LCDs available, but for this system an alphanumeric LCD with four lines of 20 characters in each line (LM2022) was used. Data-transfer between the microcontroller and the LCD module using 4-bit interface mode required four data lines dictated that the data is transferred as two 4-bit nibbles.

Four bits were used to communicate between the LCD device and the microcontroller. The upper nibble pins (11, 12, 13, and 14) were used to transfer the 4-bit data between the microcontroller and the LCD. A variable resistor was provided to adjust the amount of current into the LCD. The value as recommended in th e datasheet is from 10k to 30k. For this purpose, a

10k variable resistor was used. Pin 4 serves as the enable pin of the LCD.

The requirement to time-stamp measured parameters demanded the need to have a high-accuracy timekeeping management scheme. This was designed around the DS1307 RTC chip. The DS1307 Serial Real-Time Clock is a low-power; full binary-coded decimal (BCD) clock/calendar with 56 bytes of SRAM interfaced. Address and data are transferred serially via a 2-wire, bi-directional bus.

The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power sense circuit that detects power failures and automatically switches to the battery supply.

III. RESULT AND DISCUSSION

The result of the comparison test obtained from the test to compare the reference rain gauge and the fabricated one is presented Table 2.

Table 2: Rain gauge performance test result

Rain measured by fabricated rain gauge (mm)	Rain measured by reference rain gauge (mm)
0.54	0.61

Percentage error = $\frac{0.61-0.54}{0.61}$ = 0.07/ 0.61 = 11.47%

The result of the test to compare the accuracy of the fabricated rain gauge and a reference showed an error of 11.4%. The relatively large error could be as a result of calibration or frictions in the mechanical parts of the rain gauge. Another possible source of error could be due to approximations during calculations. The results of calculations were rounded up to two decimal places.

The goal of the project was to develop a low-cost, portable rain gauge logger suitable for small-scale farms. The design incorporated a locally fabricated tipping bucket, an ATmega328P microcontroller (widely used due to its low power consumption and reliability), and an SD card to store rainfall data with time and date stamps. This choice of components aimed to ensure affordability, ease of replication, and practical usability by local farmers.

The performance of the fabricated rain gauge was evaluated by comparing its readings to those of a reference standard rain gauge. The fabricated device recorded 0.54 mm of rainfall, whereas the reference rain gauge measured 0.61 mm under the same conditions. The computed percentage error was 11.47%**,** which, while not negligible, falls within acceptable limits for many agricultural applications, particularly where high-end meteorological equipment is not accessible.

Several factors could contribute to the observed error. First, fabrication tolerances in the tipping bucket mechanism could cause slight discrepancies in the bucket’s tipping volume. Second, environmental factors such as wind or evaporation could slightly affect the rainfall collected, especially if the rain gauge's funnel design is not perfectly optimized. Third, calibration errors in the sensor or the tipping mechanism could also influence measurement accuracy.

Despite these minor inaccuracies, the logger successfully met its intended purpose: providing small-scale farmers with a real-time, accessible means of monitoring rainfall. The device’s ability to store data on an SD card allows farmers to analyze rainfall patterns over time, aiding decisions on crop selection, irrigation scheduling, and planting strategies.

In future iterations, improvements such as better bucket calibration, use of more sensitive reed switches, and inclusion of wireless communication modules (e.g., Bluetooth or LoRa) could enhance the precision and usability of the device. Overall, the project demonstrates a cost-effective and practical solution for empowering farmers with critical meteorological data, promoting more efficient farm management, and potentially improving agricultural productivity.

IV. CONCLUSION

The design and construction of a portable rain gauge logger using a locally fabricated tipping bucket, ATmega328P microcontroller, and SD card module have been successfully achieved. The device demonstrated its capability to accurately record rainfall amounts with an acceptable percentage error of 11.47% when compared to a standard reference rain gauge. This level of precision is sufficient for many agricultural applications, particularly for smallholder farmers who require affordable and reliable weather monitoring tools.

The logger provides a practical solution for farmers to collect localized rainfall data, enabling better decision-making regarding planting schedules, crop selection, and irrigation management. By empowering farmers with accessible and reliable meteorological information, the system contributes to increased agricultural productivity and improved farm resilience against climate variability.

Overall, the fabricated rain gauge logger shows promising potential for adoption in small-scale farming communities. With minor improvements in calibration and design refinement, the device could achieve even greater accuracy and functionality, further enhancing its value as a farm management tool.

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