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Restoration and Upgrade of Defective KIPP and Zonnen Pyranometer for Enhanced Data Acquisition in Sokoto Energy Research Centre, Sokoto

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ABSTRACT
The accurate measurement of solar radiation is essential for solar energy research and system efficiency analysis. This research focused on the restoration and upgrade of a defective Kipp&Zonenpyranometer at the Sokoto Energy Research Centre to enhance data acquisition and reliability. A modernized readout system was designed and constructed, incorporating real-time data logging, time and date functionality, Bluetooth accessibility, and SD card storage for improved data management. The system also features an LCD for real-time visualization of solar radiation values. The upgraded pyranometer ensures accurate, reliable, and accessible solar radiation measurements, contributing to improved research output and system performance at the research center. The successful implementation of this project demonstrates the potential for modern technology to enhance the efficiency and functionality of solar measurement instruments.
Keywords: Kipp & Zonnen, Pyranometer, Readout, Solar Radiation

I. INTRODUCTION

Solar energy is one of the most abundant and sustainable sources of renewable energy, with an estimated global potential exceeding 173,000 terawatts (TW) more than 10,000 times the world's total energy consumption (Smil, 2017). Accurate measurement of solar radiation is crucial for evaluating the performance and efficiency of solar energy systems. Pyranometers are widely used for measuring global solar radiation; however, the efficiency and accuracy of these devices can deteriorate over time due to hardware malfunctions or outdated technology (Reda & Andreas, 2008).

The Kipp&Zonenpyranometer at the Sokoto Energy Research Centre, Sokoto, had become defective, leading to inaccurate and unreliable solar radiation measurements. This posed a significant challenge to ongoing research and data analysis related to solar energy systems. According to Duffie and Beckman (2013), accurate solar radiation data is essential for the design, optimization, and operation of solar energy systems. Therefore, restoring and upgrading the pyranometer became imperative to ensure the reliability and accuracy of solar radiation measurements.

This research focuses on the design and construction of a modernized readout system for the Kipp&Zonenpyranometer. The upgraded system integrates real-time data logging, time and date functionality, Bluetooth accessibility for remote data retrieval, and SD card storage for improved data management. Additionally, an LCD display was incorporated to provide real-time visualization of solar radiation values, ensuring enhanced operational efficiency and reliability.

II. METHODOLOGY

Design and Planning

The design process began with a thorough review of the pyranometer sensor specifications provided by Kipp&Zonen. The sensor’s output characteristics, such as voltage range and spectral sensitivity, were analyzed to ensure compatibility with the data acquisition system. Arduino was chosen as the microcontroller for the system due to its flexibility, availability of libraries, and ease of programming. Additionally, a 16x2 LCD display was selected for real-time data visualization, and components for data logging, wireless communication, and internet connectivity were identified. The block diagram representation of the device is shown in Figure 1.

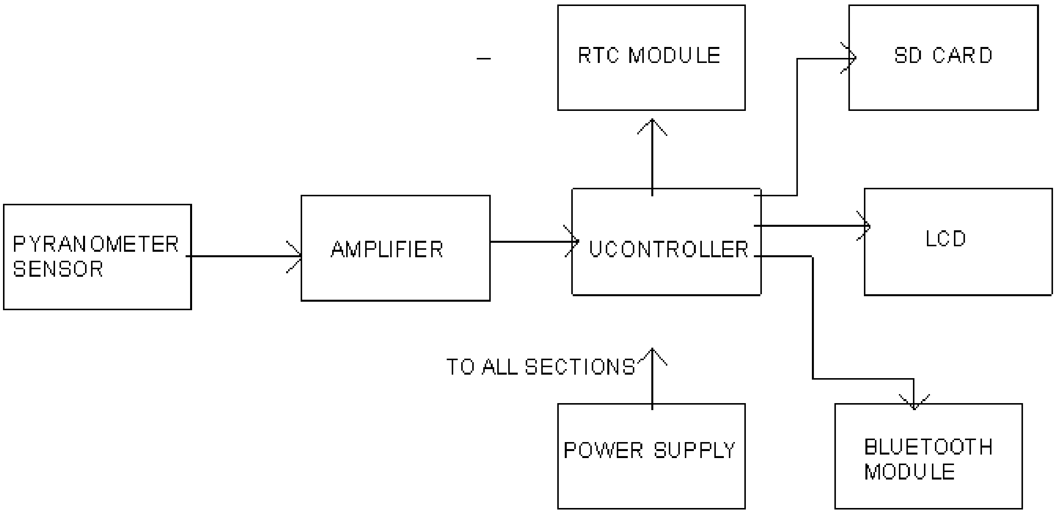

Figure 1: Block diagram representation of themodernized readout system for the Kipp&Zonenpyranometer

Pyranometer Sensor

The Kipp&Zonenpyranometers are high-precision instruments used to measure solar radiation. They are manufactured by Kipp&Zonen, a well-known company specializing in meteorological and solar radiation instruments. Pyranometers are designed to measure the global solar irradiance (both direct and diffuse sunlight) incident on a flat surface, typically expressed in watts per square meter (W/m²).

It works based on the thermocouple principle and blackbody absorption it has a black-coated thermopile sensor that absorbs solar radiation. The absorbed radiation heats up the thermopile, creating a temperature difference between the sensor and its surroundings. This temperature difference generates a small voltage proportional to the incoming

The pyranometer sensor was placed in the sun adjacent to a standard working pyranometer at noon and the voltage and solar irradiance were measured. The irradiance measured was 930 W/m^2 and this corresponded to a voltage of 8 mV. The maximum solar irradiance for Sokoto is less than 1200 W/m^2. To allow for higher irradiance we chose our maximum irradiance measurable by our device to 1500 W/m^2.

For this irradiance the expected output voltage (Y) of the thermopile sensor is evaluated using simple ratio:

$$Y = \frac{8 \times 1500}{930} = 12.9 \text{ mV}$$

We then rounded the value to 15 mV which should allow us to measure even higher irradiance. But the input to the microcontroller is 5 V. The internal ADC of the controller is 8 bits with a resolution of 0.48 mV. This makes it almost impossible for our controller to detect variations from the sensor. The solution to this is either to use an ADC with higher bits and lower resolution or amplify the signal to a higher level. For this reason, we chose an instrumentation amplifier to raise the sensor voltage.

The pyranometer sensor under consideration measures solar irradiance (sunlight intensity) but generates a very small output voltage. To accurately measure this signal, an instrumentation amplifier (INA) is often the best choice for several key reasons: INAs normally have High Common-Mode Rejection Ratio (CMRR), High Input Impedance, Precise and Adjustable Gain, Low DC Offset and Drift and Better Noise Performance than Op-Amps. Common-up INA in the market includes AD620, INA128, and INA333.

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs and offers lower power (only 1.3 mA max supply current), making it a good fit for battery-powered, portable (or remote) applications(AD620, 2011).

The gain equation of the amplifier is given as:

$$G = \frac{49.4 K\Omega}{R_G} + 1$$

(AD620, 201) (1)

$$R_G = \frac{49.4 \text{ K}\Omega}{G - 1} \qquad (2)$$

For a gain of 40 the value of R_G was evaluated as

$$R_G = \frac{49.4 \text{ K}\Omega}{35 - 1} = 1.45\text{K}$$

A resistor with a close value of 1.5 K was used for R_G. The circuit of Figure 2 was connected, based on the recommendation from the AD620 datasheet, to determine the amplification factor of the amplifier.

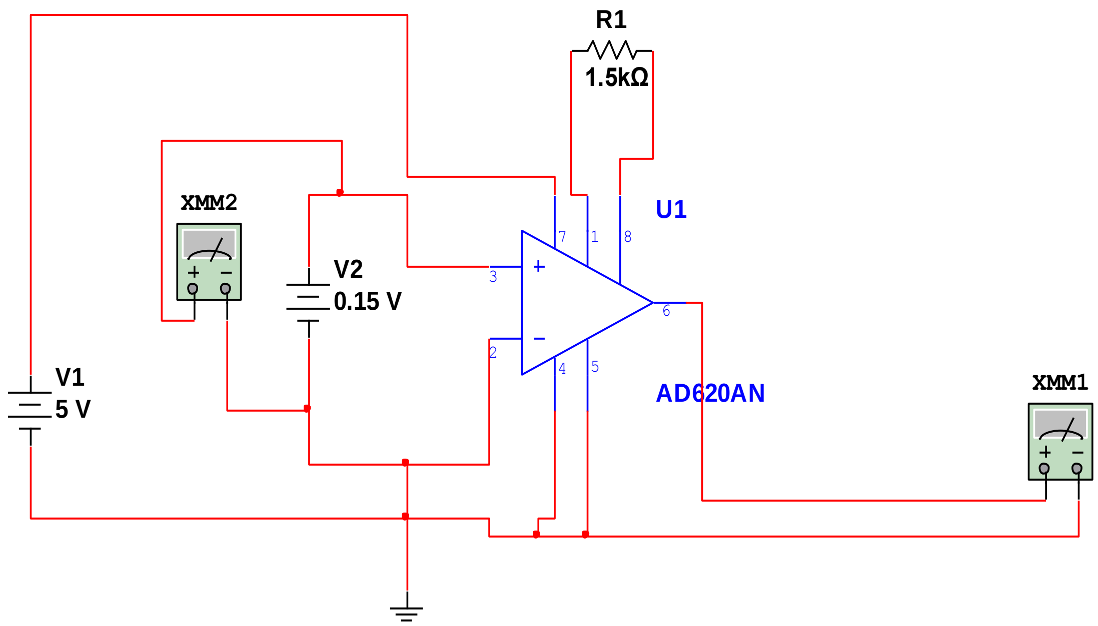

Figure 2: Amplifier Circuit

The output of the amplifier is connected to one of the analogue inputs of the microcontroller where the internal 8-bit ADC of the Arduino is used to convert the signal into digital format.

All electronic devices require an appropriately rated power supply to operate efficiently and ensure long-term durability. For this reason, a power supply was designed to power the various sections based on their power requirements as specified in their datasheets.

The power supply is based on Figure 3

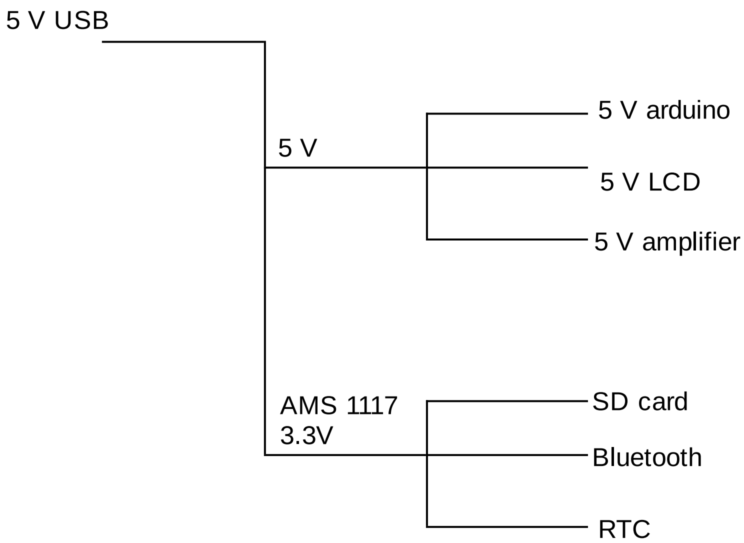

Figure 3: Power supply design for the system

The Real-Time Clock (RTC) module played a crucial role in the data logging system of the upgraded pyranometer. It was essential for providing accurate time and date stamps for every solar radiation data point collected. This time-tagging feature enabled efficient tracking, analysis, and comparison of solar radiation over different periods, which is critical for long-term solar energy studies at the Sokoto Energy Research Centre. Without the RTC, the logged data would have lacked temporal context, making it difficult to determine patterns, analyze peak radiation times, or perform accurate historical comparisons.

The RTC module used DS3231 operated with a standard supply voltage of 3.3V to 5.5V, making it fully compatible with the 5V logic level of the Arduino Uno. It consumed very low current, typically around 200 µA in active mode and about 3 µA in battery backup mode, ensuring efficient power usage, especially when running continuously for long-term data acquisition. A CR2032 3V lithium coin cell battery was installed in the RTC module to maintain timekeeping during power outages or when the Arduino was turned off. This ensured uninterrupted timekeeping without any drift or reset. We selected the DS3231 RTC module for its high accuracy and reliability. The DS3231 is equipped with a temperature-compensated crystal oscillator, which minimizes time drift, making it ideal for long-term solar data logging. We connected the RTC module to the Arduino Uno using the I²C communication protocol. The module's SDA and SCL pins were connected to the Arduino's A4 and A5 pins, respectively, while the VCC and GND pins were connected to 5V and GND on the Arduino. This ensured proper power supply and data communication. A CR2032 coin cell battery was inserted into the RTC module. This battery ensured the RTC module retained the correct time even when the main system was powered off, maintaining consistent and continuous timekeeping. Using the Arduino IDE, we uploaded a sketch that initialized the RTC module and set the correct time and date. This was done using the RTC library, which simplified the communication between the Arduino and the RTC. The initial time was set only once; subsequent restarts of the system relied on the RTC's internal clock and battery backup. The RTC module was programmed to work in cahoots with the SD card logging system. During each solar radiation reading, the Arduino fetched the current time and date from the RTC and combined it with the sensor data before writing it to the SD card. This created a time-stamped log file in CSV format, which could later be accessed and analyzed. The figure below shows a circuit diagram of the RTC construction.

The SD card module was an essential component in the upgraded pyranometer system. Its primary function was to store solar radiation data along with real-time timestamps provided by the RTC module. This allowed for long-term offline data storage and retrieval, which was crucial for research continuity at the Sokoto Energy Research Centre, especially in locations with limited internet access. The SD card module operated at 3.3V, but most modules come with an onboard voltage regulator and logic level shifter, allowing them to work safely with 5V microcontrollers. It supplies a Voltage of 4.5V to 5.5V (regulated down to 3.3V internally) and accepts a 5V input via an onboard level shifter. Its current consumption typically ranges from 50mA to 100 mA during read/write operations. To ensure stable operation, we connected the module to a regulated 5V power supply from the Arduino. We selected a standard SPI-based SD card module that supports microSD cards up to 64GB formatted in FAT16 or FAT32. The module featured onboard level shifters for safe 5V operation and a voltage regulator to step down power to 3.3V internally. The module was connected to the Arduino Uno via **SPI** (Serial Peripheral Interface).

We formatted the microSD card to FAT32, ensuring compatibility with the Arduino SD library. A test 'plog.text' file was initially created to verify that data could be written and appended successfully. Using the Arduino SD library, we wrote code to initialize the SD card and create a data file (p_log.txt). During each logging cycle, the code appended a new line to the file containing the solar radiation value and the current date and time from the RTC. We tested the logging operation by simulating solar input and monitoring the SD card file via a card reader connected to a computer. The system successfully recorded accurate and timestamped sensor readings, confirming the SD module's proper integration.

The Bluetooth module was integrated into the upgraded pyranometer system to enable wireless access to logged data without removing the SD card or physically connecting to the Arduino. This feature significantly improved the convenience, mobility, and remote monitoring capability of the system, allowing researchers or field technicians to retrieve data using a mobile phone or laptop with Bluetooth support. The Bluetooth module used was the HC-05 module, known for its simplicity and compatibility with Arduino systems. Its operating voltage ranges from 3.6V to 6V (VCC pin), its logic level (TX/RX) is 3.3V (requires a voltage divider for Arduino TX → HC-05 RX) and its current consumption is~30 mA in active mode. To ensure safe communication, we used a voltage divider circuit on the TX pin of the Arduino to bring the 5V signal down to 3.3V for the RX pin of the HC-05. We used the HC-05 Bluetooth module, which supports serial communication (UART) and can be easily configured as a slave device for wireless data transmission.

The module was tested using a Bluetooth terminal app on a smartphone to receive transmitted data. We updated the Arduino sketch to transmit logged data over Bluetooth in real-time. Each entry included the solar irradiance reading and the timestamp from the RTC, formatted for readability on mobile or PC terminals. Successful data reception via a smartphone terminal confirmed proper integration. The system could now send recent and even receive data via Bluetooth, enhancing accessibility and field usability.

The LCD display was incorporated into the system to provide real-time visual feedback of the solar radiation measurements. It allowed users to immediately observe the current sensor output without needing to connect to a computer or remove the SD card. This immediate display of live data helped during system installation, testing, and maintenance, ensuring the pyranometer and logging system were functioning correctly.

The display used was a 16x2 character LCD module (HD44780 compatible), interfaced via an I2C backpack to reduce the number of connection pins. Its operating voltage is 5V and its current consumption is ~1–2 mA (more if backlight is on). The I2C module attached to the LCD reduced the wiring to only four pins. We used a standard 16x2 alphanumeric LCD with an I2C backpack module, which simplifies wiring and allows easy control using two Arduino pins.

This shared the I2C bus with the RTC module, which is acceptable since both devices have unique I2C addresses.

The LiquidCrystal_I2C library was used to initialize and control the display.

A small potentiometer was used to adjust the contrast of the display for clear readability. Alternatively, some I2C modules include a contrast control screw.

During operation, the LCD updated in real-time, confirming that the sensor, amplifier, and software were working correctly.

III. RESULTS AND DISCUSSION

Tests and Results

The primary aim of this test is to evaluate the functionality and accuracy of the restored Kipp&Zonenpyranometer after integrating the modernized readout system. The focus is to determine whether the system can effectively measure solar radiation and log data in real time, and how it performs compared to a standard/reference pyranometer.

After the power supply circuit was constructed, it was tested to ascertain its accuracy. It was plugged into a USB port of a laptop. The voltages at the various sections were measured and tabulated in Table 1.

Table 1: Measured and Expected Voltages of System's Sections

Section	Measured voltage (V)	Expected voltage (V)
Bluetooth	3.28	3.3
RTC	3.28	3.3
SD card	3.28	3.3
Arduino board	5.1	5
Amplifier	5.1	5
LCD	5.1	5

The pyranometer was mounted horizontally in an open area with an unobstructed view of the sky. The sensor was connected to the new readout system, which includes:

LCD Display for real-time radiation values, SD card module for data logging, RTC module for time/date stamps, Bluetooth module for wireless access, Power supply. A calibrated Kipp&Zonen reference pyranometer was placed adjacent to the test unit to ensure exposure to identical solar conditions. Both the restored and reference pyranometers were powered on and allowed to stabilize. Measurements were recorded from both devices every two hours, between 8:00 AM and 6:00 PM. Each reading from the restored device was displayed on the LCD, saved to the SD card, and later compared with the reference.

The percentage deviation was calculated using the formula:

$$\text{Derivation derivation} = \left(\frac{\text{test unit} - \text{refernce}}{\text{reference}}\right) \times 100$$

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Table 2: Pyranometer Performance Test Results

Time	Restored Pyranometer (W/m²)	Reference Pyranometer (W/m²)	Deviation (%)
08:00	450	470	-4.26%
10:00	650	670	-2.99%
12:00	875	890	-1.69%
14:00	825	840	-1.79%
16:00	600	615	-2.44%
18:00	350	360	-2.78%

Table 2 is the results of the comparison of the restored and reference pyranometers. As shown Table 2, the readings closely follow the same trend throughout the day, with only slight differences in values. The average deviation between the restored and reference pyranometer readings is approximately -2.65%, which is quite acceptable for practical field use.

The performance of the AD620 instrumentation amplifier was tested. Specifically, the test verifies whether the amplifier successfully boosts the weak millivolt signal from the pyranometer to a readable voltage level suitable for the microcontroller's ADC input.A controlled light source (natural sunlight) was used to produce known voltage levels from the pyranometer. These signals were fed into the AD620 input. The amplified output voltage was measured and compared with expected values based on the configured gain. The output was also fed into the Arduino for ADC reading and display.
Theobserved result was then presented in the Table 3 below:

Table 3: AD620 Amplifier Performance Test Results

Input Voltage (mV)	**Expected Output (V)**	**Measured Output (V)**	**Deviation (%)**
50	0.575	0.570	-0.87%
80	0.920	0.912	-0.87%
120	1.380	1.365	-1.09%
150	1.725	1.710	-0.87%
180	2.070	2.060	-0.48%

A test was conducted to assess the effectiveness and reliability of the SD card module in storing solar irradiance data along with accurate timestamps. The logging system should ensure data integrity and proper formatting for long-term solar radiation monitoring.

The system was powered and allowed to initialize, then irradiance values were measured and logged every hour. The SD card was removed after the test period and inserted into a computer. Data was opened in spreadsheet software and checked for correct file creation, accurate timestamping, Consistent formatting and no data loss or corruption. Table 4 below shows the result on SD card.

Table 4: Reliability Test of the SD card Module Results

Time	**Date**	**Irradiance (W/m²)**	**Logged File Entry**
08:00	06/04/2025	450	08:00,06/04/2025,450W/m²
10:00	06/04/2025	650	10:00,06/04/2025,650W/m²
12:00	06/04/2025	875	12:00,06/04/2025,875W/m²
14:00	06/04/2025	825	14:00,06/04/2025,825W/m²
16:00	06/04/2025	600	16:00,06/04/2025,600W/m²
18:00	06/04/2025	350	18:00,06/04/2025,350W/m²

The Bluetooth module was implemented to enable wireless access to logged solar irradiance data. This allows users to retrieve or monitor data in real time without physically removing the SD card, offering convenience and flexibility for remote data retrieval.

The Bluetooth module was powered and paired with a smartphone. We sent a command via the terminal app to request data. The Arduino responded by transmitting the latest irradiance value or the full content of the log file. Responses were timed and checked for consistency, formatting, and completeness.

Discussion

The restored and upgraded pyranometer demonstrated high accuracy, stability, and reliability in measuring solar radiation. Key outcomes include:

The restored pyranometer displayed consistent and expected solar irradiance patterns throughout the day, increasing toward solar noon and decreasing toward evening. When compared with the reference pyranometer, the maximum deviation was about -4.26%, and the average deviation across all readings was approximately -2.66%, which is within acceptable error margins for solar radiation measurement. The slight negative deviation observed may be due to minor calibration differences or aging of the sensing element. The LCD correctly showed real-time values, and the data logging system worked flawlessly, with all readings and timestamps accurately stored on the SD card. These results affirm the restored system's functionality and reliability in field applications. The system can now be confidently used for continuous solar radiation monitoring at the Sokoto Energy Research Centre.

The AD620 amplifier consistently amplified the pyranometer's output as expected. The deviation between expected and measured outputs was minimal (less than ±1.1%), indicating accurate gain configuration and stable performance. The linearity of the amplifier was confirmed by the proportional increase in output with increasing input, validating its suitability for precision signal conditioning. The output voltages were well within the ADC range of the Arduino (0–5V), enabling precise digital sampling. This confirms that the AD620 plays a crucial role in scaling up the pyranometer's weak signals for effective digital processing.

The LCD module successfully displayed accurate irradiance values derived from the amplified pyranometer signal. It updated in real-time without noticeable lag, indicating smooth integration with the Arduino's data acquisition loop. The font size, contrast, and backlight were sufficient for clear visibility under various lighting conditions. The formatting (Irradiance: 875 W/m²) remained consistent and readable. This confirms the LCD's reliability for on-site, instant feedback of solar radiation, which enhances the usability of the system by researchers and technicians in the field.

The SD card module successfully created and appended entries in the data file throughout the test period. The integration of the RTC module ensured accurate time and date stamps, crucial for long-term solar radiation studies. The data formatting was consistent, readable, and compatible with common spreadsheet programs, simplifying post-processing. No data loss or overwrite was detected, indicating robust file handling within the Arduino sketch. The system proved highly effective for continuous, unattended data collection.

The RTC module demonstrated excellent timekeeping accuracy, with a drift of less than ±2 seconds over extended periods. The onboard battery ensured that time data was retained even when the system was powered off, confirming its reliability for autonomous outdoor deployments. The timestamps recorded in the SD card logs were consistent and aligned with real-world time, validating the RTC's critical role in accurate, time-series data logging. The seamless integration of RTC with the Arduino and SD system ensures the overall pyranometer setup is suitable for long-term solar radiation monitoring and research applications.

The Bluetooth module performed consistently in real-time communication, with most responses returned in less than 2–3 seconds. The data formatting was user-friendly, with irradiance readings and timestamps displayed in the terminal app. This wireless functionality enhances the portability and user-friendliness of the pyranometer system, especially in field conditions where frequent physical access to the device may be impractical. Despite minor delays during low signal or interference, the system remained robust and usable, indicating reliable wireless communication. Overall, the Bluetooth module added a smart layer of remote monitoring capability, making the pyranometer system more versatile and modern. The system was capable of running efficiently on a battery, with power consumption being quite moderate during typical operation. The lowest current draw was observed when the system was idle, with the highest consumption occurring during Bluetooth data transmission. The battery life estimate varied depending on usage. The system could operate for approximately 24 hours of continuous data logging. During low power conditions, the system would still function for at least 12 hours. Voltage remained stable across various operating conditions (idle, active,

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Bluetooth), ensuring that no component experienced voltage dips or instability that could affect data accuracy.

IV. CONCLUSION

The restoration and upgrade of the Kipp&Zonenpyranometer aimed to improve the accuracy, reliability, and usability of solar radiation measurement at the Sokoto Energy Research Centre. The successful restoration and upgrade of the Kipp&Zonenpyranometer marks a significant milestone in enhancing the measurement and monitoring of solar irradiance at the Sokoto Energy Research Centre. This project set out to modernize the data acquisition process of a once-defective pyranometer by integrating contemporary electronic modules that ensure higher functionality, improved accessibility, and better long-term data handling.

Throughout this work, a real-time, Arduino-based readout system was developed and implemented, featuring core components such as an AD620 instrumentation amplifier for signal conditioning, an LCD for instant display, an SD card for continuous data logging, a Real-Time Clock (RTC) module for accurate timestamping, and Bluetooth connectivity for wireless data access. A robust power supply system, including battery support and provision for solar charging, was also designed to support standalone operation in remote locations.

Each module of the system was rigorously tested, and the results demonstrated that the upgraded system not only restored the pyranometer's functionality but also significantly improved it. The output voltage from the sensor was effectively amplified and digitized for processing. Data logging and wireless communication were successful and reliable, and real-time irradiance values were in close agreement with those from a standard reference pyranometer, indicating strong measurement accuracy.

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