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Design and Implementation of a Wireless Wind Gauge with GUI

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Abstract

Most weather stations available where available in Nigerian schools require that data is read manually and everyday requiring much human effort, this research addresses the need to access environmental data remotely from the weather station without a break. The system incorporates A set of BGT FSI wind speed and wind direction modules, two Arduino Uno microcontrollers, two Zigbee radios, a solar panel, and deep cycle batteries. The development process begins with the integration of the sensor modules with Arduino Uno microcontrollers to capture wind speed and direction data accurately. Simulation using Proteus 8.15 was employed to validate the system's functionality and assess its performance under various environmental conditions. Calibration procedures are implemented to ensure precise measurement accuracy. Furthermore, the wireless communication aspect is realized through Zigbee radios, facilitating seamless data transmission over extended distances. To ensure autonomy and sustainability, a solar panel coupled with deep cycle batteries is incorporated to power the system, making it suitable for deployment in off-grid locations. An accuracy of $\pm(0.3+0.03V)$ m/s for wind speed and $\pm 3^0$ for wind direction was obtained due to the quality of the sensors used. The implementation of a MATLAB standalone GUI facilitated user-friendly interaction with the wind gauge system, allowing users to visualize and analyze real-time wind data efficiently.

Keywords: Wireless Wind Gauge, Wind Speed, Wind Direction, Sensor Calibration, Microcontroller, Wireless Communication.

Introduction

The measurement and monitoring of wind speed and direction are vital in various applications such as weather forecasting, environmental studies, and renewable energy management. Traditional wind gauges often rely on wired connections, limiting their deployment flexibility and requiring significant infrastructure. In response to these limitations, wireless wind gauges have gained prominence due to their ability to offer remote monitoring capabilities without the constraints of wired connections.

This research work focuses on the development, simulation, calibration, and implementation of a Wireless Wind Gauge (WWG) utilizing the RS485 wind speed and direction modules, along with Arduino Uno microcontrollers, ZigBee radios, SD card modules, solar panels, and deep cycle batteries. The integration of these components aims to create a robust and autonomous system capable of accurately measuring and transmitting wind data wirelessly.

The RS485 wind speed and direction modules serve as the primary sensors for capturing wind-related parameters. These modules offer high precision and reliability, making them suitable for various environmental monitoring applications (Alberto, 2021). The Arduino Uno microcontrollers act as the central processing units, responsible for data acquisition, processing, and transmission. By leveraging the flexibility and programmability of Arduino platforms, the WWG system can be customized to meet specific project requirements (Rowella et al., 2020).

Wireless communication is facilitated through ZigBee radios, enabling seamless data transmission over long distances with low power consumption. The integration of SD card modules allows for data logging capabilities, ensuring data integrity and enabling offline analysis. Furthermore, the utilization of solar panels and deep cycle batteries provides an energy-efficient power source, enabling autonomous operation in remote or off-grid locations.

The development of the WWG involves several stages, including simulation, calibration, and real-world implementation. Simulation studies are conducted to evaluate the system's performance under various environmental conditions and to optimize its design parameters. Calibration procedures are employed to ensure the accuracy and reliability of the wind measurements obtained by the WWG system (McWilliam's & Sprehack, 2009): (Zang et al., 2020). Finally, the implemented WWG is deployed in real-world scenarios to validate its functionality and assess its performance in practical applications.

Overall, the development of a Wireless Wind Gauge using the RS485 modules, Arduino Uno microcontrollers, ZigBee radios, SD card modules, solar panels, and deep cycle batteries represents a significant advancement in environmental monitoring technology. This research aims to contribute to the advancement of wireless sensing systems for environmental monitoring, weather forecasting, and renewable energy management applications.

SYSTEM DESCRIPTION AND DESIGN IMPLEMENTATION

The design of the wireless wind gauge system is outlined as follows:

The block diagrams

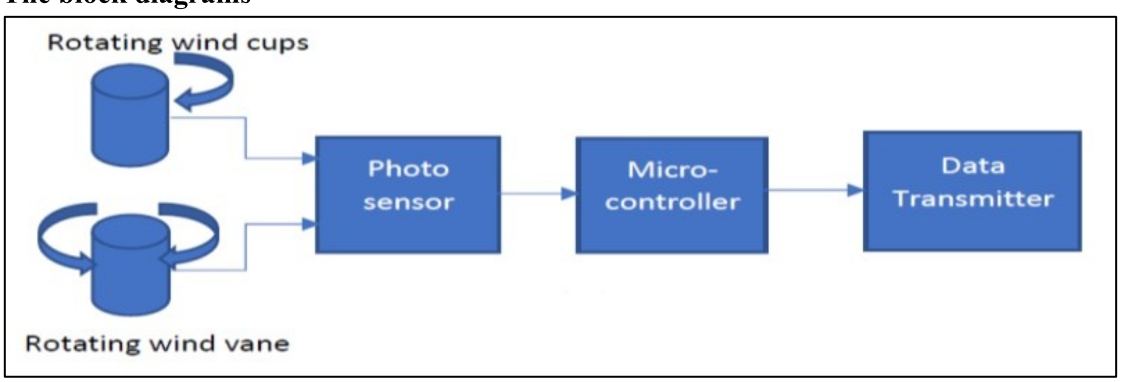

Fig. 1.0: Block diagram of the transmitting section

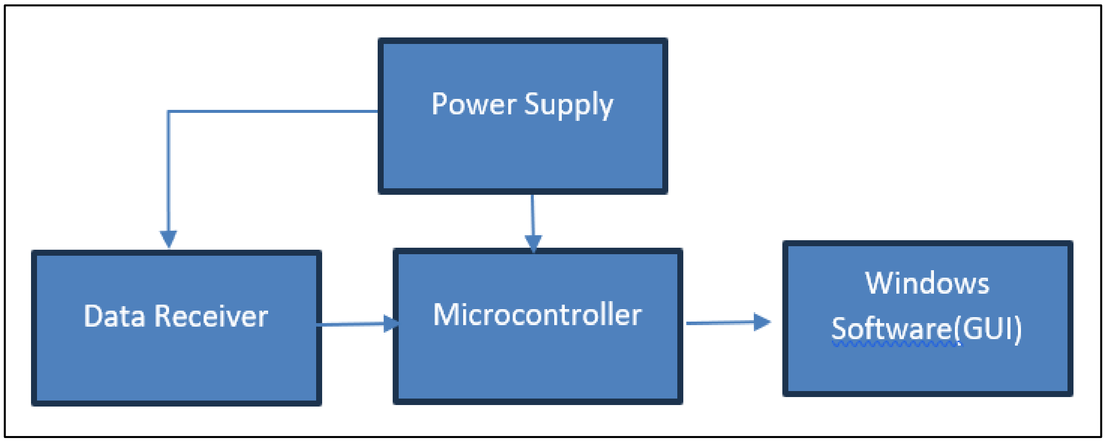

Fig. 2.0: Block diagram of the receiving section

Wind Parameter Sensors Selection
For standard calibrated wind speed and direction monitoring, the BGT-FS1 and BGT-FS2 are employed:


Fig. 3.0: The wind parameter sensors BGT-FS1 and BGT-FS2

The sensors have the following parameters:
Measuring Range: 045m/s, 0°- 359°
Accuracy: 0.30.03V m/s (V r wind speed); 3°
Resolution: 0.1m/s; 1°
Starting wind speed: ≤0.5m/s
Power supply mode: DC5V
Output: Pulse (wind speed sensor- Current: 420mA; Voltage: 05V - 15V; RS232 -ASCII; RS485-ASCII

Operating environment: Temperature -35℃~60℃,
Humidity≤100%RH

Microcontroller unit (MCU) Selection

Arduino Nano was choosing for this application because it works based on simple instructions that its IDE (Integrated Development Environment) provides, with support from a vast community and it costs less than other controller with the same processing power at 16Mhz. It has the following specifications

Table 1.0: Arduino Nano Specification

Microcontroller	**ATmega328**
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
EEPROM	1 KB
DC Current per I/O Pins	20 mA (I/O Pins)
Input Voltage	7-12V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g
Product Code	A000005

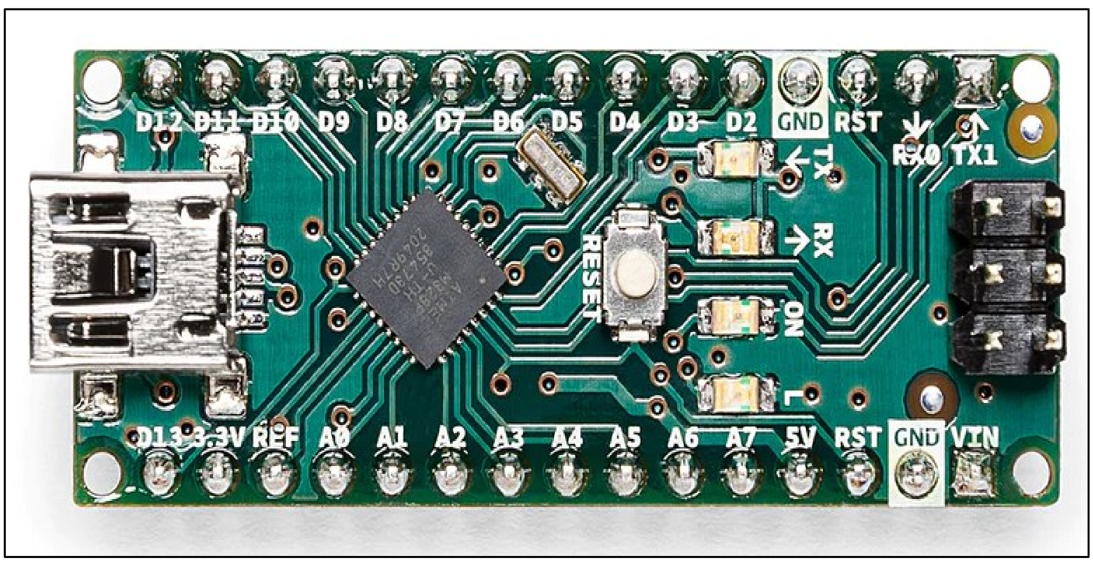

Fig 4.0: The Arduino Nano

Wireless communication module Selection

Wireless communication is achieved by the use of ZigBee radio set, one configured as a transmitter and the other as receiver. The radio was chosen because of its ease of programming and its capability and range.

Table 2.0: Zigbee radio Specifications

Wireless Parameter	Value
Freq. Band	2.4Mhz
Physical/MAC Layers	IEEE 802.15.4
Range	Indoors: up to 30 m Outdoors (line of sight): up to 100 m
Current consumption	25-35 mA (Tx mode) 3 µA (Standby mode)
Raw data rate	250 Kbps

Fig. 5.0: The Zigbee Radio Set

Power supply Design

To design the power supply, there is need to determine the total power consumption of the sensing/transmitting section of the system which is sum of power consumption of the individual components which stand at 5.5W.

To determine the total current to be consumed the following parameters were considered:

Supply voltage, Vss = 5.0V

Total power consumption, P_T = 5.5W

Total current consumption, $I_T = {}^{P_T}/_{Vss}$

= 5.5/5.0

= 1.1A (the total current consumed when all the devices are active)

To regulate this voltage, we use a 7805-voltage regulator which is capable of delivering 1.5A current.

The regulator requires a minimum of 2.0V in excess of the output 5.0V, so the battery must have a potential of $V_{batt} \geq (5.0 + 2.0)$ V, 2 number of 3.7V lithium batteries were selected to be connected in serries for a combined potential of 7.2V and fully charged potential of 8.4V.

To charge the batteries a solar panel that will deliver not more than 8.5V is required through a lithium battery management board:

A 9.0V solar panel was chosen with a diode (1N4001) connected in series with it to reduce the voltage by 0.6V and to ensure that battery potential does not reverse in the absence of solar radiation.

Light emitting diodes are used to show flow of current from the panel to batteries and from batteries to the circuit, each of the LEDs was connected via a series dropper resistor with value determined thus:

For green LED: supply voltage = Panel Voltage = 9.0V

The current consumption = 20mA and Working voltage = 1.7V (https://www.farnell.com/datasheets/1498852.pdf)

Voltage drop = 9.0 - 1.7 = 7.3V, this the voltage that the LED will drop across its terminals

Therefore, the series resistor,

$$R_t = \frac{V}{I} = \frac{7.3V}{20.02A}$$

(from Ohms law)

$$= 365\Omega$$

(standard value of 380 Ω was chosen, this resistance is needed to drop the excess of 7.3V from the 9V that is supplied to avoid damage)

For Red LED: supply voltage = 5.0V
Current = 10mA and Working voltage = 2.2V (https://www.farnell.com/datasheets/1498852.pdf)
Voltage drop = (5.0 - 2.2) = 2.8V, this is the voltage that the LED will drop across its terminals

Therefore, the series resistor, $R_2 = \frac{8V}{0.02A}$

= 140Ω (a standard value of 160 Ω was chosen, this resistance is needed to drop the excess of 2.8V from the 5V supply to avoid damage)

Complete Schematic Diagram

The complete schematic is given in figure 6.0 and figure 7.0.

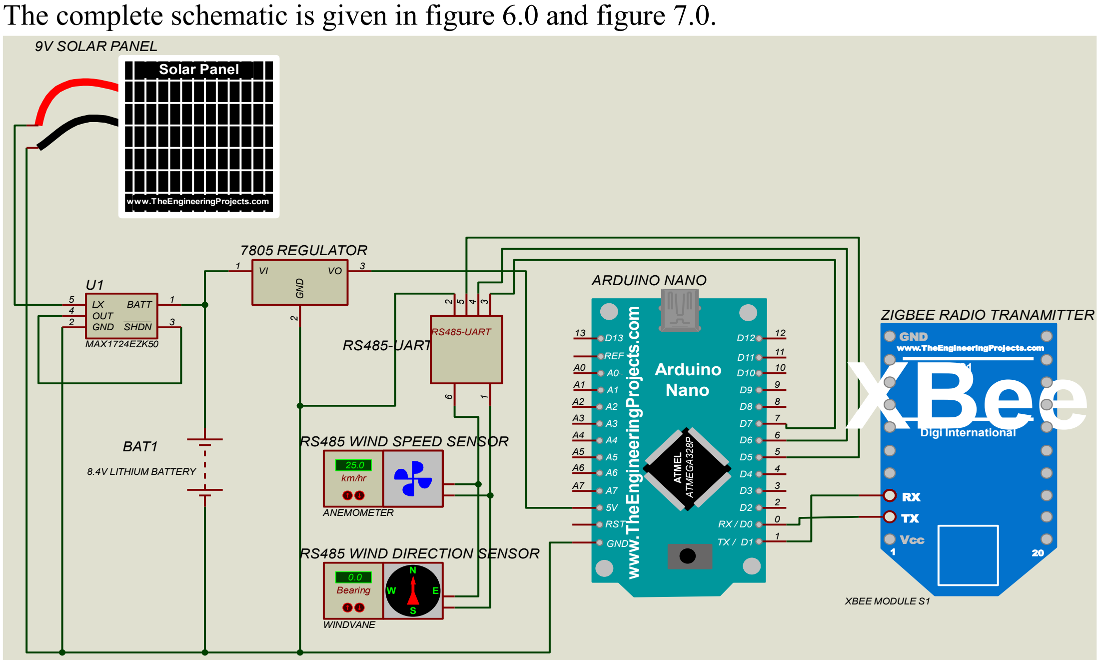

Fig. 6.0: The complete schematic diagram of the transmitter section

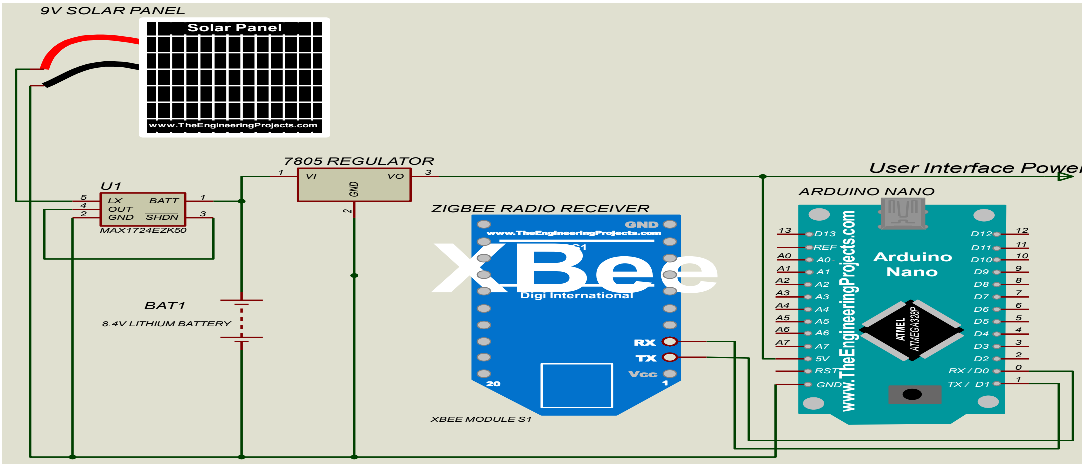

Fig. 7.0: The complete schematic diagram of the receiver section

SIMULATION AND CALIBRATION

Prior to deployment, the wind gauge system undergoes simulation and calibration procedures to ensure accurate and reliable performance. Proteus simulation software is used to model the behavior of the sensors and validate the system's response under different wind conditions. Calibration involves comparing the sensor outputs against reference measurements from calibrated instruments and adjusting the system parameters accordingly.

The designed circuit was drawn in proteus 8.0 software in windows 10 platform. All component and parameters were carefully chosen from the database. Simulation was done under five different settings for the wind speed/direction sensors.

A. Wind speed at 10m/s wind direction at 180
B. Wind speed at 25m/s wind direction at 270
C. Wind speed at 32m/s Wind direction at 320

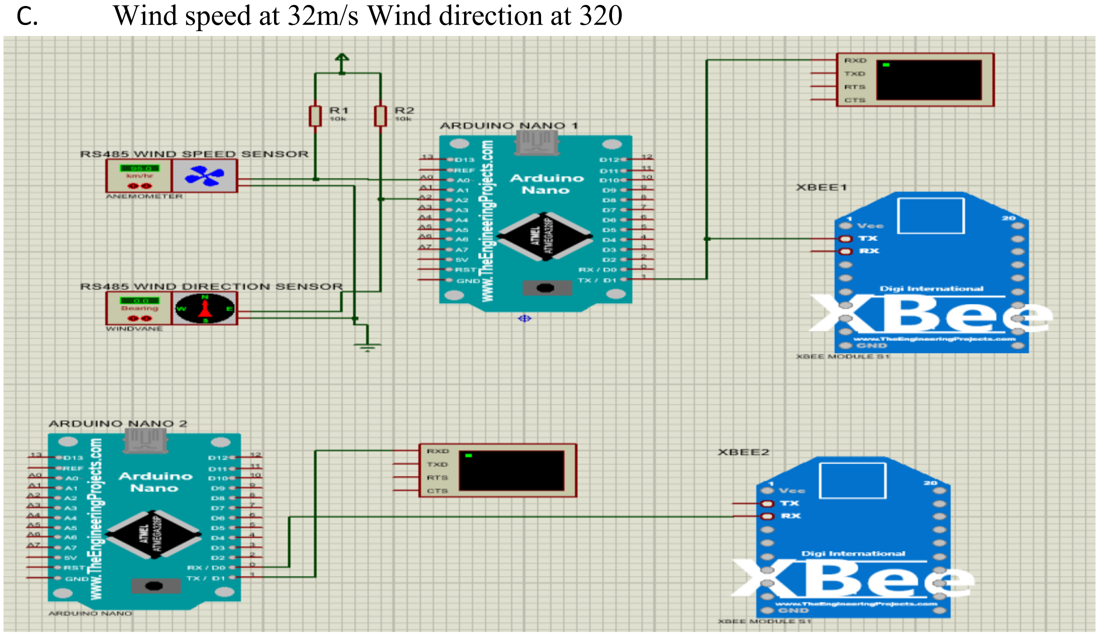

Fig. 8.0: The simulated system

According Schmidt et al. in their paper titled "field calibration of cup anemometers" the cup anemometers to be calibrated should be on a 10-m high rig and calibrated in the free wind against a reference cup anemometer. The method has been reported to improve the statistical bias on the data relative to calibrations carried out in a wind tunnel. The methodology is sufficiently accurate for calibration of cup anemometers used for wind resource assessments and provides a simple, reliable and cost-effective solution to cup anemometer calibration, especially suited for recalibration in places with limited access to high-quality wind tunnels.

IMPLEMENTATION

The developed wireless wind gauge system is implemented in a real-world environment at an appropriate height and orientation to minimize obstructions and interference. The wind direction sensor is positioned with the aid of a compass with its factory orientation calibrator mark facing the North south. The constructed and the installed systems are shown in figure 7.0 and 8.0.

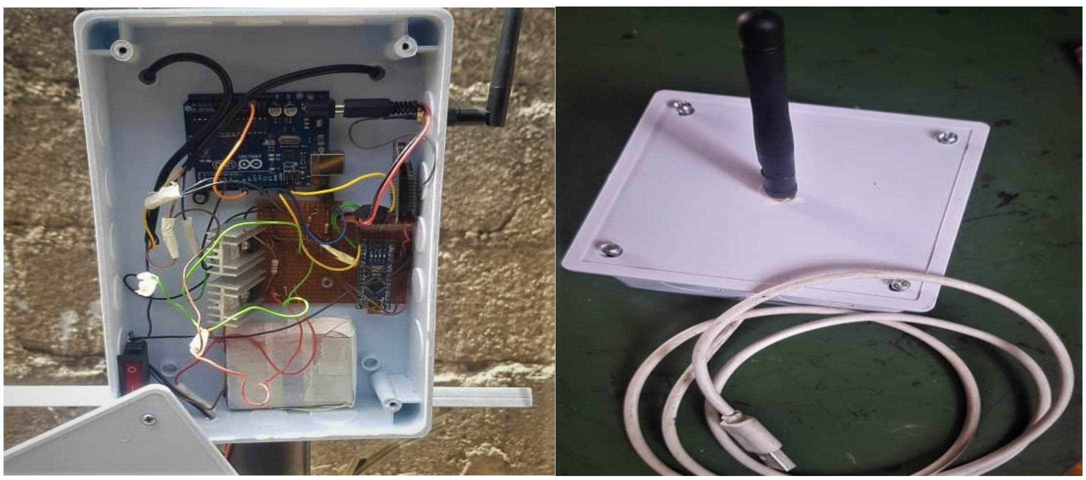

Fig.9.0: The constructed system

Fig.10.0: The Installed System

RESULTS AND DISCUSSION

Results

Results from the simulation and field tests are given in table 3.0- 5.0.

The following figure give the results for the simulation.

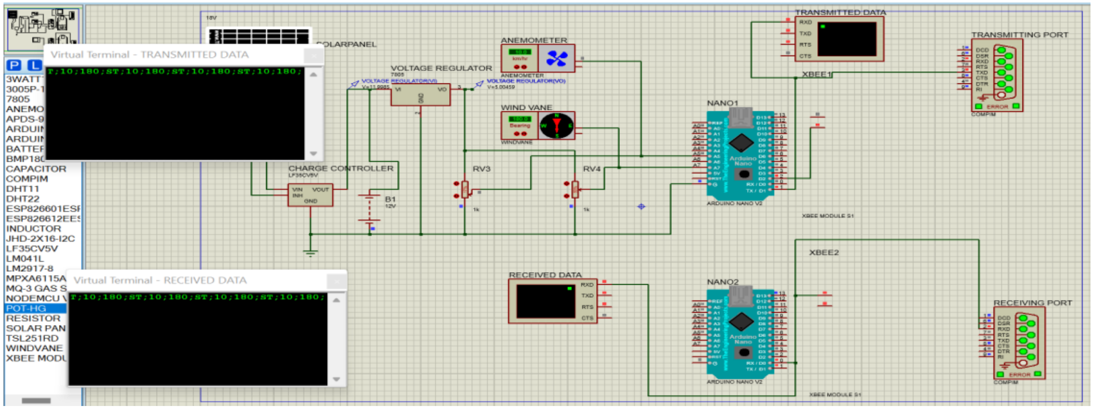

Fig. 11: Simulation result for speed = 10.0m/s, dir = 180.0

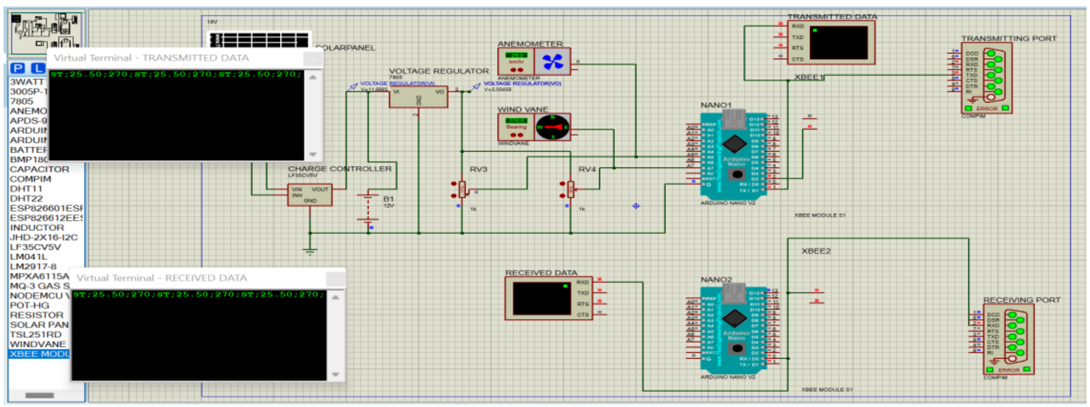

Fig. 12: Simulation result for speed = 25.0m/s, dir = 270.0

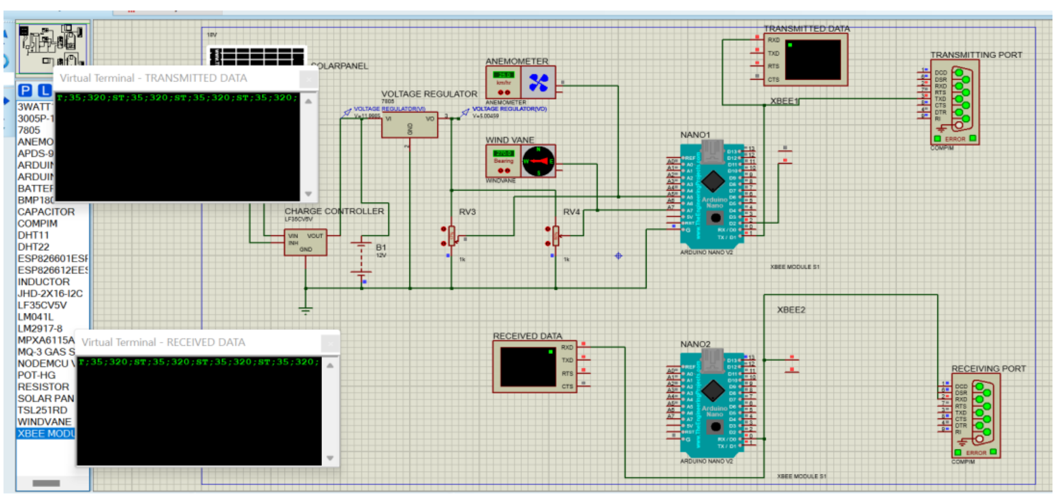

Fig. 13: Simulation result for speed = 35.0m/s, dir = 320.0

Table 3.0: Summary of Simulation Result:

S/N	Data sent		Transmission Status	Data Received	
	Speed	Direction		Speed	Direction
1	10		ON	10	
2		180	ON		180
3	25		ON	25	
4		270	ON		270
5	35		ON	35	
6		320	ON		320

Table 4.0 gives extracted results from run of the hardware.

Table 4.0: Hardware test result 1:

S/N	Date	Time	Station Wind Speed (km/h)	Measured Wind Speed (m/s)	Station Wind Direction	Measured Wind Direction (degrees)
1	13-02-2024	3:00P	10.00	2.777	NW	315
2	13-02-2024	3:30P	09.00	2.512	N	0
3	13-02-2024	4:00P	13.00	3.631	NW	315
4	13-02-2024	4:30P	05.00	1.395	NW	315
5	13-02-2024	5:00P	09.00	2.512	N	0
6	13-02-2024	5:30P	08.00	2.235	NNW	337
7	13-02-2024	6:00P	06.00	1.680	NNW	337
8	13-02-2024	6:30P	02.00	0.555	NNW	337
9	13-02-2024	7:00P	01.00	2.785	NNW	337
10	13-02-2024	7:30P	00.00	0.000	N	0
11	13-02-2024	8:00P	00.00	0.000	N	0
12	13-02-2024	8:30P	01.00	2.792	N	0

Table 5.0 gives results of performance of the wireless transmission.

Table 5.0: Hardware Test Result 2:

S/N	Distance Between Transmitter/ Receiver (m)	Reception Quality
1	50	Excellent
2	100	Good
3	200	Good
4	500	Good
5	1000	Fair
6	1500	Poor

Result Analysis

To discuss the results from an Arduino-based wind speed and direction gauge using BGT FSI wind speed/direction sensors against weather station data, the observations is broken down in terms of wind speed and direction.

Wind speeds from the weather station are provided in km/h, while the measured wind speeds are in m/s. For an accurate comparison, we'll need to convert the weather station wind speeds from km/h to m/s using the conversion factor:

$$1\ \text{Km/h} = \frac{1}{3.6}\,m/s$$

given the station wind speeds in m/s as 2.791, 2.511,3.625,1.395, 2.235,1.67,0.56, 0.28 and 0.00 respectively.

Wind Direction Comparison are provided in cardinal directions (N, NW, etc.) for the weather station, and in degrees for the measured values. The cardinal directions to degrees are:

- N (North) = 0°
- NW (Northwest) = 315°
- NNW (North-Northwest) = 337.5°

Given

i. The measured wind direction of 315° for NW is accurate.

ii. Similarly, the measured wind direction of 0° for N is accurate.

iii. The measured wind direction of 337° is slightly off from the ideal 337.5° for NNW, but this discrepancy is minor and within acceptable limits. Thus, calibration was not necessary as confirmed from the data for the sensors the sensors are pre calibrated in the factory to ±(0.3+0.03V) m/s (V: real-time wind speed) for the wind speed sensor while $\pm 3^0$ for wind direction. The only calibration necessary is orientation of the wind direction sensor as specified by the manufacturer for which a mark is made available that should be oriented south. Deviations brought about by the other circuit component elements w easily taken care of by adding deviation values into the equations in the software codes

Discussion

The wind direction measurements are generally accurate and correspond well with the weather station data, i.e. minor deviations are observed but are within acceptable limits, indicating reliable direction sensing by the Arduino-based system.

The measured wind speeds are also slightly different in a few cases but are within acceptable limits. Suggesting the sensors used are well calibrated.

The wireless wind gauge system demonstrates accurate measurement of wind speed and direction over a wide range of environmental conditions. Simulation and calibration techniques improve the system's accuracy and reliability, making it suitable for various applications including weather monitoring, wind energy assessment, and research purposes. Field tests confirm the system's performance and usability, highlighting its potential for widespread deployment in both urban and rural settings.

CONCLUSION

In conclusion, this research has successfully demonstrated the development, simulation, calibration, and implementation of a wireless wind gauge system utilizing readily available components and technologies. The integration of an Arduino Nano microcontroller, RS485 wind speed/direction sensors, a pair of ZigBee radio modules, Proteus simulation software, MATLAB standalone GUI, and a solar power supply has resulted in a robust and cost-effective solution for monitoring wind conditions. Through comprehensive simulation using Proteus software, the functionality and performance of the wireless wind gauge system were verified, ensuring accurate data acquisition and transmission. The calibration process enabled the system to provide precise measurements of wind speed and direction, enhancing its reliability and usability in various environmental conditions. The implementation of a MATLAB standalone GUI facilitated user-friendly interaction with the wind gauge system, allowing users to visualize and analyze real-time wind data efficiently. Moreover, the utilization of a solar power supply enhanced the system's sustainability and autonomy, making it suitable for remote or off-grid locations.

FUTURE WORK

Future work may focus on enhancing the system's capabilities, such as integrating additional sensors for measuring parameters like temperature, humidity, and air pressure. Furthermore, advancements in wireless communication technology and power management techniques could lead to further improvements in the performance and efficiency of the wind gauge system.

Conduct additional tests over longer periods and under different weather conditions to validate the accuracy of the wind speed and direction measurements.

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