JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

DEVELOPMENT OF A DEVICE FOR LOGGING WIND SPEED ON A WIND FARM

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Abstract : It is now very obvious that our continued existence on this fragile earth the way we do now depends on how fast we find alternative and replacement to the current main energy source. Wind energy as a potential candidate is, where available, very friendly, free and renewable. Wind turbines are used to convert the kinetic energy in wind flow to electrical energy. This study exploits the possibility of coming up with a device that could be used to monitor the performance of wind turbines on deployment. To evaluate the input power of the system, a wind speed measuring device is designed and incorporated to keep record of wind energy input to the turbine. In this work, cup-type anemometer is designed and constructed. The cup-type anemometer is made up of three conical or spherical cups mounted on a rotating shaft. The speed of rotation is proportional to wind speed. A programmed microcontroller is used to evaluate and display the instantaneous speed of wind around the wind farm. The measured quantifies could be saved in an SD card for future record. It is necessary to present the status of the monitoring system to a user, and a liquid crystal display (LCD) came handy in this respect . The 24 hour wind profile of the turbine can hence be observed and analysed. An ATmega16 AVR was used as the heart of the control and coordination of all the activities of the individual modules.

Keywords: anemometer, logger, wind farm, monitoring

1.0 INTRODUCTION

A wind turbine or wind energy converter converts typically the kinetic energy of wind into electrical energy. Over the years it has become one of the promising alternative non-renewable energy sources to the problematic fossil fuel (Pargmann et al. 2018). Wind farms are becoming increasingly popular as a sustainable and renewable source of energy generation (Chehoui et al., 2015). In fact, wind energy is considered as one of the most promising and fastest-growing installed alternative-energy production technologies (Evans et al 2008) with an annual growth rate of about 34% (Bazmi and Zahedi 2011). Literatures have shown that in comparison to other alternative energy sources wind power has the lowest relative greenhouse gas emission, the least water consumption and the most favorable social impacts (Ackermann and Solder 2000) Advances in wind energy technology have decreased the cost of producing electricity from wind. With the growing demand for clean energy (Jebaraj and Iniyan 2006)), the monitoring and analysis of wind farm performance have become crucial for maximizing efficiency and optimizing power output. One vital aspect of wind farm operations is the collection and logging of various parameters related to wind turbines. These parameters include wind speed, direction, temperature, power output, and operational status.

The study of wind speed and its variation is an essential aspect of meteorology and environmental science. Wind speed loggers, also known as anemometers or anemographs, are devices used to measure and record the speed of wind over a specific period of time (Petrone et al 2011). These instruments are designed to provide accurate and reliable data on wind patterns, which is essential for various applications.

A wind logger is a specialized device designed to gather and record data from wind turbines. It serves as a central monitoring system that collects real-time information, enabling operators and engineers to analyze and evaluate the performance of individual turbines, as well as the entire wind farm (Chehoui et al., 2015). The design and construction of a wind farm logger involve incorporating sensors, data acquisition systems, and communication capabilities into a robust and reliable device. The logger must be capable of withstanding the harsh environmental conditions often experienced in wind farm locations, including extreme temperatures, high winds, and exposure to dust and moisture (Al-Maghalseh and Maharmeh, 2018). Additionally, it should be scalable to accommodate a large number of turbines and possess the ability to transmit data securely to a central database or monitoring station. Efficient data logging and storage are essential to ensure accurate and continuous monitoring. The logger should have sufficient memory capacity and be capable of recording data at regular intervals. It must also feature robust data management capabilities, allowing for easy retrieval and analysis of recorded data.

Furthermore, the logger should incorporate a user-friendly interface, enabling operators to configure logging parameters, monitor real-time data, and generate comprehensive reports. This interface should provide intuitive visualizations and alert systems to promptly identify any abnormalities or issues within the wind farm. In this study, a wind speed logger suitable for monitoring the wind profile of a wind turbine is designed and constructed.

2.0 METHODOLOGY

2.1 Design of Wind Speed Measuring Device (Anemometer)

In this paper, a cup-type anemometer was designed and constructed. A cup-type anemometer is made up of three conical or spherical plastic cups mounted on a rotating shaft. The speed of rotation is proportional to wind speed (Ryer, 1998). The cups are mounted on the horizontal arms of a vertical shaft. Flowing air past the cups in any horizontal direction turns the shaft at a rate proportional to the wind speed. Therefore, counting the turns of the shaft over a set time interval produces a value proportional to the average wind speed (Ryer, 1998).

The cups are light so that the rotating part of the anemometer can start at low wind velocities and respond quickly to wind gusts. The anemometer has three cups to allow for better rotation reliably as two will not rotate well and more than three will add to the mass of the device. The cups are conical in shape to reduce turbulence. These horizontal arms are separated by equal angles and mounted on a vertical shaft. When wind causes the cups to rotate, the arms around the central pole (the shaft) is also rotated. For the most linear response of rotation speed, with wind velocity, it is recommended that the cup diameter be approximately half the total wheel radius (Ryer, 1998). To convert the mechanical rotation into electrical pulses a logic train, propagated at a speed proportional to the frequency of rotation, is required. This was achieved by including an optical interrupter. An optical interrupter relies on the continuity or otherwise of light between a source (LED) and a photo-detector 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 causes interruptions of the light beam, causing a pulse waveform to be generated at the output of the phototransistor.

An internal photodetector senses the 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 shown in Figure 1. As a current limiter a resistance value of 100 Ohms was considered adequate.

The photo-detector used is a phototransistor. A 1k resistor is used as the collector 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 rotating arm of the encoder 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 speed of rotation and by extension to wind speed (Figure 1

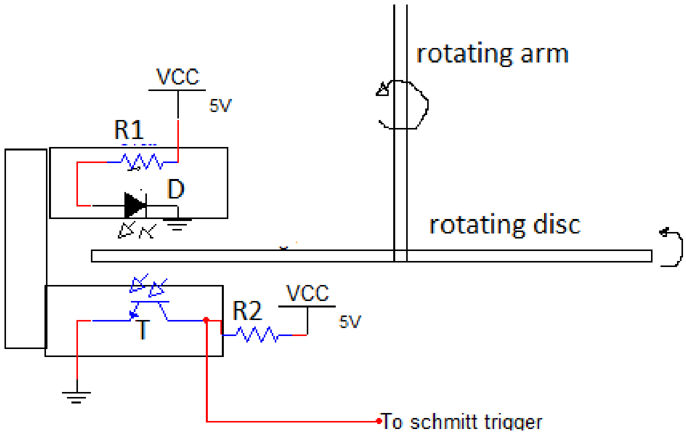


Figure: 1: The optical encoder for wind measurement

The IR LED current was fixed at 100mA at a forward voltage of 1.1 V the decision was based on the suggestion that when an LED diode is operated in 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:

$$R_1 = \frac{V_L - forward\ diode\ voltage}{IR\ LED\ Current} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$R_1 = \frac{5 - 1.1}{0.1} = 39\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

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 1 mA for the collector current. Therefore,

$$R_2 = \frac{5 - 1}{1mA} = 400\Omega \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

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 2. Pins 14 and 7 serve as the + supply and ground terminals respectively. The odd terminals are inputs while the even terminals are the outputs.

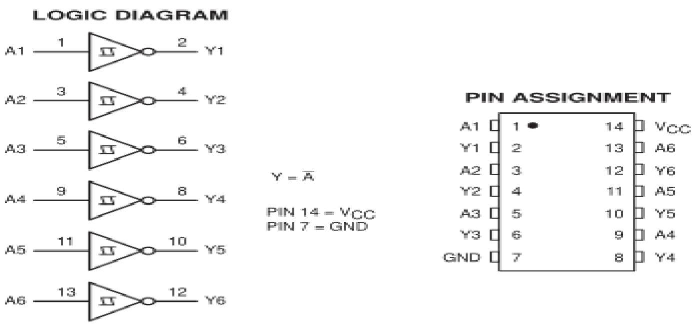


Figure 2 Pin configuration of the 74HC14 IC (Texas Instruments, 2019)

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

After the circuit design, the components were carefully soldered on Vero board with tests at various stages to ascertain the working conditions of the components and circuits. The complete assembly is shown in Figure3

Plate 1: Fabricated wind speed anemometer

2.2 Calibration of the Anemometer

To calibrate the fabricated anemometer a standard anemometer was used as a reference. The two were placed at equal distance from a slowly rotating fan (Plate 3.5).

PLATE 2: SETUP TO CALIBRATE THE FABRICATED ANEMOMETER

The number of rotations for 2 minutes for both meters were simultaneously taken and recorded. This experiment was repeated five times and the averages evaluated. An equation was then established to relate the two quantities (Table 1).

TABLE 1: RESULTS OF THE EXPERIMENT TO CALIBRATE THE FABRICATED ANEMOMETER

Anemometer	Average no. of turns in 2 minutes
Reference	143
Fabricated	117

The reference anemometer has a transfer relation between wind speed and pulse output of 2.4 km/h for every pulse. This translated into a wind speed of 0.6667 m/s.

The relationship between the reference and constructed sensor was evaluated using

Number of rotations for reference (N_1) *X* quoted reference speed (S_r): number of rotations (N_2) *X* speed of fabricated device (S_f). So That:

$$N_1 S_r = N_2 S_f$$

$143Sr = 117SS_f = \frac{143 \times S_r}{117} = 1.222S_r$

The constant, 1.222 was inputted in the software for converting the measured frequency generated by the fabricated anemometer to actual wind speed.

2.3 Microcontroller Section

A microcontroller was used to integrate the different subsystems. It was configured to deliver HTML pages to web browser using the HTTP application-level protocol implemented by web servers. A FLASH memory was used to save the pages. Provision was made for it to be modified upon request by a front-end browser. A SLIP protocol implemented in the WIZ1000 Serial- To-Ethernet Converter enabled this embedded server to receive HTTP requests over the serial port, and return requested pages to the browser via same. The server could download, log files via the browser, delete log files, update system real time clock chip, and manage network connectivity. Logs read from the attached SD card was formatted as HTML pages and presented to the browser for visualization. Semi-permanent data storage was achieved by SD card. A FAT32 file system built on El Chan's FatFs open-source file system was implemented to handle file creation and management. A real time clock chip (RTCC) was incorporated for timekeeping. A separate CMOS battery was used as back-up supply for the RTCC chip. The DS1307 RTCC supports I2C interface, and was placed on the same bus as the 24C04 512-byte serial memory chip. The I2C port was emulated in software using bit-banging as it offered a more flexible approach to implementing various checks on the I2C bus. The RTCC initialization was effected via the browser on the PC-side of the user interface.

For unattended logger operation, certain parameters needed to be retained in non-volatile memory.

To interface the logger with an Ethernet network, an Ethernet interface was integrated into the system.

The Ethernet interface was required to provide serial-to-Ethernet conversion capability, enabling the microcontroller to receive TCP-IP packets as binary data over the UART, and also send binary data over the UART to be encoded into Ethernet packets by the converter. A high-capability converter fitting this requirement was found in the WIZ1000.The WIZ1000 is manufactured by WIZnet. The device acts as a gateway between RS232 and Ethernet. It enabled remote gauging, managing, and control of a device through the network based on Ethernet and TCP-IP by connecting to the existing equipment over RS232 serial interface. It is a protocol converter that transmits the data sent over the RS232 serial port to TCP-IP data packets, and converts TCP-IP data received over the Ethernet network into serial data that is sent out over the serial port.

TheWIZ1000 was configured with a static IP address since it was configured as a server, making it reachable over the network. To emplace the logger on a wireless network an interface is required between the Ethernet port on the converter and the wireless network. A Mikrotik SX-5nD2 Consumer Premise Equipment/Router is configured as a bridge. The CPE bridges the LAN Ethernet on the WIZ1000 with any wireless network to which it is configured to connect with.

2.4 Performance Assessment of the fabricated Anemometer

After the wind speed anemometer was fabricated, its performance was evaluated by placing it at the same distance with a reference from a rotating table fan. The two anemometers (fabricated and reference) were used to measure the speeds of the wind flow from the fan (Plate 3).

Plate 3: Set up of the accuracy test of fabricated anemometer

2.5 Anemometer performance Test Result

The result of the test comparison test of the reference and fabricated is presented in Table 2. The differences between the two measurements were evaluated and used to calculate the percentage error.

Table 2: Result of the performance assessment of the fabricated anemometer

	Fabricate Anemometer (A_f) (Km/h)	Reference Anemometer (A_r) (Km/h)	Difference
1	1.32	2.15	0.83
2	2.56	2.98	0.42
3	2.86	3.15	0.29
4	3.25	3.18	0.07
5	3.68	3.47	0.21
6	4.21	4.72	0.51
7	4.62	4.96	0.34
8	4.89	3.61	1.28
9	7.34	8.87	1.53
10	8.39	9.42	1.03
∑		46.51	6.51

The percentage pyranometer, error is

$$A_C = \frac{[\sum PA_f - A_r]}{\sum A_r} x\ 100$$
$$= 13.997\%$$

To determine the linearity, transfer function sensitivity of the fabricated anemometer, the result of Table 2 is plotted in Figure 3.

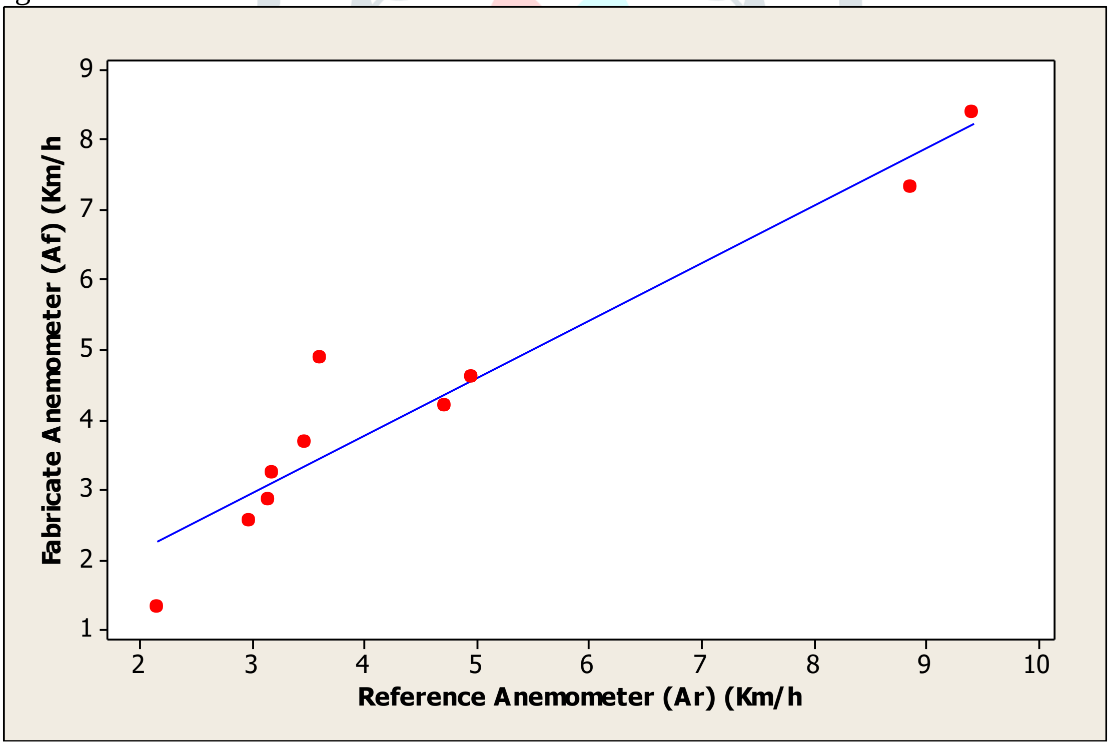


Figure 3: Correlation plots of anemometer readings

The specifications of the fabricated anemometer are summarized in Table 3

Table 3: Specifications of the fabricated anemometer

Characteristics	Value
Linearity	91.6%
Sensitivity	1.112
Range	-
Resolution	-
Percentage error	13.99%

Transfer function	y = 1.112x - 0.146

2.6 Comparison of the Systems Measurements with Online References

As a further assessment of the designed system's performance, its measurements were compared with those obtained from an INTERNET generated site (MYWEATHER.COM). The results were tabulated in Table 4 and there errors evaluated.

Table: 4. Result of the Comparison of online and system recorded wind speed

Internet Wind speed (Km/h)	System wind speed (Km/h)	Difference (Km/h)
22	9.3	12.7
29	8	21
31	10	21
28	13	15
21	8	13
18	6	12
26	7	19
30	8	22
27	5	27
29	7	22
27	4	23
24	7	17
19	5	13
18	6	12
24	6	18

2.7 System Field Assessments on Deployment

The system was placed in the open (Plate 4) to log weather data. The power required by the assembly was provided by using two lithium ion batteries, a charger and solar panel.

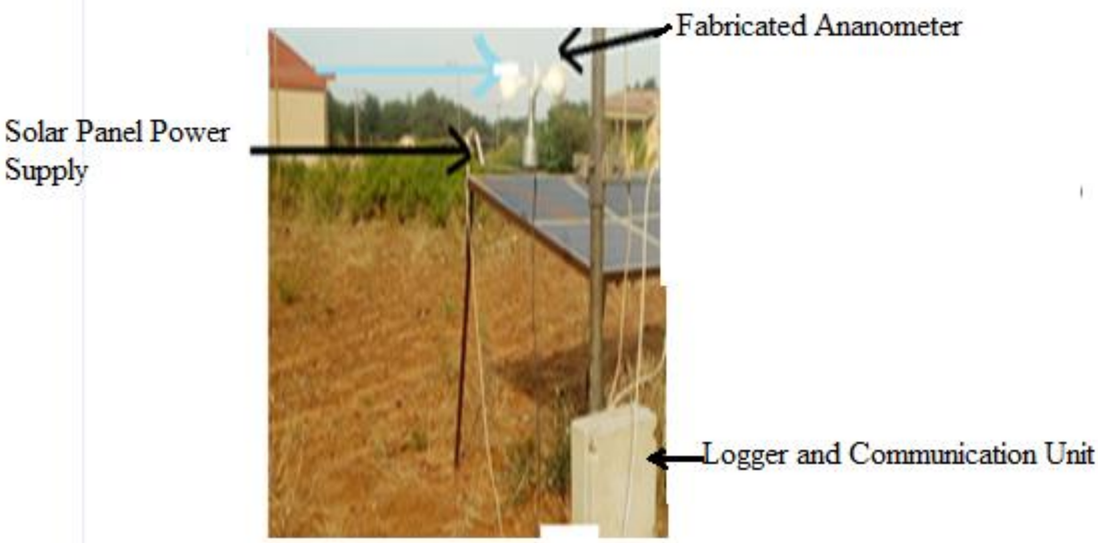
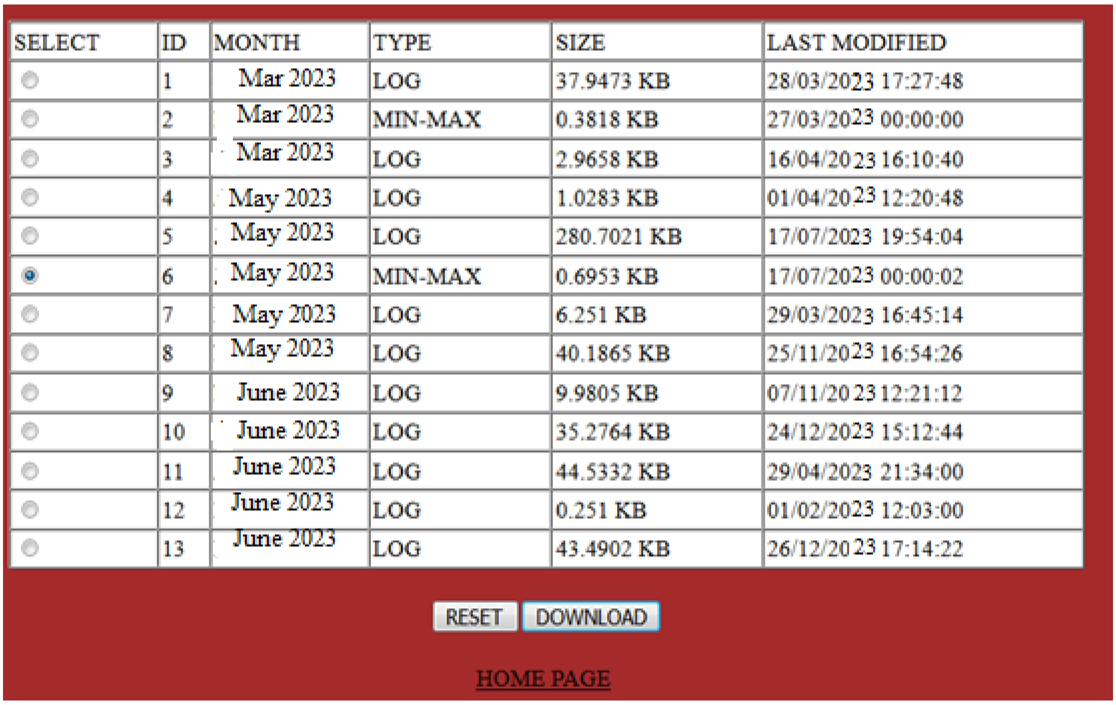


Plate 4: Deployed wind logger

Under test, the two batteries could provide supply to the system for thirty seven hours when fully charged. The system's logger was accessed through a server and a Wi-Fi radio from a laptop computer. A screen of the server logs page is shown in Plate with provision for selection of type, date modified, time and date (plate 5).



SELECT	ID	MONTH	TYPE	SIZE	LAST MODIFIED
○	1	Mar 2023	LOG	37.9473 KB	28/03/2023 17:27:48
○	2	Mar 2023	MIN-MAX	0.3818 KB	27/03/2023 00:00:00
○	3	Mar 2023	LOG	2.9658 KB	16/04/2023 16:10:40
○	4	May 2023	LOG	1.0283 KB	01/04/2023 12:20:48
○	5	May 2023	LOG	280.7021 KB	17/07/2023 19:54:04
◉	6	May 2023	MIN-MAX	0.6953 KB	17/07/2023 00:00:02
○	7	May 2023	LOG	6.251 KB	29/03/2023 16:45:14
○	8	May 2023	LOG	40.1865 KB	25/11/2023 16:54:26
○	9	June 2023	LOG	9.9805 KB	07/11/2023 12:21:12
○	10	June 2023	LOG	35.2764 KB	24/12/2023 15:12:44
○	11	June 2023	LOG	44.5332 KB	29/04/2023 21:34:00
○	12	June 2023	LOG	0.251 KB	01/02/2023 12:03:00
○	13	June 2023	LOG	43.4902 KB	26/12/2023 17:14:22

Plate 5 : Screenshot of the server logs page.

Real-time wind speed data were observed on a web browser (Table 5) for on the spot assessment of system performance while also being saved to a removable SD card.

Table 5: Sample of downloaded data

DATE	TIME	WIND SPEED (K/h)
4/6/2023	12:37:57	112.2
4/6/2023	12:38:57	116.9
4/6/2023	12:39:57	14.3
4/6/2023	12:40:58	112.5
4/6/2023	12:41:58	67.2
4/6/2023	12:42:58	18.1
4/6/2023	12:43:58	12.6
4/6/2023	12:44:58	17.5
4/6/2023	12:45:58	92.3
4/6/2023	12:46:58	83.2
4/6/2023	12:47:58	90.6
4/6/2023	12:48:58	12.7
4/6/2023	12:49:58	35.1
4/6/2023	12:50:58	38.4
4/6/2023	12:51:58	38.5
4/6/2023	12:52:58	13.2
4/6/2023	12:53:58	11.5
4/6/2023	12:54:58	12.6
4/6/2023	12:55:58	27.9
4/6/2023	12:56:58	12.5
4/6/2023	12:57:58	15.1
4/6/2023	12:58:58	11.9
4/6/2023	12:59:58	12.2
4/6/2023	13:00:58	91.4
4/6/2023	13:01:58	17.3

4/6/2023	13:02:58	56.5
4/6/2023	13:03:58	11.5
4/6/2023	13:04:58	90
4/6/2023	13:05:58	72.6
4/6/2023	13:06:58	86.4
4/6/2023	13:07:58	39.5
4/6/2023	13:08:58	90.2
4/6/2023	13:09:58	15.4
4/6/2023	13:10:58	16.5
4/6/2023	13:11:58	12.8

3.0 Discussion

The result of the wind accuracy test show a relatively good correlation between the fabricated one and the reference wind speed anemometer with a correlation coefficient of over 90%. The error recorded when the measurement of the fabricated anemometer was compared with that of a reference type showed that there was an error of 13.99%. This large error could be due to the frictional force as a result of the mechanical moving parts of the instrument. When the result was compared with the internet generated wind speed of Sokoto area the error recorded was 79.36% as presented in Table 4.4. The reason for this big recorded error may be due to the method or altitude and place where it is measured. For instance the online data is usually measured far from any building and structures that could obstruct wind blow. Wind blow could be very erratic and could vary significantly even from places that are not too far apart. Moreover, the logged wind speed is averaged over the selected period of time and does not represent wind gust which is instantaneous. So even if the wind speed is recorded by two similar devices at the same location but averaged over deferent time intervals the result could be very different. This huge error further demonstrates why it is necessary to take direct data at the installation location.

A PC or android phones could be used to communicate with the systems if located within the WI-FI network of its server. The server was able to successfully upload results on a client's request. The ADM page's security when tested was found to be secured as only the administrator with the correct password could access the page. This ensures that the data in the logger is secured and protected from corruption or tempering. It ensures that the client has access only to view instantaneous wind speed data or download historical data saved on the SD card of the logger.

The system after design and performance evaluation showed more features and improvement over Khemani and Stonecypher (2009), Gxasheka et al (2006), Pietruszko and Gradzki (2015), Huld et al. (2012), Carr, and Pryor (2013) and Forero et al (2015)).

The flexibility of the Logger GUI application allows for data management through querying by one or more fields. A client or a number of clients could download data from the logger SD card saved with ".CSV" (comma-separated values) file extension. The retrieved data can be analysed using packages such as Microsoft Excel, Matlab, or SPSS.

4.0 Conclusion

This paper has been able to develop a system for logging wind speed data around a wind farm. A cup-type anemometer is designed and constructed. The cup-type anemometer is made up of three conical or spherical cups mounted on a rotating shaft. The speed of rotation is proportional to wind speed. A programmed microcontroller was used to evaluate and display the instantaneous speed of wind around the wind farm. The measured quantifies could be saved in an SD card for future record. The 24 hour wind profile of the turbine can hence be observed and analysed. An ATmega16 AVR was used as the heart of the control and coordination of all the activities of the individual modules.

The wind speed measuring instruments was designed and its performances assessed. The performance evaluation of the instruments designed showed that their measurements are relatively accurate when compared to measurements of reference instruments. There was a correlation of over 90% between the measurements of the two sets of instruments (reference and fabricated). The output spans of the instrument showed that the measuring device could accommodate the intended range of measurement. The system was also able to log, successfully, all the parameters considered. The instantaneous and historical values of the logged data were successfully viewed from a remote computer. The logged data was also made available to clients on request.

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