Low Cost High Altitude Automatic Weather Station Design

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Abstract: When looking at installing a renewable energy generator, you need to be confident of the resource (solar, wind) at your particular location as this affects the energy generated at the selected site. With solar photovoltaic (PV) systems, this can be done by looking at historic data, generally from satellite readings, for the particular latitude. This will yield pretty accurate resource data. However, the wind resource is incredibly variable and depends upon the exact topology of the area. Houses, trees, and valleys all can affect the local wind resource. For this reason, wind speed data is collected at a potential wind turbine installation site. This gives real data which can be used to assess the wind speed. When installing a number of very expensive large wind turbines, one must be very confident about the wind speed data. The data must be robust and reliable and the developer will be willing to spend a lot of money on accurate industrial equipment to have lots of confidence in the data. This project intends to overcome this barrier by providing a low-cost, reusable, open-source wind speed recording unit, which can be left at high altitude in a remote location to record data and help improve the site's wind speed assessment. We have proposed and developed a low-cost hardware module based on Arduino open source platform, which measures the meteorological data, including air, temperature, relative humidity, wind speed and solar radiation, with two options: The first is the wireless option at which it sends the measured information to Excel spreadsheet running on a PC through wireless link. The second is the data logger option at which it records the measured data to SD card as Excel file with date and time every 10 seconds.

تصميم محطة مناخية منخفضة التكلفة لإرتفاعات عالية

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ملخص: عند التفكير في تركيب مولد طاقات متجددة يجب أن نكون على ثقة من توفر المصدر الطاقوي سواء أكان شمس أو رياح في موقع التركيب لأنه يؤثر بشكل مباشر على الطاقة المولدة في الموقع المختار. ففي منظومات التحويل الكهروضوئي يمكن فعل ذلك بالإطلاع على البيانات المسجلة عامة من قراءات الأقمار الصناعية لخط عرض معين. وهذا سوف يوفر بيانات طاقوية معقولة. ولكن

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بيانات سرعة الرياح تكون متغيرة بشكل كبير وتعتمد على جغرافية المساحة المختارة. حيث تؤثر المنازل والأشجار والوديان على سرعة الرياح في الموقع. لهذا السبب تُجمع بيانات سرعة الرياح في الموقع المُرشح لتنفيذ تركيبات لتربينات ريحية فيه. وهذا يعطي بيانات حقيقية يمكن إستخدامها لتقدير سرعات الرياح بدقة. فعند تركيب عدد من تربينات الرياح الضخمة والمكلفة يجب التأكد من بيانات سرعة الرياح. حيث يجب أن تكون البيانات رصينة وذات إعتمادية عالية بحيث يُقدم المُطور على إنفاق أموال كثيرة على معدات دقيقة لكسب الثقة في البيانات المطلوبة. هذا المشروع يهدف بتوفير وحدات تسجيل بيانات سرعة الرياح ذات كلفة منخفضة وقابلة لإعادة الإستخدام والبرمجة ويمكن حملها لإرتفاعات عالية في مواقع نائية لتساعد في تقييم موقع التركيب. فقد إقترحنا وطورنا وحدة منخفضة التكلفة تعتمد على منصة أردوينو تقوم بقياس وتخزين البيانات المناخية كدرجة حرارة الهواء والرطوبة النسبية وسرعة الرياح والإشعاع الشمسي بخيارين: الأول هو الخيار اللاسلكي حيث يرسل البيانات المقاسة لملف جداول إكسل يعمل بحاسوب عن طريق وصلة لاسلكية. والثاني هو خيار تسجيل البيانات على بطاقة ذاكرة كملف إكسل مع الوقت والتاريخ لكل عشرة ثواني.

Keywords: High Altitude; Arduino; Automatic weather station; Wind engry.

1. INTRODUCTION

Climate change is one of the most important factors affecting the quality of life and the activity of the increasing population. The current means of meteorological parameters data collection are indeed rather limited and make use of some very expensive weather stations, which leads to a lack of comprehensive monitoring due mainly to cost constraints [1]. Nevertheless, the acquisition of comprehensive meteorological data is the prerequisite condition for the accuracy of building renewable energy systems such as solar parks and wind turbines. If there isn't enough measured data of meteorological parameters, the publicly available information about weather forecast would be inaccurate. The meteorological authorities worldwide use climate monitoring tools and equipment, usually called automatic weather stations (AWSs), to monitor the condition of the atmosphere to provide weather information. An AWS is a device that can measure and store temperature, humidity, wind speed, solar insolation, etc. of the surrounding. A modern version of AWSs is the wireless weather station,

The advanced wireless weather station consists of a base station and a remote station that include temperature, humidity and other sensors to take measurements of the weather conditions. The remote station collects and transmits data through the wireless channel. The base station will receive incoming data, store it in a memory, and then be ready to receive the next data. This project has been made in two cases where the operator can choose what suits him, and this makes it more flexible in dealing with system.

The wind speeds depend on the location, so all surroundings affect the local wind speed. A careful assessment of resources is required to ensure that wind turbines are correctly identified at locations where maximum power will be generated. Knowing the frequency at which high wind speeds occur is also very useful. A site might have a high average wind speed, but it could be that there is a very high wind for a short time (which would be difficult for the wind turbine to capture) and for the rest of the time, the wind speed is too low for the turbine to function. For this reason, it is good to know the wind speed against the frequency that the wind speed occurs.

Generally, at least one year of data is required; if possible, more than a year worth of data is preferred to obtain seasonal variations. This means that collecting data for a large wind farm is an expensive business, but necessarily so as there are large sums of money being invested.

In this work, we use RF frequency module that can transmit signal from 10 to 750m. In this case, Arduino is used as a controller. The controller allows faster transfer rates and more memory. We use the wireless station model nrf24L01.

In this work, we measure wind speed, temperature, humidity, and solar radiation. However, an emphasis

on wind speed measurements is carried out because of the unavailability of wind speed measurements at altitudes up to 120 meters. This helps in assessing the productivity of the modern, large power, 120 meters wind turbines. The construction of tall towers directly without study of these variables may cost a lot if the site is not suitable for wind power generation where the cost of building these towers is very expensive, and the transfer process is more expensive and causes a great loss. In most projects, the site is studied for a period of one year, where the variables mentioned above are usually recorded every ten minutes, and by studying these variables it is decided to start or cancel the project [11].

2. ARDUINO

Arduino is an open-source environment in electronics based on easy-to-use hardware and software. Arduino boards are generally based on microcontrollers from Atmel Corporation like 8, 16 or 32-bit AVR architecture. The Arduino boards also consists of on board voltage regulator and crystal oscillator. They also consist of USB to serial adapter with which an Arduino board can be programmed using USB connection. In order to program the Arduino board, we need to use the open source Arduino software IDE. The Arduino IDE software is based on processing programming language and supports and C++ languages. There are a number of different types of Arduinos to choose from. There are common types of Arduino boards you may encounter such as Arduino Uno, Arduino NG, Diecimila, Duemilanove, Arduino Mega 2560, Arduino Mega ADK, Arduino LilyPad. In this work we use Arduino Mega shown in Figure 1 because it has more connections than other Arduino boards [2].
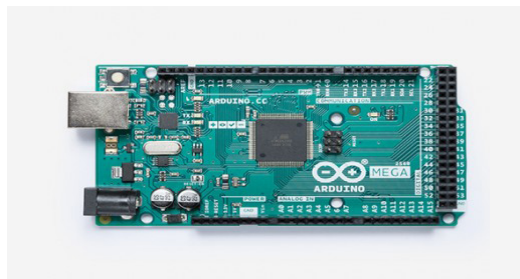

Figure (1). Arduino Mega [3]

3. METHODOLOGY

The developed system is mainly an embedded system designed for monitoring some weather parameters to help in recording data from sensors.

3.1 Sensors

In this work some sensors will be used to convert meteorological quantities such as temperature, humidity, solar radiation, and wind speed into electrical signals, which can be measured and stored using Arduino board. Figure 2 shows the main components and sensors of our developed system.

The DHT11 is a digital signal output temperature and humidity calibrated sensor. It uses the digital acquisition technology with temperature and humidity sensor technology. The sensor includes a resistive humidity measure component and a NTC temperature sensor component. The connection with 8 bits high performance single-chip microcontroller gives the sensor excellent quality, super-fast response, anti-jamming ability, and high cost-effective product. DHT11 offers an I/O port to connect with the mixed signal

microcontrollers MSP430. The 40 bits of humidity and temperature data are sent to the microcontroller every time data is checked by the cycle redundancy check CRC. So, the accuracy of the data is guaranteed. DHT11's power consumption is quite low. The required power supply voltage is 5 V, and the maximum average current is about 0.5 mA [4].
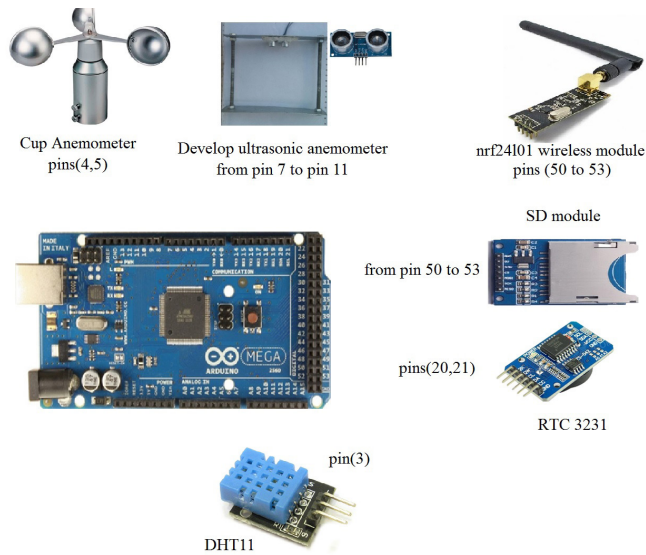

Figure (2). Sensors and components in the developed AWS.

3.1.1 DHT11 Temperature and Humidity Sensor

DHT11 uses a single bus data format. That is, a single data port completes input/output two-way transmission. One single packet is 5 Bytes (40 Bits), and the communication time is less than 3 ms. The specific sensor is shown in Figure 3. A full data transmission contains 40 bits. The high bit comes out first. The data format is as follows: 8-bits humidity integer data, 8-bits humidity decimal data, 8-bits temperature integer data, 8-bits temperature decimal data , and 8-bits for calibration. The calibration is the sum of the first four bytes.
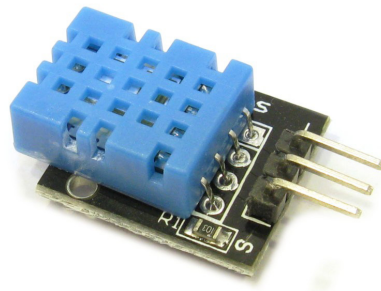

Figure (3). DHT11 Sensor

Table (1). Data output format

Humidity		Temperature		CRC
Integer	Decimal	Integer	Decimal	8-bits
8-bits	8-bits	8-bits	8-bits	

3.1.2 Ultrasonic Anemometer

One type of sonic anemometers is called the ultrasonic anemometer (UA), which uses ultrasonic propagation time as the parameter for wind speed measurements. The ultrasonic wave is generated from an ultrasonic source and the reflected wave is received by an ultrasonic receiver. Due to the fast speed of sound, the propagation time is really short. If the distance between the transceivers is 0.1 m, the theoretical propagation time is 0.3 ms. By measuring the propagation time, and knowing the effect of wind speed on the speed of sound waves, the wind speed can be determined [5].
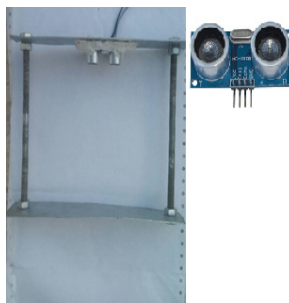

Figure (4). The developed ultrasonic anemometer

Figure 4 shows the ultrasonic sensor module that is modified to measure wind speed. It uses the ultrasonic sensor, which is made by the Quantelec Company. This sensor separates into the two parts; one part is for the transmitter and the other part is for receiver [5]. The generator provides power to the ultrasonic source which transmits ultrasound. The sound wave travels through conditioned surroundings to the receiver. The propagation time is relevant to wind speed and temperature as well. The longitudinal wave propagates by changing the density of the medium. In air, the sound propagates by changing the air pressure along its moving direction. The speed of sound is about 340 m/s at 15 °C. When the temperature increases, the speed of sound will increase [6]. The speed of sound in dry air can be calculated as:

$$V_s = 331.3 + 0.606 \times T_c \qquad (1)$$

When wind blows, sound wave interference occurs. If the sound wave has the same direction as the wind, it will go faster and vice versa. Since the speed of sound can be considered as a constant quantity in static air. The wind speed can be determined if the sound propagation speed is affected by wind flow. Now, it is possible to calculate the time the wave travels from the transmitter to the receiver. Wind speed can be calculated by defining the following relations:

$$V_1 = V_{signal} + V_{wind} \qquad (2)$$

Where V_1 is the of sound when wind blows and V_{signal} is the speed of sound wave without the effect of

wind. By as-suming the travel time for $V_{signal} + V_{wind}$ as t_1 and travel time for V_{signal} as t_2, the travel time t from transmitter to the receiver could be derived.

Let:

$$V_2 = V_{signal} \tag{3}$$

The effect of the wind speed on the propagation time can be calculated. Placing a fixed reflector at 100 mm (which is the minimum detectable length) apart from the plane of both the transmitter and receiver, the propagation time is only varied due to temperature and wind speed. From Figure 5, it is defined as the distance the transmitted sound wave travels from the transmitter until it is reflected back to the receiver. Assume that the sound speed is 340 m/s and the distance d is 200 mm. The wind speed will cause a time difference. Using Equations 2 and 3, for non-accelerated wind speed V the travel time t from the transmitter to the receiver is give as:
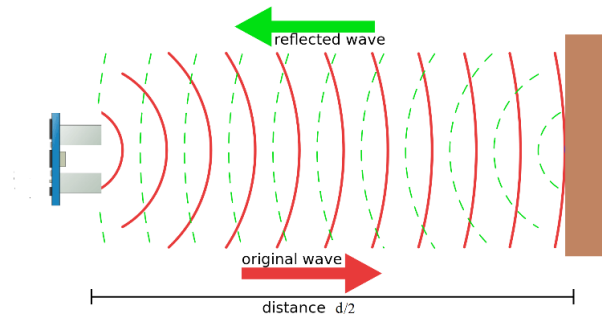
$$t = \frac{d}{V} \tag{4}$$

Figure (5). Ultrasonic basic.

It could be noticed from Equations 2 and 3 that, V_1 travels faster than V_2. So, by subtracting V_2 from V_1, a relation between V_1 and V_2 is derived.

$$V_1 - V_2 = 2 \times V_{wind} \tag{5}$$

Define Δt is the difference time between t_1 and t_2.

$$\Delta t = t_2 - t_1 \tag{6}$$

Now, V_1 and V_2 can be written as follows:

$$V_1 = \frac{d}{t_2 - \Delta t} \tag{7}$$

$$V_2 = \frac{d}{t_1 - \Delta t} \tag{8}$$

Subtracting V_2 from V_1, a relation can be derived to relate V_1, V_2, and the wind speed.

$$V_1 - V_2 = 2 \times V_{wind} = d \times \left(\frac{1}{t_2 - \Delta t} - \frac{1}{t_1 + \Delta t} \right) \tag{9}$$

Using the approximation $x \ll 1$ then

$$\frac{1}{1 - x} \approx 1 + x \qquad\qquad (10)$$

The wind speed can be simplified to :

$$V_{wind} = \frac{V_{signal}^2}{2 \times d} \Delta t \qquad\qquad (11)$$

3.1.3 Solar Radiation Sensor

Solar radiation is the light energy that comes from the sun in different forms. A general electromagnetic spectrum explains the different frequency of light waves that are emitted from the sun. The total frequency spectrum of electromagnetic radiation emitted by the sun is known as solar radiation. To calculate the amount of solar radiation reaching the earth surface, both the elliptical orbit of the earth and the attenuation by the earth's atmosphere have to be taken into account.

In this work, we use a calibrated solar cell (monocrystalline) to measure the solar radiation. Solar cells produce a current proportional to the total irradiance; this current depends linearly on such irradiance. When no load is connected, the voltage across the terminals of the solar cell is called the open circuit voltage (V_{oc}). When the load impedance is zero (short-circuited terminals), the current that flows through the shorted terminals of a solar cell. This current is called the short-circuit current (I_{SC}). Usually solar cells are tested at standard test conditions (STC) where the cell temperature is 25°C, and the solar insolation (irradiance) is 1000 W/m^2. In addition, the solar spectrum is AM1.5.

The calibration process is performed by connecting a solar cell to a trans-impedance amplifier (i.e., converts current to voltage) circuit to produce a voltage signal, which is proportional to solar irradiance. A standard Kip & Zone pyranometer is used to calibrate the solar cell. A variable intensity light source is used in the calibration process. The intensity of the light source is changed from zero to higher values. The output from the pyranometer is the light intensity in W/m^2 and the output from solar cell setup is a voltage in V. Figure 6 shows the developed solar cell radiation sensor. As a result, an empirical formula obtained from Figure 7 is plugged into the Arduino acquisition code.

The developed sensor and the pyranometer are installed in horizontal plane (i.e. 0 tilt angle) for real time measurements for several days. The climatic conditions among these days are changing from shiny to cloudy days. Fortunately, the solar radiation measurements of the developed sensor coincide with the simultaneous pyranometer measurements.
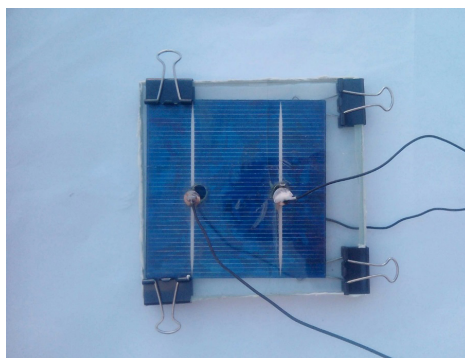

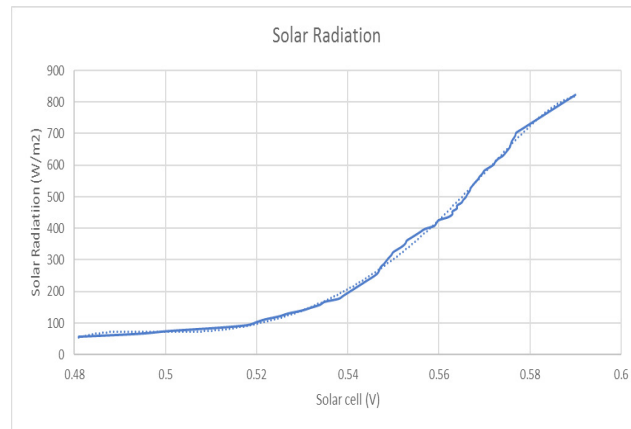**Figure (6). The developed solar radiation sensor.**

Figure (7). The relationship between solar radiation and voltage from the solar cell setup.

4. SYSTEM DESCRIPTION

The integrated system of the project is implemented with two options; the first option stores the measured meteorological data using an SD card, and the second one sends the data wirelessly to a ground station. Either option depends on the nature of the place and function. In general, the system can be described as follows:

Starting with storing data to an SD card, the system includes a real-time clock (RTC) for time-stamping the data and an SD module. It is designed to count pulses, read/write digital I/O channels and read analog channels. With a proper installation of all components, the system is ready to store the data in the SD memory card. Data is written in a human-readable format. The read/write cycles of SD cards are limited; this limitation is used to increase the useful life of the SD card. This means that the larger the size of the SD card, the longer the life in this application. However, our system consists of Arduino ATmega2560, which is the heart of the AWS, and 5-meteorological sensors; namely one for temperature, one for humidity, two for wind speed, and one for solar radiation. The system stores the data in a CSV file format, so we can read it using Excel. Finally, a commercially available standalone solar PV kit with Lithium-Ion batteries is used to power developed system.

The second option is using a wireless communication module to send the measured data to a ground station. It uses the same system components in addition to the nRF24L01+ wireless module. In this configuration we use an additional Arduino card to control the receiver side of the system. Therefore, the main Arduino card controls the transmitter side of the system. In order to increase the reception distance, we add a power amplifier to the nRF24L01+ module to increase the distance from 100 meters to 1000-meter line offsite. We set the transmission speed to 250 Kb/sec to save power. The Arduino card in the receiver side is connected with a computer, which is called the ground station. The PLX program is used to record the data directly to an Excel file. Also, to increase the reliability of this option, usually the collected data is connected directly to the computer, but if the power is disconnected from the computer, the measured data will be stored directly to a memory card to prevent data losses.

The software development is an important part of the AWS. An accurate and precise measurements will

produce a high-quality useable data, which can be done by implementing a software setup that is related to the correct timing scheme in programming the main controller. In this study, the software development mainly focuses on the Arduino card programming. The AWS timing circuit is used to control all the timing sequences starting from signal generation and analog switch control. The program is constructed using the C++ language through Arduino idle program. Eventually, the written code is burned into the ATmega 2560 microcontroller.

Because of the need for a measured wind speed data at high altitudes for wind farms applications, our system will be lifted at such altitudes as shown in Figure 8 using a balloon to get a reliable data that can be used to assess the productivity of wind turbines at specific locations and altitudes. The projected energy production is usually used in preparing the feasibility studies of wind farms. The balloon is held fixed at the required altitude using strong high-tension wires.

Figure (8). Balloon high altitude AWS

5. RESULTS

The proposed hardware board can take power directly via USB port. Four wires are attached to the balloon to fix it in place. When the instrument is switched on, the data is recorded to the memory card ground station. After setting up the hardware and all connections, the system is launched up for test purposes to a height of 16 meters, and the system starts logging the real-time weather data on CVS files, which are accessible in MS Excel spreadsheet. The measurement lasted for 7 consecutive days. The data is retrieved from the system, and they are analyzed and compared to satellite data available online. The comparison results are satisfactory.

Figure 9 reveals the measured wind speed data using both cup and ultrasonic anemometers. The two sensors almost measured the same data for the most of the time. Some wind variations are not detected using the cup anemometer. The developed ultrasonic sensor is robust against tilt variations.

As can be observed, the developed ultrasonic anemometer is better than the cup anemometer, and that is clear from Figure 9 that the cup anemometer keeps the wind speed constant while the developed ultrasonic anemometer is sensitive to minor wind speed changes. Also note that, in some periods the ultrasonic sensor does not record data for unknown reasons so far. Mau be, the cheap price and limited quality prevents it from tracking the speed of Arduino sometimes. Figures 10-12 show the humidity, temperature, and solar radiation data.
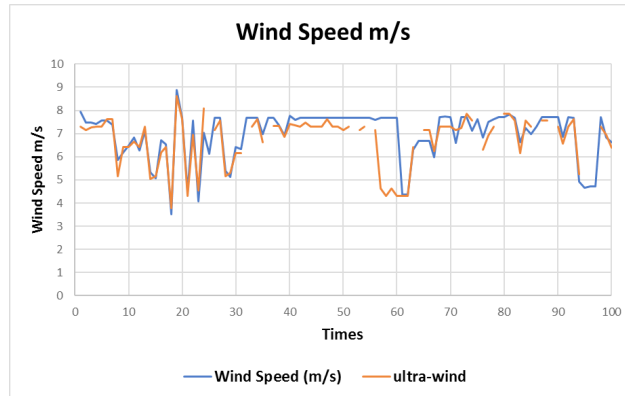
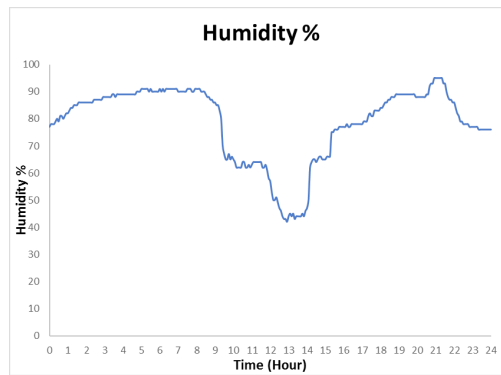**Figure (9). Wind speed for cup anemometer and developed ultrasonic anemometer.**

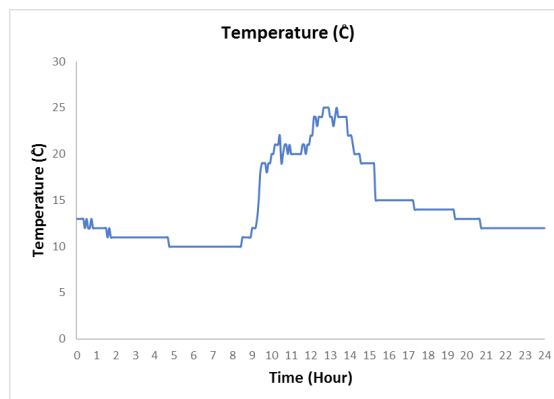**Figure (10). Humidity data.**

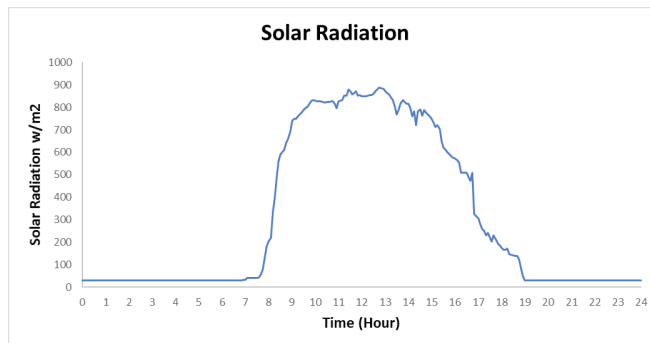

Figure (11). Temperature data.

Figure (12). Solar radiation data.

The solar radiation results when compared with the data from Photovoltaic Geographical Information System (PVGIS) interactive maps show a very good agreement with a correlation factor above 0.9..

6. CONCLUSIONS

Wind speeds are very site dependent with topology, ground roughness and other factors affecting the local wind speed. Knowing the wind speed and its variation with time, height, and location allows us to make a more accurate resource assessment. An accurate resource assessment is required for ensuring that the wind turbines are sited correctly in locations where they will generate the maximum energy.

In this paper, we have proposed a complete low-cost automatic weather station. An ultrasonic wind speed sensor is developed to overcome tilt issues in measuring wind speeds at high altitude. Also, a reference cell is configured and calibrated to measure the global solar radiation on a horizontal surface. A low-cost temperature and humidity sensor available in the local market was also implemented. A standalone solar PV system with four days of autonomy   is used to power the electrical load of the system.

The measured data is handled with two options; it is either stored in an SD memory card or sent wirelessly to a ground station. The measured data is recorded with respect to date and time using RTC timing module. The system is capable of measuring temperature, humidity, wind speed, and solar radiation data simultaneously.

The proposed system is very useful in the market due to its low cost, high accuracy compared to the used reference instruments. The readings are very clear and can be updated every 3 sec. These readings are stored in a database using proposed PLX-DAQ application and Excel spreadsheet. This has mainly been developed for use in locations with a specific application to wind turbines for future installations in Libya.

ACKNOWLEDGEMENT

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