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High resolution meteorological parameters measurement and analysis for quality weather forecasting

Shivdas P. Bankar[1]
Electronics and Telecommunication Engineering
N B Navale sinhgad college of Engineering
Solapur, India
shivdas.bankar04@gmail.com

Prof. Sunita P. Sagat[2]
Electronics and Telecommunication Engineering
N B Navale sinhgad college of Engineering
Solapur, India
spsagat.nbnscoe@gmail.com

Abstract- This project presents development of high resolution meteorological parameters measurement in a given environment with the evolution of miniaturized sensor devices coupled with wireless and wired technologies. This project presents the real-time monitoring of different environmental parameters including temperature, humidity, pressure, wind speed, rainfall as well as air pollution contents like co, ch4 and smoke using embedded sensors, raspberry pi3 board and FTP server technology at low-cost. The weather station communicates through Wi-Fi connection allowing the user to access the data remotely. An Raspberry-Pi was implemented to collect sensor data, transmission of collected data to FTP server. Acquired data from these sensors were displayed on embedded FTP web server using internet protocol and Ethernet interface which can be seen anywhere and it can be saved in external drive. Along with this all collected data has been analyzed by using ID3 and autoregressive weather forecasting algorithms for quality weather forecasting. Data gathered from the weather station was compared to a professional-grade weather station located at the same site. Results show that the low-cost weather station is a feasible option to use for site assessment purposes at a comfortable cost.

Keywords-* *weather station, raspberry pi 3, wind speed(WS),Wind directon(WD), temperature, humidity, rain gauge.

I. Introduction

Continuous changing of climate and weather conditions has been studied for a centuries. Huge importance of climate influence to human life motivated development of whole scientific areas devoted to climate and weather observation. In the beginning, simple and inaccurate instruments were used, which were inadequate for easy reading and storing of measured parameters. Nowadays, automated observatories and weather stations around the world collect environmental parameters continuously. These measured parameters are not useful if are not transferred in a fast and accurate manner to the primary users. Therefore, transfer and processing of measurement data is very important aspect of modern measurements. It is now common to use the sophisticated instruments that measures environmental parameters and transfer it to some destination. Such instruments are known as weather stations. Transfer of measured data can be accomplished by a number of means: direct wired link, satellite link, WiFi link, GSM/GPRS link, etc.

Collected and analyzed environmental parameters have a very wide utilization. The most common objective, which is widest used, is a weather forecast. However, there are numerous different purposes of these parameters, such as studying of global climate change, real-time micro location data acquisition, animal and plant protection and monitoring, etc. Next to scientific and commercial applications, weather stations can be used for educational purposes.

Various examples of low cost weather station systems have been developed for various applications in recent years, based on different microcontroller architectures and sensor hardware technologies, such as Arduino [2], [3], Raspberry Pi [4], [5], and C8051F020 [6]. However, few if any of these studies compare the data produced from the low-cost weather station to an industry-grade weather monitoring system, nor provide any metrics regarding overall data accuracy. Thus, this paper focuses on the development and implementation of a low-cost weather station to measure parameters relevant to wind farm site assessment based on readily-available off the shelf hardware. Furthermore, the data gathered from the system was compared to a professional-grade all weather sensor by Vaisala [7] located at the same site.

II. LITERATURE REVIEW

Phala, kgoputjo et al [2] presented an air quality monitoring system (AQMS) which is based on the IEEE/ISO/IEC 21451 standard.Concentrations of CO, CO2, SO2 and NO2, were measured using electrochemical and infrared sensors. Results are saved in the data server.

Xing Liu, Orlando [4] presented a comparative study on smart sensors, objects, devices and things in Internet of Things. The authors have also explained the definition and concepts of IoT in various different ways. The differences and similarities between the smart objects, smart things in IoT are presented in tabular form.

Marinov, Marin B. et al [3] monitors environmental parameters with amperometric sensors and gas sensors (infrared) using the PIC18F87K22 microcontroller. Sensor nodes are set up in different areas for real time monitoring of environment. The results are displayed on the city map.

Baralis, Elena et al [11] proposes a business intelligence engine (APA). The system is designed to aware the public International Conference on Computing, Communication and Automation (ICCCA2017) about the quality of air being affected by different factors like pollutants, toxic gases etc. Analysis of air pollution from different perspectives like meteorological data, pollutants and traffic data using APA is done. The system helps the people to realize their activities impact on deteriorating air quality.

Jha, Mukesh et al [7] presented a system for monitoring the environmental parameters, modeling and manipulating microclimate of urban areas. The system is implemented for the adaption of efficient urban infrastructure after analyzing the urban micro-climate.

Shete., R. and Agrawal S. [6] provides the framework for monitoring the city environment. Low cost Raspberry pi is used for implanting the system. Parameters like carbon monoxide, carbon dioxide, temperature and pressure are measured but no emphasis is given on particulate matter which left the environment monitoring incomplete.

Mitar simic, Goran M. et al [16] presented a system for measurement and acquisition of data of water and air quality parameters and results are shown on IBM Watson IoT platform. The system is battery powered with solar panel based charger unit.

Chiwewe, Tapiwa M., and Jeofrey Ditsela [17] collected air quality data from different cities of South Africa. Machine learning technique was applied to the data and prediction models were generated for ground level ozone.

Ruchi Mittal and Bhatia [5] propose a system in which they detect irregular patterns of sensory data with respect to time and space. They design a system which continuously queries and monitors sensor data to detect any deviations from the norm. This is essential in detecting a faulty sensor node and ensuring it can be quickly replaced. This system is especially helpful when detecting environmental activity like forest re. In order to achieve desired results, Data preprocessing and sensor data clustering is used. In data preprocessing, the sensor data is cleaned by putting in missing values and removing any unwanted data. Mittal and Bhatia analyzed this data cluster by plotting data, comparing them against expected/predicted patterns and detect anomalies.

III. METHODOLOGY

A. Block Diagram

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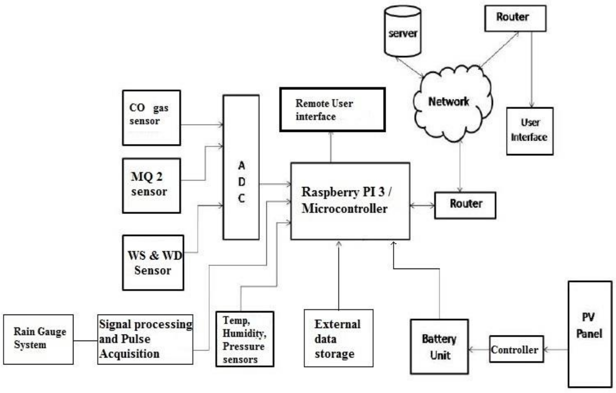

Fig. 1 Block diagram of proposed work

The development of the low-cost weather station was subdivided into four major subcomponents: 1) Data Collection 2) Solar Power System, 3) Data storage and Transmission, and 4) Data analysis and weather forecasting. Fig. 1 shows the complete block diagram of the high resolution metrological parameters measurement and analysis for weather forecasting

A. Data collection

The environmental parameters that have been brought into focus are Temperature, Humidity, Pressure, Wind speed, Carbon Monoxide and polluting gases. The data sensed by these sensors is continuously sent to the Raspberry Pi. The sensors,DHT22, BMP180 and Automatic rain gauge direct digital output that can be sensed by the GPIO pins of the Pi. The gas sensor MQ2 sends their data to the through MCP3008 ADC which is connected to the Raspberry Pi through the jumper cable. A wireless modem is used for providing internet connectivity to the system. The client can use the link for the dashboard and gets access to it. The different feeds that are shown on the dash board give dynamic data that is fed continuously to server.

A more detailed description of the measurement capabilities of each sensor relevant to wind farm site selection is presented in the next subsections.

1. Humidity and Temperature (DHT22)

DHT11 is interfaced with Raspberry Pi board at GPIO9 for humidity (in %) and temperature (in C) measurement using single wire serial interface (SPI). DHT22 has resistive type humidity measurement component and negative temperature coefficient (NTC) temperature measurement component. It gives calibrated digital output which Raspberry Pi can directly understand so no need to have analog to digital converter. This sensor needs 3-5.5V voltage supply and 0.5-2.5mA current supply, which can be given from Raspberry Pi board.

2. Pressure and Altitude (BMP180)

BMP180 is interfaced with Raspberry Pi board at SDA and SCL pin for atmospheric pressure (in Pa) and altitude (in m) from sea level measurement using I2C interface. It can also measure temperature. BMP180 works on the principle of piezo-resistive technology. BMP180 gives fully calibrated digital output so no need to have ADC. This sensor needs 1.8-3.6V supply voltage and 5µA supply current in standard mode, which can be given from Raspberry Pi board.

3. Automatic Rain Gauge System

The rain gauge used for measuring rain. The rain gauges have mechanism of self-emptying tipping bucket type. It consists of funnel used collects and sends the precipitation into a small size seesaw. When a pre-set amount of precipitation falls or rain fall, the momentary contact will form, then collected water will release. One momentary contact closure caused 0.011" (0.2794mm) of rain. This can be recorded with a digital counter.

4. MQ2 gas sensor

The MQ-2 Gas sensor can detect or measure gasses like LPG, Alcohol, Propane, Hydrogen, CO and even methane. The module version of this sensor comes with a Digital Pin which makes this sensor to operate even without a microcontroller and that comes in handy when you are only trying to detect one particular gas. When it comes to measuring the gas in ppm the analog pin has to be used, the analog pin were connected to MCP3008 analog to digital convertor and the digital signal were pass to raspberry pi.

5. Wind Speed and Wind Direction

Wind speed and direction were measured using a cupped wind anemometer and arrow-type wind vane, respectively. Both devices use a magnet placed on the rotor portion of the sensor, which is used to activate reed-switches placed on the stator. For the wind speed sensor, one reed-switch is placed on the stator such that one closure per second is equivalent to approximately 0.666 m/s (2.4 km/hr), based on the geometry of the sensor. Thus, the speed can be calculated by counting switch closures per fixed time interval. For the wind direction sensor, eight reed switches are placed at equal angular intervals of 45° and radially equidistant from the axis of rotation of the sensor. As the vane points towards a specific cardinal direction, a magnet placed on the rotating portion of the sensor will close either one or two of reed switches, resulting in a wind direction reading with an overall resolution of 22.5° Solar Power System

B. Solar power system

Power is provided to the Our Weather board and all its sensors by 24 V solar panels which were sized to provide a maximum current of 1320 milliamps (mA) to provide enough power to the entire data collection system. The power from the solar panels is routed to a charge controller which is used to charge a 3.7V, 6000 mAh Lithium-Polymer (LiPo) battery and send any excess power to a boost converter which steps up the voltage from 3.7V to the 5V required by the Our Weather board and its peripherals. During times of low solar power generation (e.g., cloudy days, night time) the charge controller uses a solid-state relay (SSR) to switch between solar panel power and battery power provided to the Our Weather board. The selected battery capacity can provide full power to the data collection system for up to 8 hours.

C. Data storage and Transmission

A common issue with meteorological data gathering for wind farm site selection is that data must be collected from remote locations for extended periods of time. Thus, a Raspberry Pi 3 was used to provide a means of remote monitoring, control, and data management of the embedded data collection system. The Raspberry Pi was used to communicate all sensor data via WiFi using a python script which was programmed to run on the Raspberry Pi at startup. In this manner, the Raspberry Pi can be either accessed directly or remotely by a host computer with access to the same subnetwork. While connected to the Raspberry Pi, the host user is then able to remotely perform basic operations on the data collection system, such as system restart, monitor the data gathering process, and store and transmit the data over the Web. To automate the data collection and storage process, the Raspberry Pi was programmed using python to save all collected data from each sensor to a database which is stored on the Raspberry Pi external storage in .csv file format. This collected data were transmitted to FTP server via TCP/IP protocol over Ethernet.

D. Data analysis and weather forecasting

Collected data were analyzed by using python script for quality weather forecasting. Two different algorithms were used to forecasting of the weather data 1) ID3 algorithm and 2) Autoregressive algorithm. By using these two algorithms weekly and monthly forecasting were given.

E. Work Flow

In [11], the required libraries for the communication are found which is installed on raspberry pi using the commands *sudo pip install adafruit-io*. These will automatically install the Adafruit IO python client code for our python script. The figure 2 depicts that user gets the data by entering the user id and password for the FTP server database.

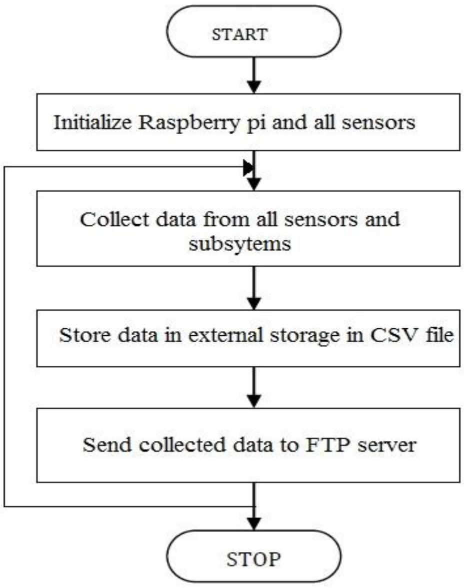

Fig. 2 System flow chart

IV. RESULTS AND DISCUSSION

The data gathered from our system developed in this work was compared to the weather data obtained from a AWS by Vaisala system located at approximately 5 meters (m) apart. The data for this study was taken at N. B. Navale Sinhgad College of Engineering Solapur from January 10, 2020 through March 31, 2020.

Fig. 3 show the data collected by our weather system for the month of February 2020. We can see in fig. 3 the

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Temperature (TEMP_M) in degree centigrade, Humidity (Humidity_M) in percentage, pressure (Pressure_M) in mbar, wind speed (WS) in m/s and wind direction (WD) in degree.

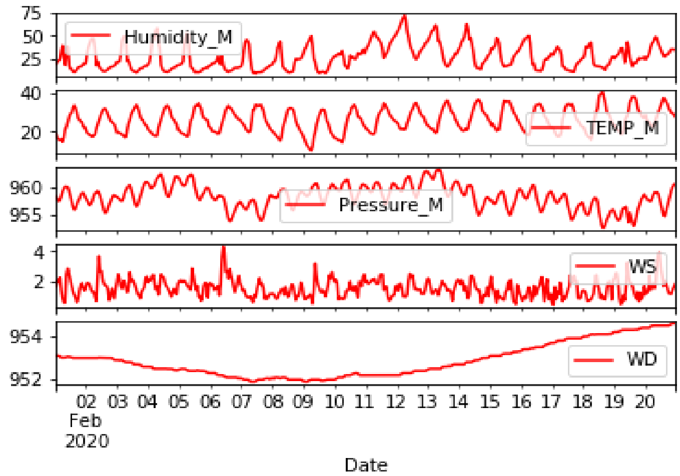

Fig. 3 weather parameters for month February 2020

Fig. 4(a) and 4(b) show the temperature data comparison and humidity data comparison, respectively for February month. The relative difference in the data remains within 5 percent for most of the sampled dates. However, as the data suggest, there is much better accuracy we get in both systems.

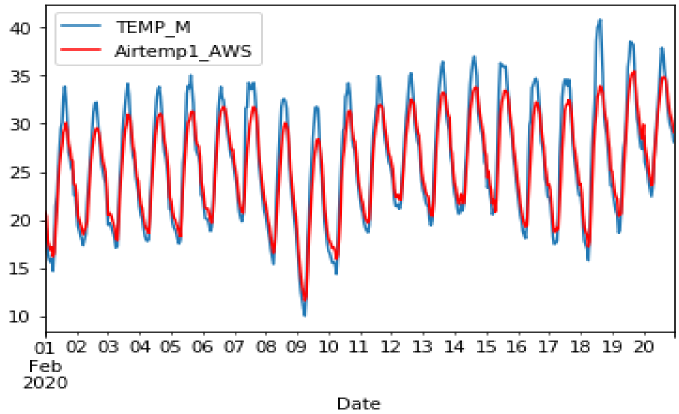

Figure 4(a). Teamperature comparison to All Weather Station

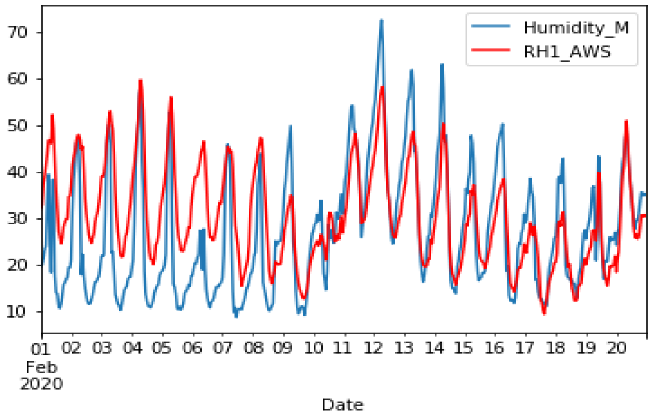

Figure 4(b) Humidity comparison to All Weather Station

Fig. 5(a) and 5(b) show the Temperature forecasting using Autoregressive algorithm and Temperature forecasting using ID3 algorithm, respectively for March month. The temperature forecasting accuracy was ~96%. Plots shows mean square error of 0.056 and 0.007 for autoregressive and ID3 algorithms, respectively. Additionally, Figure 5(b) presents higher accuracy weather forecasting than the autoregressive algorithm.

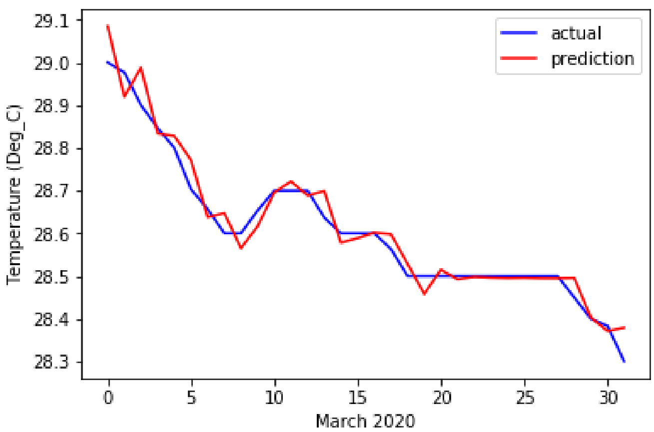

Figure 5(a) Temperature forecasting for March 2020 using Autoregressive algorithm

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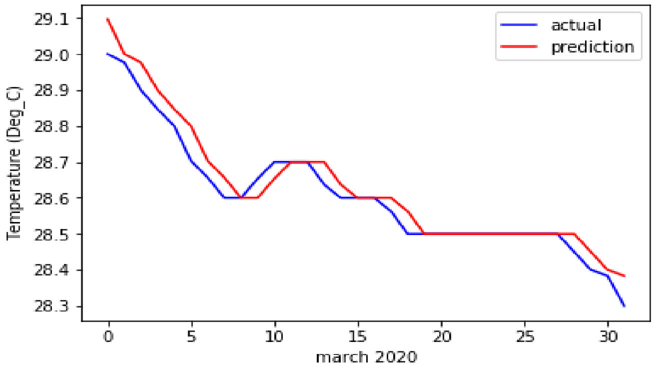

Figure 5(b) Temperature forecasting for March 2020 using ID3 algorithm

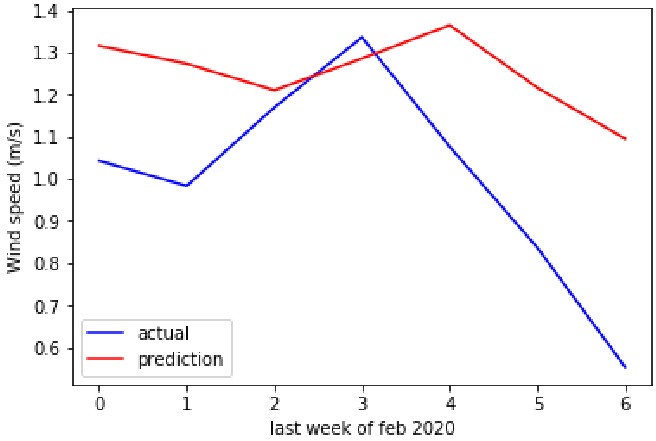

Figure 6(a) Wind speed forecasting last week of February 2020 using Autoregressive algorithm

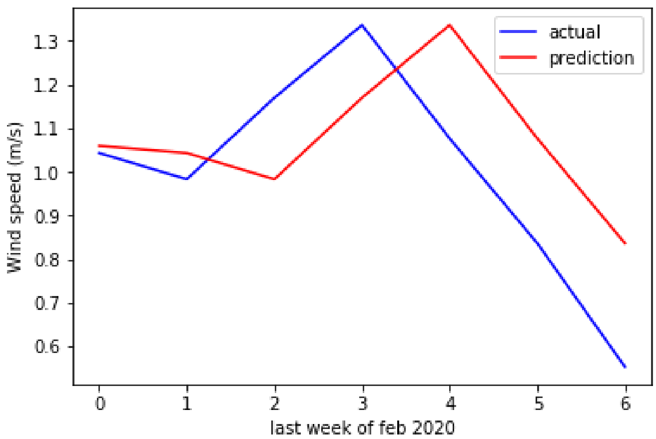

Figure 6(b) Wind speed forecasting last week of February 2020 using ID3 algorithm

Fig. 6(a) and 6(b) show the Temperature forecasting using Autoregressive algorithm and Temperature forecasting using ID3 algorithm, respectively for last week of February 2020. The temperature forecasting accuracy was ~95%. Plots shows mean square error of 0.313 and 0.039 for autoregressive and ID3 algorithms, respectively. Additionally, Figure 5(b) presents higher accuracy weather forecasting than the autoregressive algorithm.

V. CONCLUSION AND FUTURE WORK

The proposed system will provide low cost, low power, compact and highly accurate system for monitoring the environment with the dedicated sensors remotely from any place in this world. A perfect tradeoff between accuracy and cost will be achieved by making use of single board minicomputer Raspberry pi and appropriate sensors leading to a well grounded system. The ubiquitous availability of dynamic datasheets on the dashboard and the time to time graphical representation can help in planning the control measures against increasing pollution levels and create awareness among the people.

Air quality monitoring system can be more advantageous if pollutants like Sulfur dioxide, nitrogen dioxide, ground level ozone etc. are also monitored. Furthermore, long-term pollution patterns can be discovered and certain relationships between the air pollutants can be found.

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