IoT-Based Weather Monitoring System

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Abstract*: *Weather is hard to predict and has great significance in many regular activities. A weather station is an instrument or device that provides weather information in a local area. It serves a valuable role in the field of agriculture, industry, etc. for making informed decisions. The current weather stations available in the market are expensive and sometimes bulky also which causes inconvenience. The IoT-based weather station designed in the present work uses sensors and other components centrally controlled by a Raspberry Pi to detect, record and display various weather parameters such as temperature, humidity, wind speed, etc. in a specific location. The prototype design includes three DHT11 sensors for measuring temperature, a BME280 sensor for pressure and humidity, a cup anemometer for wind speed, and a rain gauge for determining the amount of rainfall. This work can be further extended to predict the weather as well.

***Keywords*:** Internet of Things, Raspberry Pi, Kalman Filter, Algorithm

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I. Introduction

Weather monitoring is an important aspect of day-to-day operations. The weather parameters cause a great impact on various regular activities in present age. People expect weather data of a certain area to be easily accessible. The data from television channel and websites which are generally available are generalized data for a large area which may have irregularities. It is therefore important to measure the weather parameters of a specified location such as homes, offices, industries, warehouses, etc. for common use. Internet of Things (IoT) makes it possible to build such a system and made the data available to user with the help of internet [1].

The main objective of this work is to build a real-time, efficient and affordable weather monitoring system. The Raspberry Pi is cheap, small and rugged processing solution which makes it perfect for real-world prototypes. For agricultural development and industrial management, the proposed system will be proved useful.

The prototype discussed in this paper will measure factors such as temperature, humidity, pressure, wind speed and rainfall with the help of various sensors. These readings will be available to the user so that they can plan their operations based on the data. Raspberry Pi, here is the central unit that analyses and processes the data from different integrated sensors and makes it available for the user.

There are some weather monitoring systems reported in literature. Examples of such IoT based systems may be consulted in [2] – [7]. However, data accuracy has been a common concern in these models as people are trying to reduce the errors in data. This highlights the need for a new weather monitoring system that prioritizes the utmost accuracy in terms of measured data.

This paper is organized as follows. Section II introduces to the proposed system and Section III presents the methodology. Section IV presents the data display process. Section V concludes the paper.

II. PROPOSED SYSTEM

Fig.1 shows the block diagram of the proposed weather monitoring system comprising of a section that consists of all the sensors. It is followed by the processor unit and finally the output section.

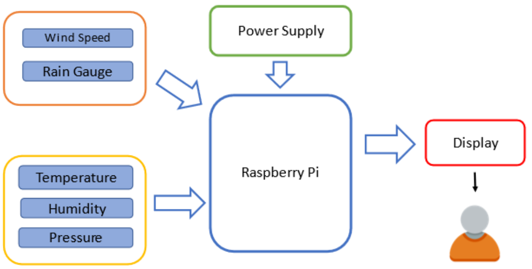


Fig.1: Block Diagram of the proposed weather monitoring system

It may be observed from the block diagram that the proposed system gets the weather data from the sensors interfaced with a Raspberry Pi processor. Different algorithms are used to minimize errors in the captured data. For instance, multi-sensor data fusion algorithm along with Kalman Filter is applied to the measured data from the temperature sensor to minimize errors. The proposed prototype uses the following components:

- Raspberry Pi board
- Temperature sensor
- Pressure and humidity Sensor
- Weather kit
- Breakout board
- Bread board
- Power adapter
- Jumper wires

In the proposed model, BME280 digital sensor is used for sensing pressure and humidity. Again, DHT11 sensor is used to capture temperature. For the measurement of wind speed and rainfall, a weather meter kit with a cup anemometer and rain gauge is used.

The following section presents how the Raspberry Pi processor, sensors and measuring kits are used in the model to capture the weather information. It also discusses about post-processing of the captured data.

III. METHODOLOGY

In the following, various components used in the present implementation of the weather monitoring system are considered in detail. The captured weather information undergo a post-processing statge before final display and the same is also discussed. Finally, the software requirements in the model are presented.

A. *Description of Hardware Components*

1) *Raspberry Pi*

Raspberry Pi offers people to realize their full potential through the power of computing and digital technologies. It uses Linux OS and is a popular processor used in IoT applications. It can be connected directly to internet as well as to USB ports to connect to Wi-Fi for direct connection with the sensors and many other devices. The operating system of Raspberry Pi supports programming languages like Python. For our purpose, we have used the Model B of Raspberry Pi 3 which is a quad-core 1.2 GHz Broadcom BCM2837 64bit CPU with 1GB of RAM, BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board. It provides facilities like 100 Base Ethernet, 40-pin extended GPIO, 4 USB 2.0 ports, 4 Pole stereo output and composite video port, full-size HDMI. The used model also has CSI camera port for connecting a Raspberry Pi camera, DSI display port for connecting a Raspberry Pi touch screen display and Micro SD port for loading operating system and storing data.

This CPU serves our purpose for integrating the different sensors as well as for analyzing and processing the captured data for visualization. Moreover, it can also help in sharing the data to a server via its wireless LAN and Bluetooth connectivity. It is powered through a micro USB power supply of rating 5V-2A.

2) *Temperature Sensor*

The temperature is measured using a DHT11 temperature sensor. This DHT11 is a basic sensor, it is an ultra-low-cost digital humidity and temperature sensor. It uses a NTC thermistor to measure these information from surrounding air and spits out a digital signal on the data pin. It is good for measuring temperature in the range from 0^0C to 50^0C.

We have considered to apply a multi-sensor data fusion algorithm to achieve accuracy and reliability in temperature measurement. Three DHT11 sensors are connected to the GPIO pins of the Raspberry Pi. The data from the three sensors are read and averaged using the standard averaging method. However, this average data is found to have uncertainties with some random variations. To overcome this, we propose to consider an estimation algorithm with the help of Kalman filter. This reduces the noise and variations by quickly estimating the true value of the temperature by using iterative data inputs. In this estimation process, the Kalman gain (KG) is computed as follows. Let e_M represents the error in measured temperature value after averaging and e_E^t represents the error in current temperature estimate. Hence, Kalman gain can be computed according to:

$$KG = \frac{e_E^t}{e_M + e_E^t} \ ,$$

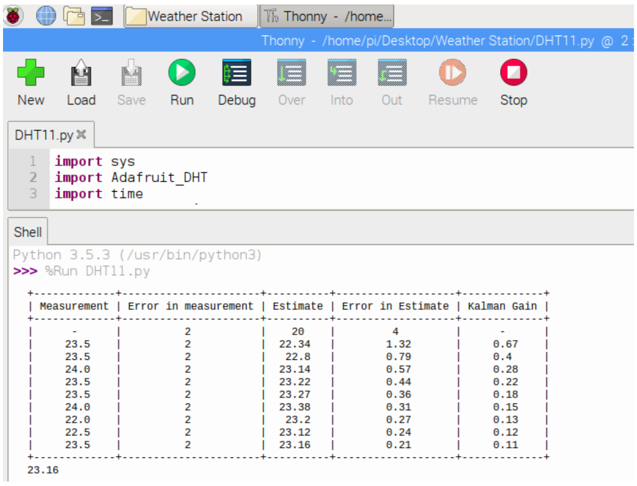
where $0 \le KG \le 1$. Again, let E^t be the current estimate and E^{t-1} be the previous estimate. Let M be the measured temperature value after averaging. Then, it can be shown that

$$E^t = E^{t-1} + KG(M - E^{t-1}) \ .$$

As introduced in above, e_E^t represents the error in current estimate. Similarly, if e_E^{t-1} is used to represent the previous estimate, then it can be obtained that

$$e_E^t = (1 - KG)e_E^{t-1} .$$

The error reduction through Kalman filtering is demonstrated in Fig.2. It may be observed here that the error in the estimated value reduces as time elapses and hence it moves towards the actual value. A comparison of temperature readings without and with Kalman filtering is presented in Fig.3. The random variation in measured temperature may be noted here which is shown with the blue line. The other line in the figure shows the estimated temperature by applying Kalman filtering. The improvement achieved with estimates may be noted here.



Measurement	Error in measurement	Estimate	Error in Estimate	Kalman Gain
-	2	20	4	-
23.5	2	22.34	1.32	0.67
23.5	2	22.8	0.79	0.4
24.0	2	23.14	0.57	0.28
23.5	2	23.22	0.44	0.22
23.5	2	23.27	0.36	0.18
24.0	2	23.38	0.31	0.15
22.0	2	23.2	0.27	0.13
22.5	2	23.12	0.24	0.12
23.5	2	23.16	0.21	0.11

23.16

Fig.2: Reduction of error after applying Kalman filtering

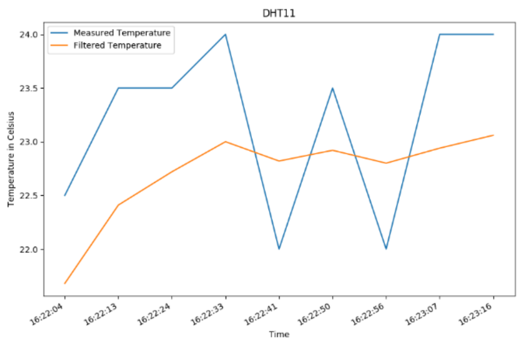


Fig.3: Comparison of temperature readings after applying Kalman filtering

3) Pressure and humidity sensor

The BME280 environmental sensor is chosen to capture pressure and humidity information because of its small size and high precision. It also provides both SPI and I2C interface. One of the GPIO pins of the Raspberry Pi is used to read this sensor data.

4) Weather Kit

The weather kit is employed to capture the wind speed and rainfall using its cup anemometer and rain gauge. It comes with specific mounting hardware. These two instruments in the weather kit do not contain any active electronics and uses sealed magnetic reed switches and magnets to take measurements. A voltage must be supplied to each instrument to produce an output. They send signals to the Raspberry Pi through RJ11 communication cables. Since Raspberry Pi does not support RJ11 connection, therefore RJ11 breakout boards are used for communication with through its GPIO pins.

The cup anemometer sends two signals per spin/rotation and the wind speed in km/hr is calculated as follows.

Wind speed = distance ÷ time

Distance = No. of rotations × Anemometer circumference

No. of rotations = No. of signals ÷ 2

The calculated speed is also calibrated using an adjustment factor of 1.18 (as per the datasheet). This adjustment is required to compensate for the loss due to the weight of the cups.

The rain gauge is used to collect and calculate the amount of rainfall in ‘mm’ during a certain period of time by determining the height of water accumulated in a given gauge. It has a tipping bucket that tips after every 0.2794 mm of rain accumulated, and hence by counting the no. of tips and multiplying it by 0.2794, we can calculate the rainfall amount.

The proposed weather station is presented in Fig.4 after connecting all the components.

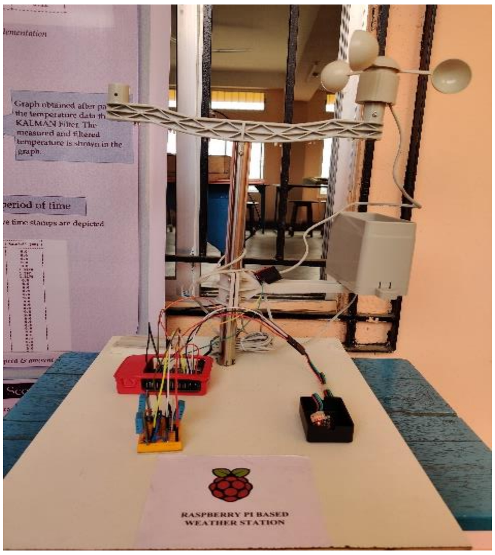


Fig. 4: Proposed weather station with all components

B. Software Requirement

Programming on Raspberry Pi can be done in many ways. It can run all those programming languages which a Linux computer can run. The GCC compiler suite is preloaded with the operating system Raspbian of Raspberry

Pi. We have used Python to the programs. It is the simplest, most dynamic, interpreted, object-oriented language. It is designed to be highly readable and the results are also displayed on the Python Shell.

IV. Results

After assembling and writing the Python scripts for different inputs, these programs are then imported as modules to a main program that displays the parameters in the shell. Fig.5 shows an example of it. The data is updated after every 60 sec.

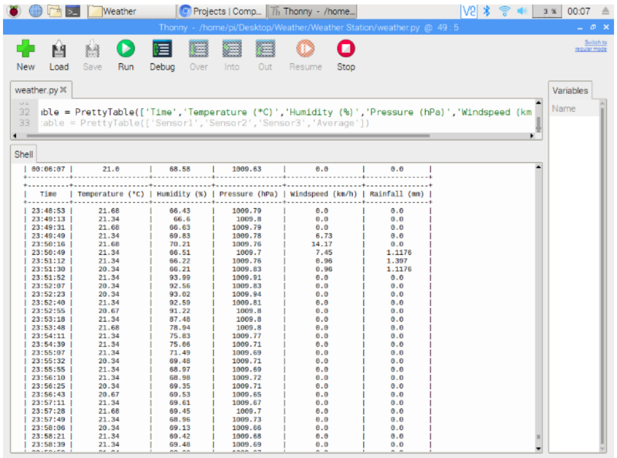


Fig. 5: An example of weather report displayed on the Python Shell

V. Conclusion

This paper has presented an IoT based prototype of a weather station built on the Raspberry Pi platform. It provides real time information on temperature, humidity, pressure, wind speed and rainfall with the help of sensors, cup anemometer and rain gauge. It is also proposed to apply a multi-sensor based data fusion algorithm for reducing error in measurement. Though this work has used sensors with digital inputs, we can easily use analog sensors with suitable ADC. As future scope, the proposed model may be further extended to monitor other weather information and send it over the internet. Since the wind direction is also an important factor in some applications, a wind vane can be integrated to determine the same. The generated data can also be reported to a cloud-based server for easy access by the user on his/her mobile phone through web pages, application or through SMS. Another area for future focus is the application of advanced data analytics techniques, such as machine learning algorithms, to extract more meaningful insights from the collected weather data. This could involve developing predictive models for weather forecasting, identifying patterns and correlations, and improving the accuracy of predictions.

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