Design and Implementation of IoT-Based Weather Monitoring System

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Abstract

Due to advancement in technology, various fields have boosted the development of systems that improve people's life quality, contributing to the welfare of the community by providing relevant and pertinent information for decision-making. On the Internet of Things (IoT), the systems demand measuring and monitoring several environmental variables. The heterogeneity of the captured data and the measuring instruments used to hinder the interoperability among the different components of the IoT. The problems are raised an interest in the development of methods and tools that support the heterogeneity of the data from the sensors, the measurements, and the measuring devices. Some existing tools have resolved some of these interoperability problems. However, it forces to IoT developers to use sensors from specific brands, limiting their generalized use in the community. Furthermore, it is required to solve the challenge of integrating different protocols in a same IoT project. Besides, by generating alerts, it may help making decisions daily, considering the data provided by the sensors. it is required to solve the challenge of integrating different protocols in a same IoT project. To overcome the limitations of the existing glitches, there is need to develop a framework based on network of sensors via software that allows communication-using protocols in a specific environment to monitor the quality of air and to alarm users about this. In this paper, a prototype of proposal is mentioned about the architecture, list of hardware, software and different APIs are utilized to gather data in a systematic way so as users can visualize data in a semantic view. The visualization is shown later by using Matplotlib, Seaborn tools of Machine Learning (ML) and Deep Learning (DL) to plot the temperature along with humidity in a historical span. The result shows that accuracy obtained via Machine Learning Classifier is 87% in the context of Weather Prediction.

Keywords: Matplotlib; Internet of things (IoT); Machine Learning (Ml); Deep Learning (DL)

1. Introduction

Nowadays, there is a growing interest in measuring and monitoring numerous variables in the environment. To deploy a smooth flow of information, the interaction of state-of-the-art sensors with various operating principles is necessary to offer higher levels of precision, greater efficiency in energy consumption and lower costs and the integration of their measurements [1] The procedure of integration and interoperability of the information generated by this class of sensors are associated with significant levels of complexity related to the heterogeneity of the devices, not only in their operating principles, but also in their formats, scales and sources. So far, there have been multiple efforts aimed at integrating these measurements associated with a great diversity of variables and protocols. Although in the review carried out, the use of standards is evidenced their limited application to the private sphere or in specific domain applications is also revealed [2] Additionally, there is need to develop architectures and systems that is identified in a community, favoring the collective construction of knowledge. Therefore, the proposal presented in this article emphasizes the use of hardware tools and free software, whose creation philosophy grants basic freedoms to the user, to use the tool for any purpose, study its operation, with the possibility of modifying it at your convenience, and having

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the availability of copies to distribute free, or with economic benefits [3] The use of tools that adopt this philosophy strengthens collaborative work and facilitates problem solving.
This Paper presents the development of a scalable prototype of a measurement and monitoring system for some environmental variables related to air quality. In this way, it is possible to have a series of data, which through subsequent processing will become highly useful information for decision-making. The structure of this document contemplates a theoretical framework that supports the prototype, followed by the description of the planned architecture. Subsequently, the components of the system, the way they are integrated into the prototype and the results obtained are described. Finally, there is a discussion and the conclusions obtained from the development of the prototype.

2. Related Work

Sensor device capable of detecting the measurement of a magnitude, called an instrumentation variable, and converting it into an electrical signal that can be processed, stored, or transmitted according to the purpose defined by the user. Depending on their use, the sensors can give a reading directly on the unit of interest Be connected to an indicator instrument that takes care of reading the signal and translating it into the desired unit. Be connected to an instrument that takes care of memorizing the signal for further processing [4][5]

Sensors are classified depending on their use, the type of output signal, or more commonly they are classified depending on the physical variable they measure [6] With the advancement of electronics, sensors are not only concerned with translating physical quantities into simpler displays but are also part of a large number of technological fields. Currently, measurement systems are used, instrumented with multiple interconnected sensors, known as sensor networks, which integrate advances in electronic, communication and computing technology, allowing the use of interconnected networks of measurement devices, seeking to obtain measurements that are more precise and distributed both spatially and temporally [7-9]

According to the International Electro technical Commission, sensor networks are "multi-channel networks, self-organized of sensor nodes, with wireless technology, which are used to monitor and control physical phenomena" [10] As per National Instruments, a company that works in the development of electronic devices and software for instrumentation, it is "A wireless network that consists of autonomous spaced distributed devices using sensors to monitor physical or environmental conditions" [11] A sensor network would normally have a main energy regulator, a sensor, and a microcontroller [12] Technological advances have made possible the massive deployment of small distributed devices, with low-cost characteristics, low energy consumption, and with local processing capacity and wireless communication, which has led to the development of in recent years, people have built a modern way of looking at the planet, called the Internet of Things[14]

The IoT is an intelligent network of artifacts, individuals, programs, and technology that enables them to process data from the real and virtual environment in tandem, in order to react according to the information obtained [15] In this way, sensor networks become a primary data source for IoT [16] , since they provide a voluminous amount of data from various sensors, not only in their principles of operation, but also in the measurement scales, the precision with which they perform the measurement, the formats and units of measurement, among other specifications. Measurements from sensors and sensor networks of a heterogeneous nature must be interoperable not only with each other, but also with additional information that people can provide on the measured variables[17] [18] The paper[19] discussed the weather parameters like temperature, humidity, PM 2.5 and PM 10 concentrations and Air Quality Index (AQI) are monitored and visualized in graphical means using the Raspberry Pi as server and data accessed over the intranet or internet in a specified subnet or world wide web. The data visualization is provided as result and proves to be a robust framework for analyzing weather parameters in any geographical location studying the effect of smog and PM 2.5 concentration.

In this chapter [20], we introduced a new architecture for ad hoc networks using Software-Defined Networking (SDN) with multiple controllers. Our concept can be applied to both ad hoc networks and the Internet of Things (IoT) context. This marks a significant initial progress in creating a secure framework for SDN tailored to the IoT environment. Authors tried to address various security challenges and potential attacks that arise when dealing with IoT and SDN technologies. The study [21]] suggested a design and implementation of a weather monitoring and controlling system, which is used to operate equipment and track environmental variables, are presented in this study. The system makes advantage of embedded controlled sensor networks, which have been successfully used in environmental monitoring

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systems to provide remote control and sensing. The proposed [22] intelligent system for climatic and water quality monitoring was created utilizing AI methods. The system's ability to predict weather events with accuracy is helpful for strengthening agricultural practices and raising crop quality. This system offers analysis that is more useful than what is offered by conventional techniques. Monitoring water quality indicators like turbidity and alkalinity also improves the quality of the soil and crops.

3. Proposed Architecture

For the approach to the architecture of the developed system, in addition to taking into account the devices to be used, the proposal of layered architecture for IoT applications has been taken as a basis, which establishes a design whose base components [19] such as sensors, actuators, gateways, edge , context servers, and ,applications. The architecture developed in Figure 1 presents as Hardware components the sensors, the development card that allows integrating the measurements and the communications interface such as Software Components the different programs, applications and APIs that integrate data on the Internet and allow interaction with other applications. Similarly, taking the base architecture as a reference [20], the following description of each of the layers that make up the system is proposed:

- Both sensor and development card layers: Physical and network: measurements done here. Measurement devices are critical to the program's performance, provide control, and function as the connection for the system, along with software on the card.
- At the next layer, the network layer, it has the job of networking the calculated data with the Web Server. Measure includes a networking module, which makes a link, a language, and a protocol, which supports data transfers.
- Back-end server: coordinates between measured values and the rest of the Internet It consists of a platform where a database is maintained, and a server implementation, where the obtained messages are stored in which a REST API capable of relating to the database is elaborated, allowing, or denying access and manipulation of the data received in the exchange language used. In addition, it is responsible for implementing a server from which the requests made by the application layer are served.
- Application layer: in this layer are the front-end clients that communicate with the transport layer server, thus showing, in a comfortable way for users, the results obtained from the requests made to the server.

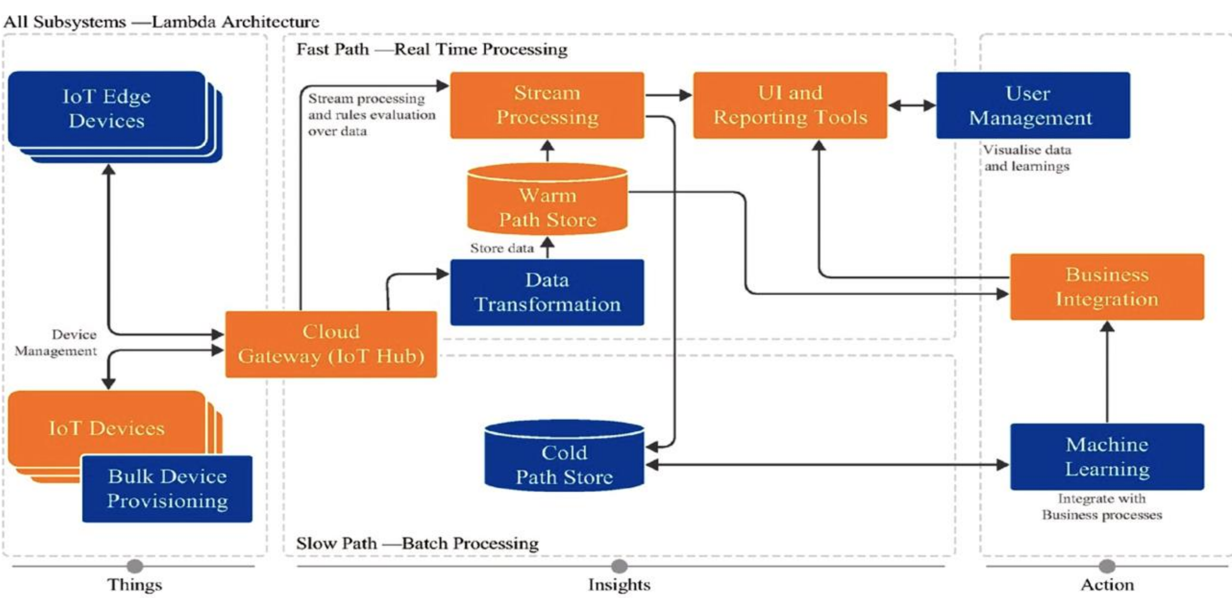

Figure 1: Architecture of IoT Architecture

Above diagram depicts the design and data movement across the layers illustrated above. Architecture for IoT applications has been taken as a basis, which establishes a design whose base components [19] such as sensors, actuators, gateways, edge, context servers, and, applications. The architecture developed in Figure 1 presents as Hardware components the sensors, the development card that allows integrating the measurements and the communications

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4. System Components

4.1 Components

- **Hardware Elements**

  The physical devices used for this system discussed below, classifying them as sensors, development cards, communication devices, and integration platform.

- **Sensors**

  The sensors is utilized in the prototype have been selected taking into account their own heterogeneity in terms of their operating principles, measurement variables, output signals, among other aspects. A brief description of the sensors and their characteristics are mentioned in table.

Table 1: Characteristics of the Selected Sensors

Sensor	Gas	γ	τ	R_0
MQ2	H_2	1416	1.346	9.8
	LPG	601.9	2.144	
	C_3H_8	1137	1.282	
	CH_4	4207	2.394	
	Alcohol	4203	2.399	
MQ4	CH_4	1083	2.786	4.4
MQ135	CO_2	120.3	2.304	3.75
	NH_3	101.1	2.737	
MQ136	H_2S	48.44	2.786	3.75
MQ6	LPG	925.2	2.577	10
MQ9	CH_4	4395	2.32	9.8

4.1.1 Development cards, communication modules and integration platforms

In this section, the use of technologies based on free philosophy is related, with the intention of allowing collaborative work between users that favors the process of design and implementation of the proposed prototype. The techniques are described in According to tables 1 and 2, the inherent heterogeneity is observed in the sensors and hardware devices that are used throughout development, which are integrated and made interoperable based on the proposal outlined in this article.

Table 2: Characteristics of the devices utilized in Proposed Framework

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	Development board	Communications module	Integration platform
Selected device	Arduino [12]	ESP8266 [13]	Raspberry Pi [14]
Relevant characteristics	This card works as the node of the sensor network that allows to centralize and process the measurements made by the sensors described above. In addition, it will have the ability to connect to the internet to send and receive information relevant to the system.	Once the connection to the Wi-Fi network is made, the module is capable of sending information from the sensors to an IP address and port that are established.	Low-cost, single-board minicomputer, designed to facilitate learning and education in computer science, created by the Raspberry Pi Foundation.
Programming interface	Arduino IDE, based on C language.	Special AT [15] commands for communication with modems and telecommunications interfaces.	It supports a specific Linux operating system for the card, called Raspbian.

4.2 Software used in the system

In order to make the measurements of the sensors described in the previous section interoperable, it is necessary to use a communications protocol that allows data to receive from different sources simultaneously. One of the protocols used for sending and receiving data from sensors in the frame- work of IoT is the MQTT (Message Queue Telemetry Transport), which consists of an extremely light publication / subscription messaging protocol that enables Machine to machine (M2M) communication. In this protocol, there is a central controller, called a broker, which sends filters and prioritizes the requests that arrive from the subscribing nodes [21] [22]

In order for the sensors or embedded systems to submit messages to the MQTT broker, the messages must have two variables that describe both the form of message and the definition of a subject. When the subject string is supplied, it acts as an email list. If a subscription is present, the address helps you to monitor and regulate that notice it [23] In this way, data from various sources could be integrated, which send their messages to the correct topics, thus helping to solve problems caused by the heterogeneity of data sources. In addition, this protocol is efficient to manage data at a low cost and is easily integrated with systems based on free software and hardware, Well-suited for a wide variety of uses such as home automation, such as smart cities [24] In order for the Raspberry to have access to the data, to be able to manipulate and visualize it, it is necessary to install some programs that are shown in table.

Table 3: Characteristics of the software used

	MQTT Broker	**Database**	**Data exchange language**	**Language for Web development**
Tool	Mosquito [17]	MongoDB[18]	JSON [19]	NodeJS [20]
Relevant Technology	It allows to carry out the publishing / subscription processes on the Raspberry. It can be integrated These sensors or small computers that are mobile, such as cellular phones, only use	NoSQL (Not Only SQL) databases that allow an approach to data management and useful database design for distributed data sets, such as those from sensors. It saves the data structures that are as identical to JSON as possible, with the goal of making data	Quite light text format that is easy to read and write for both humans and machines, being independent of the language that generates it. In general, a JSON document is	Tools that allow its treatment,visualization and connection with various applications must access the data stored in the Database. Execution environment based on JavaScript, which connects to the database and allows processing and implementation of web

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	small amounts of energy such as the Raspberry or microcontrollers such as the Arduino	incorporation in software applications simple. In databases, each entity is put in a list and a specific data values are given to this attribute are inserted, thus supporting more efficient dynamic queries than in other database systems.	structured by using an ordered list of name / value pairs.	services and applications.

4.2.1 Application programming interfaces (APIs)

Connectivity is modified and improved by the usage of two separate programming libraries for different kinds of sensors and the implementation of warnings with two APIs. Below Table shows the description of the main interfaces used in the server.

Table 4: Characteristics of the main APIs used in the back-end

Name	Contribution to the system
Express[22]	Web application infrastructure for Node.js that offers a set of features for web and mobile applications. It has a wide variety of HTTP methods and a middleware that facilitates the creation of applications.
Socket.io [23]	Library NodeJS for creating real - time applications for almost all browsers and mobile devices, using different transport mechanisms and protocols.
JADE [24]	Adceptive+gramatic, a high-performance node JS templating engine implemented in JavaScript. Allows you to create HTML documents to optimize routes in web applications.
Handlebars [25]	Template engine, similar to JADE, which is used to create templates for tables and graphs.
Chartjs [26]	JavaScript-based graphics generator that simplifies the work of creating data-driven figures and diagrams.

4.2 Tools for visualization

The applications made with NodeJS can be accessed through a Web browser, accessing the IP address where the service is hosted, this regardless of whether it is a PC, a laptop, a Tablet, a Smartphone or another kind of device. The front-end design of the client is based on the interactivity and the response of the applications to the requests of the end user. For this, some techniques, languages and APIs are used that are described in table 5.

Table 5: Characteristics of the main APIs used in the front-end

Name	Contribution to the system
AJAX [27]	Web development technique that is used to create interactive applications that are run by the client, while maintaining asynchronous communication with the server.
JQuery [28]	Large and versatile JavaScript library that works in a wide variety of browsers and makes AJAX requests and manipulation of HTML documents easier.
CSS [29]	Language used to describe the style of an HTML document. With this language, the style of the different components of a web page is designed.

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HTML [30]	Standard language in charge of the W3C [31] that defines the basic structure and the code necessary to define the content of a Web site.

4.2.1 Integration of hardware and software components in the prototype

In the previous section, various technologies that are integrated in the development of the IoT system prototype for air quality measurement have been defined. Next, in Figure 2, the solution architecture used for the prototype is shown. In this figure the different components of the system are observed and the way in which they interact for the correct functioning of the prototype can be appreciated.

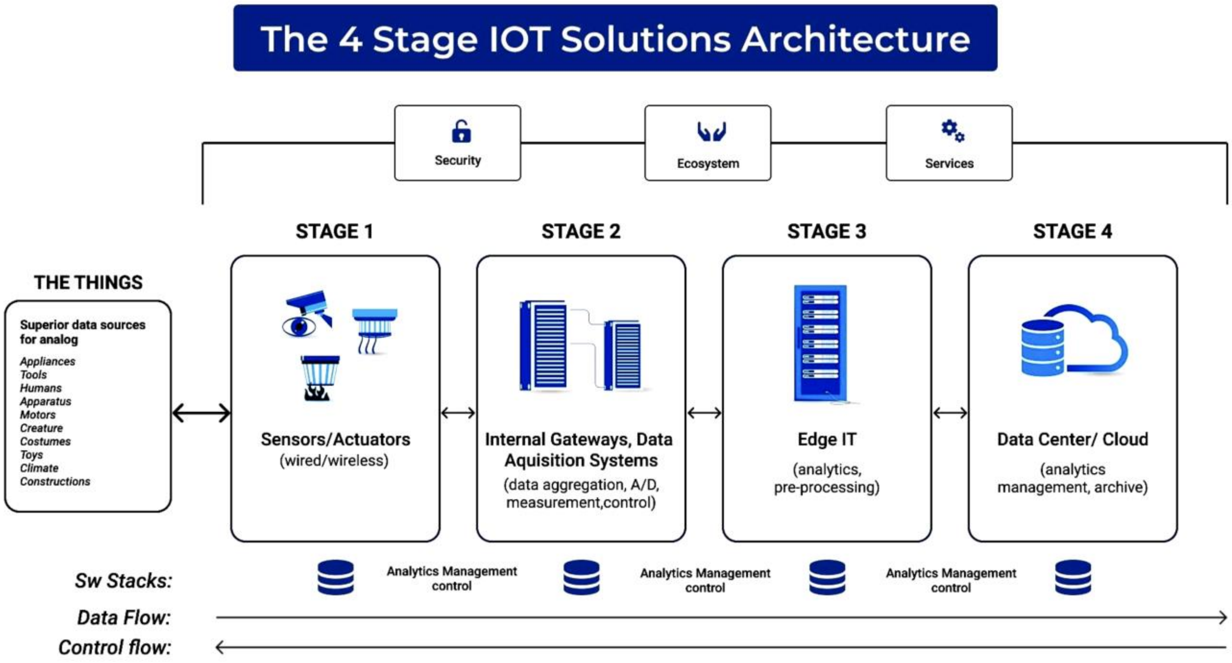

Figure 2: Solution architecture

Above diagram shows scatters plot that represents relationships between temperature and Year Scatter Plot.

5. Results & Analysis

The development of the IoT system is based on three modules that are programmed in NodeJS and run web applications directly on the Raspberry pi.

- Sensor registration module: It consists of an application that uses NodeJS, Ex- press, Socket.io and other APIs in order to make the database model and register the sensors and devices used in it.
- Prototype: This application has a graphical interface that facilitates the user to register and update sensor data. In the same way, it is in charge of making the necessary validations for the user

Table 6: Sensor log module

Arduino UNO
DHT11
MQ7

Based on above information Figure 3, proposed system will predict the temperature for desired location.

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```
lr = LinearRegression()
rf = RandomForestRegressor()
ridge = Ridge(random_state=1)
```

```
stregr = StackingRegressor(regressors=[rf,lr],
                           meta_regressor=ridge)
stregr.fit(X_train, y_train)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/ensemble/f
ange from 10 in version 0.20 to 100 in 0.22.
  "10 in version 0.20 to 100 in 0.22.", FutureWarning)
```

Figure 3: Linear Regression

Description: The authors have proposed linear regression, Random Forest regression [16], [17], Ridge Regression and our proposed hybrid approach Fig. 4, for predicting the temperature as shown in the screenshot.

```
In [34]: fr = RandomForestRegressor()
         fr.fit(X_train,y_train)
         fr.score(X_train,y_train)

/usr/local/lib/python3.6/dist-packages/sklearn/ensemble/forest.
ange from 10 in version 0.20 to 100 in 0.22.
  "10 in version 0.20 to 100 in 0.22.", FutureWarning)

Out[34]: 0.8708855045722896

In [35]: rl = LinearRegression()
         rl.fit(X_train,y_train)
         rl.score(X_train,y_train)

Out[35]: 0.6373943953621659

In [36]: rd = Ridge()
         rd.fit(X_train,y_train)
         rd.score(X_train,y_train)
```

Figure 4: Random Forest regression

The IoT-based monitoring platform receives real-time weather sensor data from sensors on the ground and processes it. Solar panel, battery charger and data logger are all housed in an enclosed water-resistant Tripod stand. Sensors are attached to the Tripod stand and the data logger and solar charger are housed in the enclosure [32-35].

- Measurement module: It is in charge of the MQTT communication between the Arduino boards and the Raspberry. It does not have a graphical interface, but implements an alert system in case the measurements exceed values determined by the user.
- Visualization module: Its task consists of making requests to the database, making some transformations of the same to organize them in a format that, through communication with Chart JS, provides the user with the visualization of the state of the variables measured by the sensors of graphic way. Two of the graphs obtained for the variables measured by the sensors are shown below.

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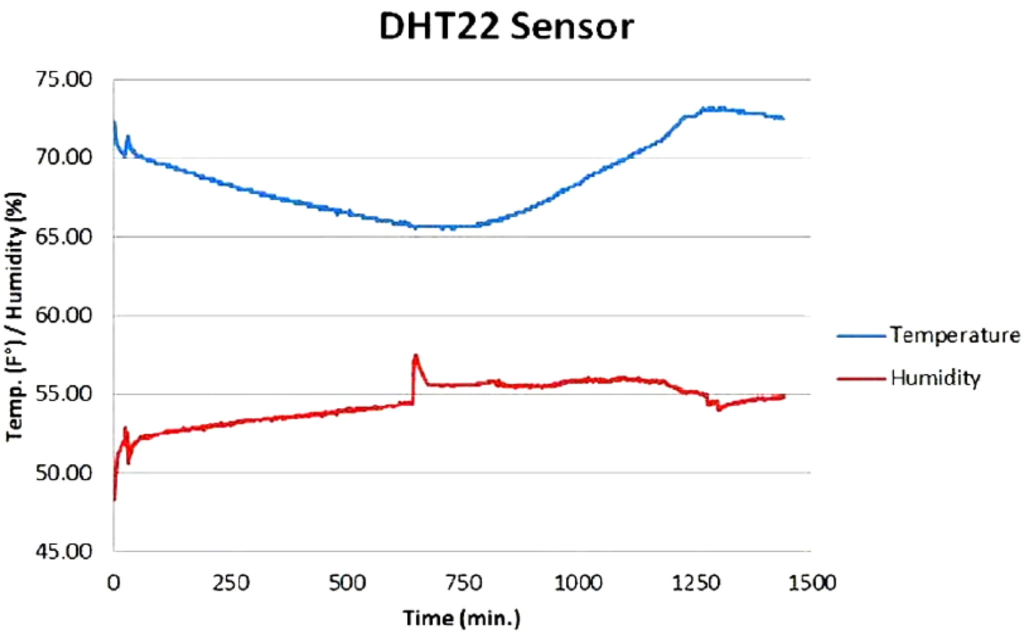

Figure 5: DHT11 and BMP180 Sensor Measurements

This module involves the creation of graphs Fig. 5 and Fig. 6 in real time in the generation of the user interface.

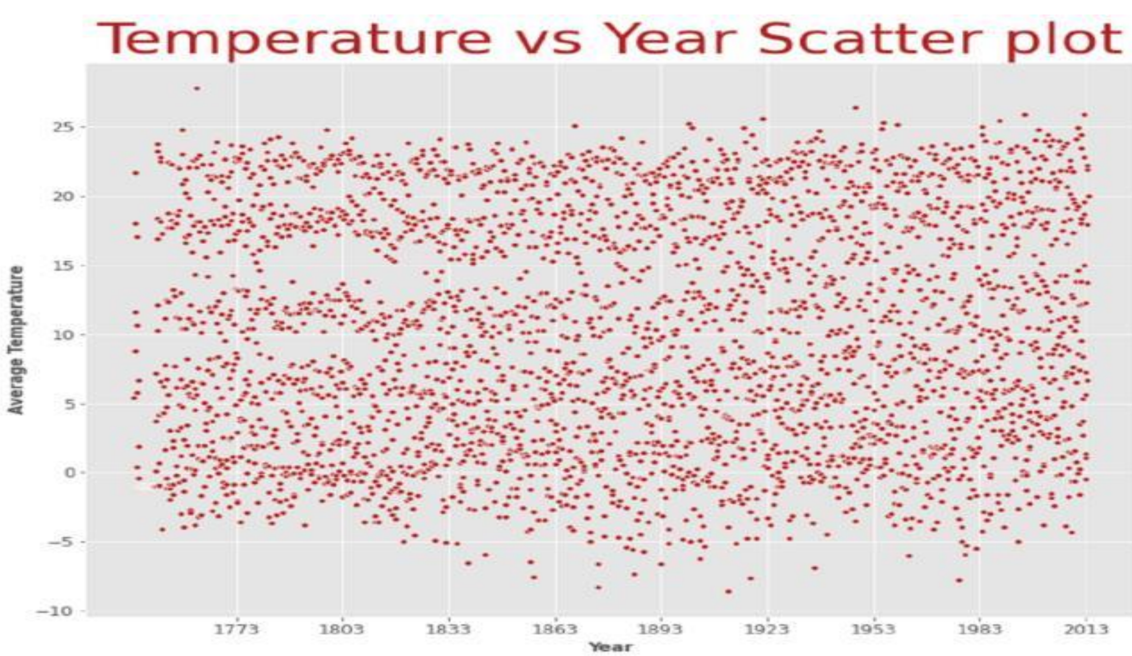

Figure 6: Sample Temp /Year Scatter plot for weather forecasting.

Above diagram shows scatters plot that represents relationships between temperature and Year Scatter Plot.

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6. Conclusion

The paper deploy the development of a prototype measurement and monitoring system for some of the environmental variables related to air quality, namely: temperature, humidity, atmospheric pressure, dust density, and concentrations of carbon monoxide and dioxide., methane and nitrogen oxides. The data captured by the sensors is integrated by the central microcontroller of an Arduino card, which establishes Wi-Fi communication with a Web server that, through the use of an MQTT protocol, facilitates the insertion of the data in a MongoDB database, to allow interoperability with the server data, it is made from the server to JSON and submitted from the client. The server also provides a browser-based treatment and visualization methods that can be by the client that allows these methods accessible through a broad spectrum of platforms. Through the use of free tools for the development of the prototype, the integration, fusion and interoperability of data from different sensors is made possible, which is a concrete advance in the interoperability of information from heterogeneous data sources. Additionally, the implemented prototype makes the solution functional for new sensors or measurement systems, through the implementation of small changes in the prototype configuration, which will allow the use of various interconnected devices, in order to carry out measurements of the variables in different points. In this way, it will be possible to have more data, which through subsequent treatment will become very useful information to guide the decision-making processes in environmental matters by users, whether they are individuals or communities.

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