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Automated Temperature Control System for Chemistry Laboratory using MQTT IoT

[1]Mary. O. Kama
Dept. of Computer Science, University of Nigeria, Nsukka. Nigeria
*mary.ofuru.pg80910@unn.edu.ng **

[1]D. U. Ebem
Dept. of Computer Science, University of Nigeria, Nsukka. Nigeria
deborah.ebem@unn.edu.ng

[2]Elmissaoui T.
Carthage University, SUP'COM, Innov'com Lab & Higher Institute of Applied Mathematics and Computer Science, University of Kairouan, Tunisia
elmissaoui.enit@gmail.com

[3]Elijah N.
Dept. of Electrical/Electronics Engineering, Faculty of Engineering Alex kwueme Federal University Ikwo Ebonyi State, Nigeria
**corresponding author -*
elijah.nwakpakpa@funai.edu.ng

Udanor Collins.
Dept. of Computer Science, University of Nigeria, Nsukka. Nigeria
Udanor.collins@gmail.com

[4]Chukwu Emenike G
Dept. of Computer Science, University of Nigeria, Nsukka. Nigeria
emenike.chwukwu.pg00267@unn.edu.ng

Abstract*— The traditional chemistry laboratory in most tertiary institutions has failed to look into the present chemical substance, its temperature, and reactions to certain optimal scales. The temperature hazards of chemicals in many chemistry or industrial sectors has gone out of measure. To this effect, most chemical substances in the laboratory due to fluctuation in temperature sometimes causes laboratory hazards. The existing system has issues ranging from reporting style, the temperature of the chemical substance either in use or not in use, and error based on human system. Chemical substances in the laboratories have imposed tremendous hazards on lives and properties. In this paper, we built an Message Queuing Telemetry Transport (MQTT) broker to monitor, report, and control the influence of temperature of a chemical substance in the laboratory to avoid hazards and ensure safety. The platform employed both hardware devices that can read the change in dynamic temperature and software program that presents the temperature to both the mobile platform and desktop system. MCUESP8266 node, temperature sensor DHT11/ 22 and Python 3 flask framework were employed. The system is a cloud-based system displays the temperature of a chemical substance in a real-time manner. Temperature laboratory hazards are avoided, controlled, and reduced to its barest minimum with this system. The laboratory system of testing the rate of reaction of chemical, relative to the temperature range, or the self-reacting chemical substances at particular room temperature is the main focus of this paper/ article. The system auto-detects the regular change in temperature reading of a chemical substance in the laboratory.

Keywords—Node MCU ESP8266, DHT11/ LED Resistor, MQTT, IoTs, Python flask

I. INTRODUCTION

Message Queuing Telemetry Transport (MQTT) is a lightweight messaging protocol that was developed by IBM [1]. MQTT is a protocol for IoT application and had been introduced for monitoring and control of government sectors, pharmaceutical or chemistry laboratory, for industrial environments, house protection and to effectively and efficiently stand out for industrial and chemical environments [1]. The MQTT is a technology developed to overcome the shortcomings of the previous technologies facing challenges of connecting the expanding physical world of sensors, actuators, and phones with software processing technologies. It addresses problems of response time, high energy consumption, throughput, and bandwidth usage [2]. Meeting with these criteria makes it ideal for the IoT application. It is an open-source messaging protocol that was created for constrained devices, to minimize bandwidth and maximize available bandwidth, to reduce update to seconds and enable faster response time. This is possible because every bit in the data packet specifically reduces the data being transferred over the network, for resource requirements and to provide some degree of assurance of delivery. MQTT is a lightweight protocol in that it can be supported by small measuring and monitoring devices. Because of its ease of implementation, the protocol is ideal for machine to machine IoT. This means that two or more devices can connect and communicate with one another directly. It can be wired or wireless. It is a preferred network for IoTs messaging. IoT is simply, devices that are connected over the Internet all the time to share resources for future purposes and decision making. This connectivity of devices can allow one to connect to the internet using a mobile phone, laptop, PC, etc. [3].

The IoT is made up of components for its network connectivity. The components consist of some devices, which are connected through the Internet to a certain online network/platform. Each device has one or more sensor which detects the environmental parameter and sends them to the cloud network (platform).

Consequently, users can monitor, manage, and control these devices through an application. Cloud data/ IoT-platform is the most important component of the IoT system. The IoT platform is simply defined as a software that is hosted online. It is a network that all devices are connected to. The platform is a network of servers that is optimized to perform high

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speed data collection with the devices', analyze the data, process it and store the data for future decision making or in real time for Industries, chemical laboratories and other sectors can access the data remotely.

For instance, a nitrogen gas is stored up in a laboratory room, there are sensors connected to it to monitor its temperature to avoid it from evaporation, these sensors are then connected to a monitor which is then connected to the internet. If the monitor detects any abnormal or low temperature which may affect the nitrogen gas, it then sends alarm to the IoT network along with the name of the chemical, its temperature level and the lab room number. The lab assistance are also connected to the network and will receive this message. Then the lab assistants will hurry up immediately to the lab and keep the temperature at its normality to avoid the nitrogen from changing to liquid. This helps to avoid delay caused by manual method of laboratory monitoring. The application is another important component of the IoT, it is the interface between the user and the platform. So, whenever the user wants to monitor, configure or control a device, an interaction with the application is feasible.

MQTT protocol uses the pub/sub model and translates messages between devices, servers, and applications where the clients request to communicate with a server known as the "broker." The broker which is also known as the server does the work of data transfer between clients. When different clients publish a topic to the broker, then the broker sends the published topics or the information to the client that requests or subscribe to them. Because the broker stands in between the server and the client, the both do not need data on the number or the locations for publishing and subscription. In MQTT protocol, any client can be a publisher, subscriber, or both. In this model, there is no direct connection between each client (subscribers and publishers) as such are not aware of each other, it is only the broker that serves as the intermediary between them. Many devices can subscribe to one topic and the broker just has to send the same topic to the many devices that need it. Brokers are flexible and they can support standard MQTT messages and topics as well as MQTT compliance specifications such as they can do with the same server at the same time and in the same level of security. It is used to manage the connection state of the client. MQTT is a bidirectional protocol this makes it powerful and easy for sharing of data as well as managing and controlling of devices [4].

This paper is aimed at determining the effect of MQTT IoT protocol on chemistry laboratory through a literature survey.

II. Breif historical background

MQTT (Message Queuing Telemetry Transport) was developed by two engineers known as Andy Stanford-Clark of IBM and Arlen Nipper of Eurotech and it was first released in 1999 [4]. MQTT uses the pub/sub pattern and translates messages between devices, servers, and applications. Their initial idea behind the creation of MQTT was to connect sensors on oil pipelines with communications satellites, with an emphasis to minimize battery loss and bandwidth consumption thereby improving a lightweight and bandwidth efficiency with support for multiple levels of quality of services (QoS). Up till today, it is still the same reason for which MQTT is chosen to implement IoT solutions. Since the inception of MQTT, it has continued and is still undergoing development, with version 5.0 arriving in May 2018. Version 3.1.1 was submitted to the OASIS consortium in 2013 and accepted as an ISO standard [5] [2].

III. Overview of MQTT IoT technology for temperature control

MQTT Internet of Things technology is the interconnectivity between things (devices), people, and cloud services via the internet which enables new (business models) activities to be carried out [6]. IoT technology has been implemented in several areas of life, one of the areas being in the chemistry or chemical industrial sectors. The MQTT IoT enables a large volume of data to be intelligently generated using any programming language. The generated data is sent to the cloud-based server via the Internet. The data is then processed and analyzed into a meaningful format to the user. This is for monitoring and controlling the chemistry lab. It systematically ensures safety and security while preventing circumstances that might result in injury, illness, or adverse environmental and laboratory effects. One of the major global problems arising from most chemical industries is that caused by hazardous chemicals due to changes in temperature.

The MQTT is majorly used in the internet of things to control and communicate the electronic device. The figure below illustrates how clients subscribe to topics to publish. For instance, CLIENT***A*** publishes temperature and humidity topics. CLIENT-***B*** subscribes to temperature topic, CLIENT-***C*** subscribes to humidity topic and CLIENT-D then subscribes to both temperature and humidity topic. So what CLIENT-***A*** does is publishing the data in temperature and humidity topics. Whenever CLIENT-***A*** sends temperature on MQTT broker, the MQTT broker will pass on the information to those clients who subscribed for the information. The same way when CLIENT-***A*** sends humidity data on MQTT broker, it passes on to clients ***C*** and **D** who subscribed for it.

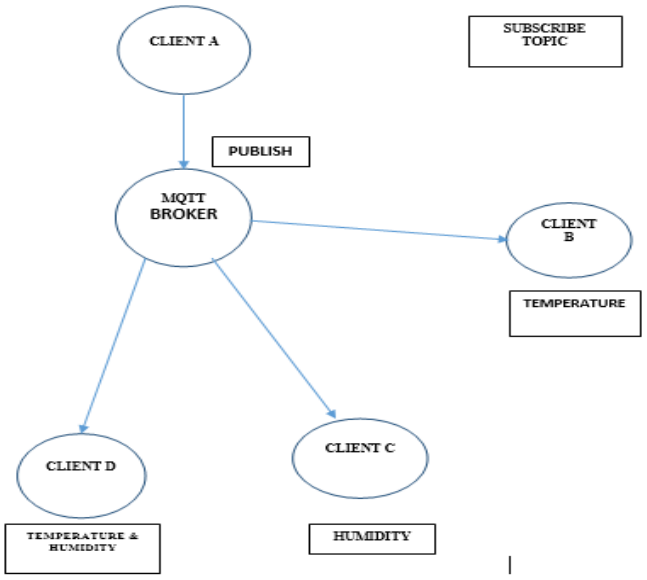

Figure 1: Illustration of the MQTT protocol.

Benefits of MQTT

- Lightweight protocol: MQTT as a lightweight protocol is seen as a machine-to-machine (M2M) /

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IoT connectivity protocol that means it can be supported by some of the smallest and many measuring and monitoring devices, and it can transmit data over far-reaching, sometimes intermittent networks, making it well suited for Internet of Things (IoT) application.

- Minimizes data packet: MQTT is very energy efficient. It minimizes power usage
- Quality of service (QoS): the quality of service levels determine how each MQTT message is delivered and must be specified for every message sent through MQTT. It is important to choose the proper QoS value for effective communication, message delivery and speed of service.
- Last will and testament: When a client connects to the MQTT server it can define a topic and a message that needs to be published automatically on that topic when it unexpectedly disconnects. When the client unexpectedly disconnects, there is a keep-alive timer at the server-side which detects the client has not sent any message. Hence, the server immediately publishes the will message on the Will topic specified by the client. This feature can be useful in some scenarios. For example, a remote MQTT client, this feature can be used to detect when there is a network disconnect in the IoT devices. The feature can be used to create notifications for an application that is monitoring client activity.
- Ease of implementation: MQTT already has libraries in programming languages such as Elixir and Python that makes the MQTT client very simple to implement.
- Retained message: topic can have one retained message that a client automatically receives when it subscribes (like a pinned post on social media) communicate through different control packets.
- MQTT is based on publish/subscribe architecture: The MQTT messages are delivered asynchronously (“push”) through publish-subscribe architecture. The MQTT protocol works by exchanging series of MQTT control packets in a defined way. Each of the control packets, has its specific purpose and every bit in the packet is carefully crafted to reduce the data transmitted over the network. An MQTT protocol has both the MQTT server and client.

IV. LITERATURE REVIEW

A. Contextual Backgound

The need for temperature control began as far back as centuries ago. People had difficulty in controlling the temperature of their homes, industries, hospitals, laboratories, etc. proper measures have been taken to control the temperature of an environment for lives and property's security and preservation.

This is a proposed system that will take care of individual health. By monitoring the state of the present health, controlling it by reporting if changes occur using the sensory devices to indicate to the doctor about the health-care changes by alarming. This can help save the life of patients from the danger and the risk associated with a person's present health-care condition such as blood pressure (BP), pulse rate, heart rate, temperature, etc. which can be monitored using the sensory system or the sensory devices. This system was limited to the manual method of alarm control and the alarm sensor is as well connected to the panel. Though the health care personnel is not limited to the alarming signal, it was not connected to the use of android. Which may not be accessed anywhere [7].

The development of the house air conditioner system for environmental and human thermal comfort has come a long way and has expanded throughout the year with many software and hardware devices for its application [8]. Much research work has been carried out on the IoT smart system with various kinds of technology, protocol, and sensor. An IoT system for the control of environmental microclimate conditions has been developed. In this research work [9], an intelligent microclimate control system based on IoT was designed to solve the problem of climatic conditions in an environment, air filtering, and high energy consumption. Air conditioning is beyond a mere lowering of the temperature of the air, it also involves filtering of the air, dehumidifying and also circulating the air all over the environment for a healthy life [10]. Home monitoring and automation are important in this present world and steps to have been taken to make it feasible and a reality. To provide a healthy life and thermal comfort of individuals, to lower energy consumption and increasing energy efficiency was achieved by controlling the temperature and humidity of an environment using sensors and Internet-of-Things technologies.

The authors [9] explores the main factors of an indoor environmental condition as well as using sensors and Internet-of-Things (IoT) to control the temperature, humidity, and other factors remotely. The researcher resolves to solve the problems of the energy-saving and energy coefficient of buildings. It also illustrated that the optimal levels of temperature, humidity, and air cleanliness in an apartment or house can be easily achieved by integrating all techniques aimed at solving all problems, i.e., a "smart home" system This will solve the problem of house heating and ventilation, high energy consumption, thereby saving energy and other necessary resources and ensuring energy efficiency of the building.

The arrival of new technologies has indeed brought about a great change in our society which has resulted in development, opportunity, and advancement in information technology and internet technology. Though challenging to the development of the society, implementation of IoT technology in chemistry is a major point of interest. In this work, [11] monitoring of chemical reactions via the cloud talks about the manual method of laboratory monitoring. During experimental performance chemistry in the laboratory, a hazardous chemical was observed and manually handled. This then causes more harm to humanity. They implemented an IoT technology for monitoring chemical reactions via the cloud using the particle photon Wi-Fi module. The system monitors Laboratory environmental conditions. To monitor laboratory equipment, chemical experimentation, and the PH reaction sample during the

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period, and remotely over the cloud in real-time. In case of any danger, the system also implements a safety measure to switch off the entire system. By connecting devices to the internet like smart-phone or computers, the experimenter can view the performance anywhere in the globe. According to them, "it improves the data reliability and transparency because the IoT facilitates the simultaneous exchange of data among scientists."

Having a study and knowledge of chemicals, the influence of temperature and humidity on these chemicals will go a long way in helping to ensure safety. The author [11], focused on monitoring chemical reaction via the cloud. Particle photon Wi-Fi module was used for monitoring the Laboratory environmental conditions, monitoring the equipment, chemical experimentation and the PH range of the sample during reaction remotely over the cloud. It is also an IoT technology system. According to [12], it will help to improve the safety limit in the environment as well as the community or even the country at large. The protection of eco-systems from pollutants can also be more effective with the control of temperature and humidity of chemicals. The impact of higher ambient temperature on the effects of simultaneous chemical stress is not clear. From all indications, it is clear that there are chances of increased risk. Therefore, in-depth research on the temperature effects is needed for the assessment and abatement of problems of environmental toxicology in tropical countries.

IoT implementation has also been conducted in the lab. In this article [13], and IoT based smart laboratory was designed to monitor the activities in the lab and also to monitor the level of energy consumption as to provide energy efficiency and comfort in the lab environment using the IoT smart hardware kits which are designed using ESP8266, Arduino UNO, relays, current transformers, Raspberry Pi3, and sensors. The dashboard developed in Node-RED or Android Studio Mobile Application has been used to control and monitor the devices of the CIT IoT in the lab. Devices in the laboratory are connected to the IoT smart hardware kit. For interfacing IoT smart hardware kit & MQTT broker, Dashboard and Mobile Application have been used. A database was created for a prototype switch to view status history. The Node MCU is used in this system to monitor and update the temperature, humidity, and light intensity inside the laboratory. They were able to develop a system that remotely monitors and controls all the appliances in the lab, thereby reducing their energy consumption considerably.

Authors [14], analyzed the growth of M2M protocol research and highlighted a framework for comparing the properties and features of various MQTT implementations, i.e. brokers and libraries found in the public domain. The authors [15], used an MQTT broker to solve the problem of room temperature and fire outbreak. In this work, the MQTT broker was utilized as a platform to provide IoT services that monitor and control room temperatures, sends an alarm when necessary, and suppress a fire. Arduino was used as the IoT end device connecting sensors and actuators to the platform via the Wi-Fi channel. Following their research efforts, many works has been done on temperature regulation but not related to the temperature monitoring and control of chemicals in the laboratory to prevent hazards and ensure safety.

B. Contributions

Many works has been done on temperature regulation but not related to the temperature monitoring and control of chemicals in the laboratory to prevent hazards and ensure safety.

Based on the gaps observed in the various reviewed literature, this research work proposes the following hardware devices and software applications to monitor and control the temperature of the chemicals. Though the above work was centered on temperature monitoring and control, our work and approach applied are different because the system will be developed using Node MCU 8266 microcontroller, DHT11 as the temperature sensor device and Python Flask which is a software application used to facilitate integration of MQTT is used for its simplicity. It is an MQTT IoT technology-based system which is designed as a lightweight publish/ subscribe messaging module that enables connectivity of several devices to the network for faster and efficiency information distribution. Furthermore, a measure is taken towards knowing and having a better understanding of the chemicals

C. Conceptual Backgorund

Message Queue Telemetry Transport (MQTT) is an open standard extremely lightweight messaging protocol based on the publish/subscribe model in that it was designed for easy implementation in software and fast in data transmission. The MQTT IoTs Sensory System for temperature control and the general concept of the research topic as seen by the other researchers. The technology is chosen in other to create an MQTT system that will display variation in temperature change of a specific chemical substance with the use of Node MCU Micro-controller and python flask. MQTT uses a client-server architecture where the client (such as a sensor device on the chemicals) is connected to the MQTT server (called a broker) and publishes messages to server topics. When a client subscribes to a topic(s), the major function of the broker is to forward the message(s) to the client(s) who subscribed to them. A single MQTT server can support up to thousands of remote clients or more and communicate with one another effectively [17]. These make it ideal for use in constrained environments where network bandwidth is low or remote devices that might have limited processing capabilities and memory, enabling faster response time, increases efficiency in information distribution [18]. The MQTT protocol is based on publishers sending messages to the topics, configured on the MQTT server known as MQTT broker. Clients can then subscribe to these topics and retrieve messages published from those topics. Its ability to measure, monitor devices, and transmit data makes it ideal for IoT applications with small sensors, devices, and other low-capacity devices [19].

To examine and analyze the usefulness of MQTT in temperature control, MQTT indeed has become an industry standard. For many-to-many communication protocol for sending messages between multiple clients through a central broker, it decouples producer and consumer by letting the clients publish messages and the broker deciding where to route and copy the messages. While MQTT supports persistence, it does best as a communications bus for live data [20]. MQTT protocol is known for its security; though it was argued that the way of implementation and configuration of

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the MQTT can cause issues. This means if the configuration is insecure, then the entire environment is compromised.
Following the widespread risk involved in the chemistry laboratory due to the high temperature which may result in explosion damaging life and properties. Many control measures have been taken to control this effect but no reliable solution had been proffered. The temperature control measure is important as it manages many physical, chemical, and biological applications thereby avoiding temperature hazards, controlling it, and reducing it to its barest minimum. A platform that would deliver a rapid data output for the lab temperature was developed with some technologies. For such control was used and ensure a high degree of accuracy within the micro system. In other to enable and facilitate homogeneous temperature regulation, an immense study on the technologies was done [21].
The international standard organization (ISO) set up a standard for the establishment, development, implementation, and maintenance of quality laboratory systems/standards. Once, a adopted, would provide healthy laboratory services. These standards are presented to and adopted by countries and applied to laboratories at every level of the health-care system. The approach provides a simple approach to meet the minimum requirements set with the ultimate objective to comply with ISO 15189 in a logical and step-by-step manner. But many countries found It difficult to implement [22] [23]. The effort made by the environmental protection Agency, to protect and prevent human health and environment from chemical accidents [23]. Was to have knowledge of the chemical, what causes, and the factors that contribute to the chemical accidents. Then measures can be taken to prevent their reoccurrence. The agency stated that major chemical accidents cannot be prevented solely through regulatory requirements. Rather, understanding the fundamental root causes, widely disseminating the lessons learned, and integrating these lessons learned into safe operations is also required. Creating awareness information to the public on the possible hazards also helped in prevention. This guidance does not represent final agency action and may change in the future, as appropriate [24].

V. METHODOLOGY

A. System Description

The approach involves the following steps:

i. Data collection using Rest API: Large datasets are made available for decision making.
ii. Data preprocessing: this involves the streaming of data through python cloud.
iii. Graphical representation of the information: the analysis result is presented using a high chart.

For this system, we chose DHT11/DHT22 because it is laboratory calibrated, accurate, and stable. It gives a digital signal output.

B. Data Collection using RESTFUL API

For environmental temperature control, several methods had been applied by researchers to ensure a successful outcome. In several ideas were brought up to design the system and the system has 5 different elements which were also used to produce a result; client data visualization, local network system, and cloud computing system, smart sensor, LED (light-emitting diode) and smart microcontroller (Node MCU ESP2866). Figure 2 gives an overview of the overall system architecture of smart temperature monitoring and controlling system. The main processing unit uses NodeMCU ESP8266 as the microcontroller which already has the embedded wifi module. The main processor unit NodeMCU ESP8266 collects experimental data from each sensor. The read data from all sensors will be sent using the MQTT protocol to the cloud server to be analyzed before it is visualized by client devices.

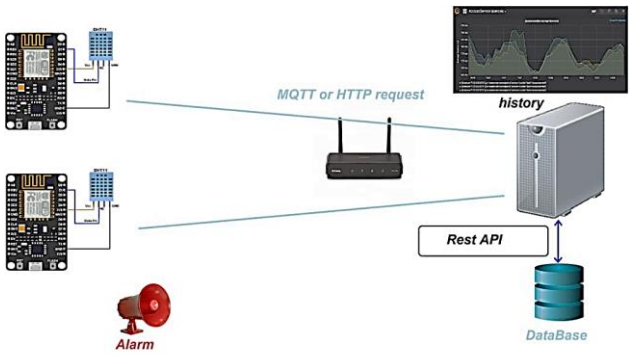

Figure 2: the system overview.

VI. DATA PREPROCESSING

A smart sensor module is a circuit consisting of temperature sensors, NodeMCU ESP8266, LED, and Resistors to read the environmental data of temperature conditions. The sensor data sent by NodeMCU ESP8266 which already has a wifi embedded module via MQTT protocol to the cloud server. The LEDs are indicators, signaling when there is a change in the temperature. The NodeMcu has several GPIO which we used 3GPIO as outputs for indicator and 1 GPIO as input for the sensor. When the web server receives a temperature value from the sensor through the microcontroller, it compares it with the minimum value and the maximum temperature value of the chemicals in the database.
In this scenario, if the temperature of the room is greater than the required temperature. The system will give a red signal indicating that there is a higher temperature and maybe immediate action has to be taken. The green LED indicates a normal temperature whereas the yellow LED shows that the temperature is too low. The figures 3 represent the system's hardware

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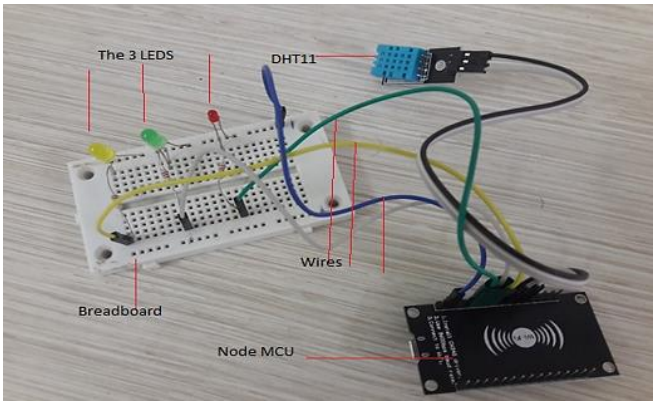

Figure 3: Design Testbed.

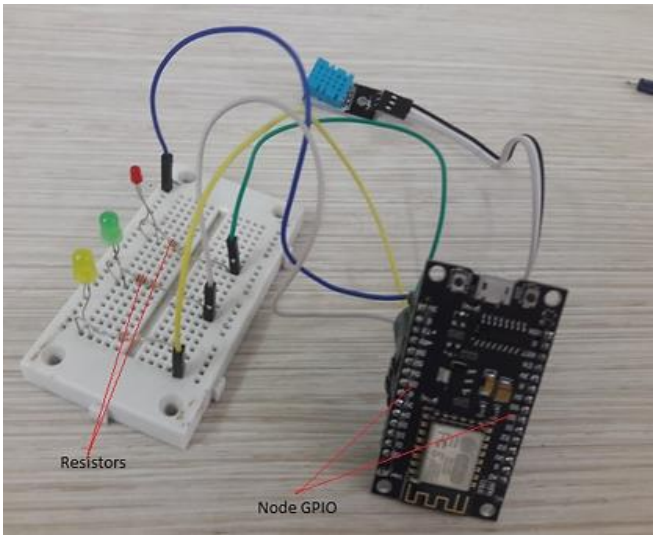

Figure 4. System hardware.

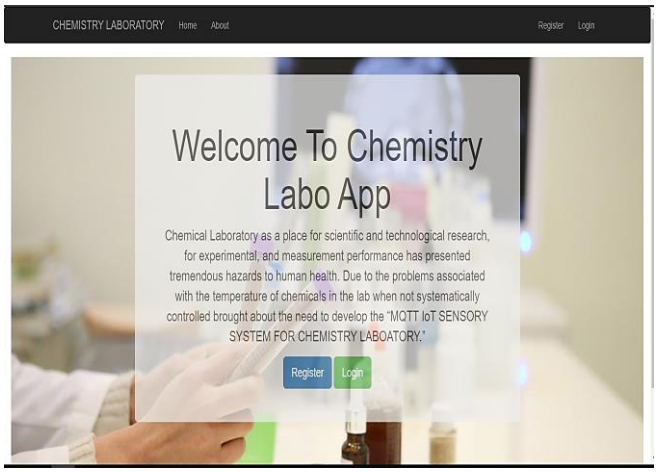

Figure 5: Screenshot of the land page of the system

VII. LOCAL NETWORK SYSTEM

Local network systems consist of modem and laptop with an internet connection (or a hotspot) which worked for sending and receiving data packets either from sensors to cloud server or from a cloud server to smart microcontroller using MQTT protocol. MQTT is limited to devices that are connected to it to send (publish) information about a given topic to a server that functions as an MQTT broker then pushes the information out to those clients that subscribed to the topic

A. Client Visualization Tool

The data published by the MQTT broker is read by as many clients who subscribe to them. In web applications, the python flask framework is used for developing the web. An MQTT client is installed in it to read data by subscribing to a certain topic or send data by publishing to a certain topic. The application has some features to optimize and support the laboratory experimental process, real-time statistic data, and multi-node supported expandable sensors.

B. Software Module

Home page: The home page is designed and implemented using HTML language with bootstrap. On this page, you have the login module and register.

- Login module: it has two inputs textbox and button which comprises username and password. This is where every user presents their username and password, and access is granted to the user to the dashboard.
- Register: This is where a user enters their full name, and access is granted to the dashboard.
- About: this talks about the topic.

ii. Dashboard: this is a page where all registered user access after proper login. On this page, you have the upload data and logout.

- History: displays the result of the system.
- Logout: This is used for ending a session.
- Admin: this is a separate module on its own that controls the entire functionality of the system. It monitors the activities of the users. A user can update, edit, view data, and logout.

VIII. RESULTS AND DISCUSSION

The results of the system are presented. Firstly, the result of the system is shown, then that of the Word Cloud. Finally, tables for the cloud-based temperature analysis and the time of the software are provided.

In this part, we present the implementation development of the hardware and software of the system. The breadboard was used to connect the devices as a circuit. Node MCU ESP8266 enables the communication between the DHT11, the computer, and LED. In this, a client can connect to a computer using the IP address of the system. There are 3 LEDs connected to the Node MCU which blinks according to the computer instructions on the temperature change. The communication is via the internet or Wi-Fi with the Internet of Things (IoTs), multiple (million) clients are enabled and also efficiency in information distribution increases.

Table I: The time and Temperature

Day (07/ 15/ 2020)	**From 12:00 AM To 09: 52PM**	
ID	Temperature	Time(Seconds)
46	25.3	000.14
47	25.4	000.23
48	25.8	000.32
49	25.6	000.41
50	25.6	000.50
51	25.1	000.59
52	25.0	001.08
53	22.5	001.17
54	22.5	001.26

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55	22.3	001.35
56	22.6	001.44
57	23.1	001.53

The results show a significant presence of the temperature ranging from the time 12:00 AM to above 9:00 PM such time was taken to get a large number of data. This calls for concern, the occurrence of time, and the temperature regulation within a second.

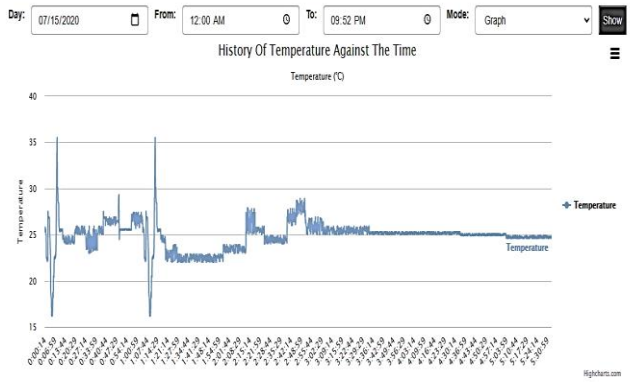

Figure 5: Graphical representation of the temperature and time.

Some intresting areas of applications of MQTT-IoT include: Cyber-Physical Network Architectures [23], Fog Network Orchestration [24], AI Assistants [25], and Automation [26] among others.

IX. CONCLUSION

In this paper an MQTT Internet of Things (IoTs) to chemical laboratory and environmental temperature conditions monitoring and regulation with microcontroller and temperature sensors. It is established in this study that temperature hazards that may appear to affect human life and property are on the increase in the chemical laboratories. The study shows that chemical laboratory temperature can be monitored and controlled. The findings can be used by government and law enforcement agencies on chemical hazards for human safety.

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