Master of Science in Engineering and Management

Thesis Title

Implementation of an IoT open-source architecture for the maintenance of building facilities

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ABSTRACT

The building facilities are permanent assets, and they need to be constantly maintained over time. Therefore, methods must be available to follow up on the facilities to provide preventive maintenance to maintain the facility in a proper condition. Over the last 20 years, Building Information Modelling (BIM) technology has greatly improved, and it has proven to be very useful for the management of buildings. BIM exploits 3D models, data, and documents regarding a building, in order to manage and coordinate the different phases of its lifecycle (plan, design, build, operation and maintenance). The main problem facing most of today's facilities is the lack of necessary information and data about their status and condition. The aim of this thesis is to apply the Internet of Things (IoT) approach to develop an open-source architecture by connecting sensors and microcontrollers inside the facilities to constantly monitor their status. Data are then transmitted through an Internet network to a database for a following analysis for preventive maintenance. the collected data are also integrated in the BIM model of the facilities to have constantly updated information about their status. Since the developed architecture is completely open source, it can be easily expanded in the future to include more types of elements and devices.

Acknowledgment

Firstly, will start by thanking those whom I will never be able to thank enough those who were and still with me, before even the beginning and during the journey they continued to support me non the less provided me with all moral and financial support and most importantly of all, confidence, trust, and patience, those are my parents, my sisters, and my brother.

Also, I would like to extend special thanks to all my professors in Politecnico especially my thesis supervisors, Prof Bruno Giulia, Prof Villa Valentina, and Mr. Khurshid for everything they have done and by letting me do what I do well without being restricted to a specific direction or path.

Finally, I want to thank all my friends who were there for me in every step of the way, not only those with whom the study brought us together but also the others. Many thanks to Hifni Elsheikh, and Hassan Khattab also special thanks to those who gave me their time Yaser Shukry, Tasneem Ramadan and Zahra Jalal.

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CHAPTER 1 – INTRODUCTION

A brief background and problem definition of the research are provided in this chapter.

BACKGROUND

Generally, building maintenance means two terms building maintenance management and building maintenance technology. There are some maintenance needs, and they are the principal aspire of care to protect the building in its early stage, and some primary rationale for maintaining structure are retaining its significance and value of investments, maintaining the building in a condition that it persists in accomplishing its purpose and presenting an excellent outer shell. Besides that, the efficient maintenance management system embraces many skills and efforts that include identifying maintenance needs and accurate and spot-on remedies. In general, there are four types of maintenance which are breakdown or corrective maintenance, scheduled maintenance, preventive maintenance, and predictive maintenance. Building maintenance is a global problem and extremely measured for the untimely route of construction that the superiority of the building can be guaranteed. There are numerous definitions that define maintenance work; for example, British Standard BS3811 defines maintenance as a special task embarked on in sequence to remain or reinstate each amenity, such as each part of a site, building and contents to a satisfactory benchmark. While the Chartered Institute of Building defines building maintenance as work is done to maintain, restore or perk up every facility for an instant, every part of the building, the services, and surrounded to a contracted criterion determined by the equilibrium between necessitate and obtainable resources. Another definition of maintenance is work done to control certain conditions of a building so that the outline lies within specific regions.

Maintenance performance indicators are utilized to assess the efficiency of maintenance performed. Those indicators could be used for financial reports, monitoring employees' performance, customer contentment, the health safety environment rating and overall equipment efficiency, and many other applications. If maintenance performance indicators are recognized correctly, then maintenance performance can offer or identify resource portion and control, problem areas, the maintenance contribution, benchmarking, personnel performance and the contribution to maintenance and overall business objectives

The growing development of the Internet of Things (IoT) has pushed the concept of digital twin technology to the forefront of cloud-based storage and virtual business operations. A digital twin is a virtual model or copy of a product, service, or process, typically paired with the physical to facilitate a greater degree of efficiency and accuracy in systems analysis and monitoring. "Digital twins are becoming a business imperative, covering the entire lifecycle of an asset or process, and forming the foundation for connected products and services. Companies that fail to respond will be left behind," said Thomas Kaiser, SAP Senior Vice President of IoT.

Digital twin technology puts monitoring, analysis, and predictive capability at a facility manager's fingertips. They can more quickly and correctly respond to outages or system failures, better maintain, and update functioning systems, and use the data their digital twin gathers and analyzes to find new opportunities. Facilities relying on a digital twin can be operated far more efficiently and at a much lower operational cost than those still depending on paper records. The digital twin can also help companies better understand their customer needs to develop ways to improve their experience.

THE PROBLEM

The operation management responsible for roughly 60% of a facility's overall lifespan expense. Maintenance and repair are the most critical elements during operations (M&R). Extreme costs are associated with reactive maintenance and repairs. Most of the maintenance work, on the other hand, is non-routine and reactive). Reactive maintenance and repairs are inefficient, costing three to four times as much as scheduled maintenance for the same repair (Sullivan et al., 2010). And now adays there are some ways to prevent or to predict the maintenance needed before the it is time to reduce cost of reactive maintenance by using BIM, the construction industry has sparked a great deal of interest around the use of BIM for facility management. Utilizing BIM for facility operations is feasible by virtue of planning prior to implementation but the use of BIM in the facility management process lags implementation in the design and build phases. So, there is a need to expand BIM in addition to the design and construction phases. It must also be used to maintain the facilities for its life cycle. A study by the US National Institute of Standards and Technology shows that $ 15.8 billion is the annual cost associated with insufficient interoperability between software systems. Two thirds of these costs are incurred by ongoing facility operation and maintenance activities [1] Therefore, between design and facilities management, there is an information and technology gap.

OBJECTIVES AND SCOPE

The goal of this thesis is to offers a deeper insight into IoT and its use in construction management and maintenance to review and explore the perceived data from the sensors and intergrade it to the BIM to explore and apply ways in which BIM and sensors can function for communication.

CHAPTER 2 - LITERATURE REVIEW

SYNOPSIS

The aim of this chapter is to determine the scientific importance of the research problem by demonstrating and reviewing prior studies in the areas, and to enhance my own research in the area, lots of previous studies and websites have been went through like "*Meet Three Ind. Revolutions* " [2] "*Industrial Revolution*" [3] "*A Guide to Achieving Operational Efficiency*" [4] "*Industry 4.0 concept*" [5] "*Industrial Revolution 4.0*" [6] "*guide to IoT-based predictive maintenance*" [7] and some of the other theses from around the world until developed a general understanding in how to connect the maintenance and the Internet of things.

GP Sullivan in his research - A Guide to Achieving Operational Efficiency – explained very well the possible types of maintenance and even the differences of each type and the other and the history of maintenance. Also, some books and papers have been reviewed spread on the industrial revolution starting from the eighteenth century until today's date and how the industry developed from mechanical steam engines to production lines to the small microcontroller and silicon era till, we reached the stage of the industry 4.0 which based in a big cyber entity two of its essential Internet of things and Big data.

MAINTENANCE

Maintenance procedures in both the private and public sectors would lead us to believe that maintenance refers to the activities involved in repairing machinery once it has damaged or about to. It can be described as "the job of holding something in good conditions". This implies that maintenance should be described as actions taken to prevent an equipment or unit from failing or to fix normal equipment damage caused by the device's operation to maintain it in good working condition.

Every maintenance team understands that under-maintaining assets can result in frequent and long breakdowns, high volumes of unplanned work and lost product and output. But the costs of unplanned corrective maintenance are less obvious—overtime salaries, expedited costs and even safety risks. This kind of maintenance can have a negative impact on the useful life of assets. And furthermore, excessive maintenance of assets can also be wasteful. Over-investing in maintenance squanders precious resources, which directly impacts cost and profitability

TYPES OF MAINTENANCE

- **Reactive Maintenance**

It is the most frequently used and known maintenance type “don't fix what's not broken”. No action has been made before you have and forced to, this type of maintenance can be used to save lots of amounts of money if it has been used in the correct place “unessential” component. And can get the whole facility out of service for a period if it has been practiced in the wrong place.

- **Preventive Maintenance**

Non reasonable maintenance that must be performed to a facility or equipment on a specific time and schedule. Most of the facilities make some annual contracts for the some of essential part in the facility like the elevators, the manufacturing or services company come each period in schedule to perform the maintenance, it is good to keep it working for a longer period, but you pay annual and sometimes with no real values.

❖ Predictive Maintenance

The predictive maintenance is prior maintenance that is been performed not by making a maintenance schedule but by known the current situation then diagnose and analyze if there are any needs. Predictive maintenance it may be the most reliable maintenance because the operator must be in direct contact most or all the time to check and see the needs of the facility, but this means extra worker and extra diagnosing methods which leads to increase the expenses.

❖ Reliability Centered Maintenance

The RCM approach solves certain primary problems that are not discussed by other maintenance programs. It admits that not every equipment in a facility is equally important to the operation of the facility's safety. It acknowledges that equipment design and operation differ, and that some equipment would be more likely than others to failure due to different deterioration mechanisms. It also approaches the planning of a maintenance program with the understanding that a facility's financial and personnel resources are restricted, and that their use must be prioritized and optimized. RCM is a comprehensive approach to evaluating a facility's facilities and services in a nutshell.

Comparison between maintenance practices				
	Reactive Maintenance	**Preventive Maintenance**	**Predictive Maintenance**	**Reliability Centered Maintenance**
Pros	- Low operating cost in general	- Reduce the failure of facilities -Increase components life cycle. - Flexibility in the maintenance periods	- Longer operating life and availability. - Less downtime in the facilities. - Prices for parts and labor are smaller. - A better performance	- Save money by avoiding repairs and overhauls that are not required by reducing number of overhauls. - Able to concentrate on essential component repairs.
Cons	- Higher repairing cost due sudden failure Additional to the cost or loss to get an immediate replacement and repair	- Not preventive Unprecedented failures. - A periodic maintenance for unneeded facilities	- An increase in the amount of money spent on diagnostic facilities and preparation for employees.	- Startup costs may be substantial

Table 1[4]

Predictive Maintenance

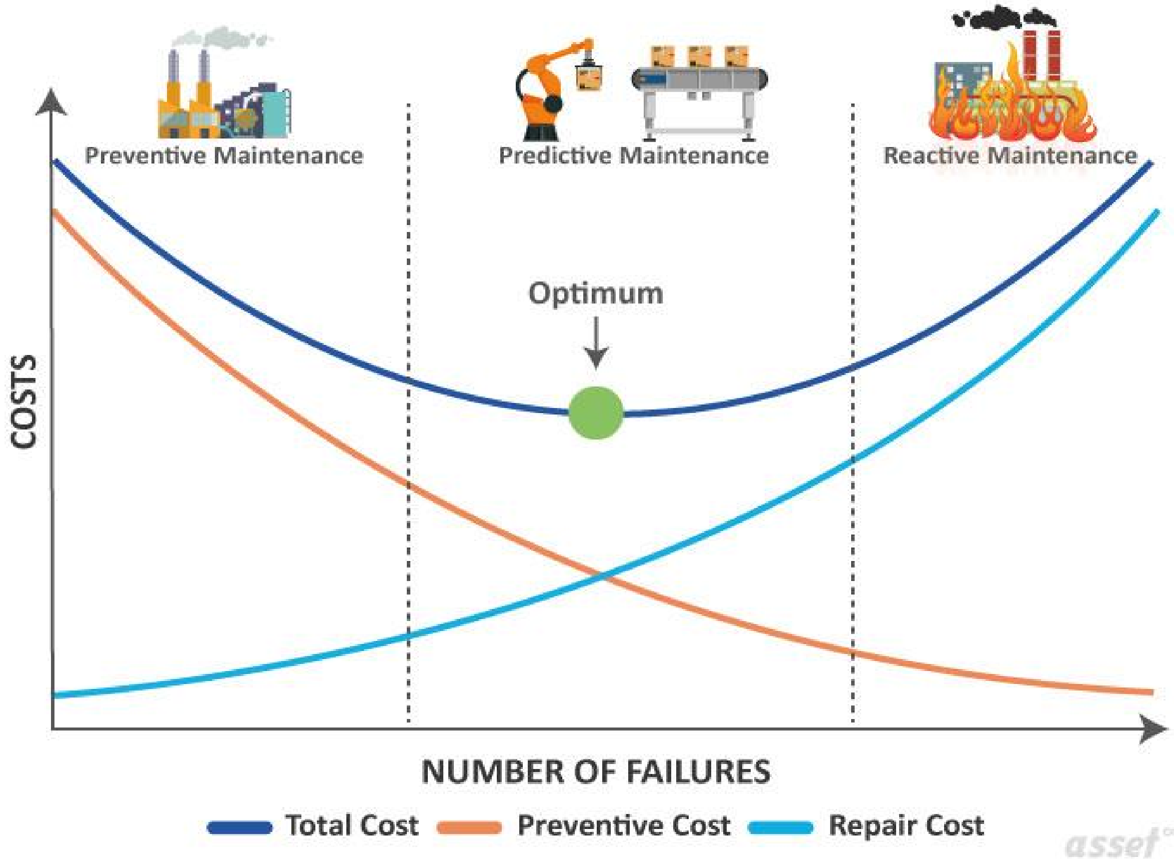


Figure 1 [8] *Reactive Maintenance Vs Preventive Maintenance Vs Predictive Maintenance*

So, how precisely does predictive maintenance function? On a high level, it is delivered by the convergence of several mega-trends, most notably big data, cloud computing, edge computing, machine learning, and connectivity. The challenge for design engineers developing IoT solutions is then to create a supporting platform using core products that are appropriate for the task at hand. Sensors wired and wireless solutions, antennas, batteries, and ever-smaller connectors and passive components enable small, frequently remote, low-power connectivity. These products must also be designed to withstand the harsh conditions that are common in industrial settings.[9]

Once installed, sensor data from assets such as actuators, motors, and drives can be filtered through field gateways before being sent to the cloud via wireless connectivity. The sensor data is then effectively repacked so that it can be streamed in a logical flow to a data lake for filtering. Once the data has been constructed in a big data warehouse into more useful information regarding specific performance metrics, such as vibration or temperature, it can be evaluated with machine learning to recognize any discrepancies. Predictive models become more reliable and useful as they are established and trained over time.[9]

What is critical here, of course, would be that the appropriate information is gathered, and the proper datasets are reviewed. IoT data used to identify the parameters of a machine may include factors such as temperature and vibration, while other static data feeding into the model may include make, model, or configuration specifics. Data from usage history and service information can also be used to enhance the model's efficiency and consistency.

There should also be a component of contextual awareness, bearing in mind the complicated static and dynamic variability of hardware devices, which is regularly impacted by the operating environment's specifics. Machine learning software can more accurately understand long-term trends and spot system failures before they trigger downtime by steadily recognizing patterns and identifying abnormal behavior in the context of the types of different circumstances found in industrial settings.

❖ The Difficulties of Tying Predictive Maintenance in Place

If the concept of IoT-enabled predictive maintenance is now well understood, and some forward-thinking companies are implementing it in their plants, why is it that new studies indicates that adoption in manufacturing has been slower than expected?

According to a survey of 600 high-tech executives conducted by the global management consulting firm Bain and Company, industrial customers were less enthusiastic about the potential of predictive maintenance in 2018 than they were two years prior. According to Bain and Company, this shift in sentiment occurred because manufacturers discovered that enforcing predictive maintenance was more difficult than they had anticipated, and that gaining insight from data proved more difficult than they had anticipated. Most of these companies had identified concerns about implementation issues, specifically, there is a lack of professional expertise, data portability, and transformation risk.[9]

The survey revealed that, while manufacturers remained enthusiastic about IoT-enabled predictive maintenance in the long term, many companies were pausing for thought as they realized that introducing digital projects might take even longer and that the return on investment might occur later.

- **Techniques for best-practice advancement**

This newly discovered sense of realism may contribute positively to the long run. As the initial euphoria surrounding predictive maintenance fades, it is likely that it will be substituted by a more thoughtful debate about the benefits and drawbacks of adoption. It also allows you to take stock and learn from best-practice advice from organizations that have blazed the trail.

For example, Hitachi has defined six main tools and methods that all effective predictive maintenance systems should have in order to operate effectively and provide a great positive impact. They are as follows:

- Small early pilot systems
- A data gathering technology suite
- Algorithms to measure historical and current data in real time
- Efficient workflows
- Performance monitoring

Such success factors could also help engineers deal with situations like the business case and guaranteed value of predictive maintenance, technological and data specifications, and the obstacles to full integration and providing on that promise.

Finally, IoT-enabled predictive maintenance expands a new phase for manufacturers trying to improve efficiency, promote security, and cut costs. The journey to that goal, however, will take longer and have more highs and lows than many people anticipated.

❖ SWOT Analysis

Strengths	Weaknesses
• Increased availability of machinery • Maintenance practices that become precise • Reduce the maintenance expenses • Satisfied staff	• Initial investment costs • Personnel requirements • Observation - based requirements • Complicatedness
Opportunities	**Threats**
• Faster ROI • Increased ability to compete • Governmental assistance	• Maintenance program misapplication • Underutilization of the solution • Resistance to change

Predictive maintenance has many benefits. A well-planned predictive maintenance system will almost completely eradicate major equipment failures. We would be able to design repair operations so that additional costs are reduced or eliminated. We will be able to keep stocks to a minimum and order component ahead of time if needed to assist downstream maintenance. We will improve the equipment's performance, lowering energy expenses and increase facility performance. According to previous research, a correctly working predictive maintenance model will save 8% to 12% more than a preventive maintenance-only system.

When compared to reactive maintenance, savings of 30 to 40 percent are achievable. Independent research shows that implementing a practical predictive maintenance framework provided in the following overall average savings:[4]

- ROI 10 Times
- Maintenance costs are reduced by 25 to 30 percent.
- Failures are eliminated in 70% to 75% of cases.
- A decrease in idle to 35 to 45 percent
- A rise in output of 20% to 25% is anticipated. [4]

Industry 1.0

Figure 2 Industry 1.0 [6]

The industry has begun 18th to 19 centuries in Britain and it was underpinned by the agricultural revolution and it is huge increasing of productions this era has seen the beginning of steam engine which powered trains, ships and factories and it was using coal and iron both in construction and fuel. The steam-powered locomotive ushered in even more massive improvements by encouraging people and goods to travel great distances in less time. Eventually, as industrial revolution grew. Cities and factories developed at a faster rate than it has ever been, and economies as well.

Industry 2.0

Figure 3 Industry 2.0 [6]

The invention of electricity and assembly line manufacturing ushered in the Second Industrial Revolution in the nineteenth century. With a series of main inventions, things began to pick up the pace. Consider aero planes and diesel engines. Many of these inventions assisted people in travelling further and accomplishing further. However, scientific progress was not confined to the laboratory. Scientific ideas were immediately implemented in the factories. The assembly line was instrumental in industrial manufacturing. Henry Ford (1863-1947) was the first to popularize the concept of mass production. the company was mass-producing the pioneering Ford Model T, a vehicle with a gasoline engine produced on an assembly line in his factories, by the early twentieth century.

Industry 3.0

The third industrial revolution, which began in the 1950s, introduced semiconductors, computer systems, digital technology, and the Network, which can now control an entire industrial operation - without any need for human interference. as is the digital revolution. Things that were formerly analog have transitioned to digital technologies. The transition from analog electronic and mechanical devices to digital mobile technology, the electronics and information technologies started automating development developed the economies, especially global communications and electricity.

Figure 4 Industry 3.0 [6]

Industry 4.0

Industry 4.0 is all about connectivity, The Industrial production is being pushed by the global competition to its limits and the need for rapid adaptation of output require developing a major change in the of computer production technology (3rd Industrial revolution) to be able to fulfill the market needs technology today.

Figure 5 Industry 4.0 and IOT (ECOT, 2020)

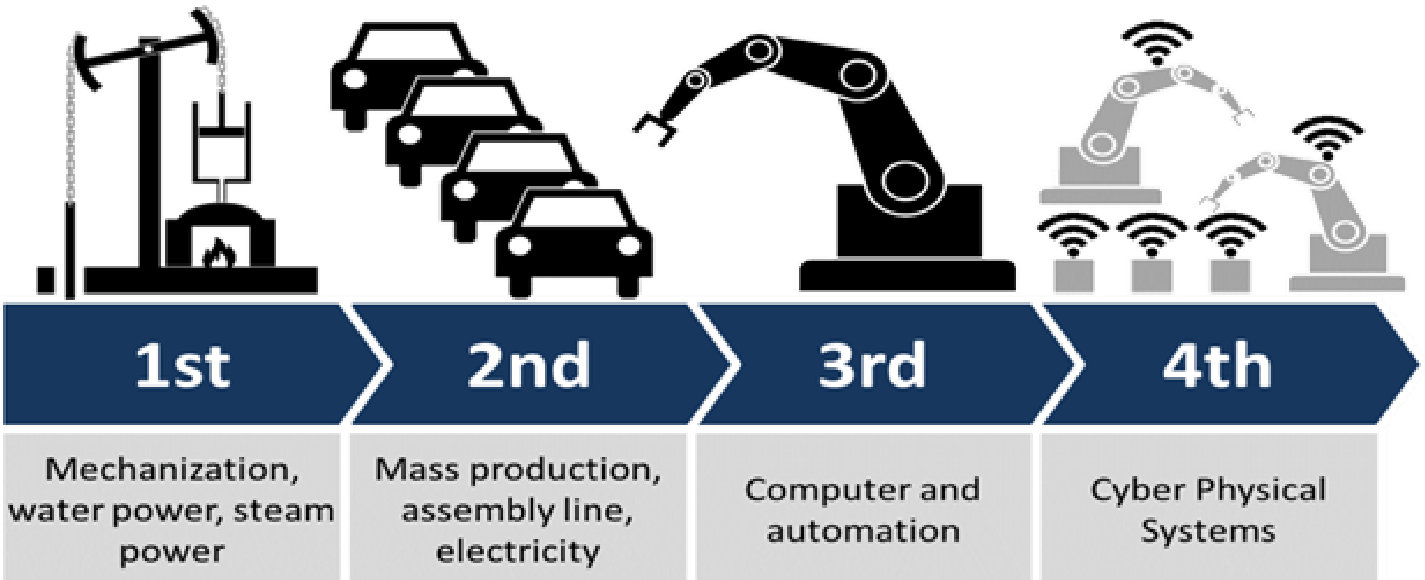


Figure 6 Industrial revolution

Industry 4.0 and IOT

Internet of Things is a common catch topic in the field of information technology, which is represented by mobile computers, is a core component of Industry 4.0. Not only can this support internal processes, but through storing data in the cloud, facilities and facilities may be streamlined by using the insights of those who use the same equipment or by providing smaller businesses with access to technologies they would not have access to otherwise.

The first use for IOT was at Carnegie Melon University in the early 1980s, Group of students was invented the first Internet appliance and it was a Coca-Cola vender machine. They created a server program that can check if the machine is empty or not and check its status through network connection to see if there was a cold drink waiting for them if they wanted to go down to the machine, But the real use of the term was by Kevin Auston in 1999 and they term starts to publish in the 2003[10]. Internet of Things develops the real-world objects (Things) into intelligent virtual objects to bring everything in the world together under a single infrastructure, helping us to control and monitor the things around us. Massive amounts of data would be generated because of Industry 4.0 and IoT the collection, analysis, and distribution of such large amounts of data would yield innovative ideas, aid decision-making, and provide a strategic advantage.

Reason behind using IoT for predictive maintenance

You may be wondering why we should implement an IoT solution when SCADA can handle all the maintenance tasks.

Predictive maintenance necessitates the ability to process large amounts of data and run sophisticated algorithms, which cannot be accomplished through local SCADA implementation. An IoT-based solution, on the other hand, allows for the storage of terabytes of data and the operation of millions of devices running machine learning algorithms on multiple computers at the same time to predict potential hazards and pinpoint when industrial equipment is likely to fail.[7]

A well-thought-out architecture is required for a reliable IoT-based predictive maintenance solution.

Let us look at which components make predictive maintenance work and how they interact with one another, as illustrated by an IoT solution that predicts the end of life of industrial batteries.

- **A predictive maintenance architecture based on IoT**

Before providing insight into the technicalities, it is critical to identify the key variables that influence the health of a battery. Temperature, voltage, and discharge are the three. Once the variables have been identified, batteries are outfitted with sensors to collect data on these parameters and send it to the cloud for processing.

Sensor data cannot be sent directly to the cloud; it must first pass-through gateways. Physical devices that filter and preprocess data are known as field gateways. A cloud gateway ensures secure data transmission and connectivity via various protocols, allowing the connection of various field gateways.

When sensor data enters the cloud component, its "lands" on a streaming data processor. Its purpose is to allow for flexibility of data and transmit data streams quickly and efficiently to a data storage – a data lake[7]

The data collected by sensors is stored in a data lake. It is still in its raw form, so it may be inaccurate, erroneous, or contain irrelevant information. It is presented as a series of sensor readings taken at the appropriate time. When the data is required for insights into the health of the battery, it is loaded into a large data warehouse.

The structured data that has been cleansed is stored in the big data warehouse. It contains temperature, voltage, and discharge parameters measured at a specific time, as well as contextual information about battery types, locations, and recharge dates, among other things. Following the preparation of the data, it is analyzed using machine learning (ML) algorithms. ML algorithms are used to uncover hidden correlations in data sets and to detect unusual data patterns. Predictive models are created, trained, and then used to determine whether a battery self-discharges, identify batteries with lower capacity than normal, and estimate the remaining useful life of batteries. The predictive models used for industrial battery maintenance are built using two approaches :[7]

- Classification approach - models developed using this approach determine whether a battery is likely to self-discharge and whether its capacity is lower than normal.
- Models provide information on how many days/cycles are left until a battery's useful life expires using the regression approach.

Predictive models are updated on a regular basis, say once a month, and their accuracy is tested. If the output differs from what was expected, they are revised, retrained, and tested again until they function properly.

Before looking into machine learning, some exploratory analytics should be performed. Data analysis is performed on machine learning data sets to identify dependencies and uncover patterns and insights. Furthermore, various technical assumptions are evaluated during the exploratory analytics stage to aid in the selection of the best-fit machine learning algorithm.

An IoT-based predictive maintenance solution can alert users of a potential battery failure through user applications.

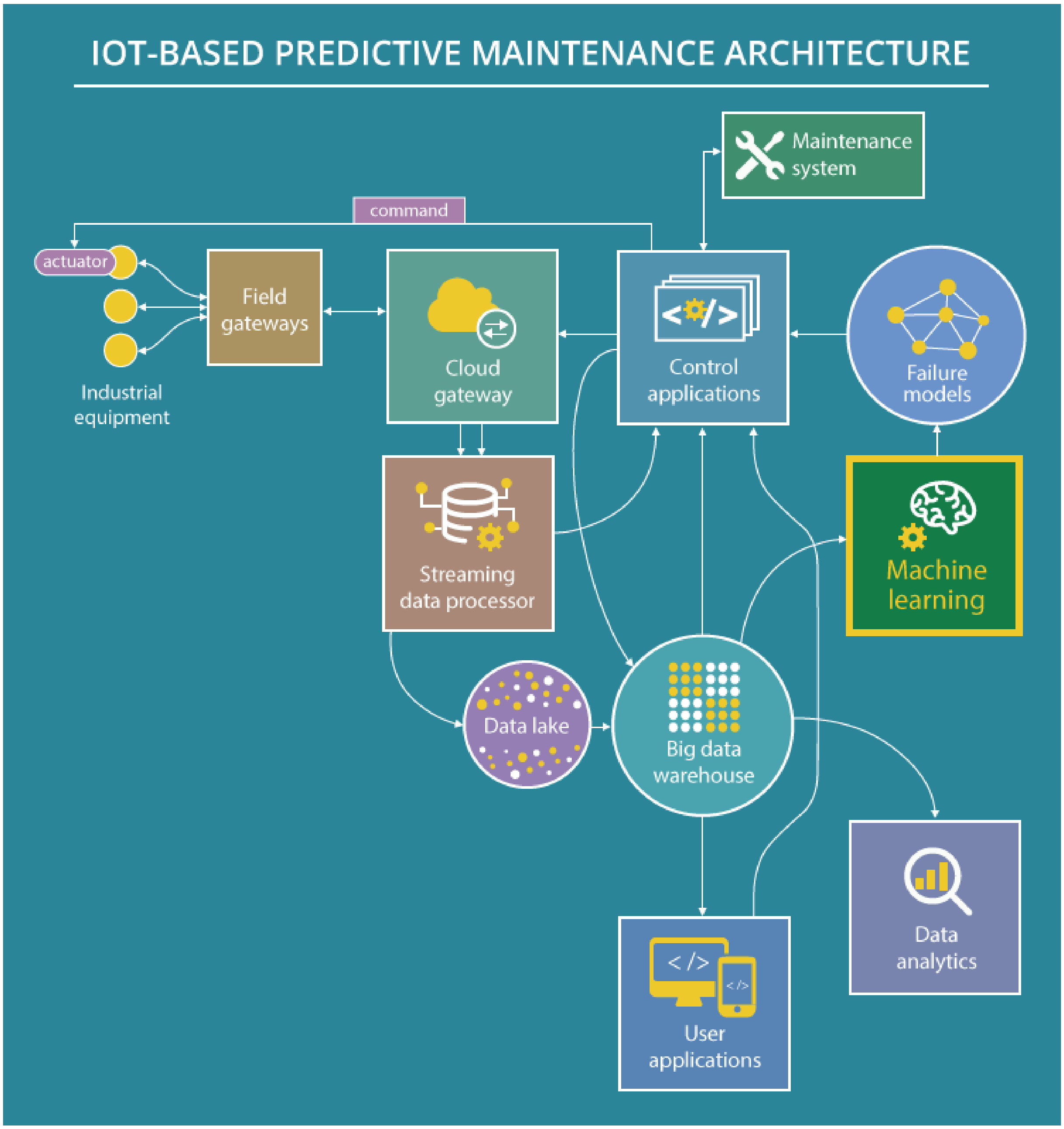


Figure 7 [7] *IOT-Based Predictive Maintenance*

CHAPTER 3 - METHODOLOGY AND IMPLEMENTATION

METHODOLOGY

To be able to collect data and information's to be used and integrated into BIM we must build an open source IoT-based architecture containing multi microcontrollers and sensors combining them into one project might become effective since the sensors offer a new technology that is not wholly grasped. The implementation of the devices depends on the evolving awareness of this technology and how it can and should be used with existing systems, in our case they will be distributed all around a building and by using local network we make the communications between them wirelessly, the sensors are connected directly to the microcontroller, but the microcontrollers will use TCP/IP (wireless) protocol to communicate. Each microcontroller will have an assigned topic and will be responsible of sending (Publishing) a message to the main server (Raspberry pi) which will act as receiver (Subscriber) the protocol we will use is MQTT

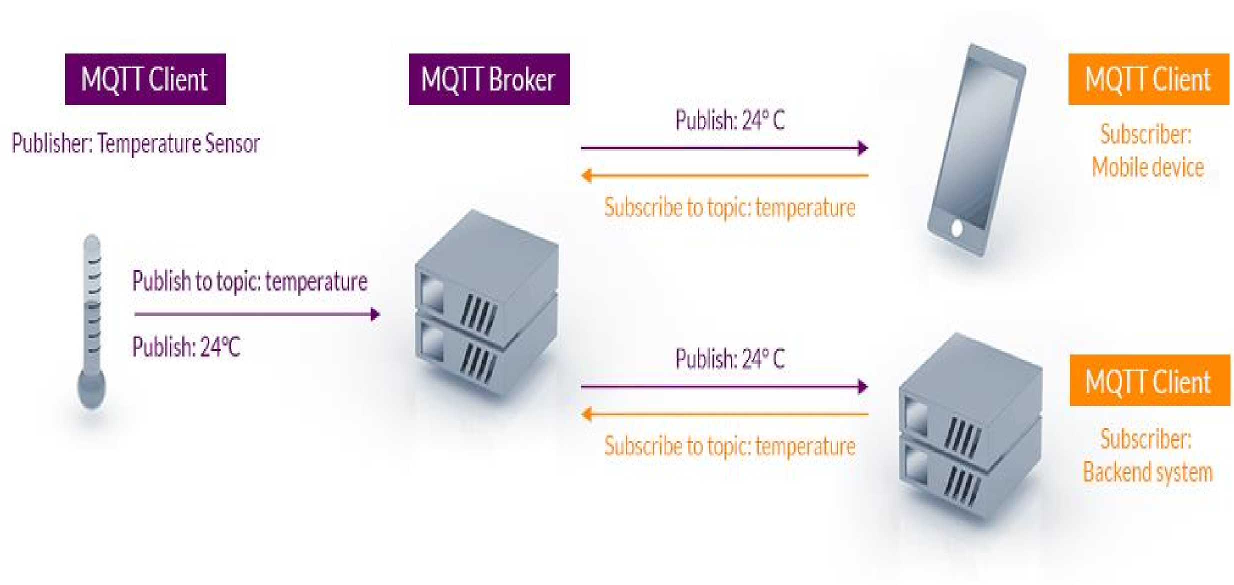


Figure 8 [11]

"MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications, oil and gas, etc."[11]

COMPONENTS:

Sensors:

Sensors are instruments that react to a physical input. Light, heat, movement, humidity, vibration, or any relevant input. Generally, the output is a signal.

- **DHT22**

  Capacitive-type humidity and temperature sensor

  Size: 24x40x9mm, 7g

  Voltage: 3.5-5v

  Pins: VCC, GND, DATA

  : -40 – 80C ± 0.5C

Temperature (°C)			Humidity (%)		
Minimum	Maximum	Tolerance(±)	Minimum	Maximum	Tolerance(±)
-40	80	0.5	20	90	1

- **Photoresistor sensor LDR**

  Semi-conductor resistor the conductance changes with variations in light intensity.

  Size:5x40x5mm

  Resistance: 1 MΩ

  Voltage:3.5-5v

  Response time: 20ms

- **MPU6050**

  Six-axis motion tracking module (Gyro + Accelerometer)

  Size:15.5x20.2x2.5mm

  Voltage:3.5-5v

  Pins: VCC, GND, SCL, SDA

  Communication: I2C protocol

- **SCT-013-030**

  Current measurement and monitoring device (transformer) clamped around a loaded wire and reacts to the magnetic field in the wire and give an output from 0-1v with rate 30A:1V

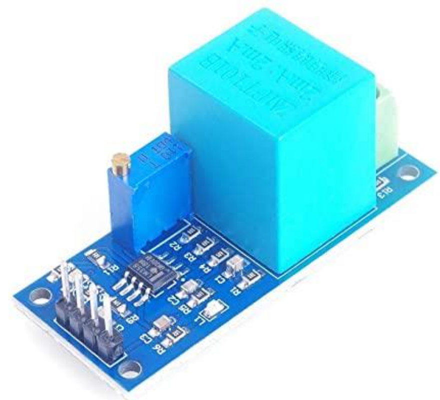
  Size:32x67x22mm

  Current: 0-30A

  Resistance = 62 Ω

  Tolerance = ±2%

- **ZMPT101B**

  Voltage transformer module has two coils, Primary coil to connect the input and secondary coil to step down the output.

  Size: 49.5x19.4x15mm

  Voltage In:0-250VAC

  Voltage out:0-5v

  Pins: VCC, GND, SCL, SDA

Microcontrollers:

Programmable, integrated circuit-chips (Small computers)

- **ESP8266 Dev**

  It is a low-cost, lightweight, and up-to-date microcontroller. It is based on the ESP8266 chip system, which is less costly microchip. It has all the essential PC components. [12]

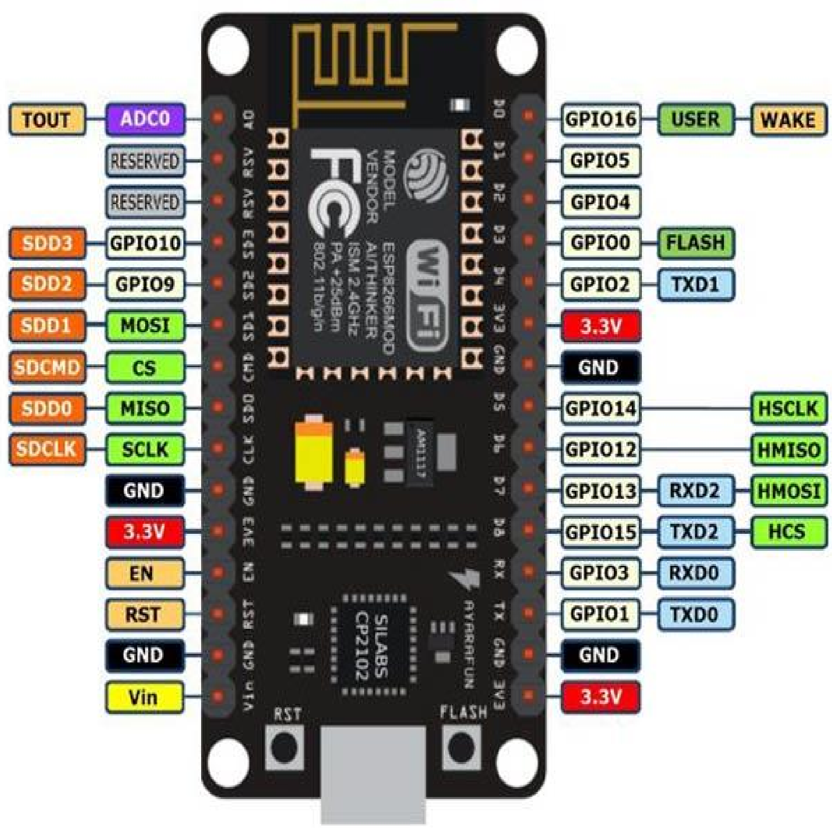


Figure 9 ESP8266 GPIO (A-hussein & Salman, 2020)

- **ESP32 Dev**

  ESP32 & ESP8266 are both low-cost microchips with integrated Wi-Fi module TCP/IP capability but ESP32 has higher specs than ESP8266 with slightly higher price

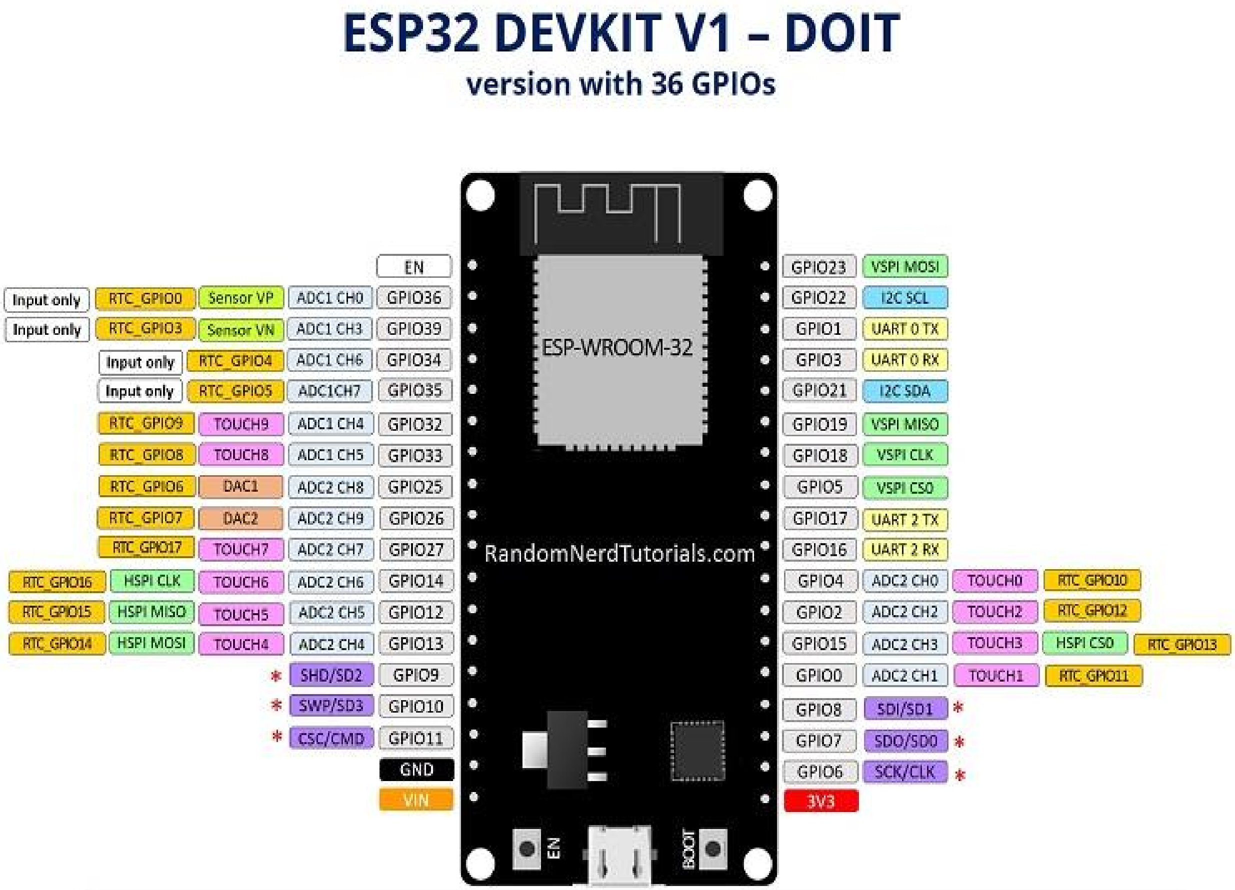


Figure 10 [13]

- **Raspberry Pi**

  Small single-board computers will me the brain and communication point, the used model in the project is 3B 2016.
  “Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
  1GB RAM
  BCM43438 wireless LAN and Bluetooth
  100 Base Ethernet
  40-pin extended GPIO
  4 USB 2 ports, HDMI, Micro SD port for
  ” [14]

Figure 11 Raspberry Pi 3B[14]

ESP8266 and ESP32 Comparison

NodeMCU	ESP-8266	ESP32
MCU	Xtensa Single-core 32-bit L106	Xtensa Dual-Core 32-bit LX6 with 600 DMIPS
802.11 b/g/n Wi-Fi	HT20	HT40
Bluetooth	X	Bluetooth 4.2 and BLE
Typical Frequency	80 MHz	160 MHz
SRAM	X	✓
Flash	X	✓
GPIO	17	36
Hardware /Software PWM	None / 8 channels	None / 16 channels
SPI/I2C/I2S/UART Serial com	2/1/2/2	4/2/2/2
ADC	10-bit	12-bit
CAN Bus	X	✓
Ethernet MAC Interface	X	✓
Touch Sensor	X	✓
Temperature Sensor	X	✓
Hall effect sensor	X	✓
Working Temperature	-40°C to 125°C	-40°C to 125°C
Price	$ (3$ - $6)	$$ ($6 - $12)
Hall effect sensor	X	✓

Table 2 ESP8266 and ESP32 Comparison [15]

The main difference (For the project) is the ADC GPIO Analog to digital converter pins, ESP8266 has only 1 ADC, And ESP32 has 12 ADC, the reading from ZPT and SCT sensors are Analog so we need 2 pins at least

IMPLEMENTATION

Wiring diagrams, set up, libraries and used codes.

OVERALL DIAGRAMS

An IoT architecture consisting of 4 separated open-source systems that can be increased and added according to the need or desire of the user.

The first system is an ESP8266 device connected to DHT22 & LDR sensors to monitor and collect information on temperature, humidity, and illumination intensity in a specific area, then send the data to the main system (Raspberry Pi).

The second system is to monitor the vibration, motion, tilt, and temperature by using the MPU6050 Module and ESP8266 microcontroller then install it in Fan Coil (HVAC) devices to monitor and study the situation and send the data to the raspberry pi.

The third system is using ZPT and SCT sensors and connect them to the ESP32 microcontroller to measure the voltage and current passing through the wire and calculate the instantaneous and total energy consumed.

The fourth system is the brain of the project (Raspberry Pi) that works as a server, router, middle communicator, monitor, and database to link all systems through Wi-Fi and log the acquired data received from the sensors to a database to be used in analysis and studies for BIM. also, to display the results in a web-interface page for follow-up and monitor data second by second. This integrated architecture is made up of many different electrical parts and microcontrollers as well as several protocols and communications methods. The overall scheme of the framework is presented in Figures 12, the Figures 13 and 14 demonstrate the computer electronic components, the flow chart, as well as the communication media, and shows how the system is installed.

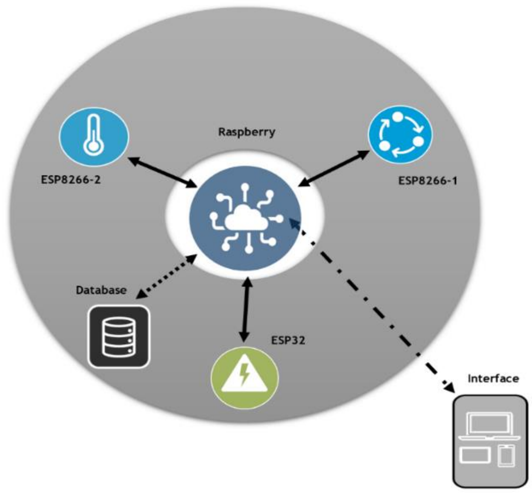


Figure 12 – Final network

In Figure 12 the flowchart explain how the raspberry connects to the other systems and entirely with server applications, the moment the raspberry pi start firstly it will open DNSmasq and start acting as a router immediately to make a communication bridge between internal and external component, DNSmasq must be set to give the same IP every time because without the knowing IP the internal apps can detect the IP but not the external component the publisher will not find the address of the subscriber, However. When DNSmasq start will give SSID and Password with an IP address to get through the network.

MQTT, MySQL and Node-Red will use this credential to run in the background to connect to the network and get the IP address from DSNmasq, MQTT protocol will open the port 1883 in the server to receive all the subscribed topics data from the publishers through TCP protocol and give the publishing devices an access to the port.

Consistently the Node-Red starts and use the same IP address to open another port which is 1880 to manage and monitor the data flow to the server and also send it BIM by using forge node, From here All the collected data from MQTT will go into two directions, The first direction will be the Dashboard where the received data and the status of MQTT, and MySQL can be monitored and viewed through any device connected to the same network by opening the IP address followed by the port number (example: http://192.168.4.1:1880), The other direction is taking the same data to MySQL.

MySQL must be set-up already and all the database and tables are ready, MySQL starts immediately after getting the IP address and open the port number 3306 but stays stand-by waiting for Node-Red to send the data to collect it and put in the queries linked to the tables. To see and export the data from the database use PhpMyAdmin and this data later will be analysis to be used in the prevented maintenance.

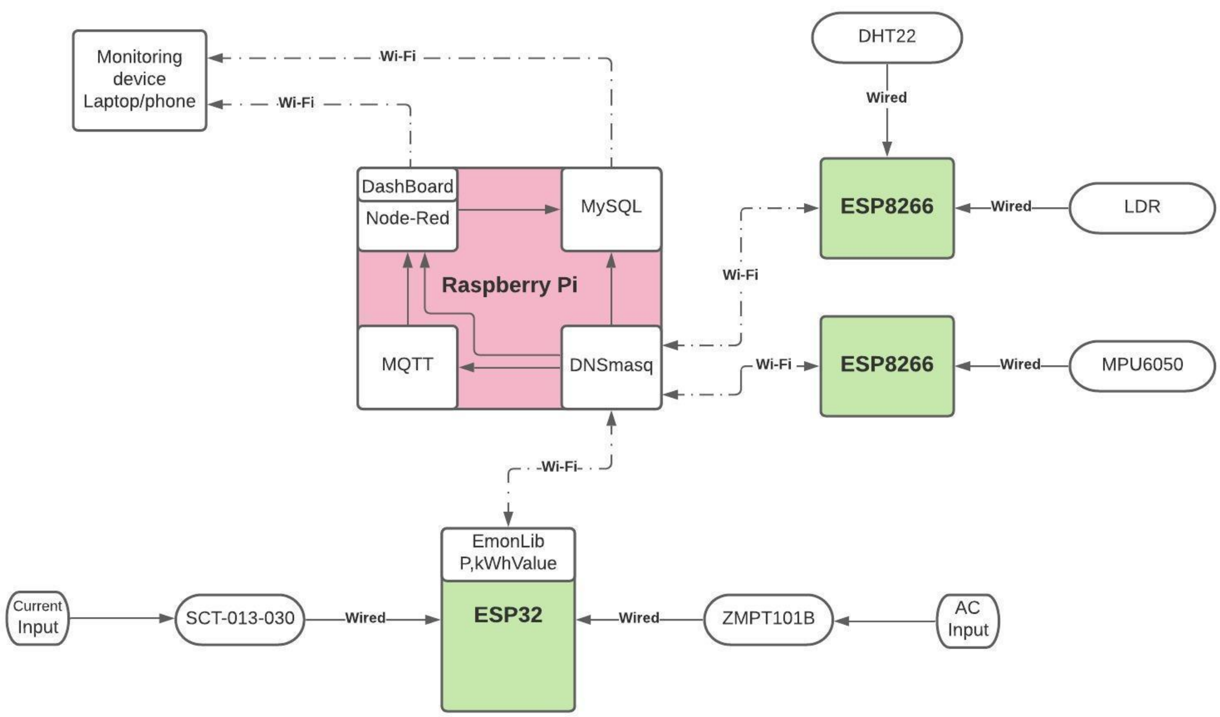


Figure 13 Over all Block diagram

ESP8266 the first one will be connected to DHT22 sensor and photoresistor LDR through wires or directly welded to the microcontroller to measure and humidity, Temperature and luminosity then publish the data through in a topic through MQTT.

The second ESP8266 will be connected to the MPU6050 Module by I2C protocol (Wired also) to get the accelerometer, gyroscope and temperature readings and send it to MQTT.

ESP32 is bit different microcontroller but still the connections to the ZMPT and SCT will be same through wires, SCT has a clipper, and the line wire will get through the clipper, ZMPT will be connected directly to power supply.

All the ESPs has an integrated Wi-Fi module and using the same Firmware (NodeMCU), so the connection details and the IP address from the DSNmasq must be uploaded with the code before starting them up.

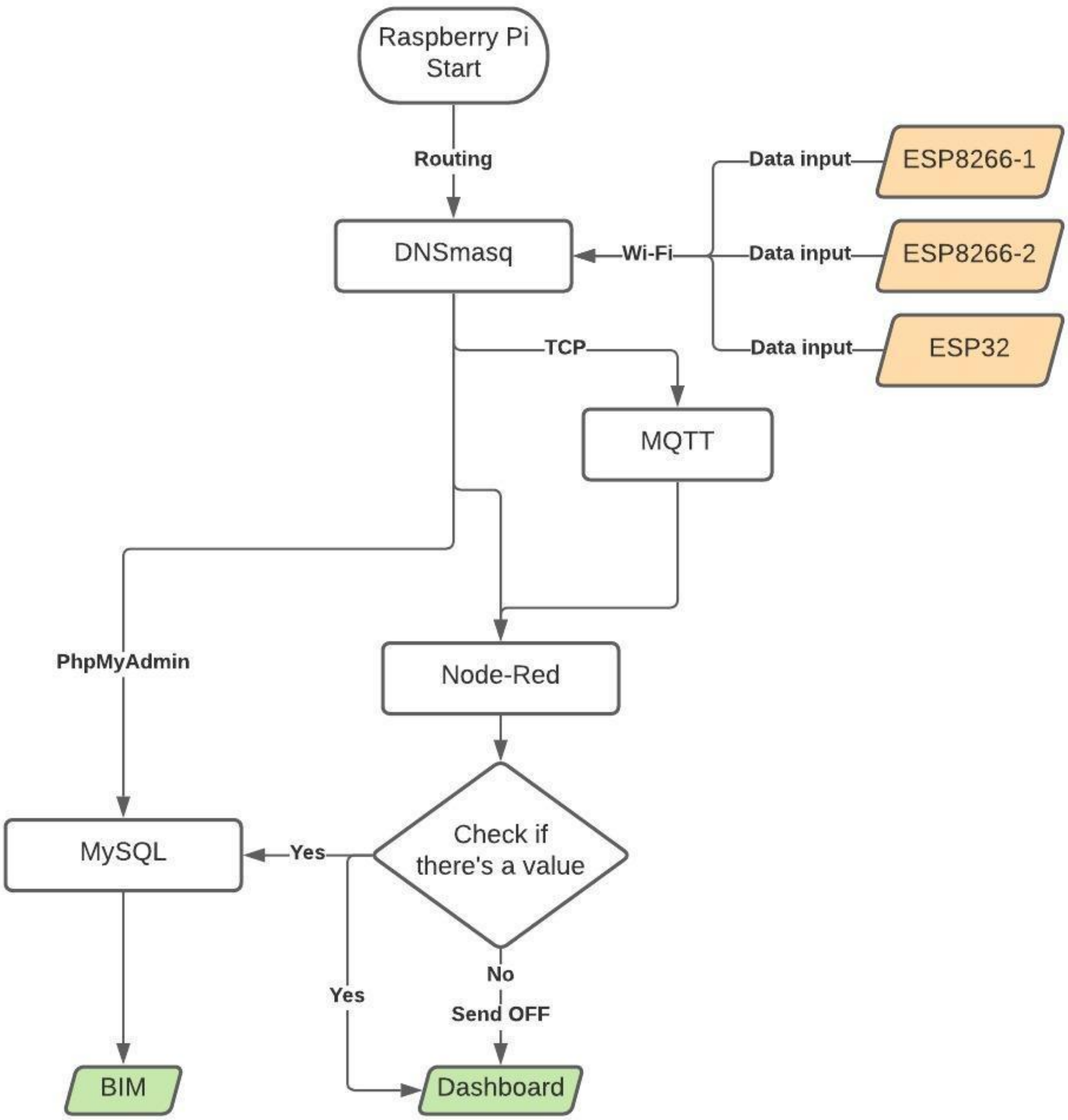
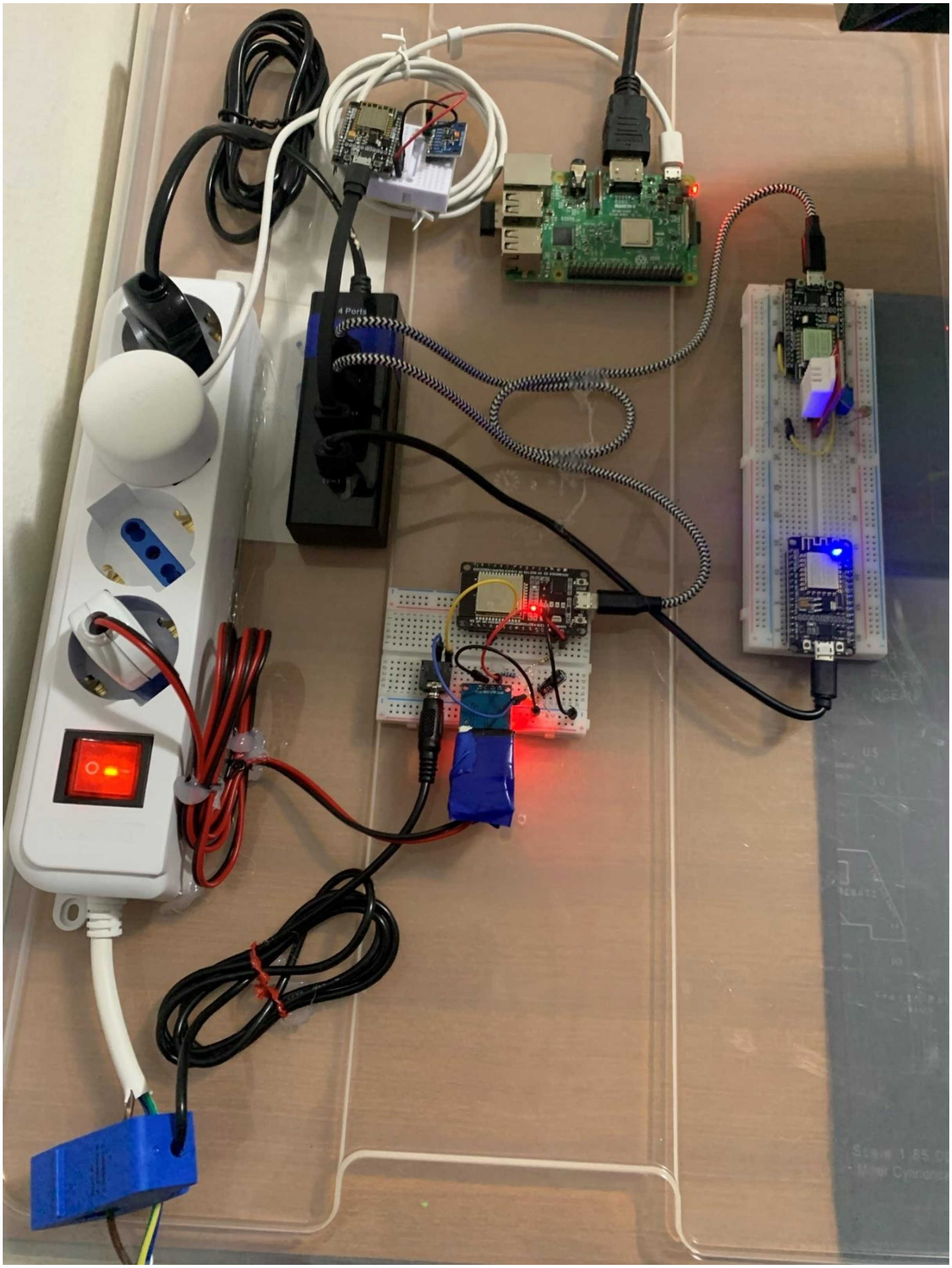


Figure 14 Overall flowchart



SETTING UP RASPBERRY PI

MQTT:

Installing MQTT protocol from the terminal by typing the following commands after updating the libraries to keep it up to date

```
sudo apt-get update
```

```
sudo apt-get install build-essential python-dev python-openssl
```

```
sudo apt install -y mosquitto mosquitto-clients
```

```
pip install paho-mqtt
```

To make MQTT runs automatically when you reboot the system type the following command

```
sudo systemctl enable mosquitto.service
```

MQTT Now is ready and installed into the raspberry pi

Node-RED:

Node-red sometimes come pre-installed or even installed depending on the operation system installed on the raspberry pi you are using, it's better to remove and reinstall it along with the node.js to the latest version or at least v12.4, To install it you just have to type the following script in the command and it'll handle everything.

```
nano bash <(curl -sL https://raw.githubusercontent.com/node-red/raspbian-deb-
package/master/resources/update-nodejs-and-nodered).py
```

To make Node-red runs automatically when you reboot the system type the following command

```
sudo systemctl enable nodered.service
```

Routing:

There are two ways to communicate between Raspberry pi and Node-Red wirelessly (TCP/IP) or wired (GOIP) and since we are going wirelessly, we must have a local network that supports assigning devices with static IP’s, because MQTT required the node-red to know the receiver (Raspberry pi) IP address. To solve this problem and make it efficient we made the raspberry pi itself acts like a router with fixed IP and network extender (DNS-like) So it becomes like a middle or translator keeping its own IP address while connecting to external network with difference IP.

Firstly, we need to install hostapd (Software to enable the network interface card to act as an access point)

```
sudo apt install hostapd
```

```
sudo systemctl unmask hostapd
```

```
sudo systemctl enable hostapd
```

Since the raspberry pi will act as an access point, we need to setup a domain name (IP) with dynamic system cashing, To do so we need to use DNSmask

```
sudo apt install dnsmasq
```

```
sudo DEBIAN_FRONTEND=noninteractive apt install -y netfilter-persistent iptables-persistent
```

Then open dhcpcd configuration by using nano and set the domain you want (IP)

```
sudo nano /etc/dhcpcd.conf
```

And copy the following lines into the nano editor. The IP in this case is 192.168.4.1

```
interface wlan0
  static ip_address=192.168.4.1/24
  nohook wpa_supplicant
```

MySQL:

When everything is set-up you need some way to collect and save the data you've got into a database, Unfortunately the hosting service are not for free and the prices depends on space and the period of time you will use the database for, so instead we will use a local database (MYSQL) , interpreter (PHP) web server (Apache).

To install them we use the following command

```
sudo apt install apache2
```

```
sudo apt install php php-mbstring
```

```
sudo apt install sudo apt install mariadb-server php-mysql
```

```
sudo apt install phpmyadmin
```

We need to setup a username and password for the database

```
sudo mysql --user=root
```

```
DROP USER 'root'@'localhost';
CREATE USER 'root'@'localhost' IDENTIFIED BY 'password';
GRANT ALL PRIVILEGES ON *.* TO 'root'@'localhost' WITH GRANT OPTION;
```

ESP8266 – 1

First, we must include all the libraries used in the code, In the first ESP8266 the libraries used were

First, the device identifies all the installed libraries and the defined variables, then it executes the uploaded code in the order where the code has written. In this case, ESP8266 will try to connect to the wireless network with credentials in the code, if there is a mistake in it or the network is unavailable the device will try to connect again after five seconds until the connection is successful and print "The connection is established" on the serial monitor.

After connecting to the Wi-Fi, MQTT will try to connect to the server in the network, if there is any error will send the error message to the serial monitor and try again until the connection is completed. After that, ESP8266 will start to collect the data from the installed sensor through the defined pins and take the readings from it and send all the inputs to the MQTT broker and the serial monitor after succus the device will repeat the reading and published process again every second.

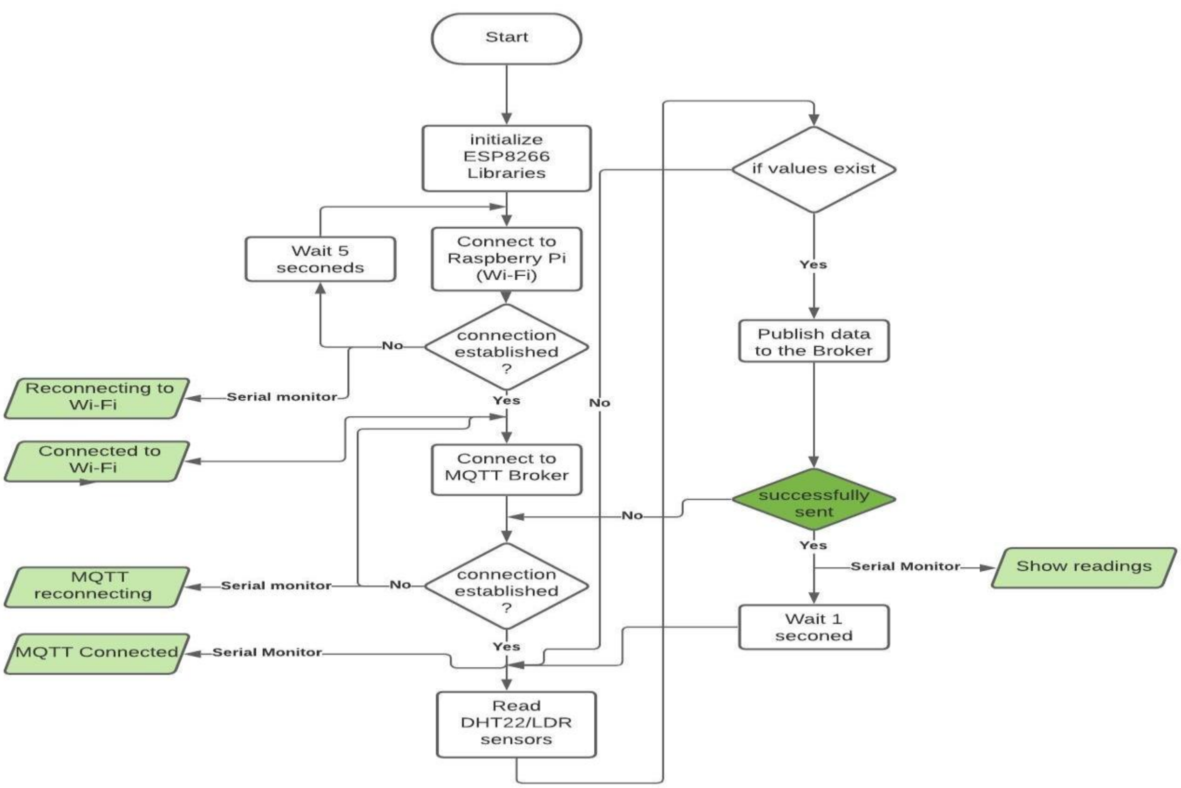


Figure 15 ESP8266-1 Flow chart

Code Explanation:

The full codes are available in the appendix.

- **Wire.h** is the library that allows us to use I2C protocol
- **Esp8266wifi** is to define ESP8266 to the Arduino IDE and let us use its environment
- **WifiClient** Creates a client that can communicate to a given IP address and port on the network [16]
- **Pubsubclient** This library allows us to send and receive data from and to ESP through MQTT.

```
#include <Wire.h>
#include <ESP8266WiFi.h>
#include <WiFiClient.h>
#include <PubSubClient.h>
```

The Wi-Fi credentials that we have made with DNSmasq, every time the credentials have been changed in raspberry pi it has to be updated here as well.

```
// Wi-Fi credentials
const char* ssid = "Waleedrasp";
const char* pass = "1234567890";
const char* mqtt_server = "192.168.4.1";
```

```
readSensor();
static char axi[7];
dtostrf(ax, 6, 2, axi);
static char gxi[7];
dtostrf(gx, 6, 2, gxi);
static char tempC[7];
dtostrf(tempCelsius, 6, 2, tempC);
```

The MPU6050 send 7 reading at every time, three reading for the accelerometer and three for the gyroscope each has three axis X,Y and Z and the seventh reading is the temperate around the sensor, the code here is partial for explanation and it is taking one float reading from each, A-X, G-X, and temperature

After connecting to the network and MQTT, then reading and collect the now the ESP8266 will publish this data to all the subscribers for the three topics (“pu6050/ax”, “pu6050/gx”, “pu6050/temp”).

```
// Publish sensor data
  client.publish("mpu6500/temp", temp);
  client.publish("mpu6500/ax", axi);
  client.publish("mpu6500/gx", gxi);
```

Diagram:

Connecting MPU6050 to ESP8266 is direct connection. Yes, we have 7 readings but since it is based on I2C the data gets on 2 wires only and power.

SCL => D1

SDA => D2

GND => GND

VCC => 3V3

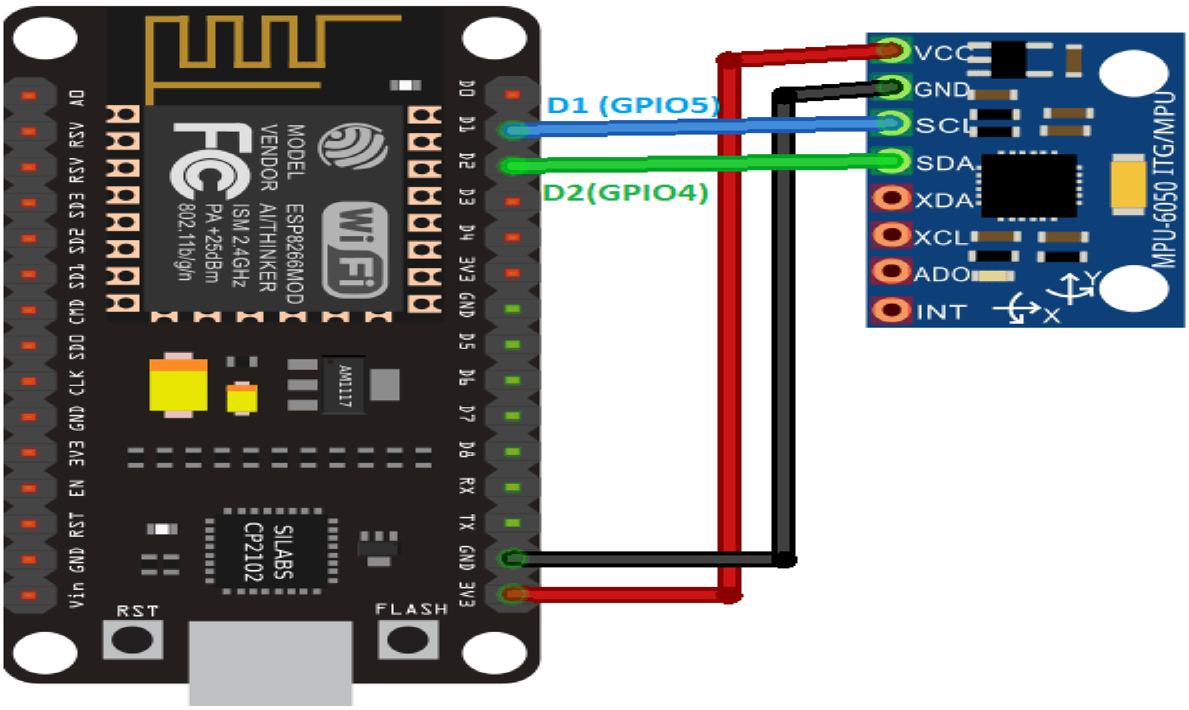
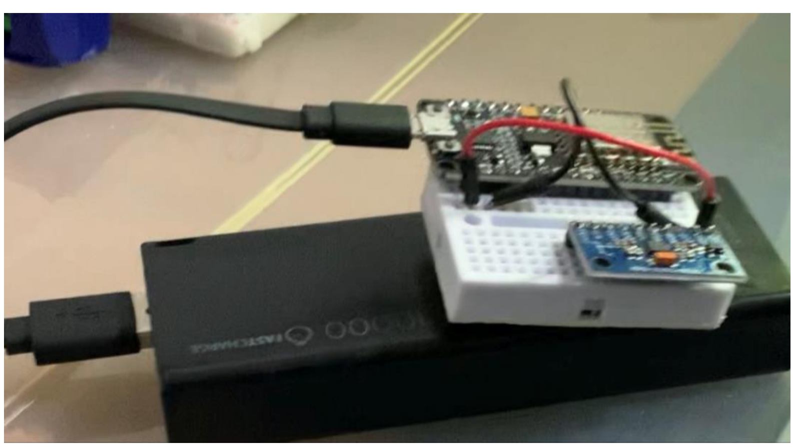


Figure 16 [17]



ESP8266 – 2

Both ESP8266 are using the same sequence and flowchart connecting to Wi-fi -> MQTT and then collect and publish the data and repeat. The code is almost the same but measure the illumination intensity needs an ADC and D pins.

Code Explanation:

The full codes are available in the appendix.

- **DHT.h** is the library to define DHT22 sensors to read the humidity and temp.
- **OneWire.h** give an access to 1-wire sensors
- **DallasTemperature** to give the reading from the temperature IC inside the DHT22 "DS18B20"

```
#include "DHT.h"
#include <ESP8266WiFi.h>
#include <PubSubClient.h>
#include <OneWire.h>
#include <DallasTemperature.h>
```

```
{
 previousMillis = currentMillis;
   hum = dht.readHumidity();
   temp = dht.readTemperature();
   uint16_t packetIdPub1 =
mqttClient.publish(MQTT_PUB_TEMP, 1, true,
String(temp).c_str());
   Serial.printf("Publishing on topic %s at QoS 1, packetId:
%i ", MQTT_PUB_TEMP, packetIdPub1);
   Serial.printf("Message: %.2f \n", temp);
   uint16_t packetIdPub2 =
mqttClient.publish(MQTT_PUB_HUM, 1, true,
String(hum).c_str());
   Serial.printf("Publishing on topic %s at QoS 1, packetId
%i: ", MQTT_PUB_HUM, packetIdPub2);
   Serial.printf("Message: %.2f \n", hum);
 }
```

This part of code gets and save the last time reading and get new DHT sensor readings, then covert the temperature readings from Celsius (Default) to Fahrenheit and publish an MQTT message on those topics:

"MQTT_PUB_TEMP, MQTT_PUB_HUM"

The same procedure for LDR sensor but without any converting.

(Sara Santos DHT22, 2020)

Diagram:

In the Figure 17, They used Arduino UNO instead of ESP8266, Of course it is more powerful than the esp8266, but we do not need all of this power also it doesn't have an integrated Wi-Fi so since NodeMCU and Arduino UNO has the same programming language C++, We used the wiring and changed the code and micro controller. The resistances are both 10k, In the ESP8266 the LDR sensor is connected the ADC pin A0, And DHT22 to pin D5

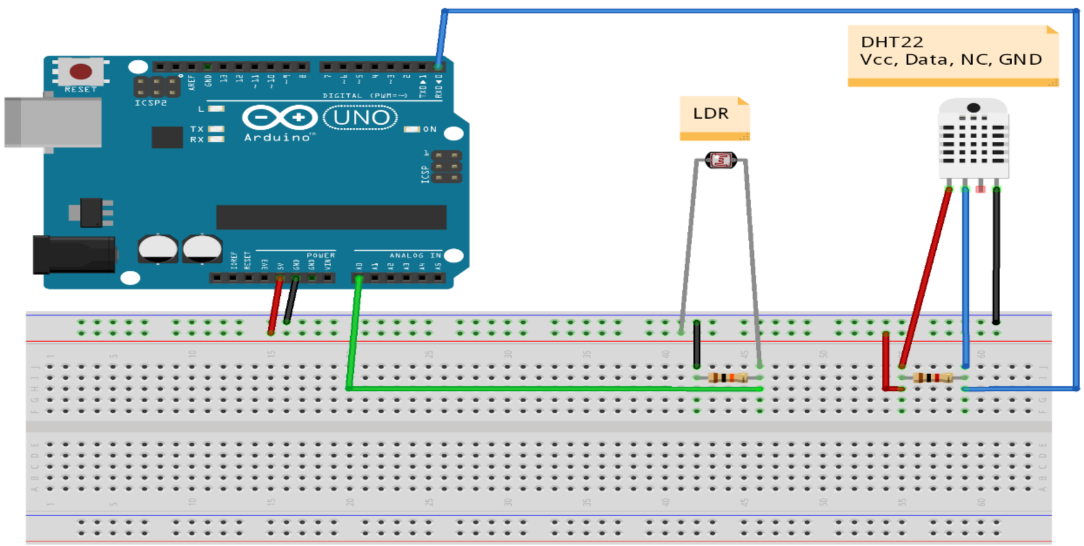
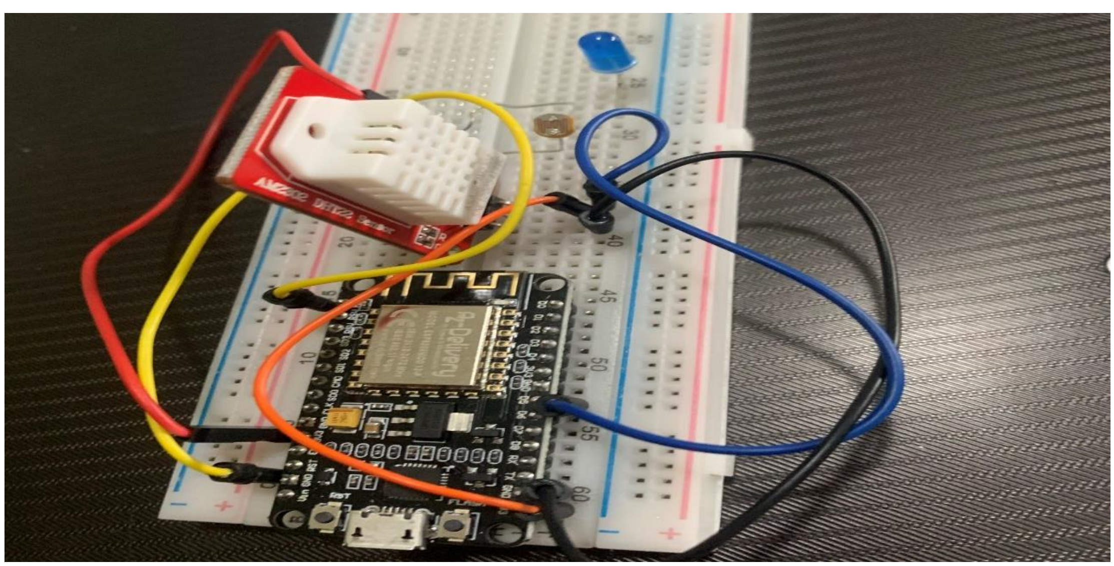


Figure 17 [19]



ESP32 – ENERGY

The connection to Wi-Fi and MQTT it is pretty the same of the ESP8266, the code is little bit different since it's a different device, but the flow chart is the same the only one different not all the published data came out of a sensor, Here EmonLib has been used to calculate the power and kilowatt-hour from the voltage and current sensors and send all of the data to the server then repeat again after a second.

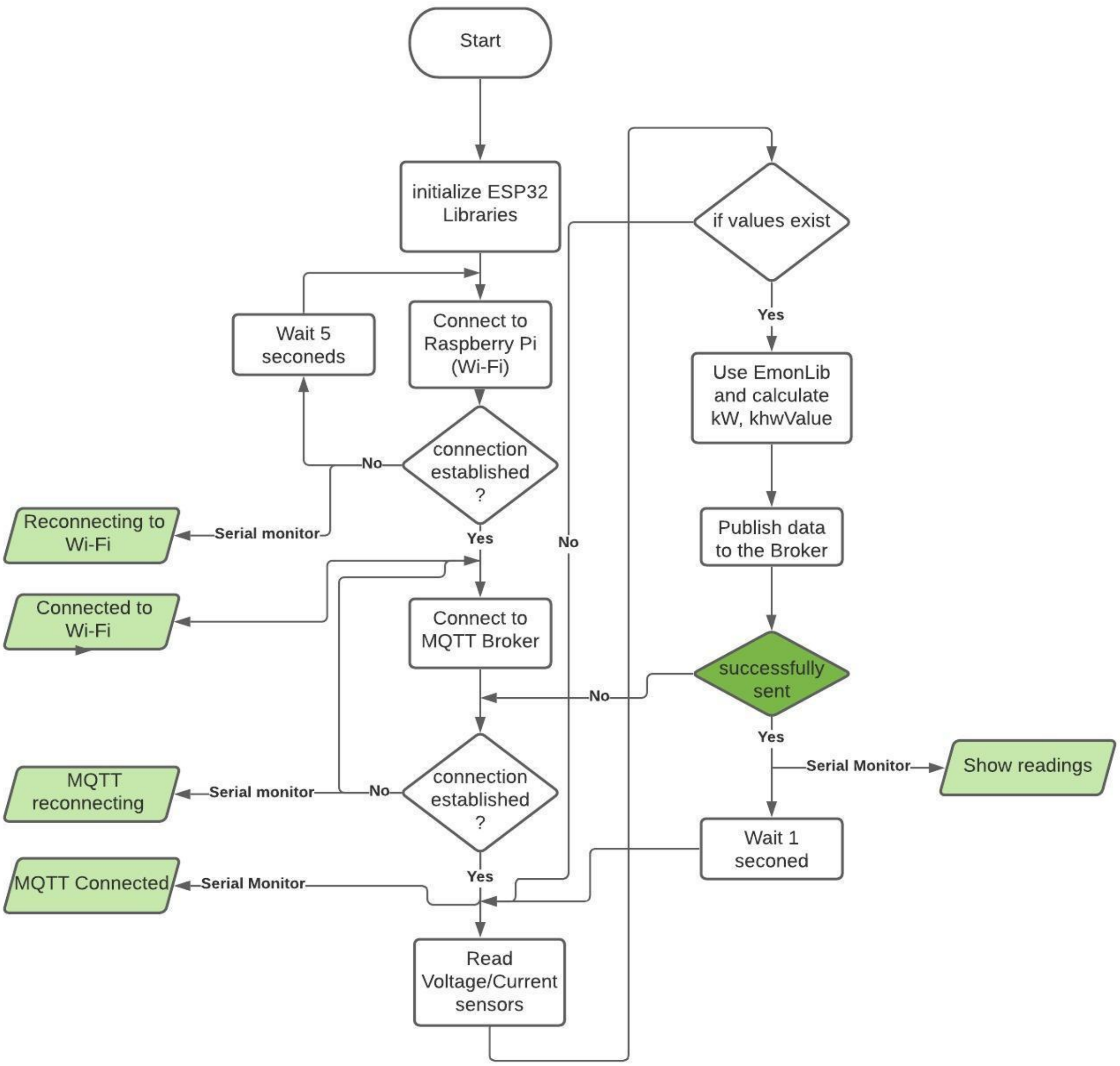


Figure 18 ESP32, Energy flowchart

Code Explanation:

The full codes are available in the appendix.

```
#include "EmonLib.h"
#include <WiFi.h>
#include <WiFiClient.h>
#include <PubSubClient.h>
```

- **EmonLib** is in charge of extracting data from both sensors, as well as measuring kWh and power values.
- **WiFi.h** is to define ESP32 to the Arduino IDE and let us use its environment

```
EnergyMonitor emon;
#define vCalibration 145.7
#define currCalibration 0.52
```

After that, the EnergyMonitor emon is formed, and the calibration values are set. These values must be determined by trial - and - error, and they will vary from any one to other, so they will be different for all.

```
void sensorData() {
 emon.calcVI(20, 500);
 Serial.print("Vrms: ");
 Serial.print(emon.Vrms, 2);
 Serial.print("V");
 Vrms = emon.Vrms;
 Serial.print("\tIrms: ");
 Serial.print(emon.Irms, 4);
 Serial.print("A");
 Irms = emon.Irms;
 Serial.print("\tPower: ");
 Serial.print(emon.apparentPower, 4);
 Serial.print("W");
 apparentPower = emon.apparentPower;
 Serial.print("\tkWh: ");
 kWh = kWh + emon.apparentPower *
(millis() - lastmillis) / 3600000000.0;
 Serial.print(kWh, 4);
 Serial.println("kWh");
 lastmillis = millis();
 Serial.println(analogRead(35));
```

This part of the code is where the data from the sensors are obtained and sent to the serial monitor. The remine data has been calculated as well by using emon.calc and printed after collected data. The kWh =

$$\frac{power*time}{3600*10^6} \text{ [20]}$$

Diagram:

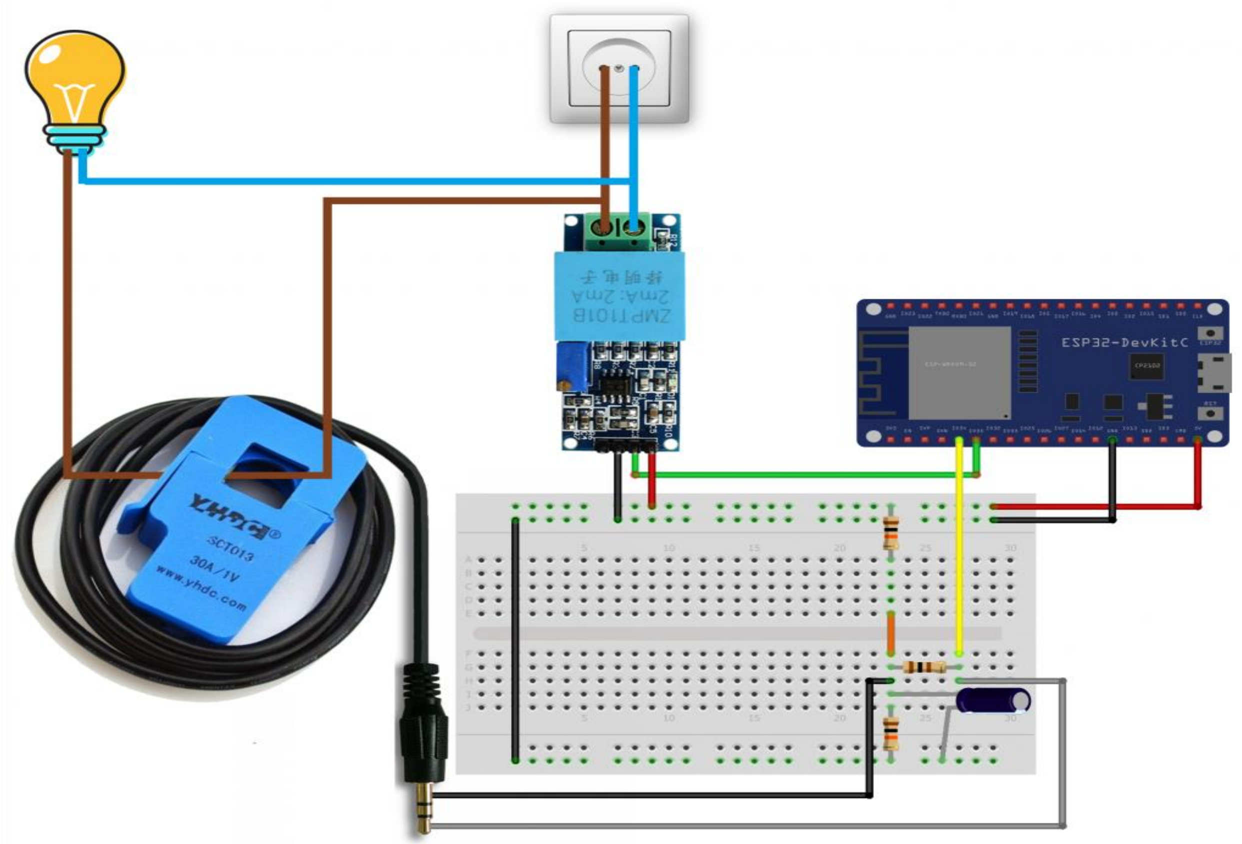
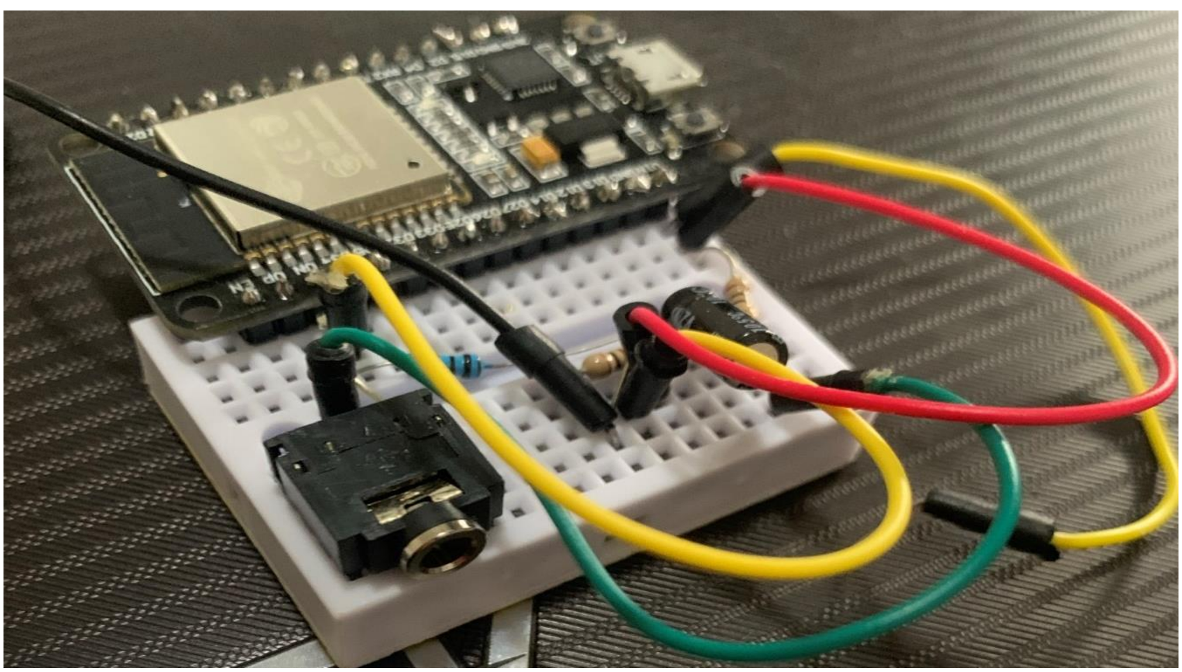


Figure 195 [20]



CHAPTER 4 - TOOLS UTILIZED

NODE-RED

Node-Red is an essential tool in the project, it is using nodes and flows to visual connections and low-code programing. Beside the existing nodes you need to install MySQL, Dashboard and MQTT. All the used flows (Energy, MPU and Home) The 3 systems are in the appendix just import it to Node-RED

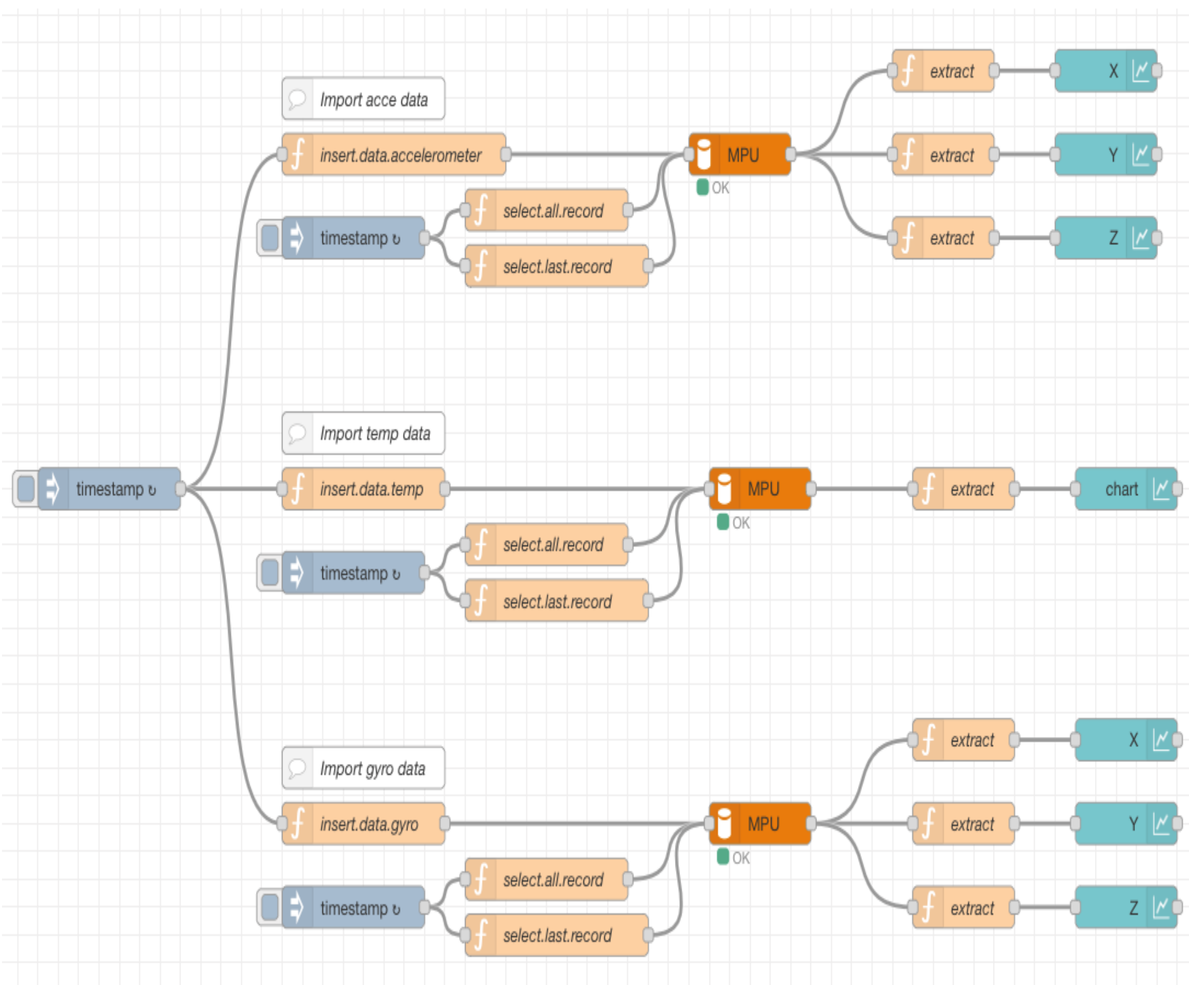


Figure 20 part of the flow chart to log the data in MySQL and show in the dashboard

NODEMCU FIRMWARE AND ARDUINO IDE

NodeMcu is an open-source firmware Lua based (Arduino-like) and it is flashable on both of ESP32 & ESP8266.

If you have ESP DEV probably it will be pre-loaded with the firmware but in case you have the chip or you need to reflash it for any reason, download Flash Download Tool from the official website and the latest NodeMCU firmware.

Once you run flash download tool you will see many microcontrollers options and choose the one you need (ESP32 or ESP8266) then locate the firmware files and select them one by one like in Figure 21, press START and wait for it.

NOTE: You must write the files name manually after the @.

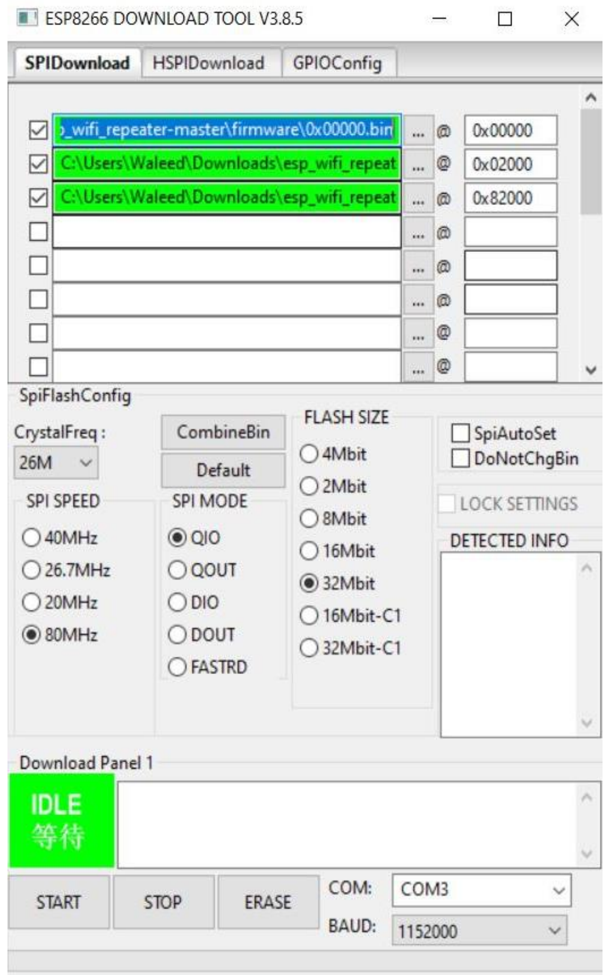


Figure 21 Download tool

To use NodeMCU firmware, write and upload codes, we should use Arduino IDE environment, it is free to use and can be downloaded from the official website but after installing Arduino IDE we need to add ESP32 and ESP8266 to board manger, to do so go to File -> Preferences and in Additional board manger URL insert the following link

https://dl.espressif.com/dl/package_esp32_index.json,
http://arduino.esp8266.com/stable/package_esp8266com_index.json

Then go to Tools -> Board Manger and install ESP8266 and ESP32, NOTE: You must choose manually which board you are using right now pr which board you are writing the code for.

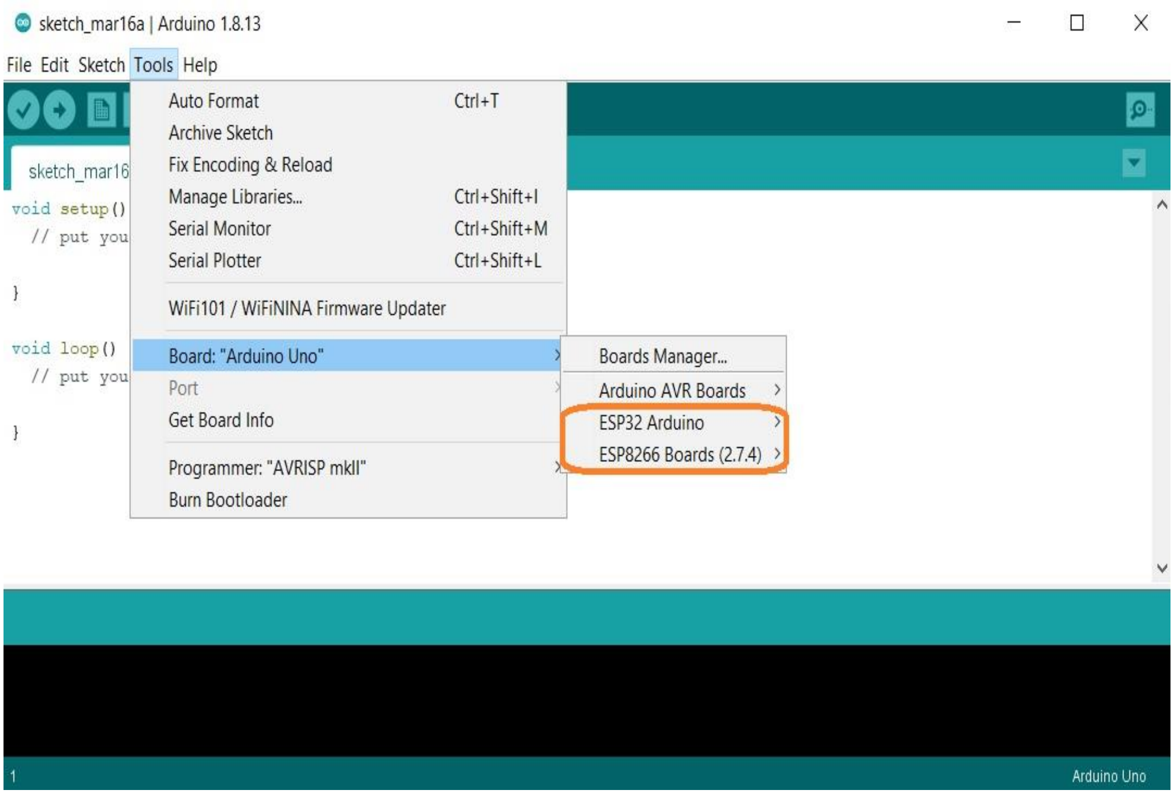


Figure 22 Arduino IDE

MYSQL

The downstream database chosen for IoT systems is important to their ultimate performance. You will need a network that can keep up with the demands of effectively handling vast volumes of data. Most IoT deployments often necessitate high availability and performance. The incorrect database will have a negative influence on the whole system.

MySQL is one of the most used database platforms in the world, with implementations in a wide range of sectors and fields. It offers a few benefits that make it a viable option for IoT deployments. Here are some of the factors that make it appealing: [21]

- Data Security

MySQL is the most stable and dependable database management system available, and it is used in popular web applications like Facebook, and Twitter. The data protection and transactional processing support that come with the latest version of MySQL can be extremely beneficial to any business, particularly if it is an eCommerce business with frequent money transfers.

- High-Efficiency

MySQL has its own storage-engine architecture, which makes things easier for system administrators to set up the MySQL database server for optimal efficiency. MySQL is designed to satisfy even the most challenging applications while maintaining maximum speed, full-text indexes, and special memory caches for increased performance, whether it is an eCommerce platform that generates a million requests per day or a high-speed transactional automated feedback.

- Round-The-Clock Uptime

MySQL promises uptime 24 hours a day, seven days a week, and provides a collection of large features such as advanced service - related and master/slave replication setups.

- Comprehensive Transactional Support

MySQL is at the forefront of the list of reliable transactional database engines on the market. It is the go-to solution for maximum data integrity, with features including total atomic, consistent, segregated, durable transaction support, multi-version transaction support, and unlimited row-level locking. It ensures immediate deadlock detection by enforcing referential consistency on the server.

- Complete Workflow Control

MySQL means usability from day one, with an estimated download and setup time of less than an hour. MySQL is a robust solution with self-management capabilities that simplify everything from space expansion and setup to data architecture and database administration, regardless of whether the operation system is.

- Reduced Total Cost of Ownership

MySQL's consistency and simplicity of management save you hours troubleshooting, which will otherwise be spent addressing downtime and performance issues.

- The Flexibility of Open Source

With My SQL's round-the-clock service and company indemnity, all your fears and concerns about using an open-source solution can be put to rest. MySQL's stable processing and trustworthy applications work together to provide reliable transfers for large-scale ventures. It simplifies servicing, debugging, and updates while also improving the end-user experience.

PHPMYADMIN

phpMyAdmin is a popular and free open-source tool for managing MySQL databases through an internet browser. The user interface is used to perform basic activities like database management, table management, index management and authorization management. phpMyAdmin can also be used to perform any SQL declaration independently.

The below are some of the platform's features:

- MySQL database administration
- Administration of several servers
- Database queries may be done on a global or subset basis.
- Web platform for monitoring MySQL server operation with live charts

CHAPTER 5 – RESULTS

Thanks to Node-Red the study has the algorithms to monitor patterns and events in real time and save big amount of data to be analyzed for the predictive maintenance

MONITROING (DASHBOARD)

The dashboard in this architecture is divided into 4 parts

- **Energy – Home – MPU**

  All the readings from the 3 separate systems have its own separate page, Energy is to show the readings from ESP32 system (Voltage – Current – Power – kWh).

  Home is for ESP8266-2 (Humidity – Temperature – Luminosity). MPU is to show accelerometer axis (X – Y – Z), Gyroscope axis (X – Y – Z), and the temperature.

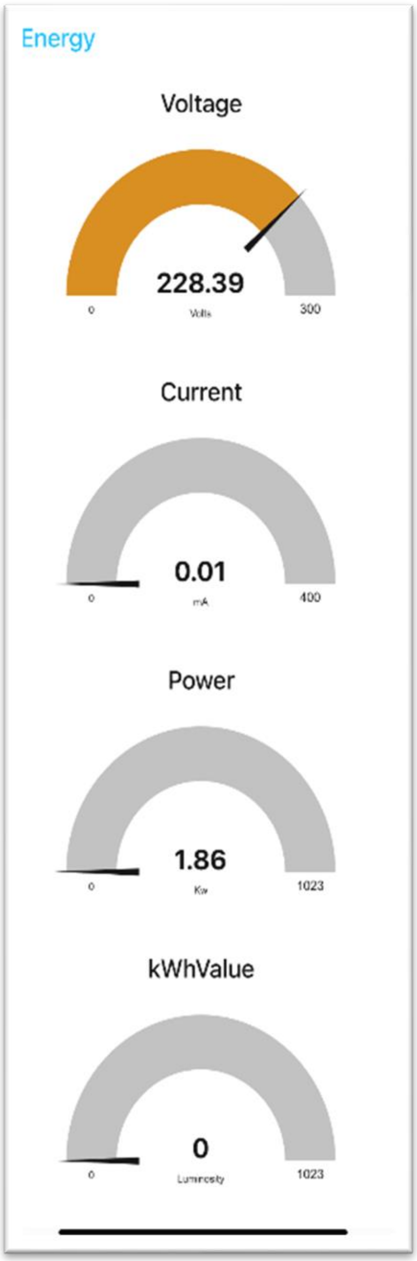


Figure 24 Energy Monitoring

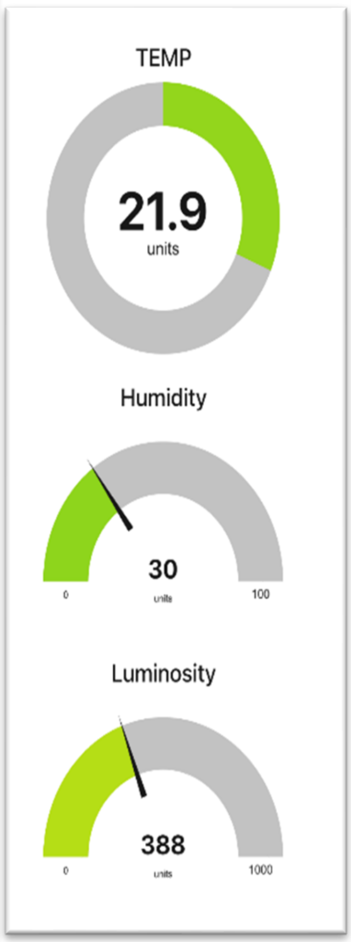


Figure 25 Home Monitoring

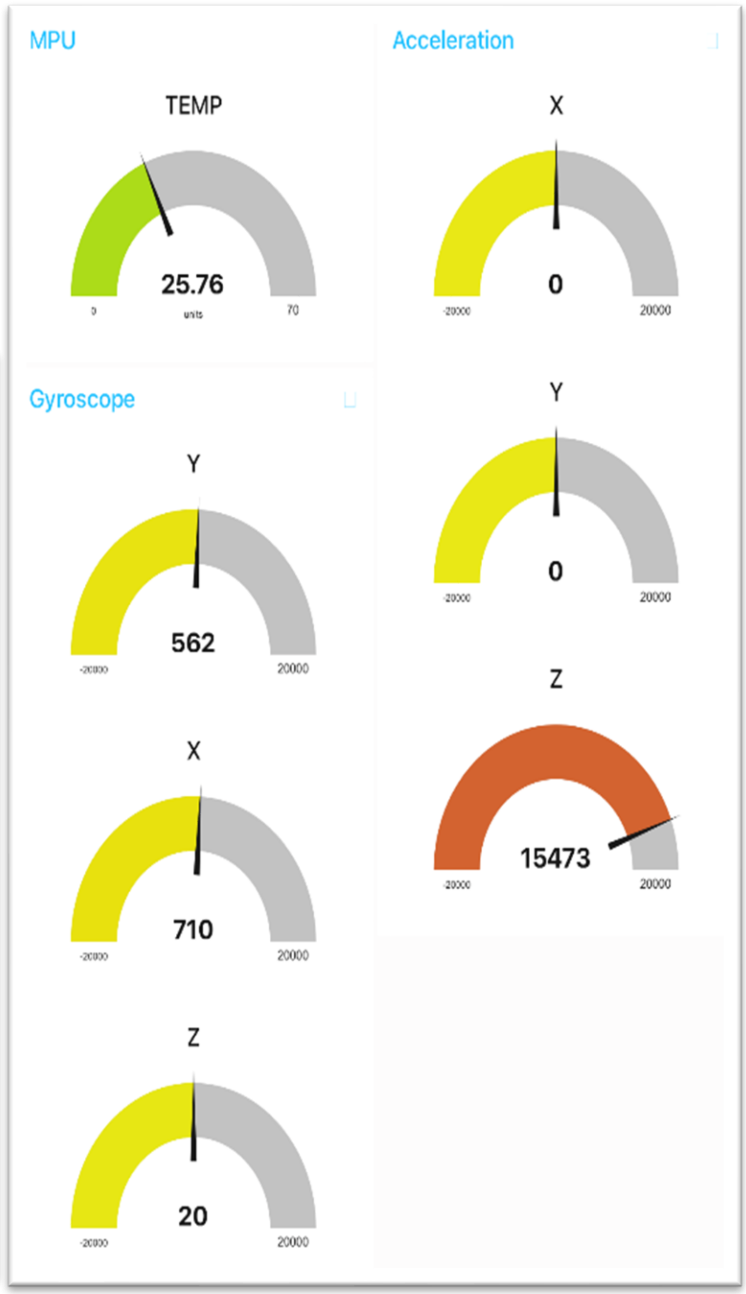


Figure 23 MPU Monitoring

- Database-Back charts

  All the previous data show up live and disappear after 5 seconds it but it all being saved in the database as queries and tables for future work and analysis, so in the dashboard some charts have been made to give a quick peek into what was happened in the last 24hours (can be adjusted) and put all this charts in a different page.

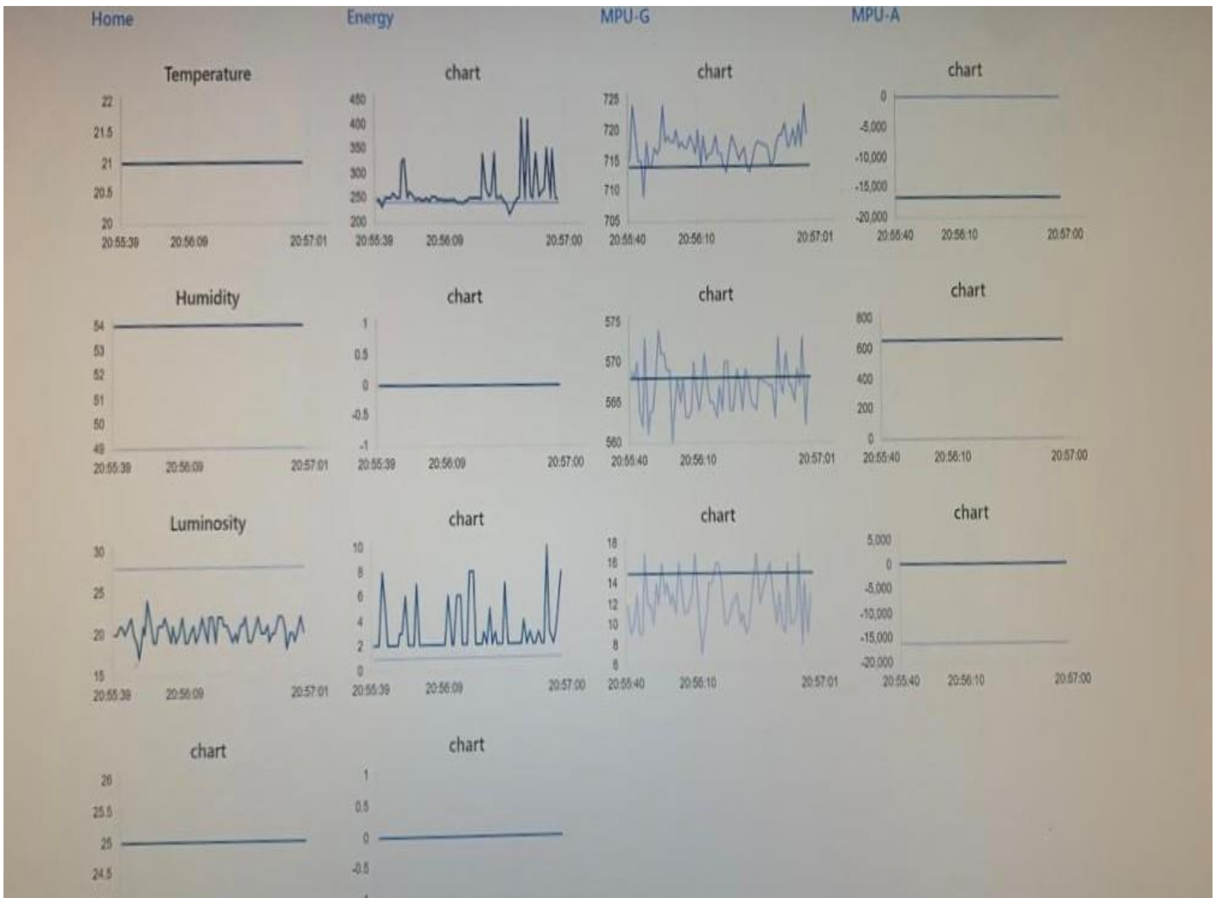


Figure 26 Database-Dashboard

MYSQL

Node-Red displays the acquired data in the dashboard and send it the pre-build tables inside the database, for each value we got a table showing its own readings, the 14 values are

ESP8266 (MPU6050) :

AX = Accelerometer X-Axis

AY = Accelerometer Y-Axis

AZ = Accelerometer Z-Axis

GX = Gyroscope X-Axis

GY= Gyroscope Y-Axis

GZ = Gyroscope Z-Axis

Temp = Temperature

ESP8266 (DHT + LDR) :

- Humidity
- Temperature
- LUX = Luminous

ESP32 :

- Voltage
- Current
- Power
- kWhValue

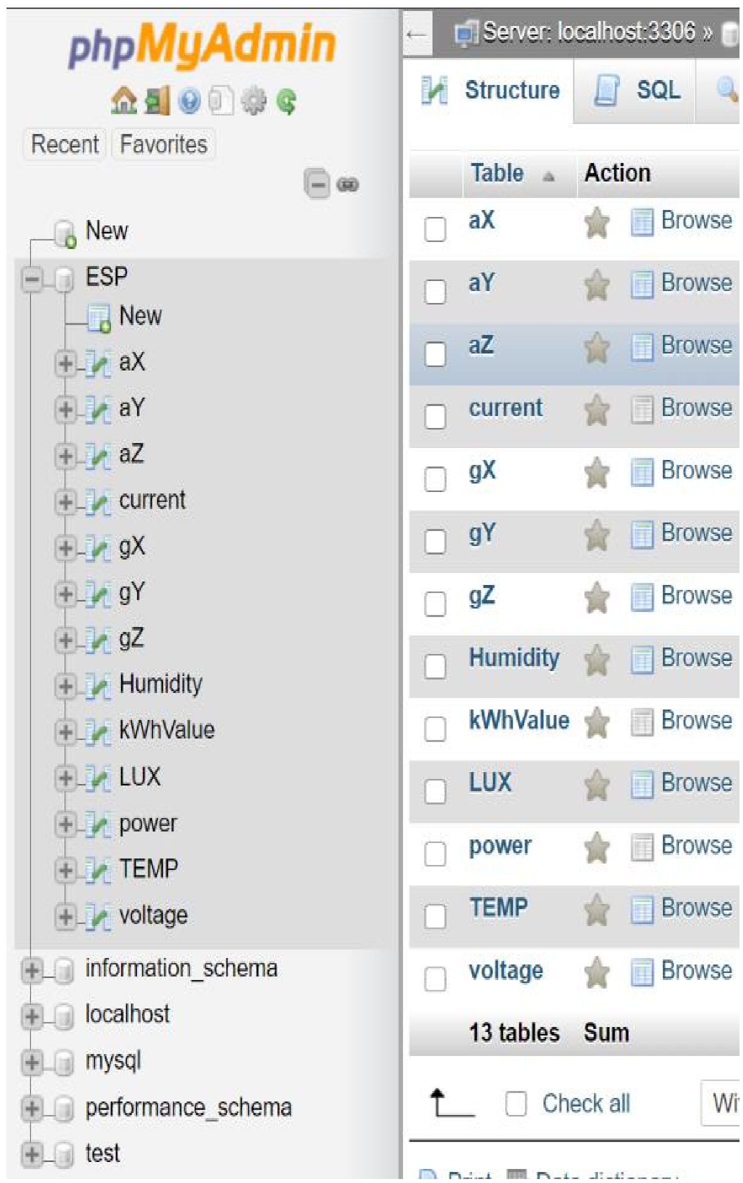
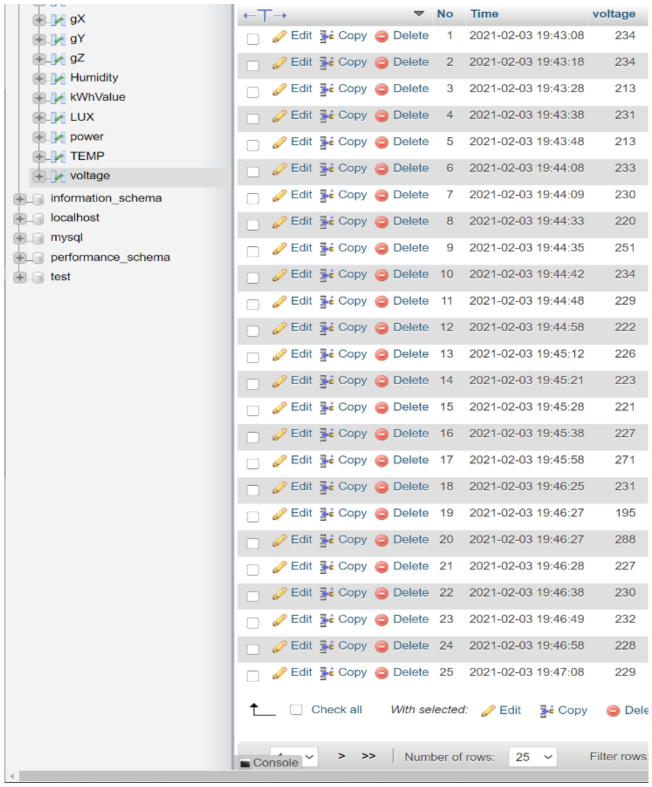


Figure 28 MySQL Results



	No	Time	voltage
Edit Copy Delete	1	2021-02-03 19:43:08	234
Edit Copy Delete	2	2021-02-03 19:43:18	234
Edit Copy Delete	3	2021-02-03 19:43:28	213
Edit Copy Delete	4	2021-02-03 19:43:38	231
Edit Copy Delete	5	2021-02-03 19:43:48	213
Edit Copy Delete	6	2021-02-03 19:44:08	233
Edit Copy Delete	7	2021-02-03 19:44:09	230
Edit Copy Delete	8	2021-02-03 19:44:33	220
Edit Copy Delete	9	2021-02-03 19:44:35	251
Edit Copy Delete	10	2021-02-03 19:44:42	234
Edit Copy Delete	11	2021-02-03 19:44:48	229
Edit Copy Delete	12	2021-02-03 19:44:58	222
Edit Copy Delete	13	2021-02-03 19:45:12	226
Edit Copy Delete	14	2021-02-03 19:45:21	223
Edit Copy Delete	15	2021-02-03 19:45:28	221
Edit Copy Delete	16	2021-02-03 19:45:38	227
Edit Copy Delete	17	2021-02-03 19:45:58	271
Edit Copy Delete	18	2021-02-03 19:46:25	231
Edit Copy Delete	19	2021-02-03 19:46:27	195
Edit Copy Delete	20	2021-02-03 19:46:27	288
Edit Copy Delete	21	2021-02-03 19:46:28	227
Edit Copy Delete	22	2021-02-03 19:46:38	230
Edit Copy Delete	23	2021-02-03 19:46:49	232
Edit Copy Delete	24	2021-02-03 19:46:58	228
Edit Copy Delete	25	2021-02-03 19:47:08	229

Figure 29 Voltage Results

No	Timestamp	Temperature	Humidity	Luminosity	Temp_MPU	A-X	A-Y	A-Z	G-X	G-Y	G-Z	Voltage_1	Voltage_2	Voltage_3	T1	T2	T
1	2021-03-10 09:25:20	20	32	296	24	0	0	12965	714	565	14	18.6	37	55.8	19.35	19.44	19.3
2	2021-03-10 09:25:25	20	32	296	24	0	0	12999	711	535	21	73.9	81	60.5	19.28	19.44	19.3
3	2021-03-10 09:25:30	20	32	297	24	0	0	12948	708	559	16	44.1	3.1	78.8	19.28	19.44	19.3
4	2021-03-10 09:25:35	20	32	297	24	0	0	12939	706	529	7	53.7	62.4	44.7	19.31	19.44	19.3
5	2021-03-10 09:25:40	20	32	296	24	0	0	12878	714	561	21	60	44.7	55.8	19.31	19.44	19.3
6	2021-03-10 09:25:45	20	31	296	24	0	0	12844	707	541	19	63.2	74.7	49.7	19.38	19.44	19.3
7	2021-03-10 09:25:50	20	31	297	24	0	0	12927	714	555	17	39.8	39.5	56.3	19.45	19.44	19.3
8	2021-03-10 09:25:55	20	31	297	24	0	0	12884	711	550	19	58.7	59.6	7.5	19.51	19.44	19.3
9	2021-03-10 09:26:00	20	31	297	24	0	0	13015	710	573	14	63.6	43.6	39.5	19.62	19.44	19.3
10	2021-03-10 09:26:05	20	32	296	24	0	0	13057	711	590	21	28.1	3	43.5	19.65	19.44	19.3
11	2021-03-10 09:26:10	20	32	296	24	0	0	12935	711	539	14	48.3	51.7	64.3	19.65	19.44	19.3
12	2021-03-10 09:26:15	20	31	297	24	0	0	12833	712	547	17	98.4	45	2.2	19.62	19.44	19.3
13	2021-03-10 09:26:20	19	31	297	24	0	0	12873	714	559	15	56	10.9	46.2	19.58	19.44	19.3
14	2021-03-10 09:26:25	19	31	297	24	0	0	12869	710	548	17	26	39.5	43.5	19.51	19.44	19.3
15	2021-03-10 09:26:30	19	31	296	24	0	0	13055	710	576	15	68.5	39.8	23.7	19.48	19.37	19.3
16	2021-03-10 09:26:35	19	31	296	24	0	0	12934	709	564	22	59.6	35	5.3	19.48	19.44	19.3
17	2021-03-10 09:26:40	19	31	297	24	0	0	12875	712	556	17	82.7	63.2	5.3	19.41	19.37	19.3
18	2021-03-10 09:26:45	19	32	297	24	0	0	12870	713	556	17	51.6	92.9	39.6	19.38	19.37	19.3
19	2021-03-10 09:26:50	19	32	296	24	0	0	13034	708	569	14	71.1	65.4	2.5	19.38	19.37	19.3
20	2021-03-10 09:26:55	19	32	295	24	0	0	13024	712	569	22	29.8	16.1	39.5	19.38	19.37	19.3
21	2021-03-10 09:27:01	19	32	296	24	0	0	12878	710	560	18	56.3	48.3	56.8	19.41	19.37	19.3

Figure 30 One Table results

CHAPTER 6 - CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

The thesis' goals were to develop an implementation of the Internet of Things (IoT) architecture and demonstrate how it could support facilities by providing information, ease, and improving maintenance efficiency. A broad variety of topics are explored in connection with the implementation of the architecture like

- The maintenance types and how it affects the lifecycle of a facility and how the protective maintenance could be the optimal option.
- A peek at the industrial revolution and how the industry has evolved from steam engines to small silicon chips communicating with each other.
- The study got deeper into the internet of thing and the implementation of the architecture and explained very well the types of microcontrollers used, all the necessary components and diagrams to build the systems.
- The study also highlighted all the software needed for both monitoring the building instantaneously and logging the data for long-term analyzing.

FUTURE WORK

Since the architecture is open source it gives the convenience for the operator to add, remove and manipulate both the hard system and programming codes.

- Evaporating, Vibration, Gas, Heat, Motion, ultra-sonic and lots of sensors can be just added by connecting its microcontroller to the main Raspberry Pi network. Sensors like CO2 also can be added to measure the air quality.

- One of the problems of using ZMPT101B sensor to measure the voltage was the calibration, most of the sensors need to be calibrated but this one must be done physically and inside the code, to do so it an oscilloscope has to be used to adjust the sign wave, there are lots of alternatives that do not need double calibration, there are more expensive but easier to be used.

- The exported data must be analyzed through BIM so the system is useful for the long-term, in the next chapter there are all the programming codes and the node-red flows, the flows must connect to Forge-node, so the data go to Revit.

CHAPTER 7 - REFERENCE

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CHAPTER 8 – APPENDIX

A full follow up guide will be available and up to date in the following link:

GitHub/waleedbakhit/Implementation-of-an-IoT-architecture

ESP8266 – 1 FULL CODE

```
//To measure and monitor Temperature, humidity and light strength by
using DHT22, LDR sensors //connected to ESP8266
/ Load libraries
#include "DHT.h"
#include <Arduino.h>
#include <ESP8266WiFi.h>
#include <PubSubClient.h>
#include <OneWire.h>
#include <Ticker.h>
#include <AsyncMqttClient.h>
#include <DallasTemperature.h>
// Network credentials
const char* ssid     = "waleedrasp";
const char* password = "1234567890";

// Raspberry Pi IP address
const char* mqtt_server = "192.168.4.1";
#define MQTT_HOST IPAddress(192,168,4,1)
#define MQTT_PORT 1883

//#define DHTTYPE DHT22
#define DHTTYPE DHT22
#define DHTPIN 14

// Temperature MQTT Topics
#define MQTT_PUB_TEMP "esp/dht/temperature"
#define MQTT_PUB_HUM "esp/dht/humidity"

// Initializes the espClient. You should change the espClient name if you
have multiple ESPs running in your home automation system
WiFiClient espClient;
PubSubClient client(espClient);
DHT dht(DHTPIN, DHTTYPE);
// Variable to hold the temperature reading
String temperatureString = "";
```

```
// Variables to hold sensor readings
float temp;
float hum;

AsyncMqttClient mqttClient;
Ticker mqttReconnectTimer;


WiFiEventHandler wifiConnectHandler;
WiFiEventHandler wifiDisconnectHandler;

// Timers - Auxiliary variables
unsigned long now = millis();
unsigned long lastMeasure = 0;
boolean startTimer = false;
unsigned long currentTime = millis();
unsigned long previousTime = 0;

unsigned long previousMillis = 0;   // Stores last time temperature was
published
const long interval = 500;         // Interval at which to publish sensor
readings

// Set GPIOs for: output variable, status LED, PIR Motion Sensor, and LDR
const int ldr = A0;

// Don't change the function below.
// This function connects your ESP8266 to your router
void setup_wifi() {
  delay(10);
  // We start by connecting to a WiFi network
  Serial.println();
  Serial.print("Connecting to ");
  Serial.println(ssid);
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.print("WiFi connected - ESP IP address: ");
  Serial.println(WiFi.localIP());
}

void connectToMqtt() {
  Serial.println("Connecting to MQTT...");
  mqttClient.connect();
}

void onMqttDisconnect(AsyncMqttClientDisconnectReason reason) {
  Serial.println("Disconnected from MQTT.");
```

```
  if (WiFi.isConnected()) {
    mqttReconnectTimer.once(2, connectToMqtt);
  }
}

// This functions is executed when some device publishes a message to a
topic that your ESP8266 is subscribed to
// Change the function below to add logic to your program, so when a
device publishes a message to a topic that
// your ESP8266 is subscribed you can actually do something
void callback(String topic, byte* message, unsigned int length) {
  Serial.print("Message arrived on topic: ");
  Serial.print(topic);
  Serial.print(". Message: ");

  Serial.println();

  // Feel free to add more if statements to control more GPIOs with MQTT
  // If a message is received on the topic esp8266/output, you check if
the message is either on or off.
  // Turns the output according to the message received

  Serial.println();
}

// This functions reconnects your ESP8266 to your MQTT broker
// Change the function below if you want to subscribe to more topics with
your ESP8266
void reconnect() {
  // Loop until we're reconnected
  while (!client.connected()) {
    Serial.print("Attempting MQTT connection...");
    // Create a random client ID
    String clientId = "ESP8266Client-";
    clientId += String(random(0xffff), HEX);
    // Attempt to connect
    if (client.connect(clientId.c_str())) {
      Serial.println("connected");
      // Subscribe or resubscribe to a topic
      // You can subscribe to more topics (to control more outputs)
      client.subscribe("esp8266/output");
    } else {
      Serial.print("failed, rc=");
      Serial.print(client.state());
      Serial.println(" try again in 5 seconds");
      // Wait 5 seconds before retrying
      delay(5000);
    }
  }
}

void onWifiConnect(const WiFiEventStationModeGotIP& event) {
  Serial.println("Connected to Wi-Fi.");
```

```
  connectToMqtt();
}

void onWifiDisconnect(const WiFiEventStationModeDisconnected& event) {
  Serial.println("Disconnected from Wi-Fi.");
  mqttReconnectTimer.detach(); // ensure we don't reconnect to MQTT while
reconnecting to Wi-Fi
}

void onMqttConnect(bool sessionPresent) {
  Serial.println("Connected to MQTT.");
  Serial.print("Session present: ");
  Serial.println(sessionPresent);
}


/*void onMqttSubscribe(uint16_t packetId, uint8_t qos) {
  Serial.println("Subscribe acknowledged.");
  Serial.print("  packetId: ");
  Serial.println(packetId);
  Serial.print("  qos: ");
  Serial.println(qos);
}

void onMqttUnsubscribe(uint16_t packetId) {
  Serial.println("Unsubscribe acknowledged.");
  Serial.print("  packetId: ");
  Serial.println(packetId);
}*/

void onMqttPublish(uint16_t packetId) {
  Serial.print("Publish acknowledged.");
  Serial.print("  packetId: ");
  Serial.println(packetId);
}


void setup() {

  // Serial port for debugging purposes
  Serial.begin(115200);
Serial.println();
dht.begin();


 wifiConnectHandler = WiFi.onStationModeGotIP(onWifiConnect);
  wifiDisconnectHandler =
WiFi.onStationModeDisconnected(onWifiDisconnect);

mqttClient.onConnect(onMqttConnect);
  mqttClient.onDisconnect(onMqttDisconnect);
  //mqttClient.onSubscribe(onMqttSubscribe);
  //mqttClient.onUnsubscribe(onMqttUnsubscribe);
```

```
  mqttClient.onPublish(onMqttPublish);
  mqttClient.setServer(MQTT_HOST, MQTT_PORT);
  // If your broker requires authentication (username and password), set
them below
  //mqttClient.setCredentials("REPlACE_WITH_YOUR_USER",
"REPLACE_WITH_YOUR_PASSWORD");


  setup_wifi();
  client.setServer(mqtt_server, 1883);
  client.setCallback(callback);
}

void loop() {

  unsigned long currentMillis = millis();
  // Every X number of seconds (interval = 10 seconds)
  // it publishes a new MQTT message
  if (currentMillis - previousMillis >= interval) {
    // Save the last time a new reading was published
    previousMillis = currentMillis;
    // New DHT sensor readings
    hum = dht.readHumidity();
    // Read temperature as Celsius (the default)
    temp = dht.readTemperature();
    // Read temperature as Fahrenheit (isFahrenheit = true)
    //temp = dht.readTemperature(true);

    // Publish an MQTT message on topic esp/dht/temperature
    uint16_t packetIdPub1 = mqttClient.publish(MQTT_PUB_TEMP, 1, true,
String(temp).c_str());
    Serial.printf("Publishing on topic %s at QoS 1, packetId: %i ",
MQTT_PUB_TEMP, packetIdPub1);
    Serial.printf("Message: %.2f \n", temp);

    // Publish an MQTT message on topic esp/dht/humidity
    uint16_t packetIdPub2 = mqttClient.publish(MQTT_PUB_HUM, 1, true,
String(hum).c_str());
    Serial.printf("Publishing on topic %s at QoS 1, packetId %i: ",
MQTT_PUB_HUM, packetIdPub2);
    Serial.printf("Message: %.2f \n", hum);
  }

  if (!client.connected()) {
    reconnect();
  }
  client.loop();

// Timer variable with current time
  now = millis();

  // Publishes new readings every 0.5 second
  if (now - lastMeasure > 500) {
```

```
    lastMeasure = now;


    // Publishes LDR values
    client.publish("esp8266/ldr", String(analogRead(ldr)).c_str());
    Serial.println("LDR values published");
  }

  }
```

ESP8266 – 2 FULL CODE

```
/To measure and monitor gyroscope, accelerometer and temperature by using
MPU6050 Module //connected to ESP8266

#include <Wire.h>
#include <ESP8266WiFi.h>
#include <WiFiClient.h>
#include <PubSubClient.h>

#define    MPU6500_ADDRESS             0x68
#define    GYRO_CONFIG                 0x27
#define    ACCEL_CONFIG                0x28
#define    GYRO_FULL_SCALE_250_DPS     0x00
#define    GYRO_FULL_SCALE_500_DPS     0x08
#define    GYRO_FULL_SCALE_1000_DPS    0x10
#define    GYRO_FULL_SCALE_2000_DPS    0x18
#define    ACC_FULL_SCALE_2_G          0x00
#define    ACC_FULL_SCALE_4_G          0x08
#define    ACC_FULL_SCALE_8_G          0x10
#define    ACC_FULL_SCALE_16_G         0x18
#define     WHO_AM_I                   0x75 // Should return 0x71 for
MPU9250 and 0x70 for MPU6500
#define    CONFIG                      0x1A
#define    LOWPASS_10HZ                0x05
#define    LOWPASS_05HZ                0x06

// Change the credentials below
const char* ssid = "FRITZ!Box 7430 KF";
const char* pass = "1234567890";
const char* mqtt_server = "192.168.178.110";

WiFiClient espClient;
PubSubClient client(espClient);

// Publish data in every 0.5 second
unsigned long interval = 500;
unsigned long now = millis();
```

```
unsigned long lastTime = 0;

int16_t ax, ay, az, gx, gy, gz;
float tempCelsius;

// This functions reconnects your ESP8266 to your MQTT broker
void reconnect() {
  // Loop until we're reconnected
  while (!client.connected()) {
    Serial.print("Attempting MQTT connection...");

    if (client.connect("ESP8266Client")) {
      Serial.println("connected");
    } else {
      Serial.print("failed, rc=");
      Serial.print(client.state());
      Serial.println(" try again in 5 seconds");
      // Wait 5 seconds before retrying
      delay(5000);
    }
  }
}

// Initializations
void setup()
{
  Wire.begin();
  Serial.begin(115200);
  delay(10);
  Serial.println(" ");
  // Configure gyroscope range
  I2CwriteByte(MPU6500_ADDRESS, GYRO_CONFIG, GYRO_FULL_SCALE_250_DPS);
  // Configure accelerometers range
  I2CwriteByte(MPU6500_ADDRESS, ACCEL_CONFIG, ACC_FULL_SCALE_2_G);
  // Configure Low-Pass filtering
  I2CwriteByte(MPU6500_ADDRESS, CONFIG, LOWPASS_05HZ);

  Serial.println("For acceleration: 1g = 16384 ");
  // Read the WHO_AM_I register, this is a good test of communication
  Serial.println("MPU9250 or MPU6500 motion sensor...");
  byte c = I2CreadByte(MPU6500_ADDRESS, WHO_AM_I);  // Read WHO_AM_I
register for MPU-9250/MPU-6500
  Serial.print("Identification from WHO_AM_I register: >>");
Serial.print(c, HEX);
  Serial.println("<<. ");
  Serial.println("It should be 0x71 (MPU9250) or 0x70 (MPU6500).");
  delay(1000);

  WiFi.begin(ssid, pass);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
```

```
  Serial.println("");
  Serial.print("WiFi connected - ESP IP address: ");
  Serial.println(WiFi.localIP());
  client.setServer(mqtt_server, 1883);
}

void loop() {
  if (!client.connected()) {
    reconnect();
  }
  if (!client.loop()) {
    client.connect("ESP8266Client");
  }
  now = millis();

  if (now - lastTime > interval) {
    lastTime = now;
    readSensor();

    static char axi[7];
    dtostrf(ax, 6, 2, axi);
    static char ayi[7];
    dtostrf(ay, 6, 2, ayi);
    static char azi[7];
    dtostrf(az, 6, 2, azi);

    static char gxi[7];
    dtostrf(gx, 6, 2, gxi);
    static char gyi[7];
    dtostrf(gy, 6, 2, gyi);
    static char gzi[7];
    dtostrf(gz, 6, 2, gzi);

    static char tempC[7];
    dtostrf(tempCelsius, 6, 2, tempC);

    // Publish sensor data
    client.publish("mpu6500/ax", axi);
    client.publish("mpu6500/ay", ayi);
    client.publish("mpu6500/az", azi);
    client.publish("mpu6500/gx", gxi);
    client.publish("mpu6500/gy", gyi);
    client.publish("mpu6500/gz", gzi);
    client.publish("mpu6500/temp", tempC);
  }
}

void readSensor()
{
  // Read accelerometer and gyroscope
  uint8_t Buf[14];
  int nrLoops = 4;
  int32_t axsum = 0;  int32_t aysum = 0;  int32_t azsum = 0;
```

```
  int32_t gxsum = 0;  int32_t gysum = 0;  int32_t gzsum = 0; int32_t
temsum = 0;
  int16_t tem;
  for (size_t i = 0; i < nrLoops; i++)
  {
    I2Cread(MPU6500_ADDRESS, 0x3B, 14, Buf);

    // Create 16 bits values from 8 bits data
    // Accelerometer
    ax = Buf[0] << 8 | Buf[1];
    ay = Buf[2] << 8 | Buf[3];
    az = Buf[4] << 8 | Buf[5];
    // Gyroscope
    gx = Buf[8] << 8 | Buf[9];
    gy = Buf[10] << 8 | Buf[11];
    gz = Buf[12] << 8 | Buf[13];
    // Temperature
    tem = Buf[6] << 8 | Buf[7];
    axsum += ax; aysum += ay; azsum += az;
    gxsum += gx; gysum += gy; gzsum += gz;
    temsum += tem;
    delay(2);
  }
  ax = axsum / nrLoops; ay = aysum / nrLoops; az = azsum / nrLoops;
  gx = gxsum / nrLoops; gy = gysum / nrLoops; gz = gzsum / nrLoops;
  tem = temsum / nrLoops;
  tempCelsius = 21.0 + tem / 333.87;
  // Display values

  // Accelerometer
  Serial.print("Accelerometer: ax=");
  Serial.print(ax, DEC);
  Serial.print(" ay=");
  Serial.print(ay, DEC);
  Serial.print(" az=");
  Serial.print(az, DEC);
  Serial.print("\n");

  // Gyroscope
  Serial.print("Gyroscope: x=");
  Serial.print(gx, DEC);
  Serial.print(" y=");
  Serial.print(gy, DEC);
  Serial.print(" z=");
  Serial.print(gz, DEC);
  Serial.print("\n");

  // Temperature
  Serial.print("Temp: ");
  Serial.print(tempCelsius);
  Serial.print(" °C \n");

}
```

```
//
########################################################################
############
// ######################## Subroutines
################################################
//
########################################################################
############

// This function read Nbytes bytes from I2C device at address Address.
// Put read bytes starting at register Register in the Data array.
void I2Cread(uint8_t Address, uint8_t Register, uint8_t Nbytes, uint8_t*
Data) {
  Wire.beginTransmission(Address);  // Set register address
  Wire.write(Register);
  Wire.endTransmission();
  Wire.requestFrom(Address, Nbytes);  // Read Nbytes
  uint8_t index = 0;
  while (Wire.available()) Data[index++] = Wire.read();
}

// Write a byte (Data) in device (Address) at register (Register)
void I2CwriteByte(uint8_t Address, uint8_t Register, uint8_t Data) {
  Wire.beginTransmission(Address);  // Set register address
  Wire.write(Register);
  Wire.write(Data);
  Wire.endTransmission();
}

// Read a byte (return value) in device (Address) at register (Register)
uint8_t I2CreadByte(uint8_t Address, uint8_t Register) {
  uint8_t Data;
  Wire.beginTransmission(Address);         // Initialize the Tx buffer
  Wire.write(Register);                  // Put slave register address in
Tx buffer
  Wire.endTransmission();
  Wire.requestFrom(Address, (size_t)1);    // Read one byte from slave
register address
  Data = Wire.read();                      // Fill Rx buffer with result
  return Data;                             // Return data read from slave
register
}
```

ESP32 – FULL CODE

```
//To measure and monitor Voltage, Current, Power and kWhValue by using
ZMPT101B and SCT-013-030 //sensors connected to ESP32


#include "EmonLib.h"
#include <WiFi.h>
#include <WiFiClient.h>
#include <PubSubClient.h>

EnergyMonitor emon;
#define vCalibration 145.7
#define currCalibration 0.52

// Change the credentials below, so your ESP32 connects to your router
const char* ssid = "waleedrasp";
const char* pass = "1234567890";

// Change the variable to your Raspberry Pi IP address, so it connects to
your MQTT broker
const char* mqtt_server = "192.168.4.1";

// Initializes the espClient.
WiFiClient espClient;
PubSubClient client(espClient);

// Variables
float Vrms = 0;
float Irms = 0;
float apparentPower = 0;
float kWh = 0;

// Publish data in every 0.5 seconds
unsigned long interval = 500;
unsigned long lastmillis = millis();
unsigned long now = millis();
unsigned long lastMeasure = 0;

void sensorData() {
  emon.calcVI(20, 500);
  Serial.print("Vrms: ");
  Serial.print(emon.Vrms, 2);
  Serial.print("V");
  Vrms = emon.Vrms;
  Serial.print("\tIrms: ");
  Serial.print(emon.Irms, 4);
  Serial.print("A");
  Irms = emon.Irms;
  Serial.print("\tPower: ");
  Serial.print(emon.apparentPower, 4);
```

```
  Serial.print("W");
  apparentPower = emon.apparentPower;
  Serial.print("\tkWh: ");
  kWh = kWh + emon.apparentPower * (millis() - lastmillis) /
3600000000.0;
  Serial.print(kWh, 4);
  Serial.println("kWh");
  lastmillis = millis();
  Serial.println(analogRead(35));
}


// This functions reconnects your ESP32 to your MQTT broker
void reconnect() {
  // Loop until we're reconnected
  while (!client.connected()) {
    Serial.print("Attempting MQTT connection...");

    if (client.connect("ESP32Client")) {
      Serial.println("connected");
    } else {
      Serial.print("failed, rc=");
      Serial.print(client.state());
      Serial.println(" try again in 5 seconds");
      // Wait 5 seconds before retrying
      delay(5000);
    }
  }
}


void setup() {
  Serial.begin(115200);
emon.voltage(35, vCalibration, 1.7); // Voltage: input pin, calibration,
phase_shift
emon.current(34, currCalibration); // Current: input pin, calibration.
  WiFi.begin(ssid, pass);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.print("WiFi connected - ESP IP address: ");
  Serial.println(WiFi.localIP());
  client.setServer(mqtt_server, 1883);
}

void loop() {
  if (!client.connected()) {
    reconnect();
  }
  if (!client.loop()) {
    client.connect("ESP32Client");
```

```
  }
  now = millis();

  if (now - lastMeasure > interval) {
    lastMeasure = now;
    sensorData();

    static char VrmsValue[7];
    dtostrf(Vrms, 6, 2, VrmsValue);

    static char IrmsValue[7];
    dtostrf(Irms, 6, 2, IrmsValue);

    static char powerValue[7];
    dtostrf(apparentPower, 6, 2, powerValue);

    static char kWhValue[7];
    dtostrf(kWh, 6, 2, kWhValue);

    // Publish sensor data
    client.publish("energy/voltage", VrmsValue);
    client.publish("energy/current", IrmsValue);
    client.publish("energy/power", powerValue);
    client.publish("energy/khw", kWhValue);
  }
}
```

NODE-RED FLOWS


```
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```

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flow.get('count9');\naz = flow.get('count10');\nmsg.topic =\"INSERT INTO `acce` (`A-X`,`A-Y`,`A-Z`) VALUES ('\"+ax+\"', '\"+ay+\"', '\"+az+\"')\";\nreturn
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flow.get('count2');\nmsg.topic =\"INSERT INTO `weather`
(`Temperature`,`Humidity`,`Luminosity`) VALUES ('\"+th+\"', '\"+hh+\"',
'\"+lh+\"')\";\nreturn
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e0df","72275f8e.b02b7"]]},{"id":"2fd9fdfc.f2c7c2","type":"function","z":"3a72d9bb.ae78b6","n
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flow.get('count5');\nek = flow.get('count6');\nmsg.topic =\"INSERT INTO `Energy`
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x[1];\nmsg.payload = y;\nreturn
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c.f2c7c2"]]},{"id":"8d83d664.8d2b98","type":"inject","z":"78db394a.92a528","name":"","props"
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d":"47a728bc.0485d8","type":"function","z":"a032c5c5.95d608","name":"insert.data.gyro","func
":"gx = flow.get('count11');\ngy = flow.get('count12');\ngz =
flow.get('count13');\nmsg.topic =\"INSERT INTO `gyro` (`G-X`,`G-Y`,`G-Z`) VALUES
('\"+gx+\"', '\"+gy+\"', '\"+gz+\"')\";\nreturn
msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":1040,"y":660,"wires":[["d4ea54
4f.71f9f8"]]},{"id":"f5ed8efa.d5fa9","type":"function","z":"78db394a.92a528","name":"select.
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d3.d5569"]]},{"id":"8f1460dc.685d4","type":"function","z":"a032c5c5.95d608","name":"select.l
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x[1];\nmsg.payload = y;\nreturn
msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":1610,"y":180,"wires":[["495e78
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","func":"\nvar go = Object.entries(msg.payload[0]);\nvar x = go[2];\nvar y =
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msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":1630,"y":720,"wires":[["e95d59
83.6b75c8"]]},{"id":"59e35a2e.3e7d64","type":"comment","z":"a032c5c5.95d608","name":"Import
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```
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0bce.9d1418"]]},{"id":"a7117203.305b2","type":"function","z":"4ee4b311.bbf09c","name":"RPICT
7V1","func":"var output = msg.payload.split(\" \");\n\nvar NodeID =
parseInt(output[0]);\nvar Vrms1     = parseFloat(output[1]);\nvar Vrms2     =
parseFloat(output[2]);\nvar Vrms3     = parseFloat(output[3]);\nvar Vrms4     =
parseFloat(output[4]);\nvar RP1     = parseFloat(output[5]);\nvar RP2     =
parseFloat(output[6]);\nvar RP3     = parseFloat(output[7]);\nvar RP4     =
parseFloat(output[8]);\nvar PF1     = parseFloat(output[9]);\nvar PF2     =
```

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parseFloat(output[10]);\nvar PF3    = parseFloat(output[11]);\nvar PF4    =
parseFloat(output[12]);\nvar Irms1      = parseFloat(output[13]);\nvar Irms2      =
parseFloat(output[14]);\nvar Irms3    = parseFloat(output[15]);\nvar Irms4    =
parseFloat(output[16]);\nvar T1   = parseFloat(output[17]);\nvar T2   =
parseFloat(output[18]);\nvar T3   = parseFloat(output[19]);\nvar T4   =
parseFloat(output[20]);\nvar RTD   = parseFloat(output[21]);\n\nvar msg1 = {payload :
NodeID};\nvar msg2 = {payload : Vrms1};\nvar msg3 = {payload : Vrms2};\nvar msg4 = {payload
: Vrms3};\nvar msg5 = {payload : Vrms4};\nvar msg6 = {payload : T1};\nvar msg7 = {payload :
T2};\nvar msg8 = {payload : T3};\nvar msg9 = {payload : T4};\nvar msg10 = {payload :
RTD};\nvar msg11 = {payload : Irms1};\nvar msg12 = {payload : Irms2};\nvar msg13 = {payload
: Irms3};\nvar msg14 = {payload : Irms4};\nvar msg15 = {payload : RP1};\nvar msg16 =
{payload : RP2};\nvar msg17 = {payload : RP3};\nvar msg18 = {payload : RP4};\nvar msg19 =
{payload : PF1};\nvar msg20 = {payload : PF2};\nvar msg21 = {payload : PF3};\nvar msg22 =
{payload : PF4};\n\n\nreturn [msg1, msg2, msg3, msg4, msg5, msg6, msg7, msg8, msg9, msg10,
msg11, msg12, msg13, msg14, msg15, msg16, msg17, msg18, msg19, msg20, msg21,
msg22];\n\nmsg.topic =\"INSERT INTO `monitoring_data`
(`Voltage_1`,`Voltage_2`,`Voltage_3`,`T1`,`T2`,`T3`,`T4`,`RTD`,`Irms1`,`Irms2`,`Irms3`,`RP1`
,`RP2`,`RP3`) VALUES ('\"+msg2+\"', '\"+msg3+\"', '\"+msg4+\"','\"+msg6+\"', '\"+msg7+\"',
'\"+msg8+\"','\"+msg9+\"', '\"+msg10+\"', '\"+msg11+\"','\"+msg12+\"', '\"+msg13+\"',
'\"+msg15+\"', '\"+msg16+\"', '\"+msg17+\"')\";\nreturn msg;\n//return [msg6, msg7, msg8,
msg9,
msg10];\n","outputs":22,"noerr":0,"initialize":"","finalize":"","x":430,"y":220,"wires":[["1
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```
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bf09c","group":"4214bb1b.cfcdb4","order":1,"width":0,"height":0,"name":"","label":"Irms1","f
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mat":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":220,"wires":[]},{"id":"de475fb3.c954d","type":"ui_text","z":"4ee4b311.b
bf09c","group":"8e996e75.46caa","order":5,"width":0,"height":0,"name":"","label":"RP4","form
at":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":260,"wires":[]},{"id":"d3e3d4d0.f4db58","type":"ui_text","z":"4ee4b311.
bbf09c","group":"3a8d4b64.91de24","order":2,"width":0,"height":0,"name":"","label":"PF1","fo
rmat":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":320,"wires":[]},{"id":"64fcbdc4.9839b4","type":"ui_text","z":"4ee4b311.
bbf09c","group":"3a8d4b64.91de24","order":6,"width":0,"height":0,"name":"","label":"PF2","fo
rmat":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":360,"wires":[]},{"id":"c82340fe.b0c1b","type":"ui_text","z":"4ee4b311.b
bf09c","group":"3a8d4b64.91de24","order":7,"width":0,"height":0,"name":"","label":"PF3","for
mat":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":400,"wires":[]},{"id":"b955722b.5c5d2","type":"ui_text","z":"4ee4b311.b
bf09c","group":"3a8d4b64.91de24","order":8,"width":0,"height":0,"name":"","label":"PF4","for
mat":"{{msg.payload}}","layout":"row-
spread","x":1010,"y":440,"wires":[]},{"id":"e3a15438.34be98","type":"function","z":"4ee4b311
.bbf09c","name":"","func":"var output = msg.payload.split(\" \");\nnodeid =
parseInt(output[0]);\nmsg.payload = nodeid;\nreturn
msg;","outputs":1,"noerr":0,"x":150,"y":140,"wires":[[]]},{"id":"d9e49d4.579a56","type":"inj
ect","z":"4ee4b311.bbf09c","name":"","repeat":"1","crontab":"","once":false,"onceDelay":0.1,
"topic":"","payload":"","payloadType":"date","x":150,"y":420,"wires":[[]]},{"id":"f4e8750d.a
d4f38","type":"mqtt
```

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in","z":"4ee4b311.bbf09c","name":"","topic":"data/nodeid","qos":"2","datatype":"auto","broke
r":"fd08f155.835d9","x":90,"y":240,"wires":[["721f9792.97cae8","a7117203.305b2","2d18f9f8.5e
e0f6"]]},{"id":"a7bf01f1.af9d4","type":"mysql","z":"4ee4b311.bbf09c","mydb":"ebef095f.ebfc08
","name":"Main
data","x":1020,"y":680,"wires":[[]]},{"id":"2d18f9f8.5ee0f6","type":"function","z":"4ee4b311
.bbf09c","name":"insert.data","func":"var output = msg.payload.split(\" \");\n\nvar NodeID =
parseInt(output[0]);\nvar Vrms1     = parseFloat(output[1]);\nvar Vrms2     =
parseFloat(output[2]);\nvar Vrms3     = parseFloat(output[3]);\nvar Vrms4     =
parseFloat(output[4]);\nvar RP1     = parseFloat(output[5]);\nvar RP2     =
parseFloat(output[6]);\nvar RP3     = parseFloat(output[7]);\nvar RP4     =
parseFloat(output[8]);\nvar PF1     = parseFloat(output[9]);\nvar PF2     =
parseFloat(output[10]);\nvar PF3     = parseFloat(output[11]);\nvar PF4     =
parseFloat(output[12]);\nvar Irms1      = parseFloat(output[13]);\nvar Irms2      =
parseFloat(output[14]);\nvar Irms3     = parseFloat(output[15]);\nvar Irms4     =
parseFloat(output[16]);\nvar T1    = parseFloat(output[17]);\nvar T2    =
parseFloat(output[18]);\nvar T3    = parseFloat(output[19]);\nvar T4    =
parseFloat(output[20]);\nvar RTD    = parseFloat(output[21]);\n\nvar msg1 = {payload :
NodeID};\nvar msg2 = {payload : Vrms1};\nvar msg3 = {payload : Vrms2};\nvar msg4 = {payload
: Vrms3};\nvar msg5 = {payload : Vrms4};\nvar msg6 = {payload : T1};\nvar msg7 = {payload :
T2};\nvar msg8 = {payload : T3};\nvar msg9 = {payload : T4};\nvar msg10 = {payload :
RTD};\nvar msg11 = {payload : Irms1};\nvar msg12 = {payload : Irms2};\nvar msg13 = {payload
: Irms3};\nvar msg14 = {payload : Irms4};\nvar msg15 = {payload : RP1};\nvar msg16 =
{payload : RP2};\nvar msg17 = {payload : RP3};\nvar msg18 = {payload : RP4};\nvar msg19 =
{payload : PF1};\nvar msg20 = {payload : PF2};\nvar msg21 = {payload : PF3};\nvar msg22 =
{payload : PF4};\n\nth = flow.get('count');\nhh = flow.get('count1');\nlh =
flow.get('count2');\nev = flow.get('count3');\nec = flow.get('count4');\nep =
flow.get('count5');\nax = flow.get('count8');\nay = flow.get('count9');\naz =
flow.get('count10');\ng = flow.get('count7');\ngx = flow.get('count11');\ngy =
flow.get('count12');\ngz = flow.get('count13');\n\nmsg.topic =\"INSERT INTO
`monitoring_data` (`Temperature`,`Humidity`,`Luminosity`,`Temp_MPU`,`A-X`,`A-Y`,`A-Z`,`G-
X`,`G-Y`,`G-
Z`,`Voltage_1`,`Voltage_2`,`Voltage_3`,`T1`,`T2`,`T3`,`T4`,`RTD`,`Irms1`,`Irms2`,`Irms3`,`RP
1`,`RP2`,`RP3`,`Voltage`,`Current`,`Power`) VALUES ('\"+th+\"', '\"+hh+\"',
'\"+lh+\"','\"+g+\"','\"+ax+\"', '\"+ay+\"', '\"+az+\"','\"+gx+\"', '\"+gy+\"',
'\"+gz+\"','\"+msg2+\"', '\"+msg3+\"', '\"+msg4+\"','\"+msg6+\"', '\"+msg7+\"',
'\"+msg8+\"','\"+msg9+\"', '\"+msg10+\"', '\"+msg11+\"','\"+msg12+\"', '\"+msg13+\"',
'\"+msg15+\"', '\"+msg16+\"', '\"+msg17+\"','\"+ev+\"', '\"+ec+\"', '\"+ep+\"')\";\nreturn
msg;\n//return [msg6, msg7, msg8, msg9,
msg10];\n","outputs":1,"noerr":0,"initialize":"","finalize":"","x":750,"y":680,"wires":[["a7
bf01f1.af9d4"]]},{"id":"33d7d39b.13fedc","type":"comment","z":"4ee4b311.bbf09c","name":"Logg
ing
data","info":"","x":750,"y":820,"wires":[]},{"id":"20e0e6ad.3572da","type":"inject","z":"4ee
4b311.bbf09c","name":"","props":[{"p":"payload"},{"p":"topic","v":"","vt":"date"}],"repeat":
"1","crontab":"","once":false,"onceDelay":0.1,"topic":"","payload":"","payloadType":"date","
x":550,"y":860,"wires":[["2d18f9f8.5ee0f6"]]},{"id":"c3200ba0.6b4df8","type":"function","z":
"4ee4b311.bbf09c","name":"insert.data","func":"ev = flow.get('count3');\nec =
flow.get('count4');\nep = flow.get('count5');\nmsg.topic =\"INSERT INTO `monitoring_data`
(`Voltage`,`Current`,`Power`) VALUES ('\"+ev+\"', '\"+ec+\"', '\"+ep+\"')\";\nreturn
msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":750,"y":1020,"wires":[[]]},{"i
d":"d878b477.97d898","type":"comment","z":"4ee4b311.bbf09c","name":"Logging
data","info":"","x":750,"y":980,"wires":[]},{"id":"e8e682c.9f2658","type":"inject","z":"4ee4
b311.bbf09c","name":"","props":[{"p":"payload"},{"p":"topic","v":"","vt":"date"}],"repeat":"
1","crontab":"","once":false,"onceDelay":0.1,"topic":"","payload":"","payloadType":"date","x
```

":550,"y":1020,"wires":[["c3200ba0.6b4df8"]]},{"id":"247e41e5.ed6f3e","type":"comment","z":"4ee4b311.bbf09c","name":"Energy","info":"","x":730,"y":940,"wires":[]},{"id":"cf0d77cc.2b8968","type":"function","z":"4ee4b311.bbf09c","name":"insert.data.accelerometer","func":"ax = flow.get('count8');\nay = flow.get('count9');\naz = flow.get('count10');\nmsg.topic =\"INSERT INTO `monitoring_data` (`A-X`,`A-Y`,`A-Z`) VALUES ('\"+ax+\"', '\"+ay+\"', '\"+az+\"')\";\nreturn msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":790,"y":1180,"wires":[[]]},{"id":"e0f39cb.eae596","type":"comment","z":"4ee4b311.bbf09c","name":"Import gyro data","info":"","x":760,"y":1340,"wires":[]},{"id":"e3a05845.614d28","type":"function","z":"4ee4b311.bbf09c","name":"insert.data.temp","func":"g = flow.get('count7');\nmsg.topic =\"INSERT INTO `monitoring_data` (`Temp_MPU`) VALUES ('\"+g+\"')\";\nreturn msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":760,"y":1280,"wires":[[]]},{"id":"9632c8f7.a58c58","type":"inject","z":"4ee4b311.bbf09c","name":"","props":[{"p":"payload"},{"p":"topic","v":"","vt":"date"}],"repeat":"1","crontab":"","once":false,"onceDelay":0.1,"topic":"","payload":"","payloadType":"date","x":510,"y":1280,"wires":[["cf0d77cc.2b8968","e3a05845.614d28","a9f08db9.1a5f3"]]},{"id":"a9f08db9.1a5f3","type":"function","z":"4ee4b311.bbf09c","name":"insert.data.gyro","func":"gx = flow.get('count11');\ngy = flow.get('count12');\ngz = flow.get('count13');\nmsg.topic =\"INSERT INTO `monitoring_data` (`G-X`,`G-Y`,`G-Z`) VALUES ('\"+gx+\"', '\"+gy+\"', '\"+gz+\"')\";\nreturn msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":760,"y":1380,"wires":[[]]},{"id":"b08126a.8989bd8","type":"comment","z":"4ee4b311.bbf09c","name":"Import acce data","info":"","x":760,"y":1140,"wires":[]},{"id":"a8868815.5406e8","type":"comment","z":"4ee4b311.bbf09c","name":"Import temp data","info":"","x":760,"y":1240,"wires":[]},{"id":"c44070cf.d9364","type":"comment","z":"4ee4b311.bbf09c","name":"MPU","info":"","x":730,"y":1080,"wires":[]},{"id":"f43c1f32.01675","type":"function","z":"4ee4b311.bbf09c","name":"insert.data","func":"th = flow.get('count');\nhh = flow.get('count1');\nlh = flow.get('count2');\nmsg.topic =\"INSERT INTO `monitoring_data` (`Temperature`,`Humidity`,`Luminosity`) VALUES ('\"+th+\"', '\"+hh+\"', '\"+lh+\"')\";\nreturn msg;","outputs":1,"noerr":0,"initialize":"","finalize":"","x":750,"y":860,"wires":[[]]}]