DEGREE PROJECT IN COMPUTER ENGINEERING AND ECONOMIC
FIRST CYCLE, 15 HP
STOCKHOLM, SWEDEN *2020*

# Simple Indoor Environmental Monitoring System for Houseplants using Web and Mobile Applications


**MAHER RIYADH JABBAR**



**KTH**
**SKOLAN FÖR KEMI, BIOTEKNOLOGI OCH HÄLSA**

# Abstract

In recent times, attention to the indoor plants in the houses has increased, which can be used to produce food or just for decoration and for health purposes. However, moving plants from their original place in nature to a closed place leads to negative effects due to changing environmental parameters around them. For instance, fluctuations in temperature, light, and soil moisture might affect indoor plant growth process. This work investigates the possibility of using the smart mobile and web applications to monitor remotely the most of changing environmental parameters around plants. These parameters can give the user the real-time information on air temperature and humidity, soil temperature and moisture, as well as amount of light. The Top-down method has been used to design a monitoring system to help the user keep informed of indoor climate changes. This system contains Raspberry and some sensors that are used in sensing various environmental conditions. It also includes the software component which defines services and actions to be taken on the data collected by sensing objects. The system is tested and evaluated in the indoor environment to prove the required concepts. The results indicated that web and mobile interfaces transfer data in real-time manner and send environmental information to the user. The data collected is visualized by different charts and figures to give a better understanding of the surrounding conditions in which the plant grows. It is concluded that the proposed system provides a user-friendly monitoring application to monitor the most indoor environmental parameters.

**Keywords**
Houseplant monitoring system, Environmental sensors, Raspberry, Web Application, Mobile Application, Internet of Things.

## Acknowledgement

I would like to express my gratitude to ***Mr. Bengt Molin,*** and ***Mr. Anders Sjögren*** my supervisors for their excellent guidance and advice that they offered me during the whole period and discussing problems and solutions with me. Furthermore, I would like to express my special gratitude to ***Mr. Fadil Galjic*** and ***Prof. Gerald Q. Maguire Jr.*** for their valuable notes and the continues guidance in writing this project. Also, I want to thank **Mr. Ibrahim Orhan** my examiner for his guidance and advice. Furthermore, I want to thank my friends for their enormous support.

Stockholm, June 2020
Maher Riyadh Jabbar

# Table of Contents

# List of Acronyms and Abbreviations

| | |
|---|---|
| ADC | Analog to Digital Converter |
| API | Application Program Interface |
| BLE | Bluetooth Low Energy |
| CCTV | Closed-Circuit Television |
| CO | Carbon Monoxide |
| CO2 | Carbon Dioxide |
| GND | Ground |
| GPIO | General-Purpose Input/Output |
| GUI | Graphical User Interface |
| HTTP | HyperText Transfer Protocol |
| I2C | Serial protocol for two-wire interface |
| IDE | Integrated Development Environment |
| IEEE | Institute of Electrical and Electronics Engineers |
| I/O | Input/Output |
| iOS | iPhone Operating System |
| IOT | Internet of things |
| IP | Internet Protocol |
| JSON | JavaScript Object Notation |
| LAN | Local Area Network |
| M2M | Machine to Machine |
| MAC | Media Access Control |
| MQTT | Message Queuing Telemetry Transport |
| PC | Personal Computer |
| pH | Potential of Hydrogen |
| PHP | Hypertext Pre-processor |
| POC | Proof of Concept |
| POST | Power on Self-Test |
| RoHS | Restriction of Hazardous Substances |
| RPI | Raspberry Pi |
| RQ | Research Question |
| SCL | Serial Clock |
| SDA | Serial Data |
| SDK | Software Development Kit |
| SMS | Short Message Service |
| SQL | Structured Query Language |
| TCP | Transmission Control Protocol |
| USB | Universal Serial Bus |
| WiFi | Wireless Fidelity |

# 1. Introduction

In this chapter the general introduction of research area is introduced and the problem of this project is described. The research questions and project goals are also formulated. Finally, research methodology, delimitations, and the outline of the project are presented in the end of the chapter.

## 1.1 General Introduction

The importance of plants is not limited to their role in meeting our material and economic needs, but there are many studies documenting a wide range of positive effects of plants on humans [1]. Plants are beneficial to humans whether they are outdoor plants or indoor plants. Some of these benefits include the positive contribution of plants to mental and physical health of humans. The use of indoor plants have been enormously increased our past years due to more congestion in cities and less available space for outdoor plants. Cities have turned to concrete heavens with large skyscrapers roaring the clouds. More people have now moved to these tall buildings for their livings and does not find enough time to move around in parks or open areas. In order to maintain a connection with nature indoor plants are widely used by residents of these buildings. Generally, Indoor plants contribute to cleaner and healthier air, thus improving our safety and comfort. It also makes our surroundings more pleasant [2]. It is presented in various researches that indoor plants reduce the carbon dioxide level by 10 percent for an air-conditioned room and this reduction is 25 percent if room non-air-conditioned [44]. Oxygen and carbon dioxide levels can easily be monitored by the use of environmental sensors in rooms and buildings.

The rapid growth of information technology in the world is more available than ever. More and more information technology applications are available for every field of life. Internet, software and hardware devices like sensors are becoming more popular for the monitoring and control of systems. Mobile phones are becoming widespread and improvements in the communications field have shown encouraging results. Mobile phones are connected with internet via application which monitor real time data and provide it to user any time on mobile. Wireless sensors are important devices when it comes to monitor and control systems [45]. The main advantage of them is being wireless, which enables user to take control of device while not being in physically contact with device and from any distance via internet application. Wireless devices are used in wide applications like monitoring thermal parameters, humidity, moisture in air, the ratio of carbon dioxide and oxygen air, and also in many other industrial applications. Tracking environmental parameters by wireless sensors at real-time will benefit in many fields. One of these fields is indoor agriculture because it will allow monitoring of the environmental parameters around the plants.

## 1.2 Problem Description

The indoor plant growth is greatly affected by the environmental parameters. If any environmental factor is less than ideal, it limits a plant's growth. One of the common problems of indoor plants is that they are damaged, and it is difficult to determine the reason whether it is due to the amount of irrigation water or because of the amount of light needed by the plant. The wrong temperature may lead to burns or freezing plant damage. There are, of course, more reasons for the cause of plant death or damage, such as soil moisture or acidic of irrigation water. So, it is important to monitor and track the environmental parameters of the plant so that it knows exactly what the plant needs and therefore it will be easier to take care of the indoor plants.

## 1.3 Research Questions

One of the solutions that attempts to address this problem requires designing a monitoring system that allows to track the environmental conditions. This will be done by conducting a thorough research using a literature review, and design and development to investigate and identify how the use of web and mobile applications with existing sensors technologies be applied for environmental monitoring process in order to take the appropriate action and treatment at the right time. This work aims to answer the following main research questions:

**RQ1** ***Can an environmental monitoring system be established to improve indoor plants?***
**RQ2** ***Which are economic benefits of using such this monitoring system?***

## 1.4 Project Goals

The goal of this project is to create a solution to the aforementioned problem. In achieving this following goal should be considered.

- A monitoring system with an application that enables the user to monitor and track the indoor environmental parameters with the aim of permitting a more effective care of indoor plants.
- It also aims to benefit the user in many ways like decision making and helps to use the water in an efficient way.
- The user will be able to use smart mobile and web applications to monitor remotely the most of weather and soil parameters. These parameters can give information on real-time air temperature and humidity, soil temperature and moisture, an amount of light and the acidity of irrigation water.
- In addition to that there is also an academic goal, which is to build a system (hardware and software implementation) that collects important data from environment and display it on web and smart mobile applications. This data is visualized by different charts and figures to give a better understanding of the surrounding conditions in which the plant grows.

## 1.5 Research Methodology

The choice of method is dependent on the type of project, time constraints and experience. Several types of methods were considered: Quantitative, Qualitative, Applied research, and Top-down method. Due to this project needing a practical solution of an experimental nature, the soundest choice that could be made was that of the Top-down method. Quantitative/Qualitative is better suited for research and theoretical projects than practical, thus does not fit perfectly [3]. Applied research method focuses on analysis and solving social and real-life problems and it is an investigation for ways of using scientific knowledge to solve practical problems. The idea behind the Top-down approach is to start from the big picture and then define the different parts that compose it and then divide it, respectively, into smaller sub parts and finally soon, each of the parts will be easy to code and accomplish.

Since there will be only one person working on this project and the project is of an experimental nature, the Top-down method is sufficient.

## 1.6 Delimitations

The boundaries that have been set for this work are: The system should collect and present information, but not affect the situation or system in which indoor plant is placed. Only one system must be created to prove that it is possible to create such a system. There should be no more implementations, with the possibility of comparing them, and examining their advantages and disadvantages.

## 1.7 Structure of thesis

Chapter 2: Theoretical background, presents the effects of environmental parameters on the plants. As well, the effect of indoor plants on human health. An overview of technical background will be introduced that includes the hardware components and communication protocol which is used. Finally, an overview of some works which are related to this project will be introduced.

Chapter 3: Methods, describes the choices of available methods for the study, that are used to implement the monitoring system. It is divided into seven sections: the chosen research method, data reliability and validity, system testing, software documentation, an overview of the hardware components, the communication protocol which is used, and software components that are used in the design process.

Chapter 4: System Implementation, presents the system requirements, the design phases and the implementation of the proposed monitoring system in this work. It has been done by four stages, from simple prototype to the final and completed design.

Chapter 5: Results, aims to run the software to make the hardware functional and deliver the desired results to the user. It presents the results of system operation that are supported by tables and charts.

Chapter 6: Analysis and Discussion, discusses the results and system performance that is evaluated after monitoring different indoor environmental parameters. It represents the proof of concept in terms of practical using and technical capabilities. Finally, it presents the answers of project questions that includes the economic benefits.

Chapter 7: Conclusion and Future Work, presents the conclusion and gives suggestions for future work that related to this project.

# 2. Theoretical Background

In this chapter, the effects of environmental parameters on the plants will be presented and as well, the effect of indoor plants on human health. Finally, an overview of some works which are related to this project will be introduced.

## 2.1 Indoor Environmental Parameters

Generally, fluctuations in environmental parameters may lead to plant death. It also leads to changes in water availability and soil degradation and can directly and significantly influence plant growth.

When bringing plants indoor, the climate must also be brought in the interior in which they grow. Creating such an environment for all potential plants that must be indoors is a big challenge. The main parameters to consider are temperature, stable light source, correct humidity, nutritional soil, irrigation and pest control.

### 2.1.1 Effect of Light

Plants may not get enough light to grow when brought indoor. This is partly due to the low light intensity when passing through windows and the places of windows may affect growth process. Therefore, additional lighting sources may be required which will affect the intensity of the light and which in turn affect the temperature.

Plants get energy from light through a process called photosynthesis. This is how light affects the growth of a plant. Without light, a plant would not be able to produce the energy it needs to grow. Sometimes a plant will not get enough light and will have problems with too little light. Plants affected by light shortages or too little blue light will have the following signs: stems will be leggy or stretched out, leaves turn yellow and too small, leave or stems are spindly, brown edges or tips on leaves, and lower leaves dry up [4]. The information from light sensor gives the possible range 0.001-0.02 lx for night, 50-500 lx for cloudy outdoor, 100-1000 lx for sunny indoor, greater than 1000 lx for sunny outdoor. If light levels are too high, the plant will heat up, resulting in a difference between plant temperature and air temperature.

### 2.1.2 Effect of Air Temperature

It is very important for irrigation process to track the value of air temperature. Air temperature is a key factor in plant growth and development. Along with the levels of light, carbon dioxide, air humidity, water and nutrients, temperature influences plant growth. All these factors should be in balance. Temperature influences the plant in the short term as well as the long term. High temperatures affect plant growth in numerous ways. The most obvious are the effects of heat on photosynthesis, in which plants use carbon dioxide to produce oxygen, and respiration, an opposite process in which plants use oxygen to produce carbon dioxide [5]. The information from air temperature sensor gives the surrounding air temperature for the range -40 to 80°C.

### 2.1.3 Effect of Air Humidity

Humidity is not easy to control and generally is less than what plants require in order to function properly, which can decrease in indoor plant health during seasonal changes in colder and darker seasons.

When air humidity levels become too high, the water evaporation (part of the transpiration process) cannot be done by plant. Also, the planet cannot draw nutrients from the soil. On the other hand, when humidity levels drop too low, the plants transpire at a rate much quicker than that of nutrient uptake. The nutrients do not spread through the plant, only the water does. So, the nutrients concentrated level in the plant will be left behind and then nutrient burn will be resulted. Humidity in the range 50 to 60 percent is possibly perfect for plants [6]. The information from air humidity sensor gives the surrounding air humidity in the range 0 to 100 %.

### 2.1.4 Effect of Soil Moisture

This value is the quantity of water contained in the soil. Generally, the acceptable value will range from 10% to 45%, but can be higher during and after watering. If a plant's soil has too much water, the roots can rot, and the plant cannot get enough oxygen from the soil. If there is not enough water for a plant, the nutrients it needs cannot travel through the plant. A plant cannot grow if it does not have healthy roots, so the proper balance of water is key when growing plants. Soil moisture is an important factor to support plant growing. So, too much moisture causes wasted water and root disease, but too little moisture causes plant loss [7]. The information from soil moisture sensor gives the ratio of water contained in the soil for the range 0 to 100 %.

### 2.1.5 Effect of Soil Temperature

Soil temperature affects plant growing indirectly by affecting nutrient and water uptake. At a constant moisture content, a decrease in temperature results in a decrease in water and nutrient uptake. Soil temperature is influenced by: climate, season, aspect, water levels, soil color, plant cover and soil depth. The temperature in a soil will determine the speed of chemical and biological activity. The normal soil temperature for root growing of spring wheat was found to be equal or less than 22°C [8]. The information from soil temperature sensor gives the temperature for soil for the range -55° C to +125° C.

### 2.1.6 Effect of Hydrogen

The value of pH range for normal plant growing differs among plants. While some plants grow best in the 6.0 to 7.0 range, others grow well under acidic conditions. The pH balance of water affects the acid and alkaline content of soil. If water is too acidic, calcium, magnesium and potassium levels are reduced. Calcium is required for cell growth, magnesium for chlorophyll formation and potassium for synthesizing proteins. Soil pH is important because it influences several soil factors affecting plant growth, such as: soil bacteria, nutrient leaching, nutrient availability, toxic elements, and soil structure. The pH is not an indication of fertility, but it does affect the availability of fertilizer nutrients. The information of the crop and the soil is important in handling soil pH for the best plant performance [9]. The information from pH sensor gives the levels of pH from 0 to 14, with 7 being neutral, below 7 acidic and above 7 alkaline.

## 2.2 Effects of Indoor Plants on Human Health

It is known that air pollutants (CO and CO2) can be reduced by plants. It has been shown that plants can reduce their volume in the air indoor by up to 25% [10]. There have also been studies showing that the very presence of indoor plants can increase productivity and reduce symptoms of stress.

Plants can regulate the relative humidity in the air by transpiration. The amount of evaporated water from plants decreases when the relative humidity in the air increases, which means that there is a limit to how high the humidity is. Indoor humidity is normally low and not good for plants or human (increases the risk of a cold). The reason why we are more susceptible to cold in the winter is because we spend more time indoors as the humidity is usually less [11]. So, getting more indoor plants increases air humidity and thus increases our chance of staying healthy.

## 2.3 Indoor plant monitoring approaches

Today there are many research studies available that investigate the connections between individuals and plants [12][13]. The range of documented benefits is very broad: air quality has been improved [14], stress has been reduced [2], disease recovery faster [15], mental impairment is diminishing [16], and productivity is higher [17]. Studies or articles on the benefits of plants add to the expanded use of plants to address both environmental and medicinal issues.

PYTHO for the monitoring of indoor plants [18] can measure air temperature, air humidity, light intensity, water levels and soil moisture. pH parameter is missing from this application that is considered very important for indoor plants. The pH balance of water affects the acid and alkaline content of soil. If water is too acidic, calcium, magnesium and potassium levels are reduced.

Parrot Flower Power [19] is a standalone sensor of IoT device for outdoor and indoor plants. It can measure light, air temperature, soil moisture, and fertilizer level. The communication protocol is Bluetooth. The Flower Power application does not work with iOS 12 and the Android users experience Bluetooth connection issues. It also does not read air humidity which it is important since it helps plants to growth.

FYTA Beam [20] is a smart plant sensor that can measure air temperature, light intensity, nutrition levels and soil moisture. There is also a database containing lots of data about different plants and their needs. The communication protocol is Bluetooth and there is a base station which can be connected to the internet. Air humidity and pH parameter are missing from this device that are considered very important for indoor plants.

*Figure 2. 1: The FYTA Beam and its Mobile Application [20]*

Black & Decker [21] have a flower like garden sensor called PSC10. This one is for outdoors and measures the air temperature, light intensity, and soil moisture. To gather data from this device, it must be connected to a computer via a USB cable. It is also missing the option to connect several units with each other.

The proposed work is looking for a wireless solution and measuring the air humidity and the pH acidity of irrigation water, which is important because it helps indoor plants to grow which none of the mentioned above works can do. Table 2.1 shows a comparison of related works with the proposed system. The proposed system will provide the user with easily accessible information regarding the current environment and therefore enable him to make the most suitable choice for his plants. Hopefully plants will growth and create a more interestingly pleasing surrounding, while improving the health.

*Table 2. 1: Comparison of related works with proposed system*

| **Model of monitoring system** | **Connection type** | **Sensing Element** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Air Temp** | **Air Humidity** | **Soil Temp** | **Soil Moisture** | **Light intensity** | **pH** |
| PYTHO [17] | WiFi | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ |
| Flower Power [19] | Bluetooth | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ |
| FYTA Beam [20] | Bluetooth | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ |
| Black & Decker [21] | USB | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ |
| Proposed System | WiFi | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# 3. Methods

This chapter will discuss the approach on a solution to the research question ***(RQ1)***: ***Can an environmental monitoring system be established to improve indoor plants?*** How will the implementation be done? First, the chosen method will be described and why it was selected. In order to confirm that the system is working as intended, the data reliability and validity of both the method and the gathered data will be described. Then system testing procedure is presented. Also, the way the project will be documented will be stated. An overview of technical background will be introduced that includes the hardware components and communication protocol which is used. One of the most important decision to make the proposed project meet the requirements is the right choice of software technological methods, so the last section presents the choice of software components on which the proposed system is based.

## 3.1 The Chosen Research Method

The chosen method for achieving the project goal is the Top-down method. The idea behind the top-down approach is to start from the big picture and then define the different parts that compose it and then divide it, respectively, into smaller sub parts and finally soon, each of the parts will be easy to code and accomplish [23].

The advantages of this approach are:

- Breaking the problem into parts could be helped to clarify what needs to be done.
- At each step of refinement, the new parts become less complicated and, therefore, easier to figure out.
- Parts of the solution may turn out to be reusable.
- Decisions can be made and implemented very quickly. This is particularly important when time is limited.

The top-down approach is commonly used when there is a comprehensive picture of what the system should look like or how it should work when finished. Figure 3.1 shows the framework of Top-down approach to the problem is described [24].

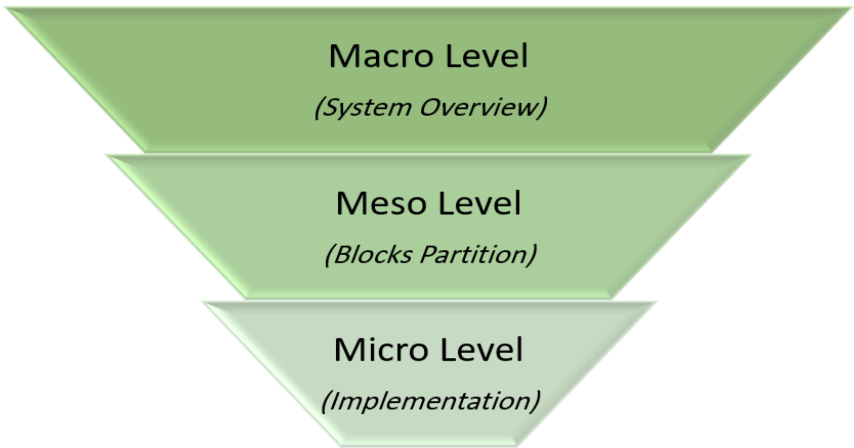



*Figure 3. 1: Framework for Top-down research process [24]*

The system overview serves as the first step for the project where the purpose of the system is determined. Using the initial line of research questions and information from the literature review, a result of the system function can be reached. This function will be the determining factor for the type of outcome to be expected at the end of the project. What indoor plants need for growth and how the proposed system can help to reach this goal. When the system design is defined, it must be determined how it is actually implemented and then divided into parts. These parts represent the architecture of the system, when combined together they achieve a final system design.

## 3.2 Solutions provided

The system is divided into three blocks (figure 3.2):

1. Reading the indoor environmental parameters (sensor node).
2. Validating the received information and store it (base station).
3. Visualizing information in client application (web and smart mobile).

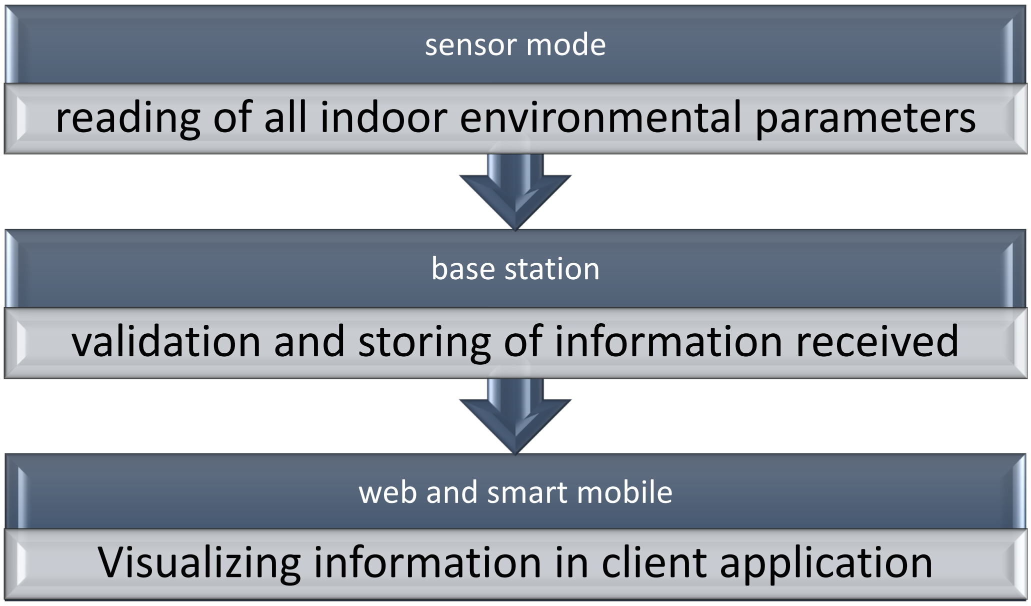



*Figure 3. 2: Top-down process for proposed system*

After each block determination process is complete, specific components can be identified to achieve the purpose of each block.

## 3.3 Data Reliability and Validity

To verify the reliability of the data, measurements of environmental parameters (light intensity, air temperature, humidity, soil temperature, soil moisture, and acidity of irrigation water) will be taken in different indoor conditions and locations. In this way it can be observed whether the readings have the same values despite the change of location and environmental parameters. The data reliability from sensors will also be ensured by using authentication process between user and system in both web and smart mobile applications. In order to ensure the validity of the data, a database consisting of different tables is used to process and store data to its final destination. The database will contain a table for every parameter and must be sent in the correct order with the correct title and time stamps, otherwise it will be ignored.

## 3.4 System Testing

To ensure that the system is operating as intended, it must be tested. The focus will be on the sensor node, the web server (base station) can be connected to the Internet and communicate with client applications (web browser and smart mobile). To see if the base station (Raspberry) is successfully connected to the Internet and transmitting sensor readings, it is sufficient to check the values stored in the database. The testing process should be also done in a controlled environment where all indoor parameters can be adjusted manually and set to a specific value. By using certified tools for measurements, it would permit to compare the difference in accuracy in the same location and to verify that the factory calibration of the sensors was valid.

## 3.5 Software Documentation

GitHub [25] is a web-based platform used for version control. Git simplifies the process of working with other people and makes it easy to collaborate on projects. It can be worked on files and easily merge the changes in with the master branch of the project. All the source codes and programming directions for this work has been documented (Appendix A).

## 3.6 Communication Protocol

There are many communication protocols standardized for internet of things (IoT) applications. Performances of these protocols may significantly deviate from each other even under the same operating conditions [26]. The message queuing telemetry transport (MQTT) comes with much lower power requirements in comparison with other reliable protocols, such as HTTP, and thanks to its lighter header, making it one of the most prominent protocol solutions in constrained environments [27].

MQTT protocol is used to transmit data that sensor node collects from the environment to the base station (Raspberry PI), where it will be finally stored in a database. This protocol uses publish/subscribe operations to exchange data between clients and the server designed for lightweight M2M communications [29]. MQTT has a client/server model, where every sensor is a client and connects to a server known as a broker over TCP. It is message oriented and every message is a discrete chunk of data, opaque to the broker. Every message is published to an address known as a topic. Clients may subscribe to multiple topics. Every client subscribed to a topic receives every message published to the topic. For example, figure 3.2 shows a simple network with three clients and a central broker. All three clients open TCP connections with the broker. Clients B and C subscribe to the topic temperature (figure 3.2 (a)). At a later time, Client A publishes a value of topic temperature. The broker forwards the message to all subscribed clients (figure 3.2 (b)). The publisher/subscriber model allows MQTT clients to communicate one-to-one, one-to-many and many-to-one.

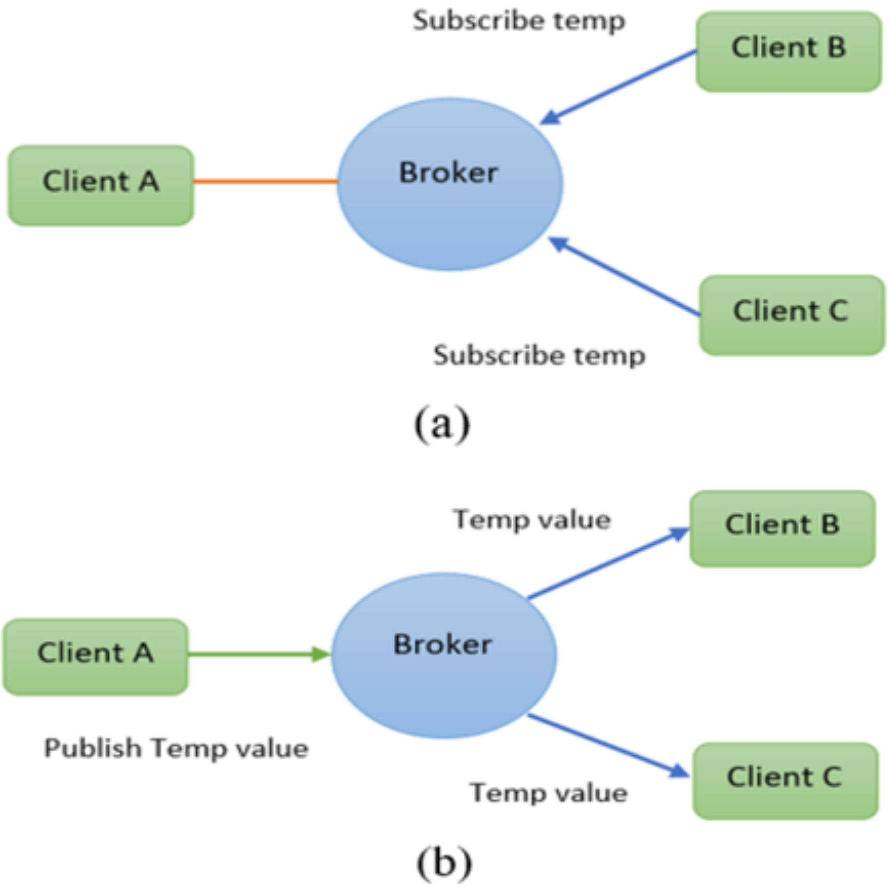



*Figure 3.3: MQTT protocol*

## 3.7 Hardware Components

The system hardware consists of sensing components that observe or take action in the environment they are placed in, and the networking components (base station and sensor node) which permit objects to exchange information with each other or to external components.

All used components were selected to achieve the restriction of hazardous substances directive (RoHS) [29][30].

- This means that the amount of hazardous substances contained in it is limited and facilitates sustainable recycling process.
- Another thing is to keep the cost of components down to make the proposed system cheaper.

### 3.7.1 Base station

Raspberry PI 3B+ (figure 3.3) works as the base station and web server that runs the website to control the entire system along with mobile application. It has the following specifications: 1.4GHz 64-bit quad-core processor, dual-band wireless LAN, Bluetooth 4.2/BLE, faster Ethernet, and Power-over-Ethernet support [31]. One of the easiest and most practical uses of the Raspberry Pi is as a low-cost web server, which can be used to host simple websites. Cloud-based hosting is possibly easier and more practical, but setting up a basic server is good way to get to grips with server and networking technology.

*Figure 3.4: Base station (Raspberry PI 3B+)*

### 3.7.2 Sensor Node

The chosen communication technology is WiFi because it is available indoors in most locations and it allows to send data easily to a database in a base station. A commonly used WiFi module is the sensor node ESP32. The Sensor node can perform processing, gathering data from sensing elements and communicates with the other nodes. It consists of the following components (figure 3.4) [32]:

- Microcontroller: It is a small computer that can be configured to establish connection to external devices. It contains processor, internal memory, and general purpose I/O ports.
- Transceiver: It is deployed for wireless radio communication. It works for sending and receiving data. Usually, it has its own internal microcontroller that can be used for buffering packets, validating them and implement low-level protocols, such as Bluetooth.
- Sensing element: An element that captures data from the environment. Examples of sensors are humidity, temperature, and light sensors.
- External memory: It allows the possibility to store huge amounts of data permanently, to avoid sometimes streaming it to the base station. An additional slot such as a MicroSD can be found as an external memory.
- Power supply: Every sensor node requires energy to operate.
- Serial adapter: Usually, every sensor node comes with serial communication. It is a cable that can attach the sensor node to other devices like PC. The adapter is used for programming, debugging and recharging the nodes.

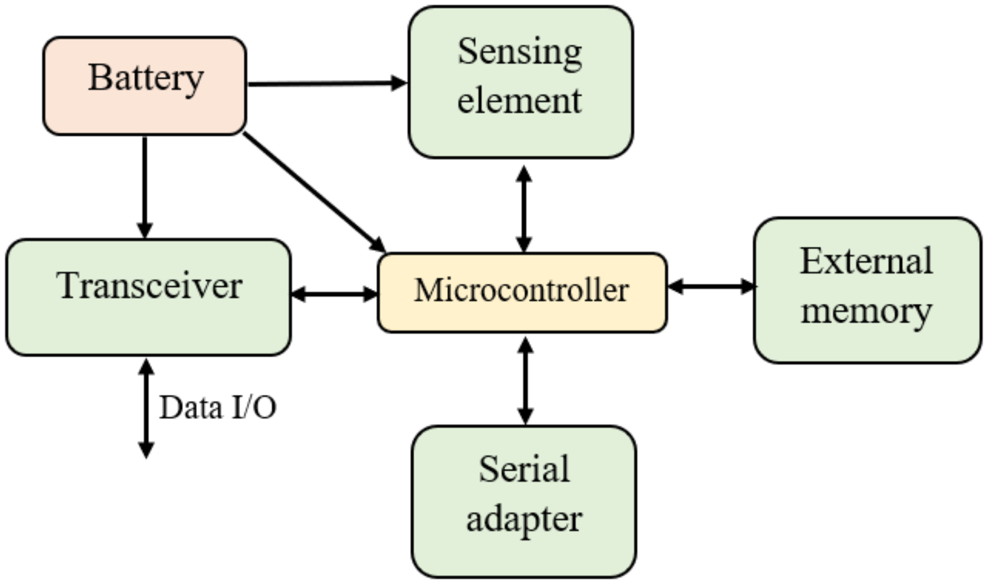



*Figure 3.5: Architecture of sensor node*

The sensor nodes are typically small size and contain different sensing elements, radio transceivers and embedded microprocessors. Hence, they have not only sensing ability, but also communicating abilities with data processing. They communicate over a short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, battlefield surveillance, and industrial process control.

*Figure 3.6: The micro controller (ESP32)*

ESP32 (figure 3.5) is a micro controller with Bluetooth and WiFi capabilities. It works as a sensor node that controls the readings of all the sensor elements and converts these data into readable form. The sensor node collects data from the environments by deploying the sensors elements and then the collected data will be transmitted to the base station where it will finally be stored in the database.

### 3.7.3 Sensing Elements

The benefit of using sensors is to monitor all related data required to enhance a certain job for the stakeholders.

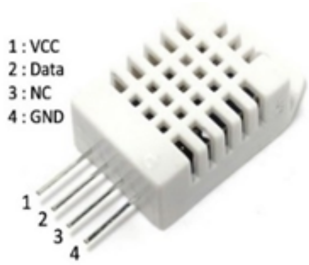



*Figure 3.7: (DHT22) Weather sensor*

*Figure 3.8: (DS18B20) Soil temperature sensor*

*Figure 3.9: (FC-28) Soil moisture sensor*

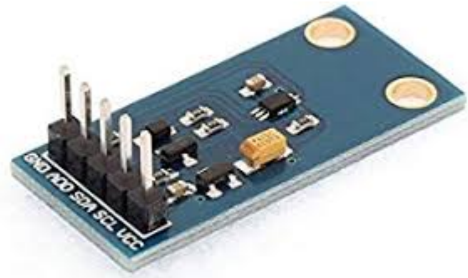



*Figure 3.10: (GY-30) Light intensity sensor*

*Figure 3.11: (Liquid PH0-14) pH sensor*

It is a tool deployed for sensing environmental parameters (such as humidity, temperature, sunlight and soil moisture) and then convert the collected data to electrical signals for processing.

**a. Temperature sensor**

Temperature sensor is used for sensing any change in temperature according to sensing ability. This sensor collects the data about temperature from an environment and convert the data into an understandable form for a device or an observer. The temperature is one of the critical factors significantly determining plant growth and development. A reduction in temperature below the optimal conditions often results in suboptimal plant growth. Figure 3.6 (DHT22) shows the weather sensor that is used for measuring both the air temperature and humidity, while figure 3.7 shows the soil temperature sensor (DS18B20) that is used for measuring the soil temperature.

**b. Humidity sensor**

Humidity sensor is used for detecting the relative humidity of the immediate environment in which they are placed. It is important to cultivate plant by providing the water nutrient small spray in the air. Thus, the humidity is another important parameter and its control is recognized to be very important for significant plant growth. Figure 3.8 shows the soil moisture sensor (FC-28) that is used to detect the amount of moisture content in the soil.

**c. Light intensity sensor**

All vegetable plants and flowers require large amounts of sunlight, and each plant group reacts differently and has the different physiology to deal with light intensity. Some plant performs well in low light intensity and some in high light intensity. The farmer could be able to monitor light intensity without any human interference. Figure 3.9 shows light intensity sensor (GY-30) that is used to measure the intensity or brightness of light and is useful for controlling the irrigation process.

**d. Potential of Hydrogen Sensor**

It measures the level of potential of hydrogen (pH) in water in soil by measuring the activity of the hydrogen ions in the solutions. This activity has a range 0 to 14 to determine the level of acidity (or alkalinity) in the soil. Figure 3.10 shows the pH sensor (Liquid PH0-14).

### 3.7.4 Power Supply

The base station (Raspberry PI 3B+) can be powered through the external power cable (Android phone charger) or with micro USB power connector (5 Volt, 2.5 Amp). It consumes about 400 mA of current at 5.0 V (which is about 1.9-2.1 Watt) when no USB devices are connected to it and it’s in idle state. While adding more accessories to it, then the power consumption will increase. The sensor node (ESP32) can be powered through micro USB port or from external power supply (through the breadboard) to the 5V pin and ground pin. At 5V, the current draw is 128 mA. It can be used battery pack with at least 4 AA cells to power it. The sensing elements can be powered from external power supply (through the breadboard) with voltage values as shown in Table 3.1 [33][34][35][36][37].

Table 3. 1: Sensors voltages

| Sensor | Required Voltage | Max Current |
|---|---|---|
| Weather sensor (DHT22) | 3.3 to 6V DC | 1 to 1.5 mA |
| Soil temperature sensor (DS18B20) | 3V to 5V DC | 1 to 1.5 mA |
| Soil moisture sensor (FC-28) | 3.3 to 5V DC | 35 mA |
| Light intensity sensor (GY-30) | 3V to 5V DC | 1 to 1.5 mA |
| pH sensor (Liquid PH0-14) | 5V DC | 5 to 10 mA |

## 3.8 Software components

One of the most important decisions to make for the proposed project meeting the desired requirements is the right choice of technological methods. These methods should satisfy the requirements like:

1) Low complexity and Easy to apply.
2) Can be integrated together.
3) Well documented/supported/maintained.
4) Fit the long term aims for the system.
5) Have not limit the system in the future.
6) There is no risk from using it.

These technological methods that have been chosen for this work are as following:

- The suitable protocol for nodes data processing.
- Type of the system interfaces for the system (web and mobile GUI).
- Database tables that used to manipulate and store the required environmental information.
- The selection of application programming interfaces that helps to move and exchange data among the different parts of the system.
- The software frameworks and programming languages to assign each functionality in the prototypes to its respective hardware.

## 3.9 System Interfaces

The purpose of running the software is to assign each functionality to its respective hardware. In order to simplify the interactions between client and the system, a set of graphical user interfaces (GUI) are proposed to the system. These interfaces are web and mobile applications that are used at real time monitoring to all of the system parameters. The web application is the main GUI between the user and the system.

It has the function to deal with incoming data from all sensors. The website is designed by using the latest Laravel framework of PHP as the main webserver with SQLite as a database service. The system manages the following controllers:

- **User Controller:** it manages user login, and password changing process. It can be added new user by the system administrator to use and control the functions in the application.
- **Table Controller:** it manages all things about viewing data in the database air temperature and humidity, soil temperature and moisture, pH value, and light intensity.
- **API Controller:** it controls API login and token management and provides data to third party or other interfaces in the system. Each one need to get token first to can use or get data from these services.
- **Chart Controller:** it manages data view as chart for air temperature and humidity, soil temperature and moisture, pH value, and light intensity. It shows the graph of parameters within period of time.

Both mobile and web applications can read data from sensors controlled by node with get http request using ESP32 API. To access the data base, mobile application uses Web API and POST request to get token and get request for the rest of communication. A mobile application has been developed to perform most of the functionalities of the website and it can be controller over the internet connection to the IP of base station, which massively facilitate the administrative tasks for the user. The first thing in the application is the authentication. This step is to let the system administrator to add new users and change their registration information like website. All functions in the mobile application are adopted to all services on the web API. Since the mobile application needs token, the mobile app has to send an email and password using post HTTP request to the web API. If the email and password are valid (which are already stored in the database on base station), the token is sent back to the mobile application otherwise an error page will be appear to the user.

## 3.10 Application Programming Interfaces

Application Programming Interface (API) is an interface that helps to move data between two software inside or outside the system in a synchronization method. There are three types of API which are used in the monitoring system design:

- ESP32 API: used to read data from sensors. Both mobile and web applications can read data from sensors controlled by node with get http request.
- RPI API: used to identify the sensor node. This API uses get http request. The sensor node (ESP32) sends MAC address and current IP address over WiFi to the base station (Raspberry pi) when sensor node starts.
- Web API: this API is used by mobile application to access the data base. It uses POST request to get token (mobile auth method) and get request for the rest of communication.

## 3.11 Software Frameworks and Tools

The purpose of running the software is to assign each functionality to its respective hardware. The software part consists of the following frameworks and tools that are used in this work: MicroPython, Python, Laravel PHP, database Service, and Android Platform.

### a. MicroPython

MicroPython is a tiny open source Python programming language interpreter that runs on small embedded development boards [38]. With MicroPython it can be written a clean and simple Python code to control hardware instead of having to use complex low-level languages like C or C++. The ESP32 sensor node chip is a great platform for using MicroPython to connect to the network, communicate with the Internet, and control external components like sensor elements that are used in this project.

### b. Python

Python is the main programming language that is used for the base station (Raspberry Pi). One of the main advantages of Python is the simplification, which enables to write clear code. Also, the large number of available libraries. For programming the Raspberry Pi, Python is considered a good choice for building monitoring applications that control some pins, and retrieve data from a web service. In addition, Python is recommended for prototyping purposes, in building applications such as smart home systems, smart plants or others. This is because Python enables fast programming and with a wide array of libraries at hand, controlling the Raspberry Pi pins is not a difficult task [39].

**c. Laravel PHP Framework**

Laravel is a PHP based application framework for creating web applications with an easy to use syntax. The idea behind Laravel is that it makes common development tasks easy such as routing, authentication, sessions, and caching. The framework provides an easy way to organize authorization logic and control access to all resources. It allows extensive customization and comes with pre-designed packages. Laravel allows creating a local or cloud-based mailing service and sending notifications through various delivery channels [40].

**d. Database Service**

SQLite is a popular choice as embedded database software for local/client storage in application software such as web application. There are many advantages to using SQLite as an application file format, including: better performance, reduced application cost and complexity, portability, reliability, and accessibility [41].

**e. Android Platform**

The Android SDK is a set of development tools used to develop applications for Android platform. Kotlin programming language is a general purpose, open source language for the Android that combines object-oriented and functional programming features. It is focused on interoperability, safety, clarity, and tooling support [42].

# 4. System Implementation

As mentioned in problem description in chapter one, the indoor plant growth is greatly affected by the environmental parameters. If any environmental factor is less than ideal, it limits a plant's growth. One of the common problems of indoor plants is that they are damaged and it is difficult to determine the reason whether it is due to the amount of irrigation water or because of the amount of light needed by the plant. One of the solutions that attempts to address this problem requires designing a system that allows the user to monitor and track the indoor environmental conditions through web and mobile application in order to take the appropriate action and treatment at the right time.

## 4.1 System Requirements

The current work purposes to continuously monitor the indoor environment parameters, such as air and soil humidity, air and soil temperature, light intensity, and the pH acidity of the water. The overall system consists of three components:

- Sensing component: this component consists of sensor elements that observe or take action in the environment they are arranged in. Objects can be of different specifications or constructions and can come from different vendors.
- Data exchange component: this is the component which permits objects (node and base station) to exchange information with each other or to external components. It is a set of communication protocols to allow data flow.
- GUI application component: is the component which defines services or actions to be taken on the data collected by objects. The acquired data can be used in various domains, such as a web application in a simple monitoring room or mobile monitoring application. This component also defines and manages the behaviors of sensor objects.

The approach provides a user-friendly and scalable houseplant monitoring application. It is important to consider the following requirements:

- The system hardware should not obstruct user activities while at home.
- Web and mobile applications should be easy to use for non-experts and should not involve complicated processes.
- Hardware and software components should be operated under many conditions without changing the facilities and equipment at home.
- The system should monitor and track most indoor environmental parameters under various conditions.
- It should make effective use of monitoring information in real-time to let the user to take the required action.

## 4.2 Collecting and Transmitting Data

The process of reading data from indoor environment is done by sensor elements. The sensor node collects data by deploying the sensors elements and then the collected data will be transmitted to the base station (Raspberry PI), where it will finally be stored in a database. This step of collecting and transmitting data is done by using Micro Python programming language. The data is transferred by deploying the MQTT protocol that uses publish/subscribe operations to exchange data between clients and the server. The server in the system is the Raspberry PI and the clients are classified into two groups, the first one is node (ESP32) as a publisher, and the second one is the base station (Raspberry PI) as a subscriber. The data flow of MQTT protocol can be shown in figure 4.1. ESP32 sends data over four elements (weather, soil, pH and light sensor elements). For each element, there are two information (sensor value, and date of reading).

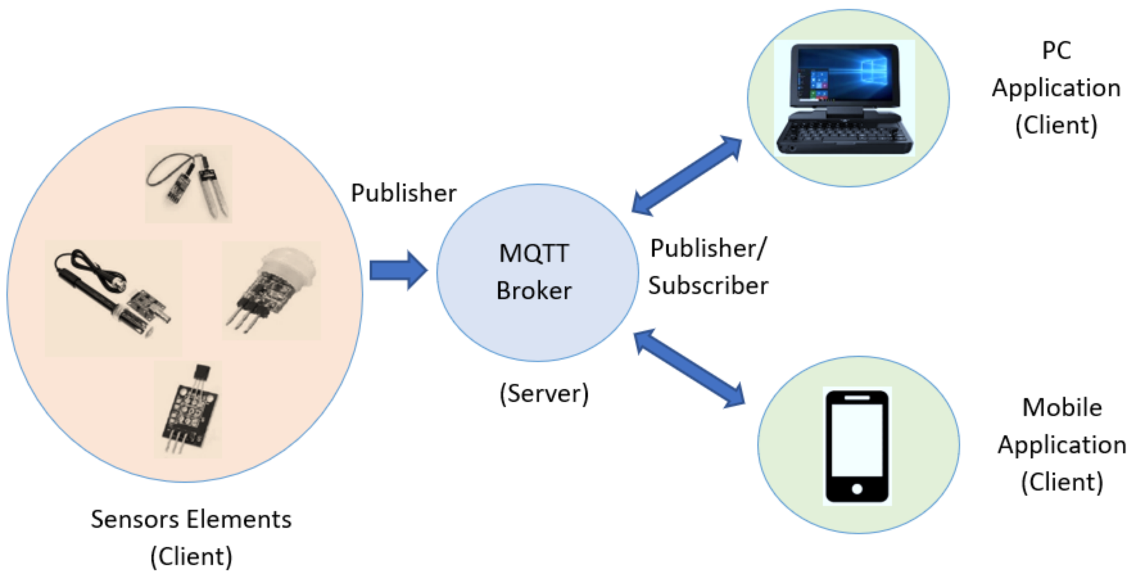



*Figure 4. 1: Data flow of MQTT protocol*

## 4.3 Database Management

The database of the system (figure 4.2) consists of different tables that are used to manipulate and store data to its final destination. In order to ensure the validity of the data, a database consisting of different tables is used to process and store data to its final destination. The database will contain a table for every parameter and must be sent in the correct order with the correct title and time stamps, otherwise it will be ignored.

1) Weather Table: contains the weather parameters (humidity and temperature).
2) Soil Table: stores the moisture and temperature of soil.
3) pH Table: all the data about pH will be stored in this table.
4) Light Table: information about the light is stored in this table.
5) User Table: all the user credentials are stored in this table along with the user permissions.

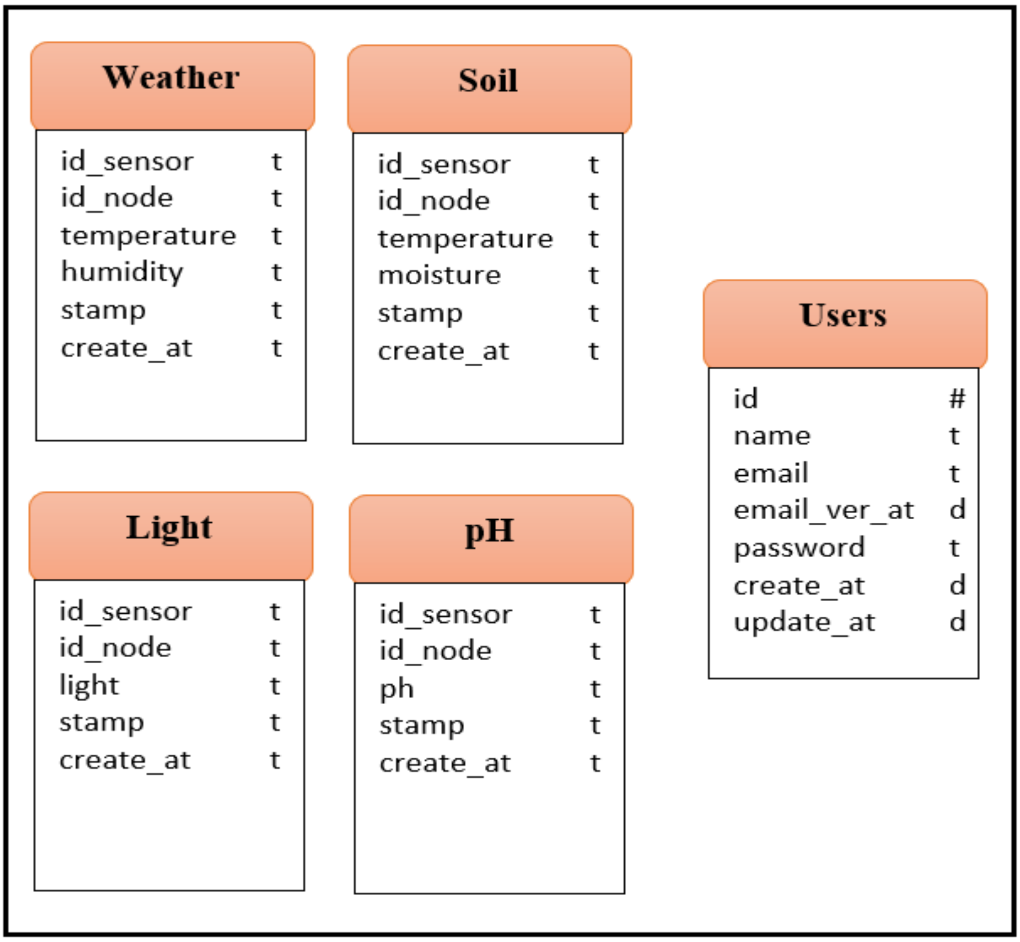



*Figure 4.2: Database Tables*

## 4.4 Web and Mobile Interfaces

In order to simplify the interactions between the user and the system, a set of graphical user interfaces (GUI) are proposed to the system. These interfaces are web and mobile applications that are used at real time monitoring to all of the indoor environmental parameters. The web application is the main GUI between the user and the system. It has the function to deal with incoming data from all sensors. The website is designed by using the latest Laravel framework of PHP as the main webserver with SQLite as a database service. The website manages many controllers:

- The user controller that manages user login, password changing process, and adding new user by the system administrator.
- Another controller that website could handle is the table controller. This controller manages all thing about viewing data in the database. There are many different types of data tables that can be viewed by website GUI such as air temperature and humidity, soil temperature and moisture, pH level, and the light intensity.
- The last controller that website could handle is the chart controller. It shows the charts for all environment parameters for air temperature and humidity, soil

temperature and moisture, pH level, and the light intensity. The data is displayed for specific period of time.

Figure 4.3 represents the interfaces diagram of the monitoring system. Both mobile and web applications can read data from sensors controlled by node with get http request using ESP32 API. To access the data base, mobile application uses Web API and POST request to get token and get request for the rest of communication.

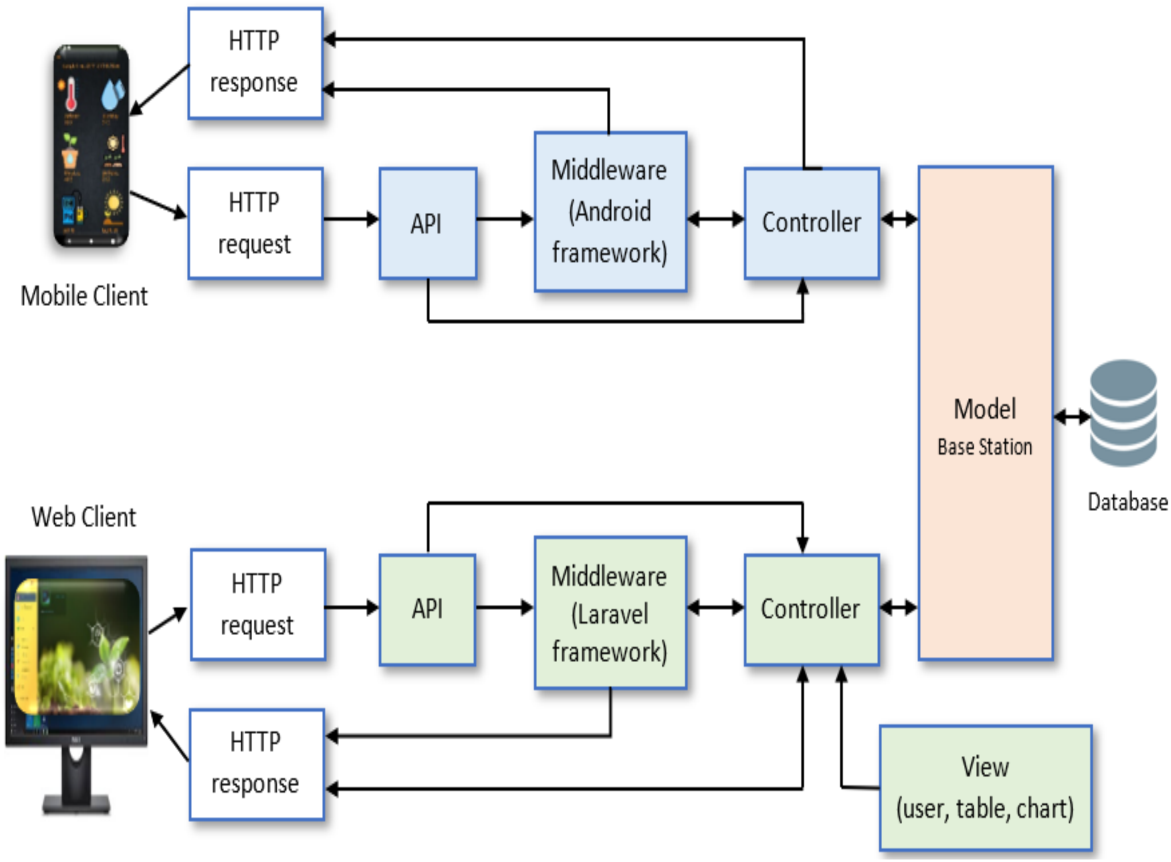



*Figure 4.3: Web and mobile Interfaces*

## 4.5 Implementation method

The procedure that will be taken to implement this system will involve the following parts:

- Implementing a hardware monitoring system using base station (Raspberry Pi) and sensor node (ESP32) with arranging several sensor elements on the place that designated for indoor plants.
- Selecting the appropriate software to assign each functionality to its respective hardware. Micro Python is selected to program ESP32, Python for Raspberry Pi, SQLite for database service, Laravel framework with PHP to create Web application, and Kotlin language for mobile application.

- Exchanging data between clients and the server by deploying the MQTT protocol that uses publish/subscribe operations.
- Testing the system by reading sample of a real time environmental parameters and finally evaluating the software operation of web and mobile applications.

The implementation of the proposed monitoring system in this work has been done in four stages. Starting from simple prototype (first iteration) to the final and completed design containing all sensors. The types and specification of each implementation method can be shown in table 4.1.

*Table 4. 1: Implementation Methods*

<table>
<tr><th rowspan="2">Implementation method</th><th rowspan="2">Prototype</th><th colspan="3">Monitoring Mode</th></tr>
<tr><th>Direct Console</th><th>Web application</th><th>Mobile application</th></tr>
<tr><td>1</td><td rowspan="2">Simple prototype uses only 1 sensor (temp sensor)</td><td>✓</td><td>✗</td><td>✗</td></tr>
<tr><td>2</td><td>✓</td><td>✓</td><td>✗</td></tr>
<tr><td>3</td><td rowspan="2">Final design uses all available sensors</td><td>✓</td><td>✓</td><td>✗</td></tr>
<tr><td>4</td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>

## 4.6 Simple Prototype Implementation

This is the primary prototype that uses only one sensor. It represents a first iteration in developing of monitoring system and also to test the functionality of the system working. The prototype consists of two stages depending on the monitoring mode: first design that reads the sensor environmental information from console display, and the second design that reads the information from both console and web application GUI. The sensor that is used here is the weather sensor that reads the air temperature and humidity. Both implementation methods use the following components:

- Base station (Raspberry PI)
- Sensor node (ESP32)
- Weather sensor (DHT22)

The hardware connection can be shown in figure 4.4. The connection between sensor node (ESP32) and base station (Raspberry PI) is Wi-Fi (IEEE 802.11 b/g/n).

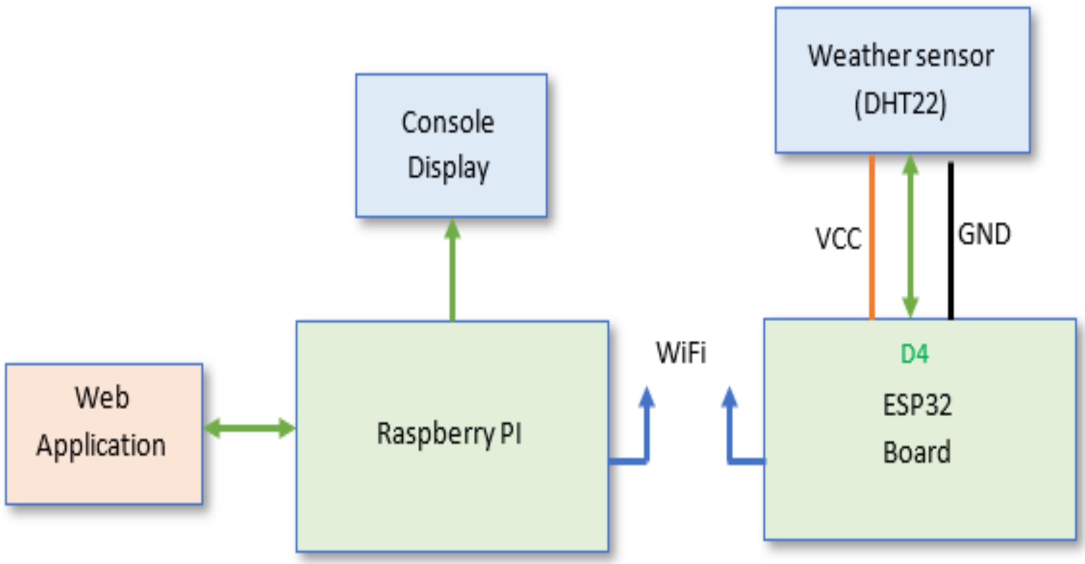



*Figure 4. 4: Block diagram of simple prototype*

The weather sensor is controlled by the sensor node ESP32 and connected with it by a wire connection as following:

- Connecting data pin of the sensor to the digital GPIO 4 on the ESP32.
- Connecting VCC pin on the sensor to the 3.3V pin on the ESP32 and ground to ground.

In the first implementation method, the data will be read from weather sensor (using Micro Python to program ESP32) and then moved to the sensor node ESP32 to be processed and convert this data to a correct format and prepared to transfer to the base station Raspberry PI. The data will be transferred over the Wi-Fi using MQTT protocol and then sent to console display in Raspberry PI as shown in figure 4.5.

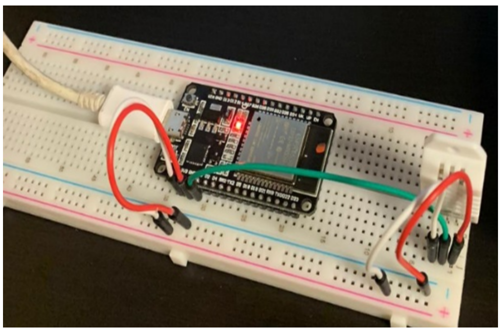


*Figure 4. 5: Hardware connection of simple prototype*

In the second implementation method, a website is designed by using the latest Laravel framework of PHP as the main webserver with SQLite as a database service to deal with incoming data from the weather sensor. The three components of MQTT protocol here are: publisher (ESP32), broker to receive data temporary, and subscriber to store data permanently in the database (Raspberry PI). The database will be the final destination to this data. The output data in second implementation method is displayed in simple website GUI application as shown in figure 4.6.

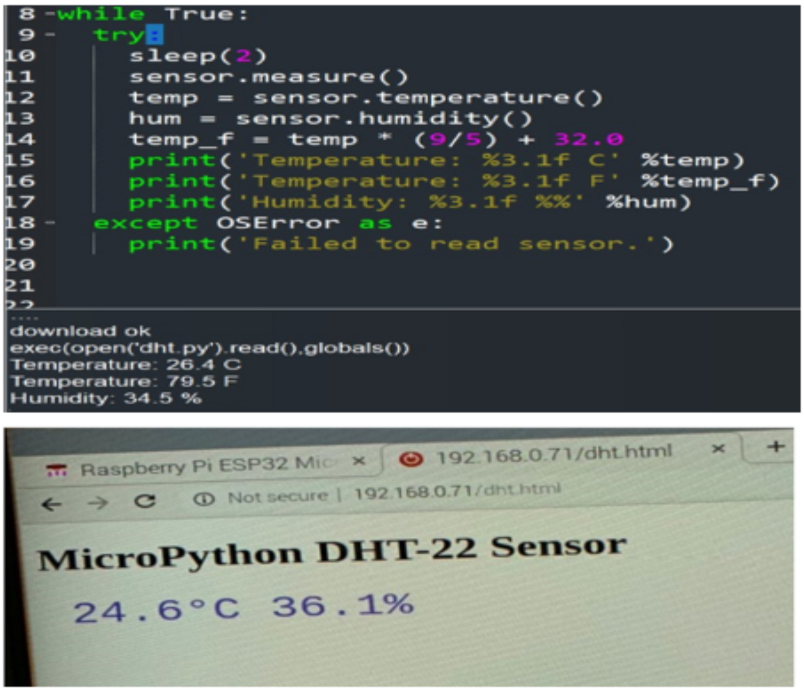



*Figure 4. 6: Sample data output on console display and in simple website application*

## 4.7 Final Design Implementation

This is the completed design that uses all available sensors that are assigned to this work. It represents the final iteration in developing of monitoring system. The design consists of two stages depending on the monitoring mode: third design that reads the sensors environmental information from both console display and website application GUI, and the fourth design that reads the information also from mobile smart phone application. Both designs use the following components:

- Base station (Raspberry PI)
- Sensor node (ESP32)
- Weather sensor (DHT22)
- Soil temperature sensor (DS18B20)
- Soil moisture sensor (FC-28)
- Light intensity sensor (GY-30)
- pH sensor (Liquid PH0-14)

The hardware connection can be shown in figure 4.7.

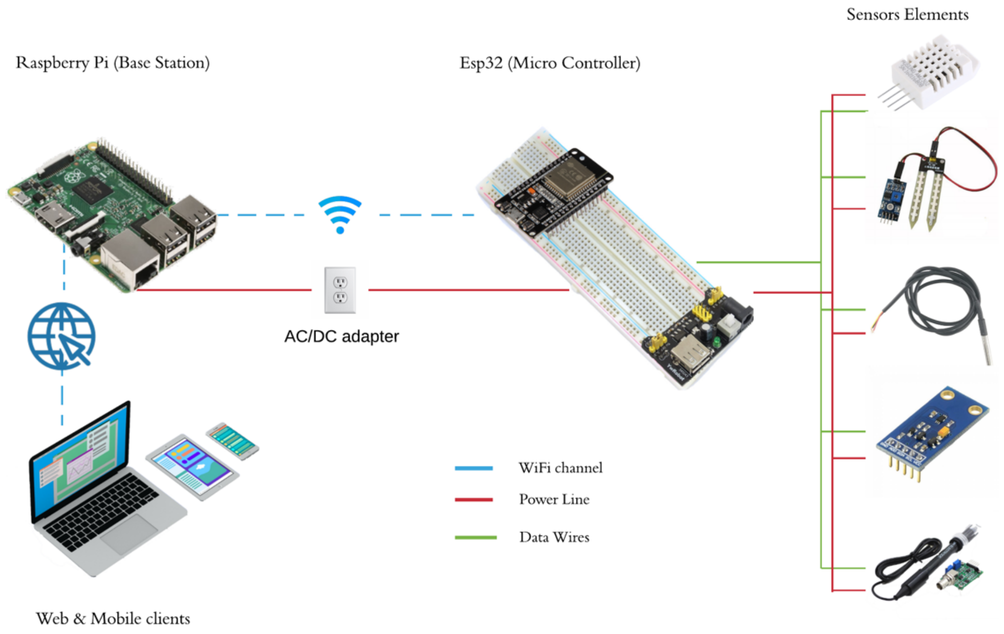



*Figure 4.7: Block diagram of final design*

The connection between sensor node (ESP32) and base station (Raspberry PI) is Wi-Fi (IEEE 802.11 b/g/n). All sensor elements are controlled by the sensor node and connected with it by a wire connection. Each sensor has a different method for connection:

- Air temperature and humidity sensor operate by connected them to digital GPIO (pin 4).
- Both pH sensor and soil humidity sensor connect to ADC GPIO (pin 39 and pin 34).
- Light intensity sensor connects to I2C GPIO (pin 23 as SDA and pin 22 as SCL).
- The last sensor which is controlled by ESP32 is soil temperature sensor which used 3 wires - Red connects to 3-5V, Black connects to ground and White is digital GPIO (pin 2).

The soil temperature sensor is different than other sensors and gives the ability to connect multi sensors on the same pin and later ESP32 scans this pin and can read all sensors on that pin consecutively.

In the third implementation method, the data will be read from all sensors (using Micro Python to program ESP32) and then moved to the sensor node ESP32 to be processed and convert these data to a correct format and prepared to transfer to the base station Raspberry PI. Figure 4.8 shows the processing stage of ESP32 after sending the data to the base station where it will be finally stored in the database. The data is transferred by deploying the MQTT protocol which requires server and clients. The server in the system (which is a broker in the same time) is the Raspberry Pi and the clients is classified into two groups, the first one is sensor node as a publisher, and the second one is the base station (Raspberry Pi) as a subscriber.

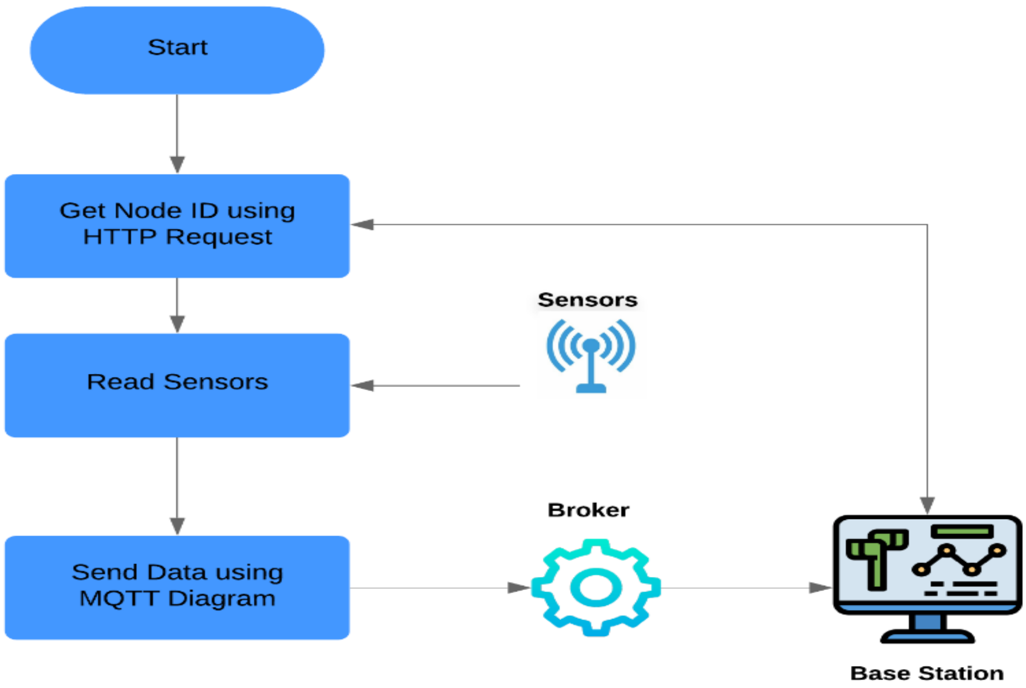



*Figure 4.8: Processing stage of sensor node*

Figure 4.9 shows the RPI API processing diagram. The node is getting unique identifier by using RPI API. This API uses get http request. Then this node sends MAC address and current IP address over WiFi to Raspberry pi when node started. RPI searches in the database if the node record is existing, it would update the node IP address and send the identifier. If the node record is not existing, it would create new identifier and send it to node. This identifier will use later in MQTT protocol when node sends data.

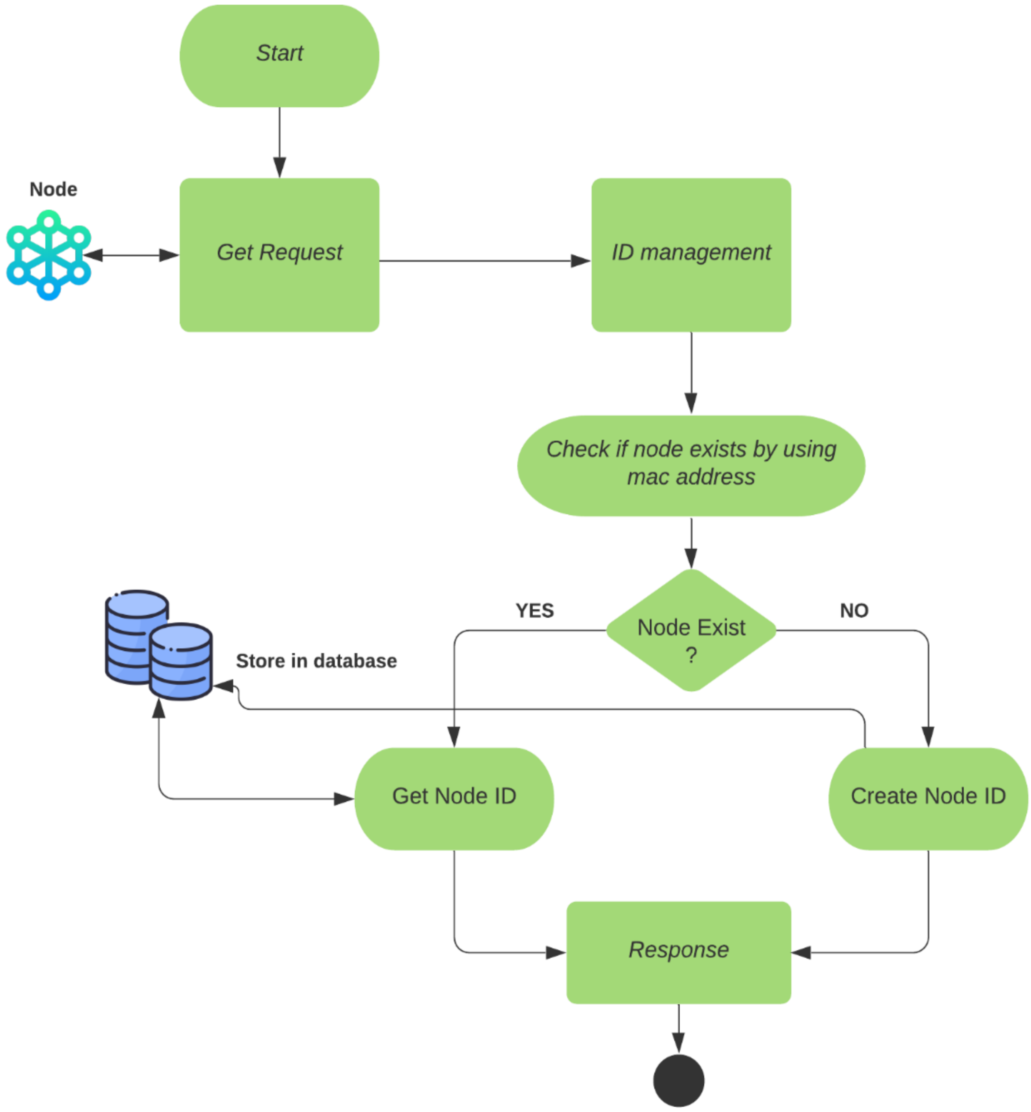



*Figure 4.9: Base station API processing diagram*

The data will be transferred over the WiFi using MQTT protocol and then sent to console display in Raspberry PI as shown in figure 4.10.


*Figure 4.10: Hardware connection of final design and data output on console display*

In the fourth and final implementation method, the environmental data will be displayed in website GUI and smart mobile application. The database will be the final destination to these data. The system database is designed using SQLite because it can be fit in such embedded devices which have limited resources.

A mobile application has been developed to perform most of the functionalities of the website and it can be controlled over the cloud which massively facilitate the administrative tasks for the user. The first step of the mobile application is the authentication and this step is to let the system administrator to add new users and change their registration information as in website application. Figure 4.11 shows the sequential diagram of mobile login process.

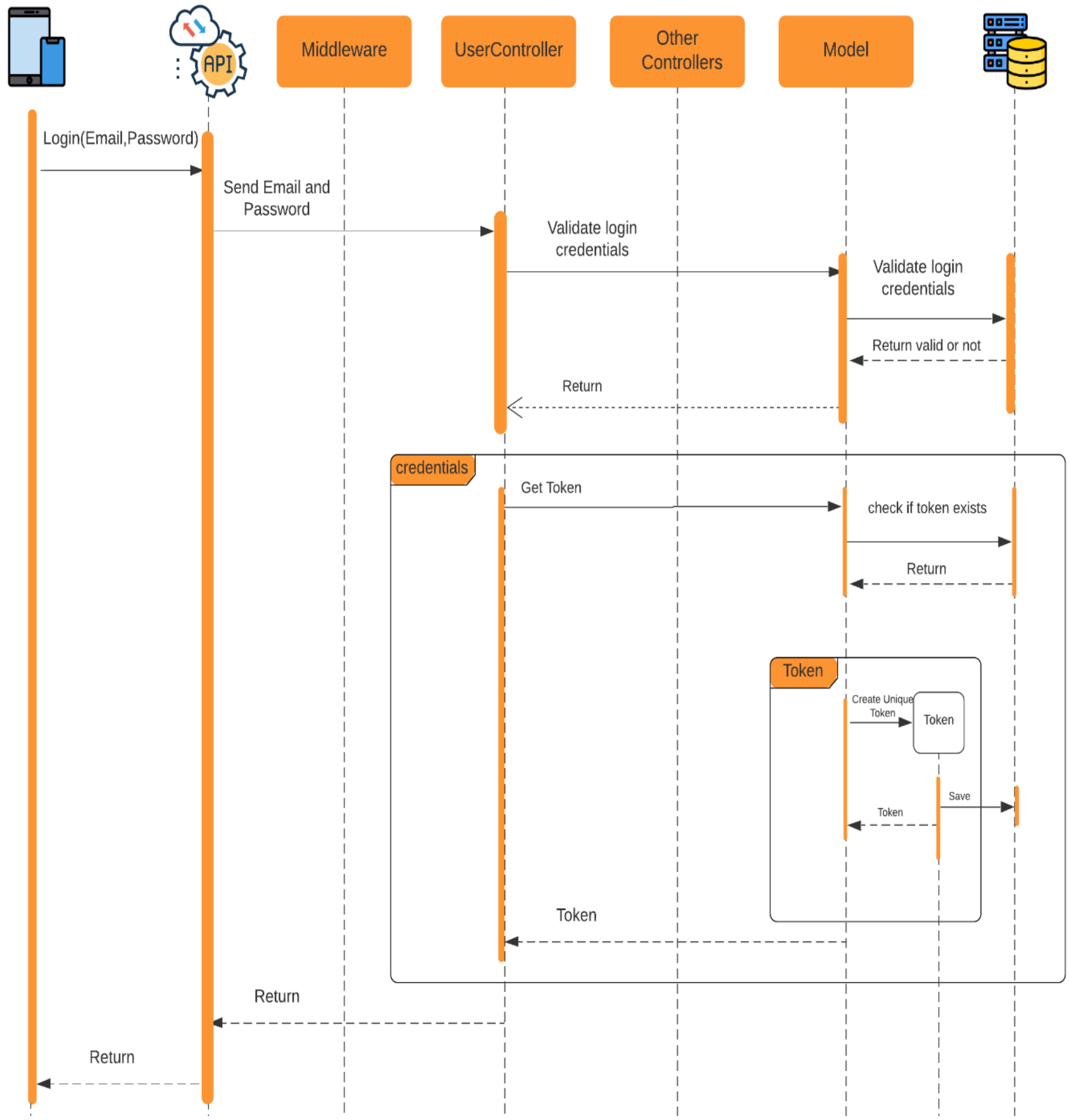



*Figure 4.11: Diagram of mobile authentication process*

The second step is to show the sensors status and reading live data from the sensor node. Figure 4.12 shows the procedure of the services for the mobile application that will facilitate to the user to use the monitoring system. The results of operation of final design method (web and mobile applications) for monitoring system will be presented in the next chapter.

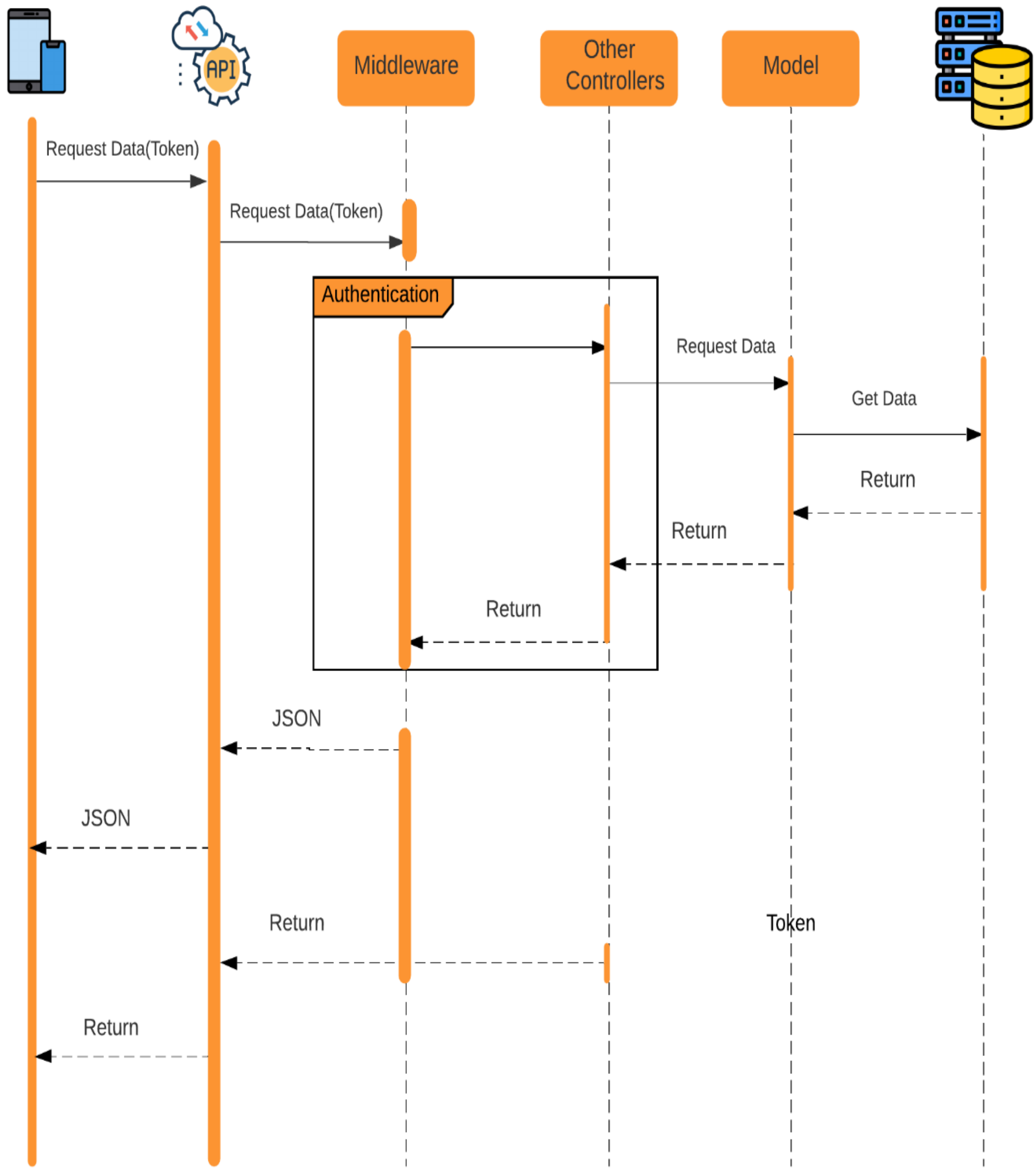



*Figure 4. 12: Diagram of mobile services process*

# 5. Results

The purpose of this chapter is to run the software to make the hardware functional and deliver the desired results to the user. The system operation is based on monitoring different indoor environmental parameters such as air and soil temperature, humidity, light intensity, and pH level using different sensors.

## 5.1 Running the Software

The proposed web application manages many controllers, one of them is user controller which manages user login, password changing process, and adding new user by the system administrator. Figure 5.1 shows the login page while figure 5.2 shows the home page and user controller of the web application. The user here can change the sample size of information and sets the time interval. Figure 5.3 shows the active nodes and chart controller of Web GUI. The other controller that website could handle is the table controller which manages all things about viewing data in the database. There are many different types of data tables that can be viewed by website GUI, such as air temperature and humidity, soil temperature and moisture, pH level, and the light intensity.

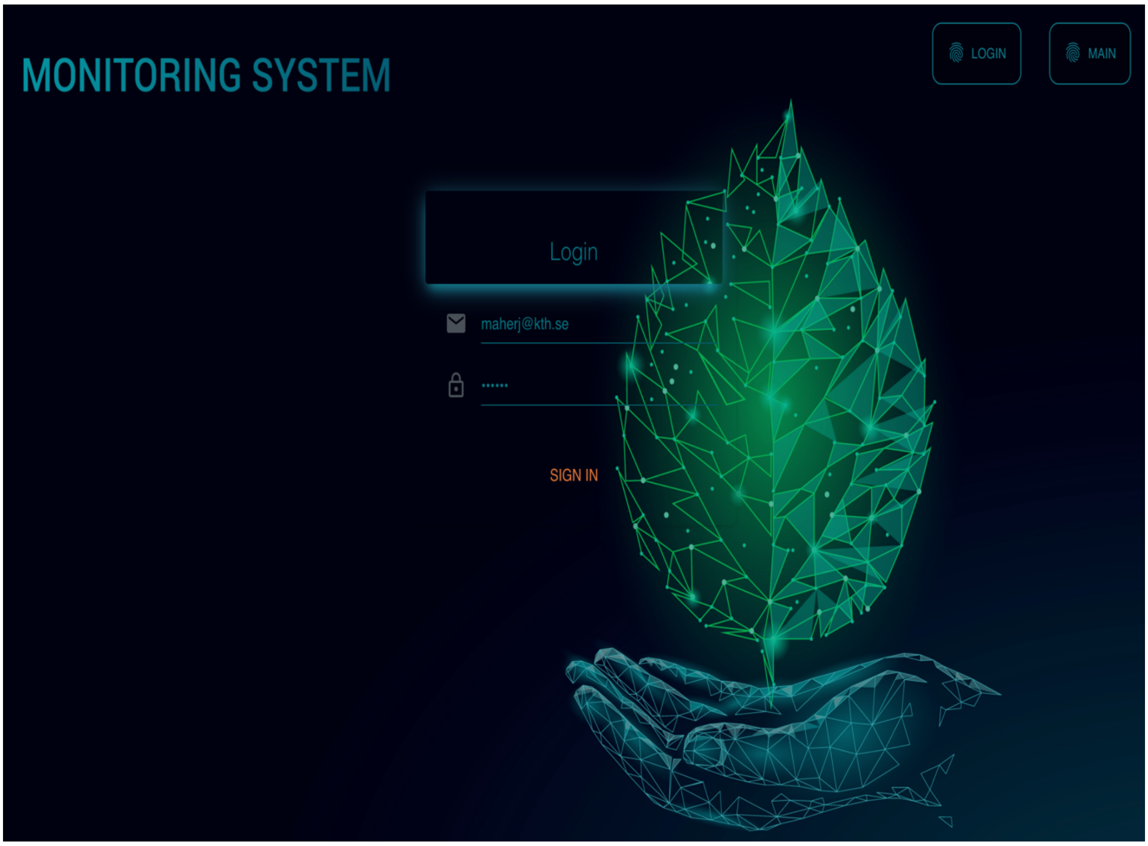



*Figure 5. 1: Login page of Web GUI*

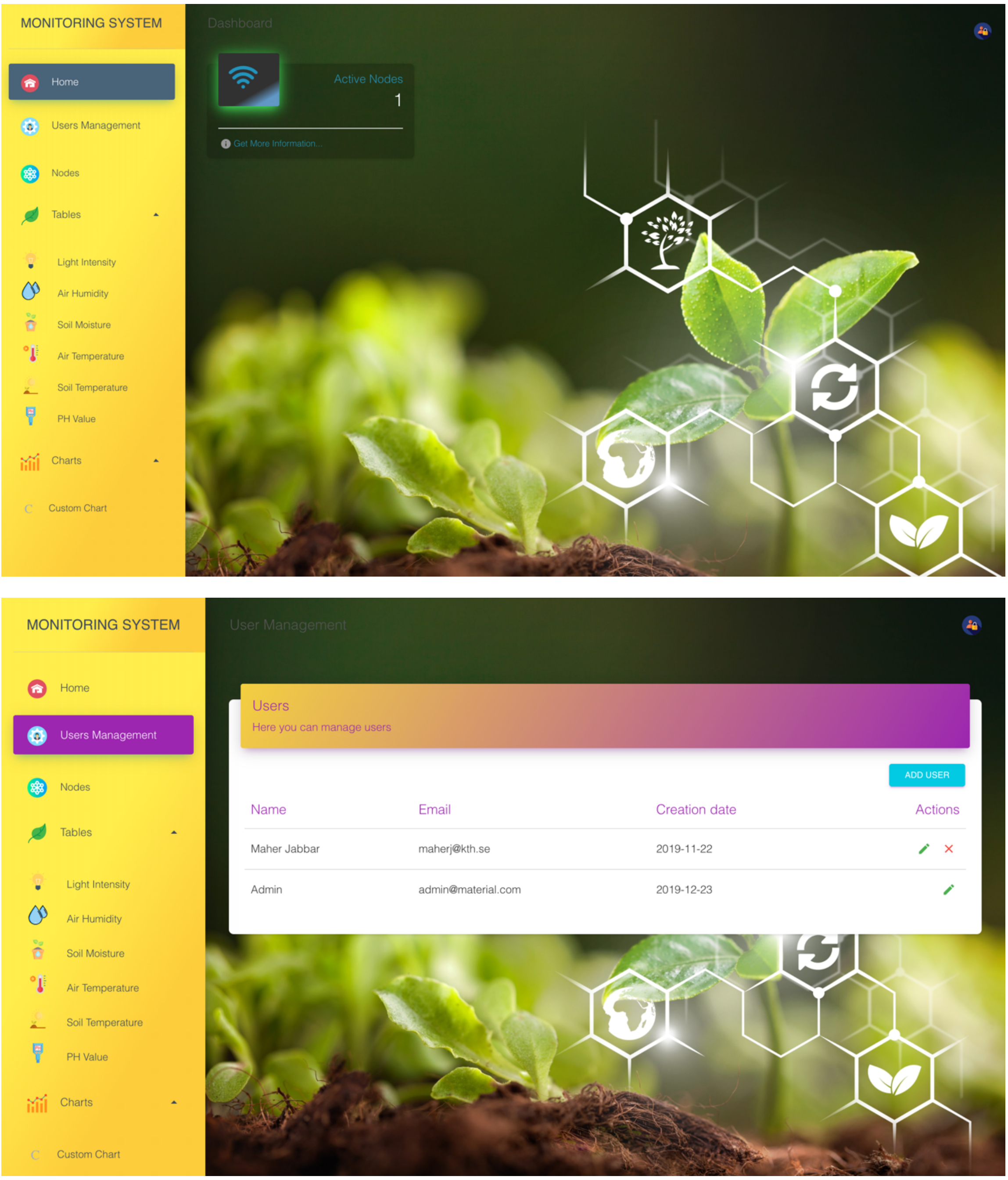
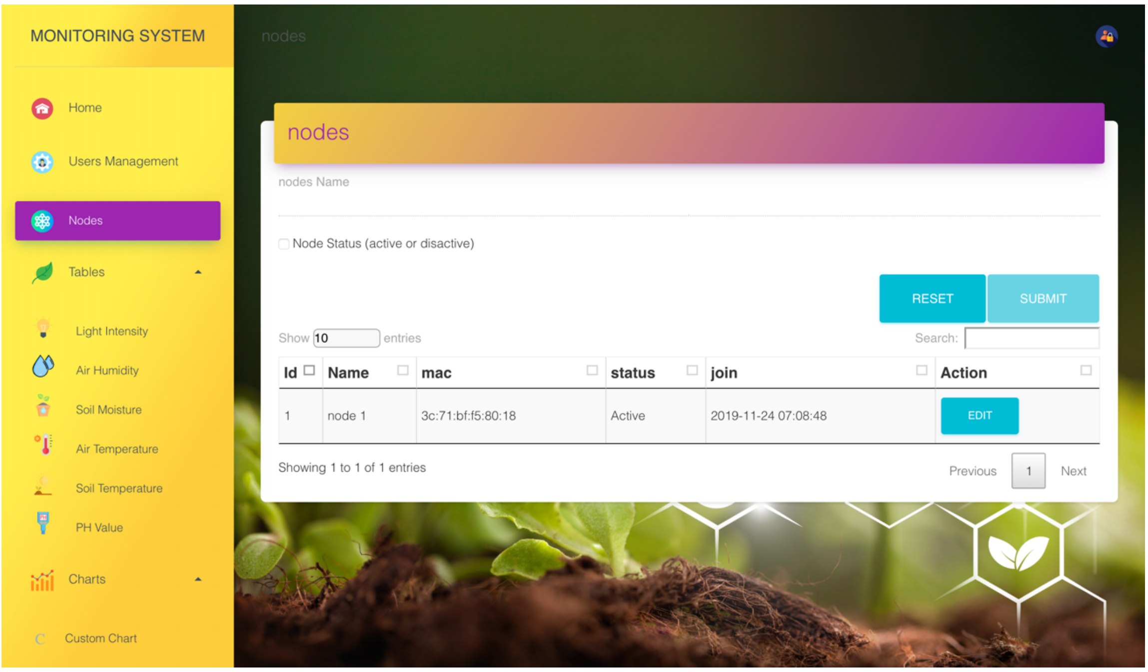



*Figure 5. 2: Home page and user controller of Web GUI*



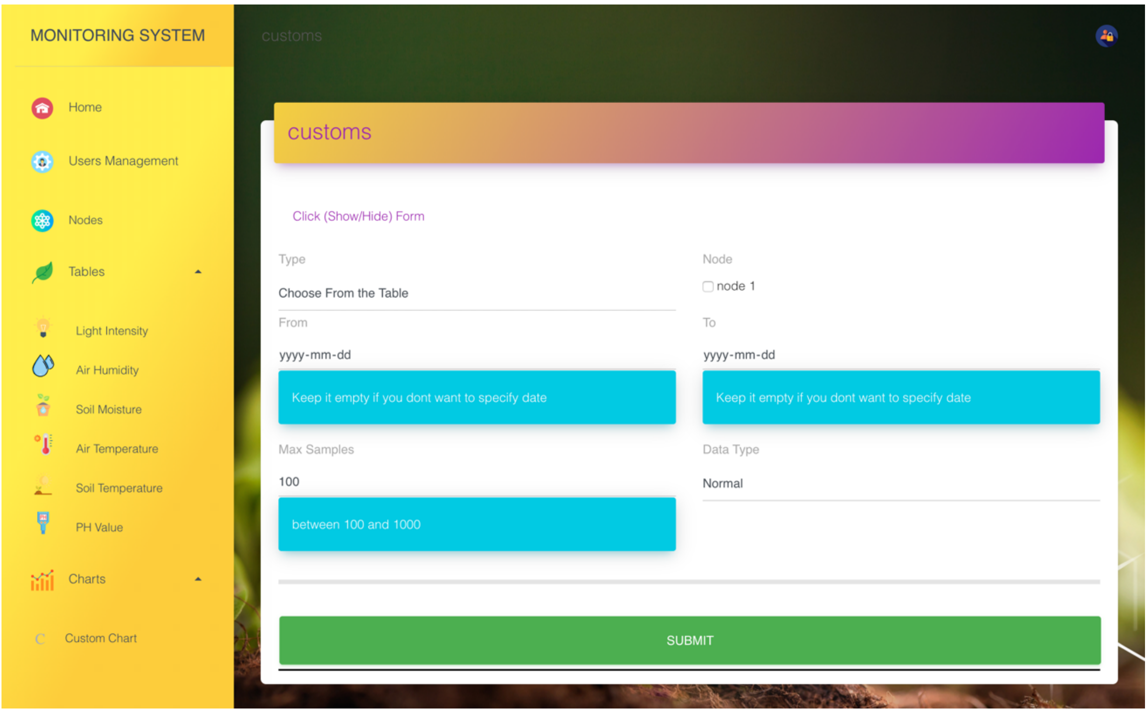




*Figure 5. 3: Active Nodes and chart controller of Web GUI*

## 5.2 Web Application

For the web application to work it needs a web server, application server and database. Web server (base station) handles client requests while the application server completes the requested task. The database can be used to store sensors information. Laravel PHP based application framework is used for creating the web application. It makes common development tasks easy such as routing, authentication, sessions, and caching. The framework provides an easy way to organize authorization logic and control access to all resources, and it allows extensive customization and comes with pre-designed packages.

### 5.2.1 System Operation

The sensors in the system will monitor a small pot (indoor environment) and information are stored in a database. The data which will be taken from pot are soil moisture, soil temperature and pH level, while other data will be taken from sensors which will monitor parameters surround that pot (figure 4.10).

The information will be read using different sensors and in different ways and then moved to the sensor node (ESP32), to be processed and prepared to transfer to the base station (Raspberry Pi). The node will convert these data to a correct format depending on what these sensors will measure. The data will be transferred over the WiFi using MQTT protocol using 4 parts:

1) Weather part to transfer data from weather sensors.
2) Soil part to transfer data from soil sensors.
3) Light part to transfer data from light sensor.
4) PH part to transfer data from pH sensors.

### 5.2.2 Information of Light Sensor

Figure 5.4 shows the data table of the light sensor. The light range between 0 and 65535 luminous (lx). The possible range is 0.001-0.02 lx for night, 50-500 lx for cloudy, 100-1000 lx for sunny indoor, greater than 1000 lx for sunny outdoor. If light levels are too high, the plant will heat up, resulting in a difference between plant temperature and the indoor air temperature.

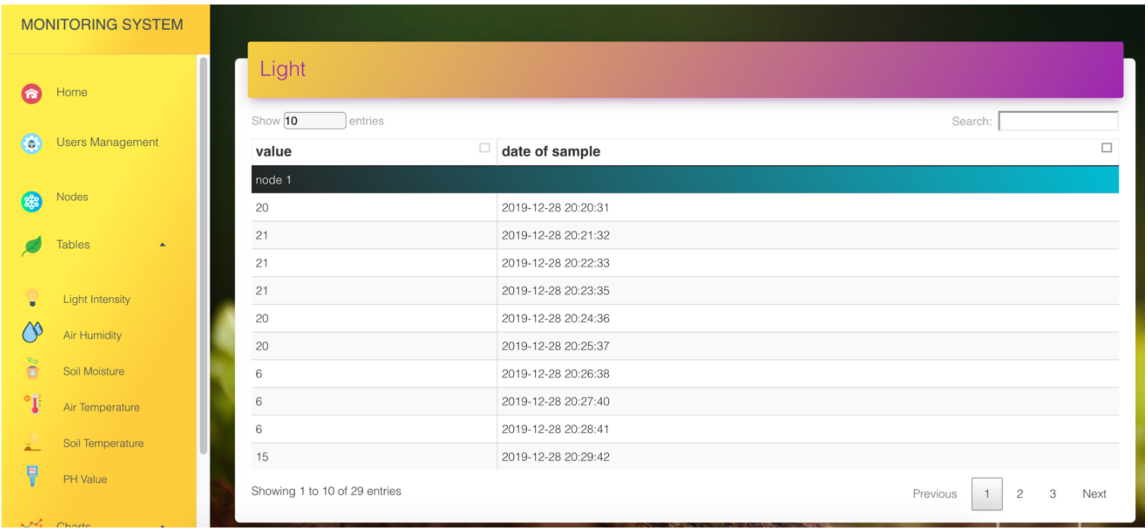



*Figure 5. 4: Data table of light sensor in Web GUI*

### 5.2.3 Information of Air Temperature Sensor

Figure 5.5 shows the data table of air temperature sensor. It measures the surrounding air temperature for the range -40 to 80°C. It is very important for irrigation process to track the value of indoor air temperature.

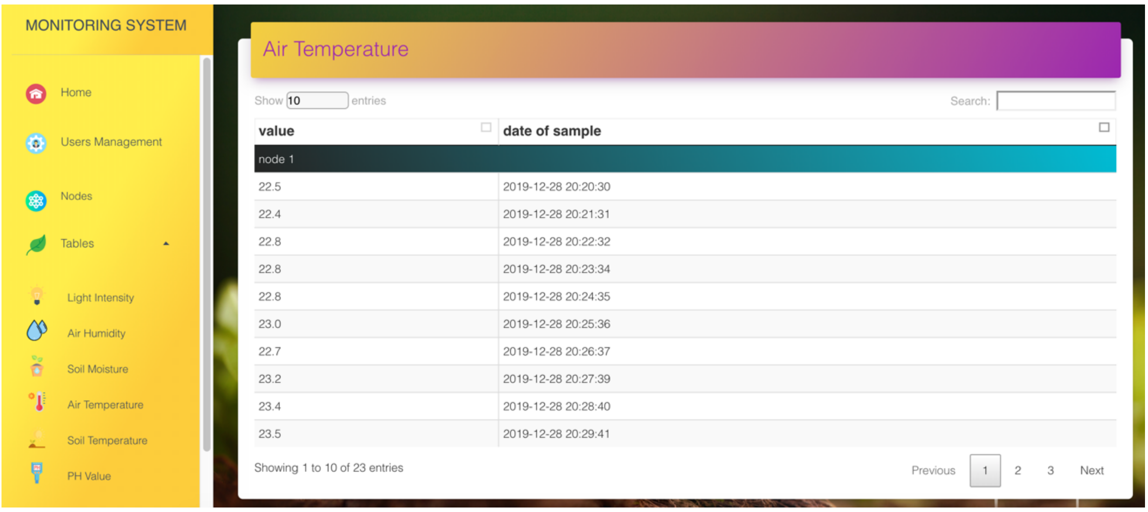



*Figure 5. 5: Data table of the air temperature sensor in Web GUI*

### 5.2.4 Information of Air Humidity Sensor

Figure 5.6 shows the data table of air humidity sensor. It measures the surrounding air humidity in the room for the range 0 to 100 %.

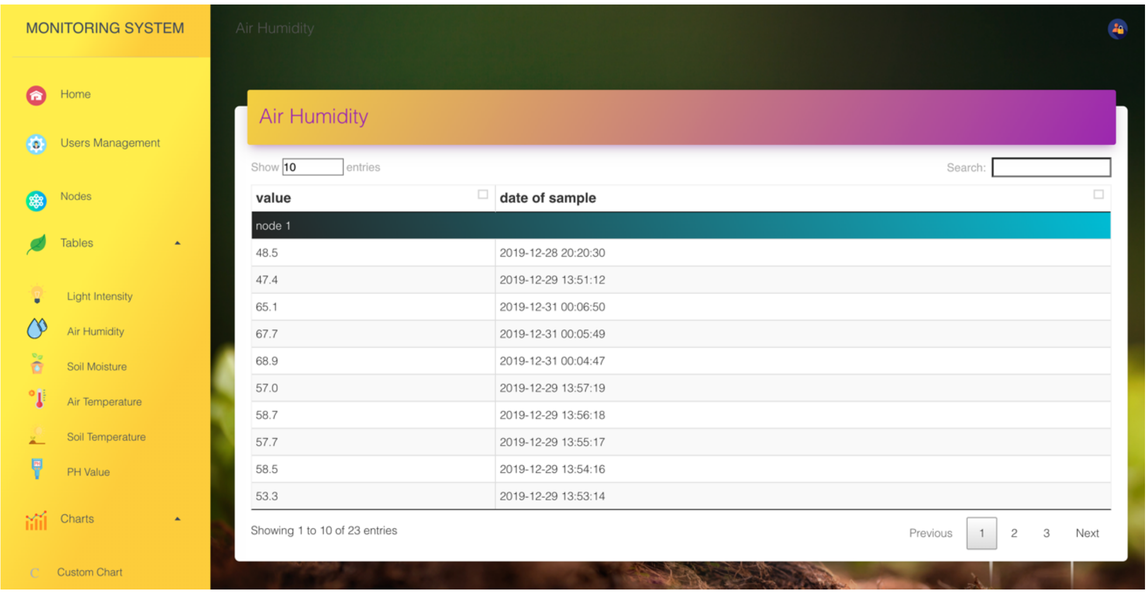



*Figure 5. 6: Data table of the air humidity sensor in Web GUI*

### 5.2.5 Information of Soil Moisture Sensor

Figure 5.7 shows the data table of soil moisture sensor. It measures the soil moisture for the range 0 to 100 %. This value is the quantity of water contained in the soil. Generally, the acceptable value will range from 10% to 45%, but can be higher during and after watering.

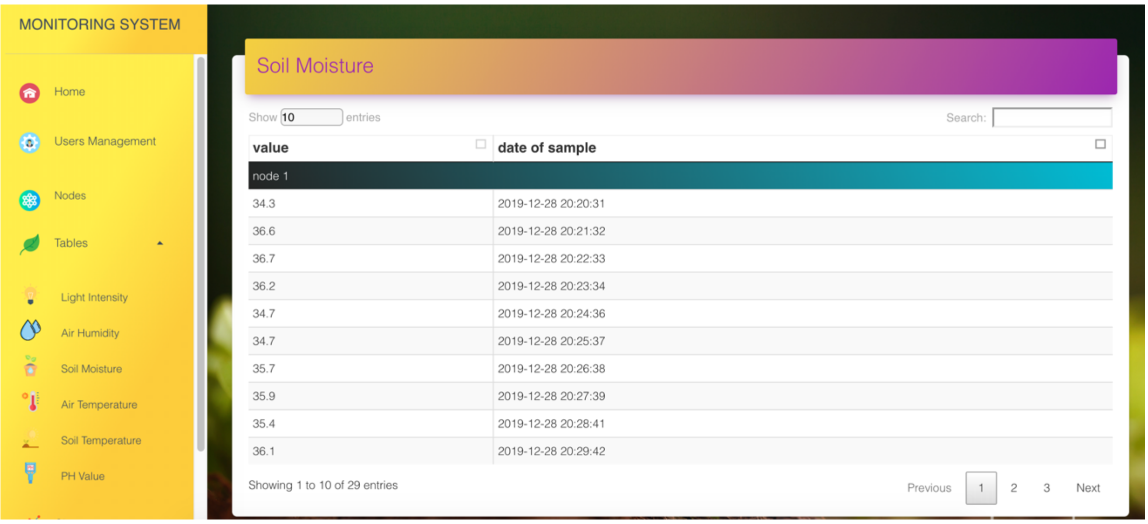



*Figure 5. 7: Data table of the soil moisture sensor in Web GUI*

### 5.2.6 Information of Soil Temperature Sensor

Figure 5.8 shows the data table of soil temperature sensor. It measures the soil temperature for the range -55° C to +125° C. Soil temperature affects plant growing indirectly by affecting nutrient and water uptake.

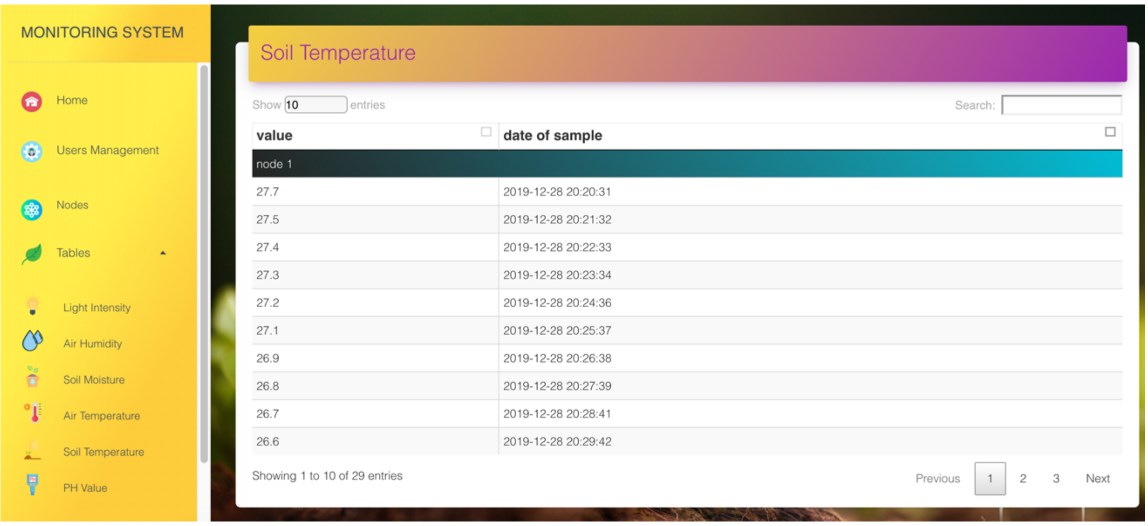



*Figure 5. 8: Data table of the soil temperature sensor in Web GUI*

### 5.2.7 Information of pH Sensor

Figure 5.9 shows the data table of pH sensor. Soil pH is a measure of the acidity (or alkalinity) in soil. The levels of pH vary from 0 to 14, with 7 being neutral, below 7 acidic and above 7 alkaline. The information of the plant and the soil is important in handling soil pH for the best plant growth performance.

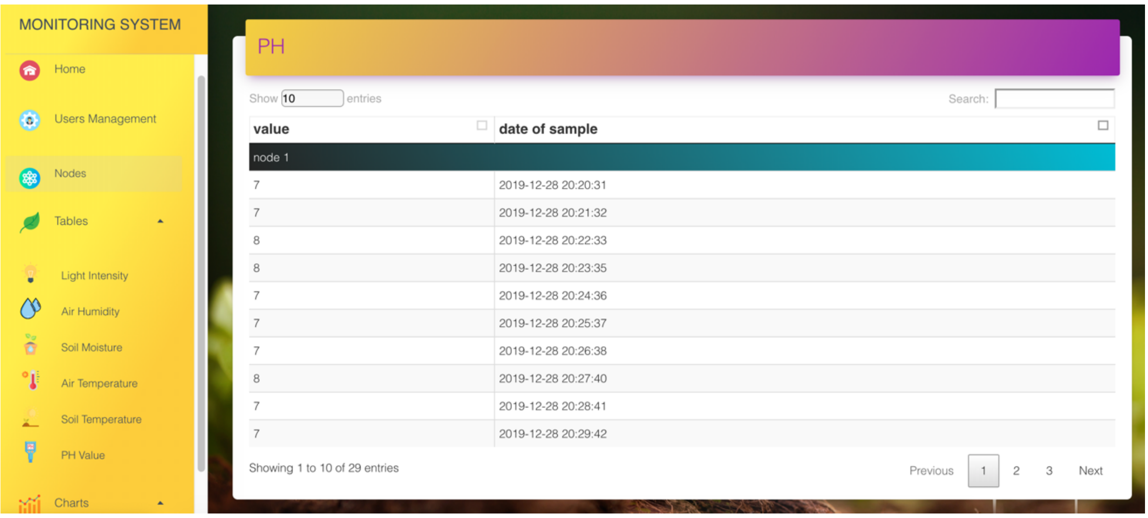



*Figure 5. 9: Data table of the soil PH sensor in Web GUI*

### 5.2.8 Website Chart Controller

The last controller that website could handle is the chart controller. Figure 5.10 and Figure 5.11 show the charts for all indoor environmental parameters for air temperature and humidity, soil temperature and moisture, pH level, and the light intensity. The data is displayed for specific period of time.

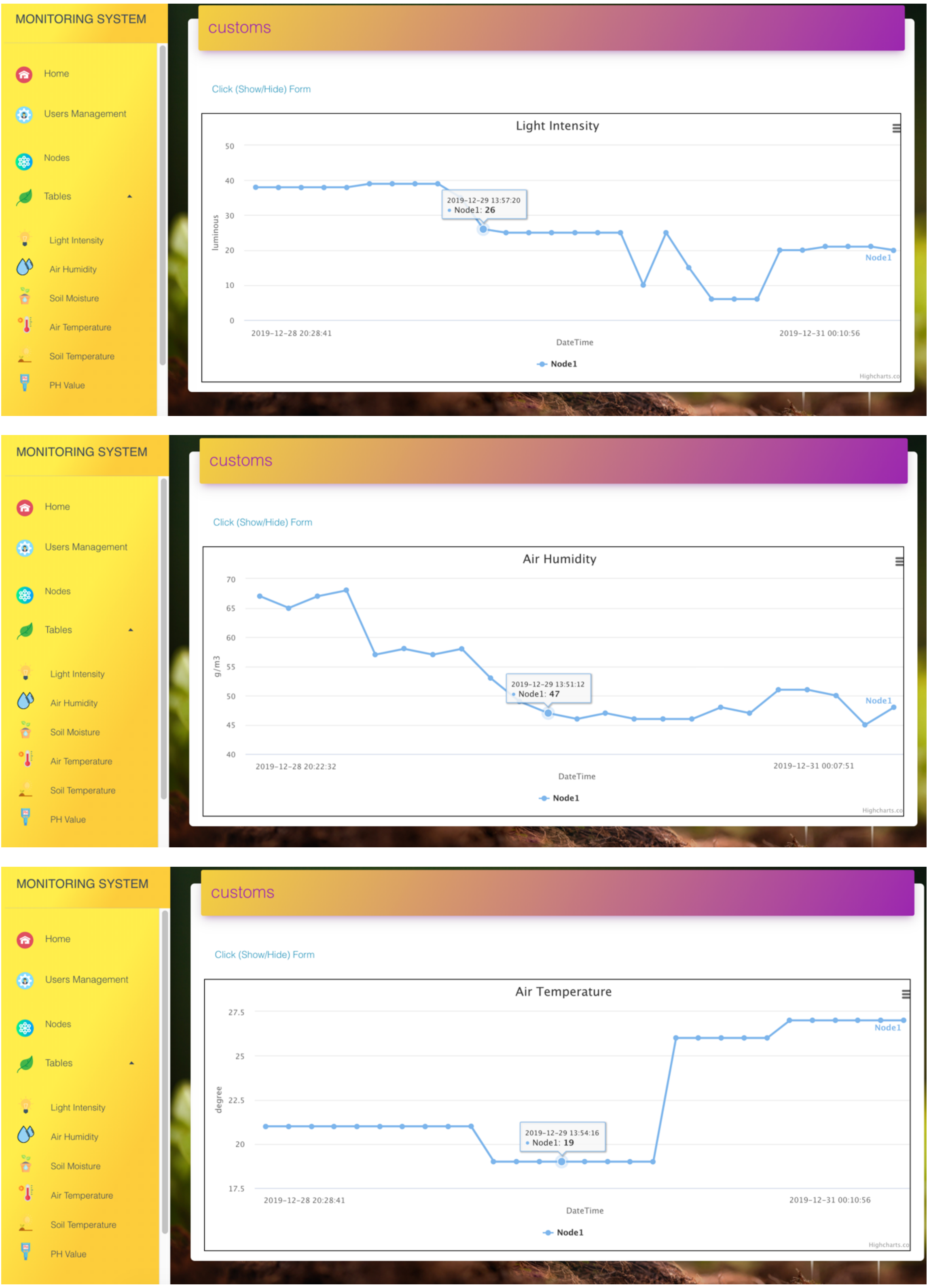



*Figure 5. 10: Charts for indoor environmental parameters in Web GUI*


*Figure 5. 11: Charts for indoor environmental parameters in Web GUI (continued)*

## 5.3 Smart Mobile Application

The Android SDK is used to develop an application for smart mobile based on Kotlin programming language. This language prevents common programming mistakes by design, resulting in fewer system failures and application crashes. It also helps to reduce errors and bugs in the code.

### 5.3.1 Application GUI

A mobile application has been developed to perform most of the monitoring functionalities of the web application. It can be controlled over the internet by connecting to the IP of base station (hosted database), which massively facilitate the administrative tasks for the user. There are two steps to run the application.

- The first step is the authentication and this step is to let the system administrator to add new users and change their registration information, as in web application. Figure 5.12 shows the user login process in mobile GUI.


*Figure 5. 12: Login page of mobile application*

- The second step is to show the sensors status and reading a live information from the sensor node. Figure 5.13 shows the home screen to monitor and track all six sensors information on mobile GUI.

The functions of mobile application are adopted to all services on the web API. Since the mobile application needs token, it has to send an email and password using post HTTP request to the web API. If the email and password are valid (which are already stored in the database on base station), the token is sent back to the mobile application, otherwise an error page will be appear to the user.

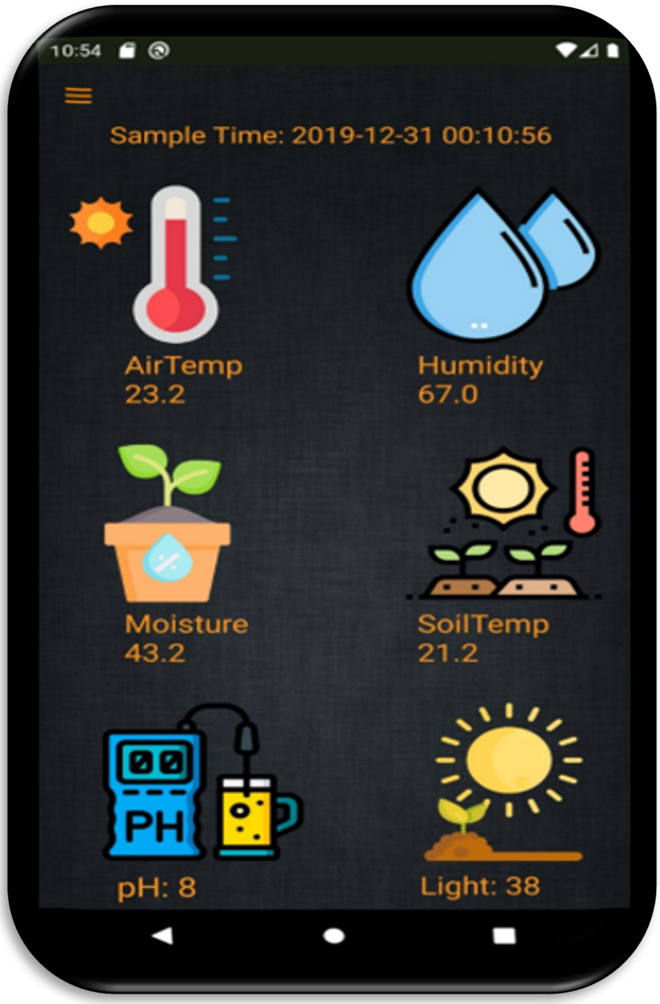



*Figure 5. 13: GUI of mobile application*

# 6. Analysis and Discussion

This chapter discusses the results (with the aim of verifying that the system has practical potential) and system performance that is evaluated after monitoring different indoor environmental parameters, such as air and soil temperature, humidity, light intensity, and pH level, using different sensors. This section is also representing the proof of concept (POC) (in terms of practical using and technical capabilities) to verify concepts wireless sensor theory have the potential for real-world application and it is designed to determine feasibility.

On the basis of results obtained through monitoring system, the evaluation of these results has been done based on the research questions and main goals. The mean goal is to develop a user-friendly monitoring system and provide user such interface that is easy to use by seeing the results in both web GUI and mobile applications. I think the proposed system that have been developed is quite easy to operate and also efficient and do not involve complicated processes. Anybody can access the monitoring system by simply using the mobile application or web GUI as shown in the results chapter. The proposed system provides personal login facility so that anyone can exclusively monitors its indoor plants. Web GUI shows very promising results when comes to monitoring, it has all the interfaces like for monitoring light, air temperature, air humidity, soil moisture, soil temperature, and pH level. For the detailed checking of sensors and results provide by them, node 1 has been used as an example to analyze sensors. It can be seen in figures 5.4-5.9 that all the sensors worked correctly as all measurements taken by them are in the range of sensors. This concludes that all the sensors are perfectly working and monitoring all the required parameters efficiently.

Practically this system aims to help user acquire information about the indoor environmental parameters and gives opportunity for him to use the mobile device to be in contact with the weather changes. Also, the availability of system materials on the market and their cheap price makes possible to the system be widespread in many areas. It needs only three main components: sensing, data exchange, and GUI application component. Sensing component consists of sensor elements that observe or take action in the environment they are arranged in. Objects can be of different specifications or constructions and can come from different vendors. Information and data is exchanged among different objects of system via data exchange components. Data exchange components have a set of communication protocols to allow data flow. GUI application component defines services or actions to be taken on the data collected by objects. The acquired data can be used in various domains, such as a web application or smart mobile application. This component also defines and manages the behaviors of sensor objects. The system provides a user-friendly and scalable houseplant monitoring application with the following characteristics:

- The system hardware does not obstruct user activities while at home.
- Web and mobile applications are easy to use for non-experts and do not involve complicated processes.
- Hardware and software components operate under many conditions without changing the facilities and equipment at home.
- The system monitors and tracks most indoor environmental parameters under various conditions.
- It should make effective use of monitoring information in real-time to let the user to take the required action.

The system designed and proposed has also got many societal, ethical and environmental benefits. Plants can provide humans with essential substances such as medicine, food and fiber for daily use, even if they are indoor plants [1]. It also affects a person's physiological and psychological health [2]. Thus, increasing the quality of life and well-being of their caregivers and by empowering people with the opportunity to increase plant productivity to be more self-sufficient. From an ethical point of view, no negative impacts on human life and society were observed as a result of using this application. Talking about environmental benefits or impacts, one thing is pretty clear that plants are always considered good for environment whether they are small or large, outdoor or indoor plants. Plants produce oxygen and absorb dangerous gasses like carbon dioxide from environment thus making clean environment. The system we propose to monitor indoor plants is also very environmentally friendly as it does not alter any environmental parameters of room or building, it only monitors the temperature, humidity, and many other parameters by simple environmentally friendly devices. None of the devices utilized in monitoring system are equipped with anything mechanical, they are all electrical devices thus not producing any waste for environment.

## 6.1 Performance Analysis of the Monitoring System

Based on the first research question (***RQ1 Can an environmental monitoring system be established to improve indoor plants?***), many subquestions have been formulated with their answers.

**SQ1. How to use the sensors to handle various indoor environmental parameters?**

The process of reading data from indoor environment is done by sensor elements. The sensor node collects data from the environment by deploying the sensors elements and then the collected data will be transmitted to the base station, where it will finally be stored in a database. MQTT protocol can be used for this purpose because[28]: packet agnostic (the data could be text or binary, it does not matter as long as the receiving party knows how to interpret it), reliability, scalability (the publish / subscribe model scales well in a power-efficient way), time (a device can publish its data regardless of the state of the subscribing server). As previously shown in figure 3.2, that shows a simple network with three clients and a central broker. All three clients open TCP connections with the broker. Clients B and C subscribe to the topic temperature (figure 3.2a). At a later time, Client A publishes a value of topic temperature. The broker forwards the message to all subscribed clients (figure 3.2b).

**SQ2. How to establish a communication between the sensors and a software application?**

There are many communication protocols standardized for IoT applications. Performances of these protocols may significantly deviate from each other even under the same operating conditions. MQTT is a lightweight M2M communication protocol for constrained devices and unreliable networks. It has publisher/subscriber client which runs over TCP/IP. Also, TCP provides message reliability and bidirectional connections between nodes. The nodes can publish messages with some specific topics on Broker, and accordingly, different nodes can subscribe these topics to receive messages. The Broker, which must control the traffic of this message, takes part in communication. In fact, Broker is a server where clients can publish/subscribe topics and the message traffic run through [46].

**SQ3. How to handle the indoor environmental parameters in a web application?**

The web application is the main GUI between the user and the system. It has the function to deal with incoming data from all sensors. The website is designed by using the latest Laravel framework of PHP as the main webserver with SQLite as a database service. The web application uses many controllers, one of them is user controller which manages user login, password changing process, and adding new user by the system administrator. The user here can change the sample size of information and sets the time interval. The other controller is the table controller which manages all things about viewing data in the database. There are many different types of data table form that can be viewed by web GUI, such as air temperature and humidity, soil temperature and moisture, pH level, and the light intensity. Another controller is chart controller, which shows the graph of parameters within period of time.

**SQ4. How to handle the indoor environmental parameters in a smart mobile application?**

A mobile application has been developed to perform most of the monitoring functionalities of the web application. It can be controlled over the internet by connecting to the IP of base station (hosted database). The application is designed to provides a user-friendly GUI monitoring application with clear visualization for parameters values. There are two steps to run the application: the first step is the authentication to let the system administrator to add new users and change their registration information. The second step is to show the sensors status and reading a live information from the sensor node.

**SQ5. How to test and evaluate the proposed system?**

To ensure that the system is operating as intended, it must be tested. The focus was on the sensor node, the web server (base station) can be connected to the Internet and communicate with client applications (web browser and smart mobile). To see if the base station (Raspberry) is successfully connected to the Internet and transmitting sensor readings, it is sufficient to check the values stored in the database.

To verify the reliability of the data, measurements of environmental parameters (light intensity, air temperature, humidity, soil temperature, soil moisture, and acidity of irrigation water) have been taken in different indoor conditions and locations. In this way it can be observed whether the readings have the same values despite the change of location and environmental parameters. The data reliability from sensors has also been ensured by using authentication process between user and system in both web and smart mobile applications. In order to ensure the validity of the data, a database consisting of different tables has been used to process and store data to its final destination. The database contains a table for every parameter and must be sent in the correct order with the correct title and time stamps, otherwise it will be ignored. The evaluation of the monitoring system in this work has been done in indoor environment. After experimenting with operating the system and reading the information received from the sensors in the web and mobile applications, no major problems or failures resulted from the process of sensors reading, data exchangeability, data visualization, environmental parameters reliability, or even applications usability. Therefore, it can be said that the system will not hinder user activities due to the lightness of the hardware components and ease of use. Web and mobile applications do not need expert to deal with them and do not include any complex operations.

## 6.2 Economic Benefits

Based on the second research question (***RQ2 What are economic benefits of using such this monitoring system?***), many subquestions have been formulated with their answers.

**SQ6. How can the proposed system in general be used for?**

The monitoring system with an application enables the user to monitor and track the indoor environmental parameters with the aim of permitting a more effective care of indoor plants. It benefits the user for many reasons like decision making and helps to use the irrigation water in an efficient way. The user will be able to use smart mobile and web applications to monitor remotely the most of weather and soil parameters. These parameters can give information on real-time air temperature and humidity, soil temperature and moisture, an amount of light and the acidity of irrigation water.

**SQ7. How can control of the water enhance the houseplant?**

The monitoring system has not only saved the time, but has also reduced the excessive use of resources such as water. As a result of the immediate information that the user will get about the indoor environmental parameters, the irrigation period will be limited only to specific times. Thus, there will be an economy in the use of irrigation water, especially in places where water is scarce.

*The best time for irrigation process is when:*

- Light sensor level is too high, the plant will heat up [4].
- Air and soil temperature sensors level are high [8].
- Soil moisture sensor level is too low, moisture can result in plant death [7].

**SQ8. How can control of the soil fertilization enhance the houseplant?**

Fertilizers supply plants with the elements that can be used by the plants for faster growth. Most fertilizers supply nitrogen, phosphorus and potassium [43]. The design of affordable monitoring system aims to maintain and improve soil fertility through optimizing the use of fertilizers, effective care of indoor plants through the use of mobile application.

*The best time for soil fertilization process is when:*

- Soil temperature sensor level is high. Affects plant growth indirectly by affecting nutrient uptake as well as root growth [7].
- pH sensor level is too low or too high. Increasing acidity or alkalinity in the soil [9].

Figure 6.1 shows the best time for irrigation and fertilization process for effective care of indoor plants through optimizing the use of water and fertilizers.

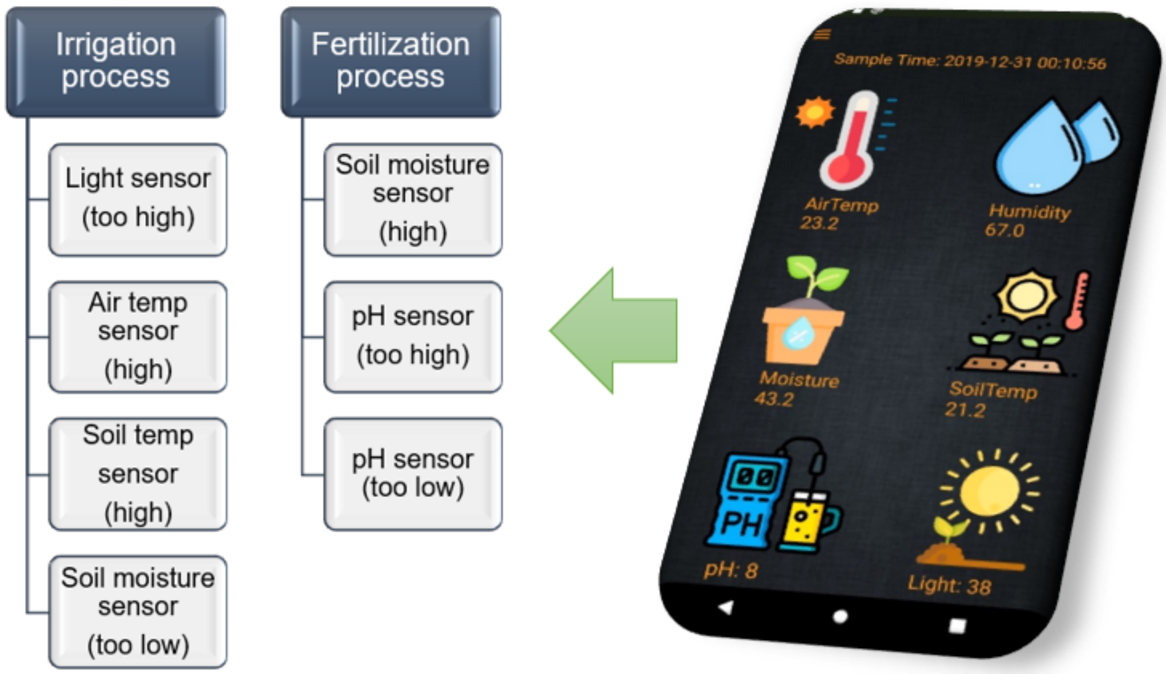



*Figure 6. 1: Best time for irrigation and fertilization process*

Table 6.1 shows the effect of knowing this information on the houseplant and what is the required action [4][6][7][8][9].

*Table 6. 1: Houseplant problems and the related required action [4][6][7][8][9]*

| Sensor type | Problem type | The required action |
|---|---|---|
| Light | Light levels are too high, the plant will heat up, resulting in a difference between plant temperature and air temperature | Irrigation process |
| Air temperature | Risk for plant diseases | Irrigation process, Pesticides |
| Air Humidity | Plant disease | Use preventive pesticides |
| Soil temperature | Affects plant growth indirectly by affecting water and nutrient uptake as well as root growth | Irrigation process |
| Soil moisture | Too little moisture can result in plant death, but too much causes root disease and wasted water | Irrigation process, and use fertilizers |
| pH | Increasing acidity or alkalinity in the soil | Use fertilizers |

Another important factor in economic feasibility is the system cost. The goal here is to keep the cost as low as possible in order to make the hardware and applications easier to deploy for the users. The software and tools that are used to implement the monitoring system are open source. Regarding the hardware (Appendix-B), the cost is described in table 6.2.

*Table 6. 2: Cost of the system components*

| Item | Model | Price (SEK) |
|---|---|---|
| Base station | Raspberry PI 3B+ | 450 |
| Microcontroller (Sensor Node) | ESP32S | 42.34 |
| Weather Sensor | DHT22 | 32.86 |
| Soil Temperature Sensor | DS18B20 | 35.79 |
| Soil Moisture Sensor | FC-28 | 9.57 |
| Light Intensity Sensor | GY-30 | 10.52 |
| pH Sensor | Liquid PH0-14 | 124.95 |
| **Total** | | **706.03 SEK = 85 $** |

According to this table, the final cost does not exceed 85 $, and this cost appears small, compared to the benefits and facilities that this system will offer to monitor and track the indoor environmental parameters remotely.

# 7. Conclusion and Future Work

This chapter contains conclusions about the project from the hardware and application development aspects. Ideas for future work will be presented in this chapter as well.

## 7.1 Conclusion

On the basis of results obtained, it is concluded that the proposed monitoring system works rightly for the problem it is made which is monitoring of environmental parameters associated with the indoor plants. The final system works as intended, although the goals that were presented at section 1.4 were achieved but the environmental sensors were not 100% accurate. This is due to these sensor elements are affected by the heat generated as a result of the electronic parts. The information from sensors will help the user in order to monitor the indoor environmental parameters and allow them to take decisions according to them. The immediate information about climate from sensors allow user to restrict the irrigation periods. Economically, as a result thus lets to use water in more efficient way and save the natural resource. The major advantage that comes out of this monitoring system is its remote usage, anyone can access and monitor the environmental parameters linked to plants via mobile application or web application through connection with Wi-Fi. Web and mobile applications are easy to use for non-experts and do not involve any complicated processes. The system monitors and tracks most indoor environmental parameters under various conditions so the user can get real time information about temperature, humidity, soil, at any place via mobile application. The proposed system is pretty flexible as it works wirelessly, thus it can be modified, expand, altered, and can be used in any condition.

## 7.2 Future works

Despite the scale of the problem, the initial objectives were achieved. In this section, we will focus on some potential changes that can be addressed in future work.

1. The current system can be extended to control the irrigation process (controlling the water valve operation) by choosing the suitable amount of water for plants. Creating an automated irrigation system will directly affect the general control of water consumption and keep the soil safe.

2. The current web and mobile applications can be developed to deliver alerts to the user (as example, best time for irrigation and fertilization process) using an email or SMS.

3. The testing process was performed in a controlled environment where all indoor parameters can be manually adjusted using certified measurement tools (this will allow comparison of difference in accuracy at the same place and validation of factory sensor calibration). It was concluded that there was a difference in accuracy. By solving this problem (choosing more accurate sensors) it will make the system more practical to use, as it will fully meet the goal set in relation to its planned functions.

4. Adding more information in the web GUI application about the different plants such as general information about the plant, how seasons affect the plants, and much more. The possibilities that comes with web GUI seems to be infinite, one can change and customize the controls in web GUI depending on added functionality, the needs for users and especially input from the users.

5. It is possible to use some of the advanced sensors to develop the current system such as:
    - Taking periodic images to plant by installing closed-circuit television (CCTV) to monitor the growth progress.
    - By measuring nutrient level in the soil, it is possible to let the user knows when to add nutrient to the water during irrigation process.

# References


[1] L. V.I., "WHAT ARE THE BENEFITS OF PLANTS INDOORS AND WHY DO WE RESPOND POSITIVELY TO THEM? | International Society for Horticultural Science," Nov. 2010. http://www.actahort.org/books/881/881_111.htm.

[2] K. Dijkstra, M. E. Pieterse, and A. Pruyn, "Stress-reducing effects of indoor plants in the built healthcare environment: The mediating role of perceived attractiveness," *Prev. Med.*, vol. 47, no. 3, pp. 279–283, Sep. 2008, doi: 10.1016/j.ypmed.2008.01.013.

[3] A. Håkansson, "Portal of Research Methods and Methodologies for Research Projects and Degree Projects," 2013, pp. 67–73, Accessed: Jun. 07, 2020. [Online]. Available: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-136960.

[4] R. Heather, "How Light Affects The Growth Of A Plant & Problems With Too Little Light," *Gardening Know How*. https://www.gardeningknowhow.com/plant-problems/environmental/how-light-affects-the-growth-of-a-plant-problems-with-too-little-light.htm.

[5] S. Mondal, "Impact of elevated soil and air temperature on plants growth, yield and physiological interaction: a critical review," *Sci. Agric.*, vol. 14, no. 3, May 2016, doi: 10.15192/PSCP.SA.2016.14.3.293305.

[6] L. Hogdson, "Humidity for House Plants," *HowStuffWorks*, May 09, 2007. https://home.howstuffworks.com/how-to-care-for-house-plants.htm.

[7] L. Pitts, "Monitoring Soil Moisture for Optimal Crop Growth," *Help Desk*, Mar. 2016. http://observant.zendesk.com/hc/en-us/articles/208067926.

[8] "Soil moisture and temperature consideration," *Alberta*, 2019. https://www.alberta.ca/soil-moisture-and-temperature-consideration.aspx.

[9] C. Synder, "Soil pH - Nutrient Management," *Mosaic Crop Nutrition*, 2019. https://www.cropnutrition.com/nutrient-management/soil-ph.

[10] J. Tarran, F. Torpy, and M. Burchett, "USE OF LIVING POT-PLANTS TO CLEANSE INDOOR AIR – RESEARCH REVIEW," p. 9, Oct. 207AD.

[11] B. Henson, "Flu Weather: It's Not the Cold, It's the Humidity | Weather Underground," *wunderground*, Feb. 2018. https://www.wunderground.com/cat6/flu-weather-its-not-cold-its-humidity.

[12] C. Pearson-Mims and V. Lohr, "Reported Impacts of Interior Plantscaping in Office Environments in the United States," *HortTechnology*, vol. 10, pp. 82–86, Jan. 2000, doi: 10.21273/HORTTECH.10.1.82.

[13] V. I. Lohr, P. D. Relf, and N. E. Looney, "A FOCUS ON HUMAN ISSUES IN HORTICULTURE: AN INTRODUCTION TO THE OPENING PLENARY COLLOQUIUM - APPLYING THE ART AND SCIENCE OF HORTICULTURE TO IMPROVING HUMAN LIFE QUALITY," *Acta Hortic.*, no. 642, pp. 69–70, Oct. 2004, doi: 10.17660/ActaHortic.2004.642.7.

[14] R. A. Wood, R. L. Orwell, J. Tarran, F. Torpy, and M. Burchett, "Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air," *J. Hortic. Sci. Biotechnol.*, vol. 77, pp. 120–129, Jan. 2002, doi: 10.1080/14620316.2002.11511467.

[15] R. Ulrich, “View through a window may influence recovery from surgery,” *Science*, vol. 224, no. 4647, pp. 420–421, Apr. 1984, doi: 10.1126/science.6143402.

[16] C. M. Tennessen and B. Cimprich, “Views to nature: Effects on attention,” *J. Environ. Psychol.*, vol. 15, no. 1, pp. 77–85, Mar. 1995, doi: 10.1016/0272-4944(95)90016-0.

[17] V. I. Lohr and C. H. Pearson-mims, “Particulate matter accumulation on horizontal surfaces in interiors: Influence of foliage plants,” *Atmos. Environ.*, vol. 30, no. 14, pp. 2565–2568, Jul. 1996, doi: 10.1016/1352-2310(95)00465-3.

[18] M. J. C. Samonte, E. P. E. Signo, R. J. M. Gayomali, W. P. Rey, and E. A. Serrano, “PHYTO: An IoT Urban Gardening Mobile App,” 2019, doi: 10.1145/3322645.3322659.

[19] “Support - Parrot Flower Power,” *Parrot Official*, 2019. https://support.parrot.com/global/support/products/parrot-flower-power.

[20] “FYTA Beam - the smart plant sensor by FYTA — Kickstarter,” 2020. https://www.kickstarter.com/projects/fyta/fyta-beam-the-smart-plant-sensor.

[21] E. Daugherty, “Black and Decker’s PlantSmart PCS10 Plant Sensor Review: The Gardener’s Fish Finder – The Gadgeteer,” May 2011. https://the-gadgeteer.com/2011/05/18/black-and-deckers-plantsmart-pcs10-plant-sensor-review-the-gardeners-fish-finder/.

[22] L. Bickman and D. J. Rog, “Applied Research Design: A Practical Approach,” 2009, doi: 10.4135/9781483348858.n1.

[23] S. Herbert, “Top-Down Design (Introduction to Statistical Computing),” Sep. 2012. http://bactra.org/weblog/950.html.

[24] B. Jackson, “Top-Down Learning — An Approach to Understanding Machine Learning | by Jackson Bull | Medium,” *medium*, 2020. https://medium.com/@jacksonbull1987/top-down-learning-4743f16d63d3.

[25] “Build software better, together,” *GitHub*. https://github.com.

[26] B. H. Corak, F. Y. Okay, M. Guzel, S. Murt, and S. Özdemir, “Comparative Analysis of IoT Communication Protocols,” *2018 Int. Symp. Netw. Comput. Commun. ISNCC*, 2018, doi: 10.1109/ISNCC.2018.8530963.

[27] J. Dizdarevic, F. Carpio, A. Jukan, and X. Masip, “A Survey of Communication Protocols for Internet of Things and Related Challenges of Fog and Cloud Computing Integration,” *ACM Comput. Surv.*, vol. 51, Apr. 2018, doi: 10.1145/3292674.

[28] A. Stanford-Clark, “MQTT For Sensor Networks (MQTT-SN) Protocol Specification - PDF Free Download,” Nov. 2013. https://docplayer.net/20709748-Mqtt-for-sensor-networks-mqtt-sn-protocol-specification.html.

[29] “Electrical and electronic waste - Environment - European Commission,” *europa*, Apr. 2020. https://ec.europa.eu/environment/waste/rohs_eee/index_en.htm.

[30] “RoHS Guide,” *RoHS*, 2020. https://www.rohsguide.com/rohs-faq.htm.

[31] “The final revision of our third-generation single board computer,” *raspberrypi*, 2020. https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/.

[32] T. Bouguera, J.-F. Diouris, J.-J. Chaillout, R. Jaouadi, and G. Andrieux, “Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN,” *Sensors*, vol. 18, no. 7, Jun. 2018, doi: 10.3390/s18072104.

[33] T. Liu, “Weather sensor (DHT22).,” p. 10, 2019.

[34] “DS18B20 Temperature Sensor.” https://components101.com/sensors/ds18b20-temperature-sensor.

[35] “Soil moisture sensor (FC-28),” 2020. http://www.uruktech.com/product/fc-28-soil-hygrometer-sensor/.

[36] “Light intensity sensor (GY-30),” 2020. http://qqtrading.com.my/digital-light-intensity-sensor-module-gy-30-bh1750fvi.

[37] “pH sensor (Liquid PH0-14),” *amazon*. https://www.amazon.com/Liquid-PH0-14-Sensor-Electrode-Arduino/dp/B01LWLHPRR.

[38] “MicroPython : Adafruit Industries, Unique & fun DIY electronics and kits,” 2020. https://www.adafruit.com/category/924.

[39] “Programming Languages for the Raspberry Pi,” 2020. https://wyliodrin.com/post/programming-languages-for-the-raspberry-pi.

[40] S. Matrunchyk, “Top 7 reasons why Laravel is better for businesses than other PHP frameworks,” *Medium*, Feb. 05, 2018. https://medium.com/@serhii.matrunchyk/top-7-reasons-why-laravel-is-better-for-businesses-than-other-php-frameworks-c0f5e85c5b85.

[41] “Benefits of SQLite As A File Format,” 2020. https://www.sqlite.org/aff_short.html.

[42] Sommerhoff, “Kotlin vs. Java: 9 Benefits of Kotlin for Your Business | Udemy for Business,” *Udemy Blog*, Feb. 16, 2020. https://blog.udemy.com/kotlin-vs-java-9-benefits-of-kotlin-for-your-business/.

[43] K. LaLiberte, “Fertilizer Basics: Organic Fertilizer, NPK Ratio | Gardeners.com,” Mar. 2020. https://www.gardeners.com/how-to/fertilizer-ratios/5161.html.

[44] C. Gubb, “Plants as a building service: Improving indoor air quality and reducing energy consumption -a critical review” April. 2019. https://www.researchgate.net/publication/333450759_plants_as_a_building_service_improving_indoor_air_quality_and_reducing_energy_consumption_-a_critical_review

[45] A. Venkatesh, “Environmental Parameter Monitoring using Wireless Sensor Network | Request PDF,” *ResearchGate*, Jul. 2013. https://www.researchgate.net/publication/243964444_Environmental_Parameter_Monitoring_using_Wireless_Sensor_Network

[46] C. Burak Han, “Comparative Analysis of IoT Communication Protocols, Page 4” Jun 2018. https://www.researchgate.net/publication/329495401_Comparative_Analysis_of_IoT_Communication_Protocols.

# Appendix A: Source Code

All the source codes and programming directions for this work can be obtained freely from the following website:

https://github.com/Maher-RJ/Monitoring-system

# Appendix B: Specifications and Prices of System Components

The specifications of system components are shown in table b.1 and the prices of components (from eBay company) are shown in figure b.1.

Table b.1 Specifications of the System Components

| Item | Specification |
|---|---|
| Base station Raspberry PI 3B+ (1) | • SoC: Broadcom BCM2837B0 quad-core A53 (ARMv8) 64-bit @ 1.4GHz<br>• GPU: Broadcom Video core-IV<br>• RAM: 1GB LPDDR2 SDRAM<br>• Networking: Gigabit Ethernet (via USB channel), 2.4GHz and 5GHz 802.11b/g/n/ac Wi-Fi<br>• Bluetooth: Bluetooth 4.2, Bluetooth Low Energy (BLE)<br>• Storage: Micro-SD<br>• GPIO: 40-pin GPIO header, populated<br>• Ports: HDMI, 3.5mm analogue audio-video jack, 4x USB 2.0, Ethernet, Camera Serial Interface (CSI), Display Serial Interface (DSI)<br>• Dimensions: 82mm x 56mm x 19.5mm, 50g |
| Microcontroller ESP32 (2) | • CPU: dual-core (or single-core) 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS<br>• Memory: 520 KiB SRAM<br>• Wireless connectivity: Wi-Fi 802.11 b/g/n. Bluetooth v4.2 BR/EDR and BLE<br>• Peripheral interfaces: 12-bit SAR ADC up to 18 channels. 2 × 8-bit DACs. 10 × touch sensors (capacitive sensing GPIOs). 4 × SPI. 2 × I²S. interfaces. 2 × I²C interfaces. 3 × UART. SD/SDIO/CE-ATA/MMC/eMMC host controller SDIO/SPI slave controller. Ethernet MAC interface with dedicated DMA and IEEE 1588 Precision Time Protocol support. CAN bus 2.0. Infrared remote controller (TX/RX, up to 8. channels). Motor PWM. LED PWM (up to 16 channels). Hall effect sensor. Ultra-low power analog pre-amplifier.<br>• Security: IEEE 802.11 standard security features all supported, including WFA, WPA/WPA2 and WAPI. |
| Weather sensor (DHT22) (3) | • Power supply 3.3-6V DC<br>• Operating range humidity 0-100%RH; temperature -40~80Celsius<br>• Resolution or sensitivity humidity 0.1%RH; temperature 0.1Celsius<br>• Sensing period Average: 2s |
| Soil temperature sensor (DS18B20) (4) | • Programmable Digital Temperature Sensor.<br>• Communicates using 1-Wire method<br>• Operating voltage: 3V to 5V<br>• Temperature Range: -55°C to +125°C<br>• Accuracy: ±0.5°C<br>• Output Resolution: 9-bit to 12-bit (programmable)<br>• Unique 64-bit address enables multiplexing<br>• Conversion time: 750ms at 12-bit<br>• Programmable alarm options |

| | |
|---|---|
| Soil moisture sensor (FC-28) [5] | • Operating voltage: 3.3V~5V<br>• Dual output mode, analog output more accurate<br>• A fixed bolt hole for easy installation<br>• With power indicator (red) and digital switching output indicator (green)<br>• Having LM393 comparator chip, stable<br>• Panel PCB Dimension: Approx.3cm x 1.5cm<br>• Soil Probe Dimension: Approx. 6cm x 3cm |
| Light intensity sensor (GY-30) [6] | • Chip: BH1750FVI<br>• Power Supply: 3 - 5V<br>• Light Range： 0 - 65535 lx<br>• Sensor Built-in: 16-bit AD converter<br>• Size (L x W): Approx. 3.2cm x 1.5cm |
| pH sensor (Liquid PH0-14) [7] | • Heating voltage: 5 ± 0.2V (AC · DC) Working current: 5-10mA<br>• Detectable concentration range: PH0-14 Detection Temperature range: 0-80 ℃<br>• Response time: ≤5S Settling Time: ≤60S Component Power: ≤0.5W<br>• Working temperature: -10 ~ 50 ℃, Humidity: 95% RH |

(1) https://magpi.raspberrypi.org/articles/raspberry-pi-3bplus-specs-benchmarks
(2) https://www.espressif.com/en/products/hardware/modules
(3) https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf
(4) https://components101.com/sensors/ds18b20-temperature-sensor
(5) http://www.uruktech.com/product/fc-28-soil-hygrometer-sensor/
(6) http://qqtrading.com.my/digital-light-intensity-sensor-module-gy-30-bh1750fvi
(7) https://www.amazon.com/Liquid-PH0-14-Sensor-Electrode-Arduino/dp/B01LWLHPRR.

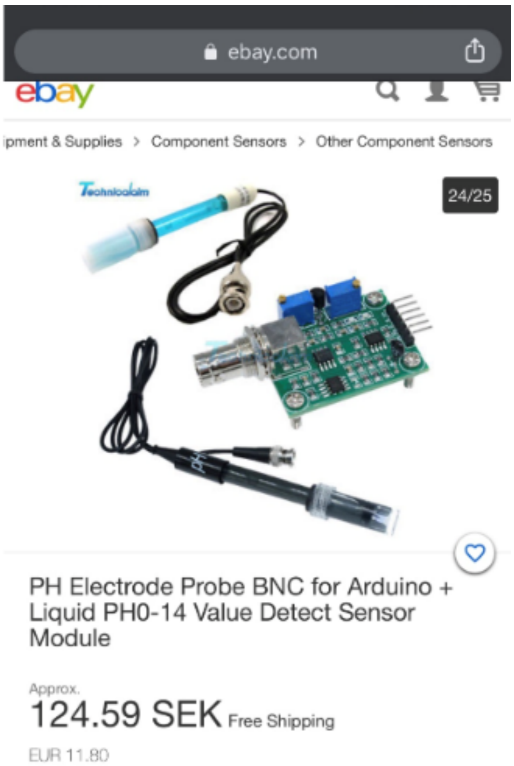
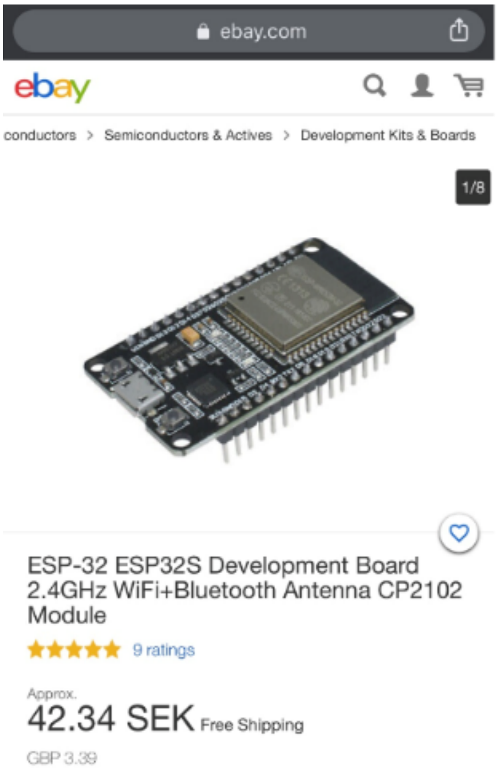
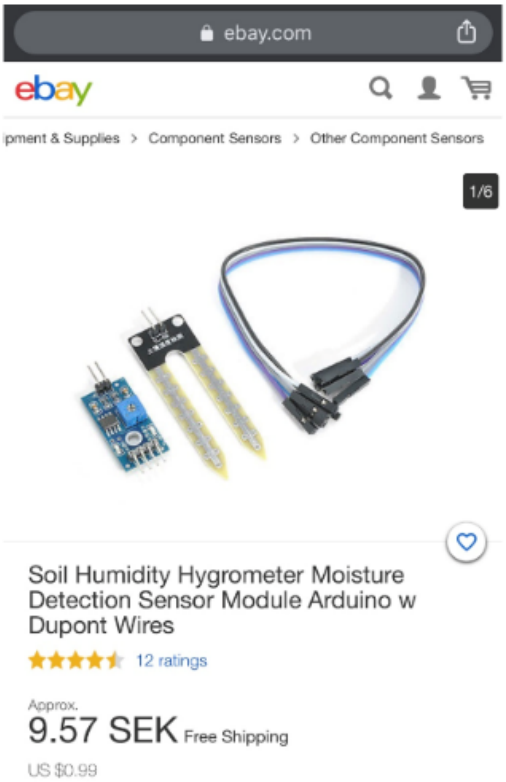





*Figure b.1 Prices of the System Components (from eBay company)*



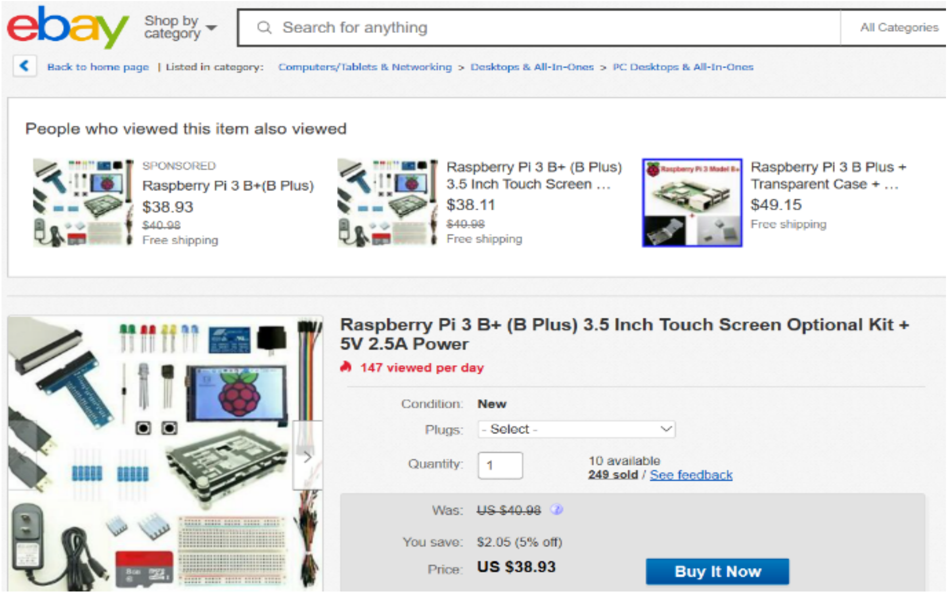



*Figure b.1 Continued*

TRITA CBH-GRU-2020:XX