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This article describes a project developed using principles of Project Based Learning (PBL) and aims to use an embedded system for soil monitoring, thus measuring soil moisture and implementing automatic irrigation, as well as, the temperature and humidity of the environment. The configuration data for irrigation time control and the lower and upper limits of soil moisture percentage can be adjusted through a PHP page, where also the monitoring of the variation of soil moisture through a graph can be done in real time. The proposed project is divided into two steps using PBL. Phase one focuses on developing a circuit with sensors capable of doing measurement of ambient parameters and soil moisture, and phase two, on developing an irrigation system to control soil moisture, both using Internet of Things (IoT) concepts.

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# **Construction of soil moisture and irrigation IoT monitoring system using Project Based Learning**

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## **Abstract**

*This article describes a project developed using principles of Project Based Learning (PBL) and aims to use an embedded system for soil monitoring, thus measuring soil moisture and implementing automatic irrigation, as well as, the temperature and humidity of the environment. The configuration data for irrigation time control and the lower and upper limits of soil moisture percentage can be adjusted through a PHP page, where also the monitoring of the variation of soil moisture through a graph can be done in real time. The proposed project is divided into two steps using PBL. Phase one focuses on developing a circuit with sensors capable of doing measurement of ambient parameters and soil moisture, and phase two, on developing an irrigation system to control soil moisture, both using Internet of Things (IoT) concepts.*

**Keywords:** Internet of Things; Monitoring; Project Based Learning.

## **1. Introduction**

The Project Based Learning (PBL) is applied to enabling students to confront issues and real-world problems that they consider meaningful, determining how to address them and then acting cooperatively for solutions [1].

In proposing PBL as a guiding reference for the teaching of these technical subjects, it is intended to contribute, not only to instrumentalization in the technical domain of methodologies, but also to the appropriation of a new form of teaching/learning technique, which can be collectively constructed, updated and reformulated.

On the other hand, plants need a good quality soil to grow healthily, however, there are several types of environmental situations that hinder their growth [2], among them:

- Excessive solar radiation
- Lack of nutrients in soil
- Low humidity soil
- Pests

All these situations can lead to losses. For this reason, it is necessary to use automatic systems that assist the farmer in the monitoring of his crops, in order to obtain an increasing efficiency and consequently reduce the occurrence of undesired situations [3].

The Internet of Things (IoT) refers to the integration of physical and virtual objects into networks connected to the Internet, allowing "things" to collect, exchange and store a huge amount of data in the Cloud, where once they are processed and analyzed, they generate information and services on a big scale.

Thus, the present article has the objective of finding a solution to this problem, thus making soil moisture monitoring in real time of an environment with plants and an IoT system for irrigation control [4], using PBL principles.

The NodeMCU development board has an ESP8266 microcontroller and has become popular in recent years [5, 6]. This becomes relevant since on a small board are available Input/Output (I/O) pins, voltage regulator, USB interface for programming and Wi-Fi connectivity featuring an ideal board for IoT projects [7].

IoT consists of equipment that connects to others or to services over the Internet [8]. Despite of having a definition since 1982, IoT only became popular with the diffusion of the Internet and with the cheapness of embedded systems. A well-known IoT device is Raspberry Pi that can be used without technical knowledge [9].

For the irrigation IoT system the use of NodeMCU 12E programmed by Arduino's IDE (Integrated Development Environment) is proposed using free and easy to use microcontroller software development platform [10] together with a hygrometer and signal conditioning circuit based on operating amplifier LM393 which are two precision single-acting operational amplifiers on a single chip [11] and one actuator module with one channel responsible for triggering the water pump. The NodeMCU connects via the Internet to an API (Application Programming Interface) responsible for persisting the data, which consists of saving the data in a database for later consultation [12]. The system also has a web page that can configure and display the data acquired by NodeMCU.

## **2. Bibliographic Review**

The ESP8266 is an ideal microcontroller for IoT applications. This microcontroller has small size, requires only 3.3 Volts and embedded Wi-Fi modem. In [13] a software was developed to measure soil moisture, so an LED lit according to the sensor reading. If a red LED is lit, that is because the soil has low humidity, if a green LED is on, the soil has regular humidity and the blue LED indicates adequate humidity.

In [14] a project was developed using a type of analog sensor that detects humidity levels (HL-69). A light and sound system using Arduino was also used to inform when the plant needs water.

In [15] a system with an Arduino was created in which values were recorded in a micro SD card and combining the temperature sensor, the light sensor and the soil sensor, allowed the monitoring and the irrigation of a plant. The soil sensor was developed by the author himself, using nails to do the soil sensing. A system that implements IoT with RFID modules to Cloud control of a farm production is proposed in [16]. The project proposed by [17] implements the monitoring of soil moisture, soil water level and light intensity using Arduino and Raspberry Pi. Data is sent via GSM (Global System for Mobile

Communications) using SMS (Short Message Service) for mobile phones. In this sense, the present project proposes a solution in low cost using the microcontroller ESP8266 NodeMCU that costs in the market around \$ 3,00 USD in 2018. The data is sent via Wi-Fi to a database in the Cloud. The use of the Wi-Fi network allows the system to be installed in places where the Wi-Fi network is already available, thus being a project with low complexity of installation and maintenance.

### **3. Materials and methods**

According to [18] a microcontroller is like a computer system, where CPUs (Central Processor Unit), RAM (Random Access Memory), ROM (Read Only Memory), I/O pins other internal peripherals are integrated in the same component.

The ESP8266 IoT microcontroller has a single 10-bit analog port with a voltage range from 0 to 1 Volts [7]. The hygrometer has an analog output that alternates between 0 and 3.3 Volts which makes them incompatible, however the NodeMCU board has a voltage divider capable of connecting these different voltages by dividing the output voltage of the hygrometer by three thus making the sensor output compatible with the input of the microcontroller.

In the subtopics below, the specific materials used for the IoT system for soil moisture monitoring and the IoT System for irrigation monitoring and control, respectively, are described.

#### ***3.1 IoT system for soil moisture monitoring***

The following materials were used in this project with IoT concepts:

- 1 Wi-Fi Module ESP8266 NodeMCU.
- Protoboard.
- 1 Humidity and Temperature Sensor DHT22.
- 1 Soil moisture sensor.
- 1 Resistor 100 Ohm.
- 1 Resistor 200 Ohms.
- Some connection cables.

The DHT22, (Figure 1) is a 1-wire temperature and humidity sensor that allows temperature readings from -40 to +80 degrees Celsius and humidity between 0 to 100%, and is very easy to use with Arduino, Raspberry and other microcontrollers.

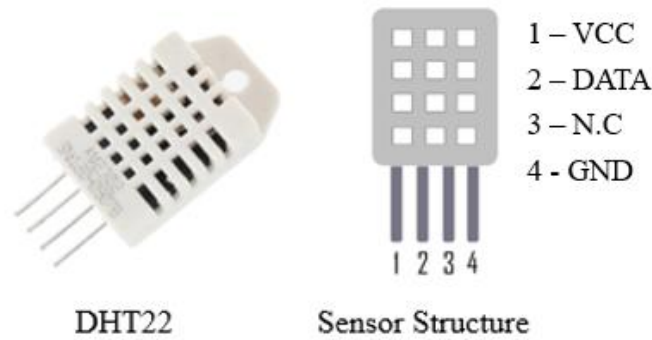


Figure 1. Temperature and humidity sensor [19].

The soil moisture sensor or hygrometer (Figure 2) consists basically of two rods that are tucked into the soil and of a comparator circuit that returns the level of soil conductivity. This circuit consists of a total of six pins, two of which are used to connect the metal rod to the comparison circuit. The other four inputs have the functions of feeding the circuit and returning the soil moisture level. The determination of soil moisture level can be done in two ways:

1. A digital signal that basically informs if the ground is dry or not (less precision but not dependent on an analog-digital converter (ADC) circuit). ADC is an electronic device capable of generating a digital representation from an analog quantity, usually a signal represented by a voltage level or electric current.
2. An analog signal that can be used to estimate how humid the soil is (more accurate but will depend on an ADC circuit).

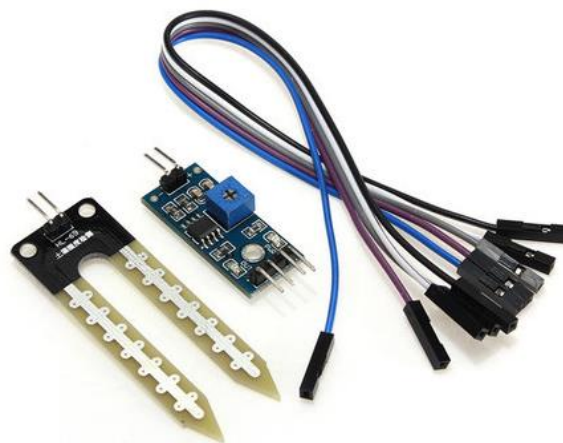


Figure 2. Soil moisture sensor (hygrometer) [20].

### 3.2 IoT system for irrigation monitoring and control

The submersed water pump (Figure 3) used for soil irrigation is characterized by having voltage from 2.5 to 6 Volts and submerged installation (Vertical) from 40 to 110 cm. The water pump offers an output flow between 80 and 120 l/h, with external diameter of 7.5 mm and internal diameter of 5 mm. The pump is made of injectable plastic and it is powered by direct current (DC).

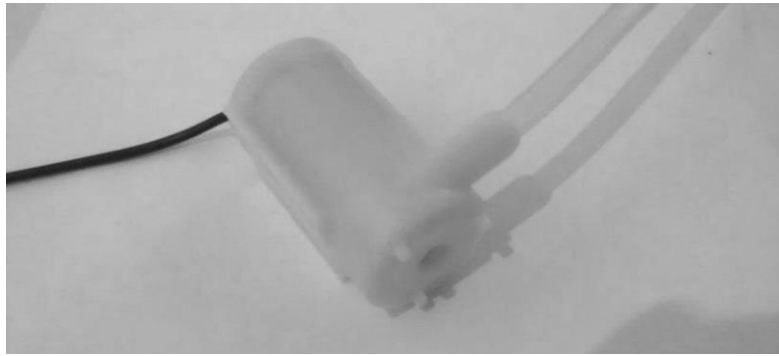


Figure 3. Submerged water pump.

Connected to another output pin of the microcontroller, there is a relay, which is an electrically driven switch that allows the electrical isolation of two circuits that when driven by electromagnetic induction closes the contacts of the switch [18]. This relay is responsible for activating the water pump.

For data transmission, the ESP8266 connects to a Wi-Fi network via the Internet and sends JSON-encapsulated data that is a lightweight and independent language format for exchanging information for a remote page using HTTP (Hypertext Transfer Protocol) [21] and the Internet base communication protocol [22]. The page receiving the information responds acknowledging receipt and with the parameters for actuation and updating of the system which are: interval between measurements, minimum and maximum humidity and actuation if the minimum and maximum are outside the defined range.

The web page has been configured with four sections: startup, status, settings, and data. On the homepage there is a short introduction to the system. In the status area, the status of the pump and the indication whether the system should be actuated or not can be monitored and configured. In 'Settings' there are two possible configurations: time between measurements and minimum and maximum desired humidity value. Finally, in the data area, the history of readings of the hygrometer are available.

## 4. Development of the proposed IoT monitoring project

In the following subtopics, the development of the proposed project divided into two parts is described. The first is the IoT plant monitoring system and the second is the IoT system for irrigation monitoring and control.

### 4.1 IoT system for soil moisture monitoring

The choice of the project to be developed in the area of embedded systems is fundamental in the application of the PBL, since the project must motivate and lead the students to new discoveries, covering at least the programmatic content defined for the course [23].

For the development of the proposed project, it was necessary to know the disciplines of embedded systems taught at the laboratory of an education institution. In order to optimize teaching and learning, and according to the PBL methodology, the teacher and the students begin to play roles, linked to a specific responsibility in the elaboration of the project.

In this practical sense, for the realization of the project, the ESP8266 NodeMCU microcontroller was

connected to ThingSpeak, showing how to send data from the plant to the Cloud. ThingSpeak is an IoT analytic platform service that allows to aggregate, visualize and analyze data flows in real time in the Cloud. Data can be sent to ThingSpeak from computational devices, instant data views can be created, and alerts using Web services like Twitter can be sent. With MATLAB analytics within ThingSpeak, it is possible to write and execute MATLAB code to perform pre-processing, visualizations, and analysis. ThingSpeak allows engineers and scientists to prototype and create IoT systems without configuring servers or developing web software [24]. The main features of this platform are:

- Configuration of devices to send data to ThingSpeak using an API REST or MQTT;
- Getting instant views of real time sensor data or through historical data;
- Processing and analyzing of collected data using integrated MATLAB;
- Acting on data and communication using third-party services such as Twitter.

For sending data to ThingSpeak, an HTTP request is made to the ThingSpeak server. An HTTP request is a string (which contains the HTTP request information) sent via TCP client socket to TCP server socket (server that will receive the request, in this case the ThingSpeak server) through port 80.

This experiment consists in having the NodeMCU sending, every few minutes, the percentage humidity measured for a ThingSpeak channel. That way generating graphs or doing analysis with MATLAB is possible. Figure 4 shows the flowchart of the monitoring system.

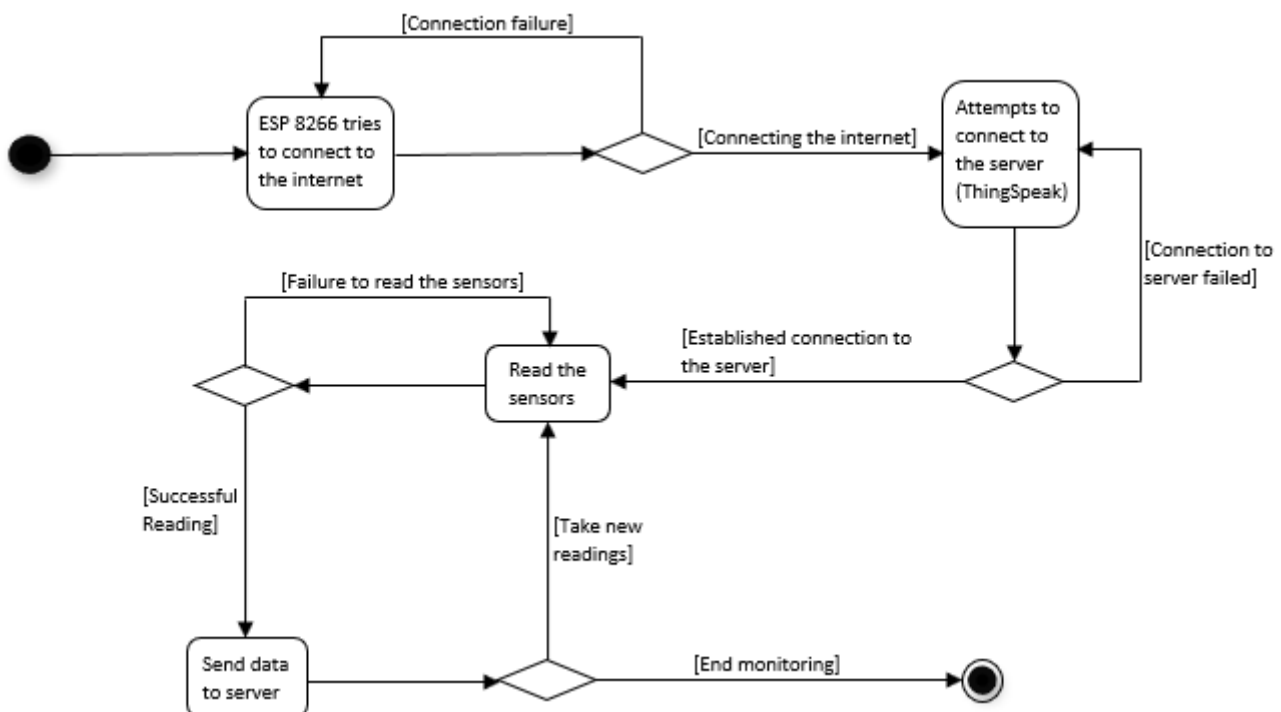


Figure 4. Monitoring system flowchart.

The power for ESP8266 microcontroller is supplied via USB cable (the same cable used in programming). The hygrometer sensor is read through the single ADC pin of the NodeMCU (A0), which allows reading



of the percent humidity (0 - 100%). The voltage divider is necessary because the output voltage A0 of the sensor provides 5 V, while the analog input of the NodeMCU accepts a maximum of 3.3 V. Figure 5 shows the schematic circuit of this experiment.

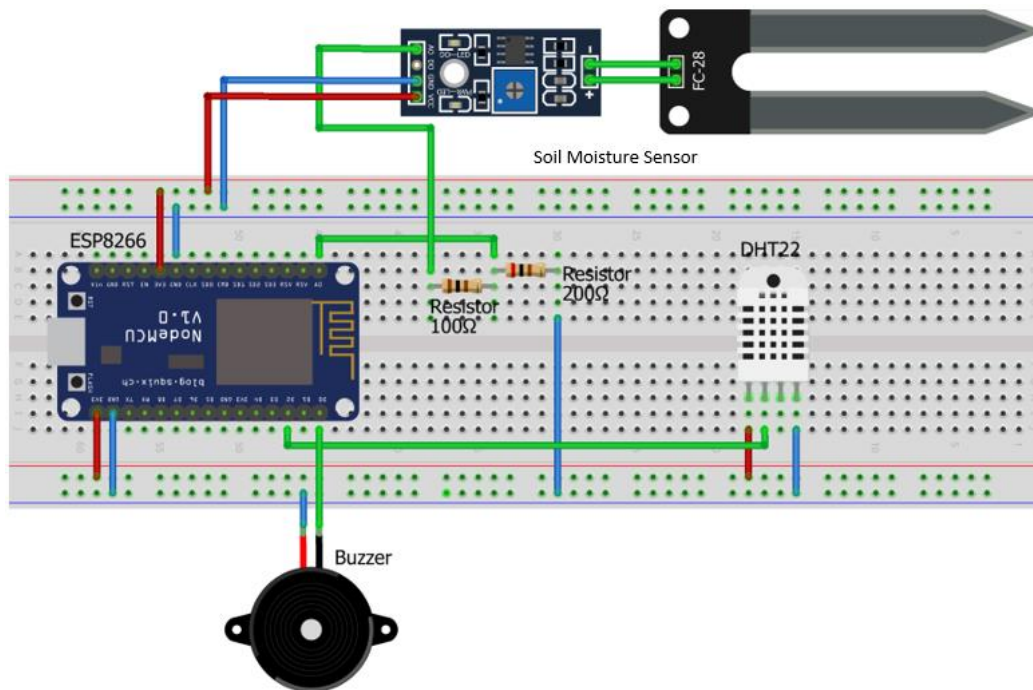


Figure 5. Proposed circuit diagram of phase one.

The programming was performed in C Language. After loading the source code for the NodeMCU, the Serial Monitor (with baud rate at 9600 baud) port to debug what the NodeMCU is doing can be open. Also, opening the channel site in ThingSpeak, each arrival of data in a graph can be seen in real time. The result of the final circuit is shown in Figure 6. A buzzer has been added to the project for emitting a beep as soon as the ESP8266 sends a message to the server, so whenever a new data is collected the system will inform.



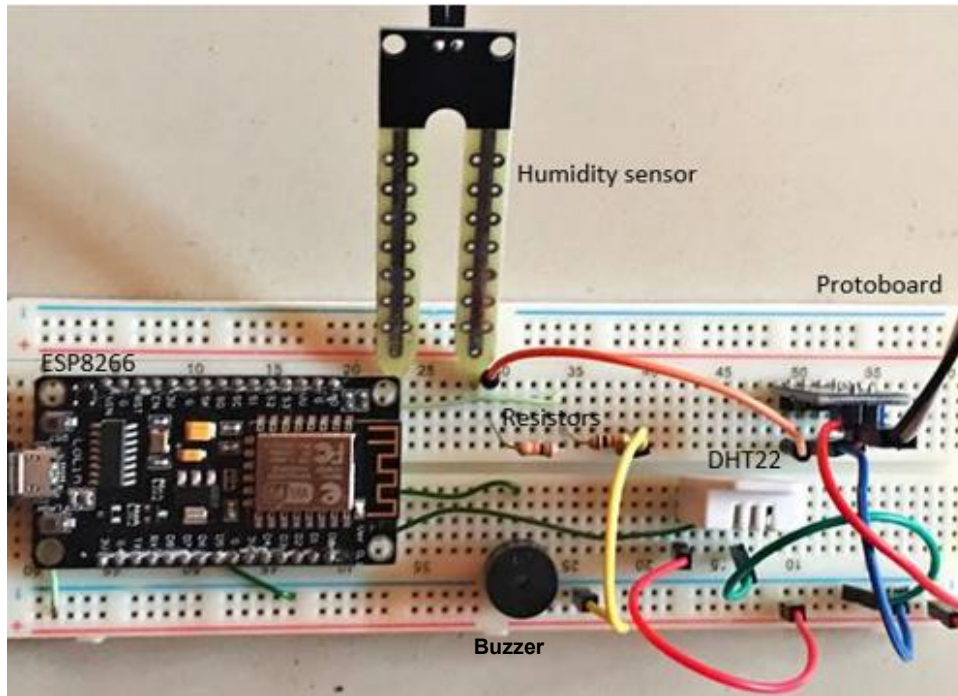


Figure 6. Final Project Circuit of phase one.

Figure 7 shows the developed circuit of the proposed phase one applied for monitoring the soil moisture of a small plant pot. The circuit can be powered with a 5 V battery or with a cell phone charger.



Figure 7. Circuit Monitoring a Plant.

#### 4.2 IoT system for irrigation monitoring and control

The phase two system follows the following cycle: initially the microcontroller assumes a value of one second among measurements and must act to maintain the minimum or maximum values of humidity. Then

it sends the result of the first sensing to the API, where the data is stored in the database and receives with the server response the parameters of minimum or maximum, interval of measurements and whether to drive the water pump or not. The electrical schematic can be seen in Figure 8.

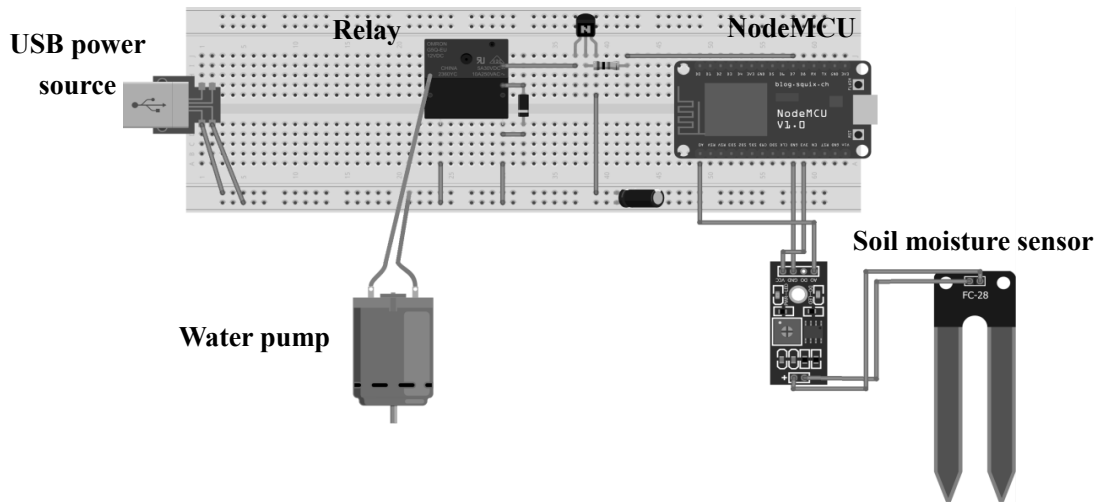


Figure 8. Circuit of the schematic project.

In Figure 9 the schematic of Figure 8 can be observed in operation.

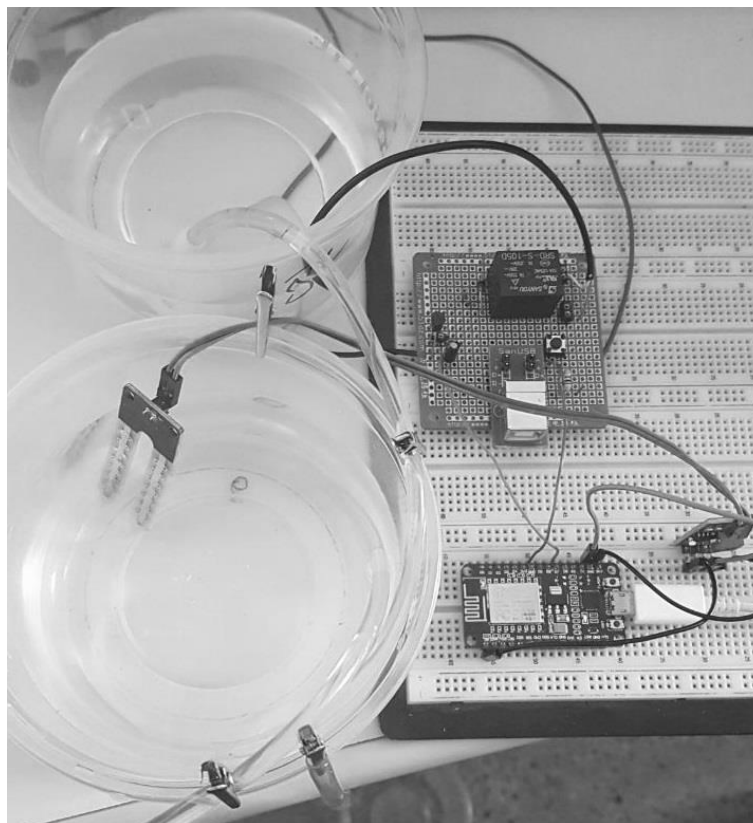


Figure 9. Complete circuit in operation.

The software running on NodeMCU was written using the C language libraries created by Dennis Ritchie at the Bell Labs in 1972 [25]. The web page was developed using PHP, which is a language developed by Rasmus Lerdoff using the C language itself in 1994 [26].

### 5. Results

The graphs of Figure 10 show the phase one results. The ambient temperature (Figure 10 (a)) remained constant with a slight rise in the end of the evaluated period. On the other hand, the humidity of the environment (Figure 10 (b)) had a slight oscillation. In soil moisture (Figure 10 (c)), which is the main parameter to monitor, there has been a sharp drop.

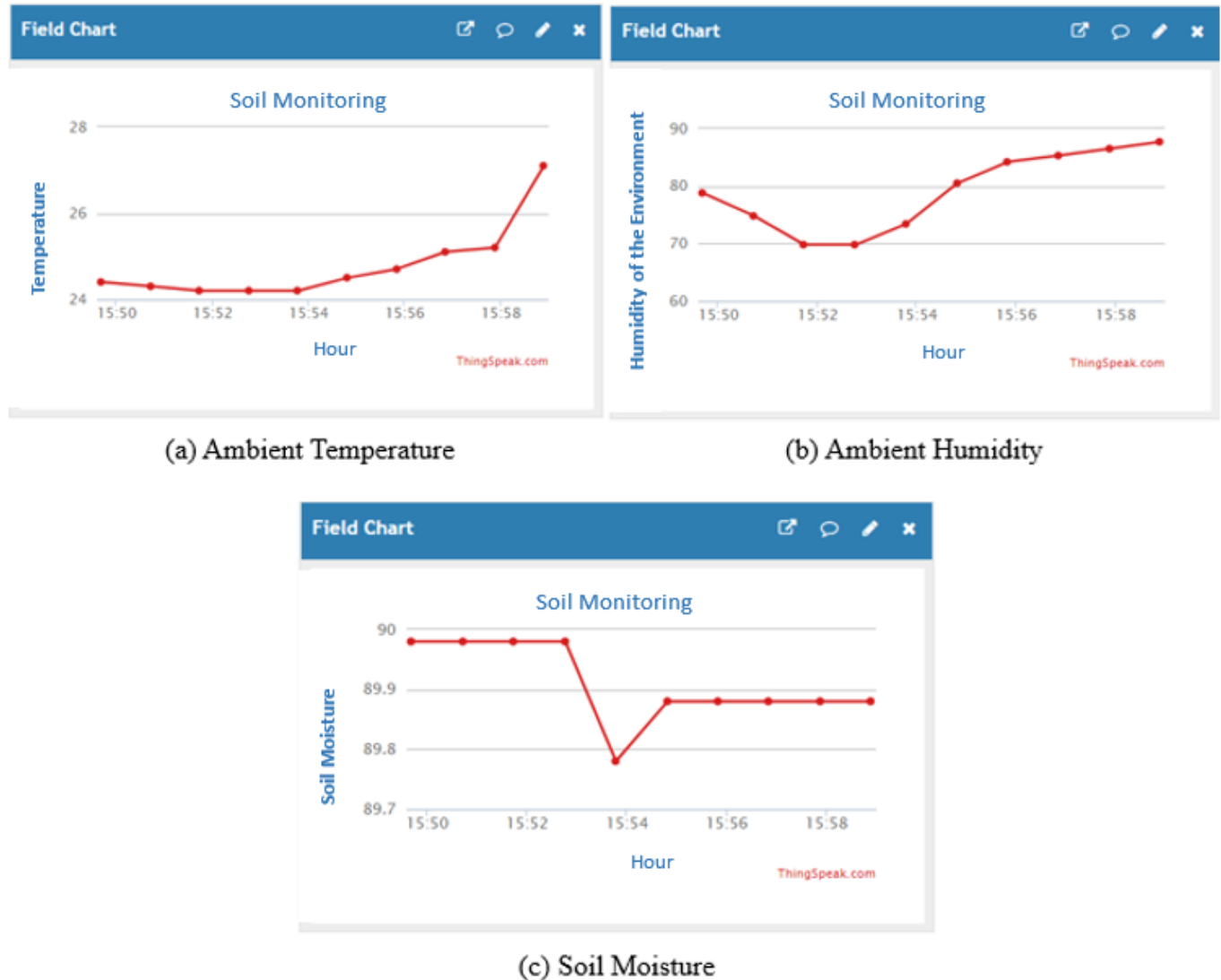


Figure 10. Graphs with phase one results.

In phase two, the data is stored in a MySQL database, which is an open source relational database maintained by Oracle [27]. Each measurement performed by the microcontroller is stored with date and time information, thus facilitating the generation of reports with the acquired data [28]. If the ESP8266 runs out of connectivity, the data is unfortunately lost. This data loss can be seen as white space in reports. One solution would be to store the values locally for later sending to the server [29].

Observing the graph of the developed Web interface for soil moisture monitoring and time generated by the system (Figure 11), it was seen that it succeeded in detecting a fall in moisture and correcting soil moisture, thus maintaining a constant environment. It was also relevant for real-time remote analysis of

reports, thus allowing remote analysis of the current moisture and moisture search in other periods, since the data is stored in the database as historical data.

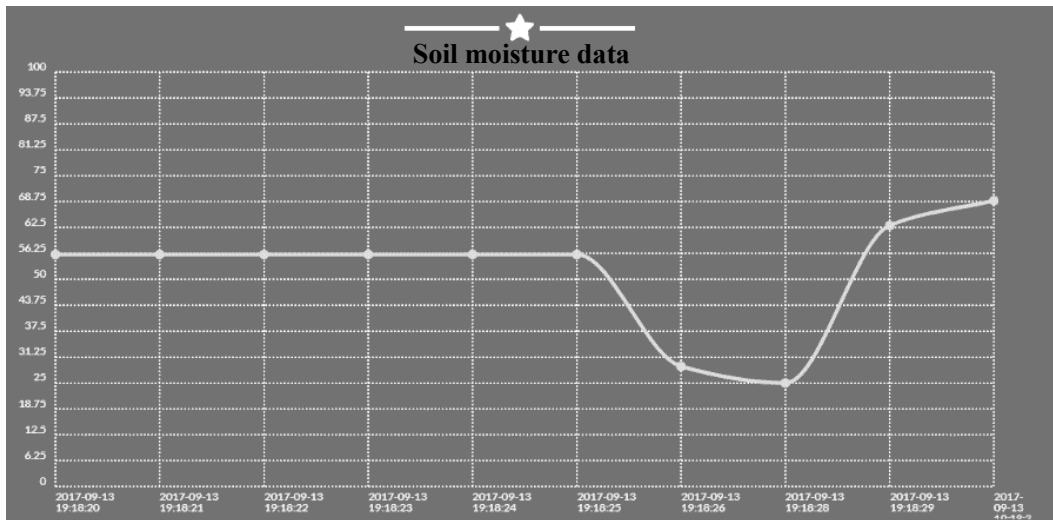


Figure 11. Developed Web interface for soil moisture monitoring.

## 6. Conclusion

This project reported a Project-Based Learning (PBL) application in teaching the disciplines in the area of embedded systems taught to undergraduate students in an educational institution. The ESP8266 IoT microcontroller made it possible to develop a versatile IoT project using low-cost embedded systems. With the proposed project, the use of ESP8266 applied in a real-world problem became satisfactory, since with small lines of code, numerous applications can be achieved, opening several possibilities for future projects in PBL, mainly with concepts of Internet of Things (IoT). The configuration data for irrigation time control and the lower and upper limits of soil moisture percentage could be adjusted through the developed PHP Web interface, where the monitoring of the variation of soil moisture through a graph can be done in real time. Considering that the monitored data could be accessed using the IoT ThingSpeak platform in phase one and using the Web interface developed in phase two, the obtained results were satisfactory.

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