Chapter 54
Arduino and NodeMCU-Based Smart Soil Moisture Balancer with IoT Integration

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Abstract Without proper moisture in the soil, the process of agriculture can fall in danger, which can lead to even an economic collapse for a country. However, over-irrigation, under irrigation, or improper water distribution can result in crop damage and reduced productivity, which leads to waste of valuable resources including water. To contribute to addressing this issue, a smart soil moisture balancer is developed based on Internet of Things (IoT), with the help of a soil moisture sensor, water pump control, water flow meter, water level indicator, Arduino Uno, and NodeMCU with built-in Wi-Fi (IEEE 802.11b Direct Sequence) module. The developed system intelligently controls the irrigation pump's switching based on the data collected from a soil moisture sensor. The water level indicator provides data on water availability in the storage, and the water flow meter provides data on water flow rate, which gets transmitted to the ThingSpeak IoT server that stores the data and generates graphs to help with the analysis and making future decisions. A prototype of the developed system is made, verified, and tested to be working perfectly as designed and programmed. In the experiment with the prototype, it is found that the system saves 36.17% of water in case of sandy soil, 37.08% and 32.90% in case of clay soil and loamy soil, respectively. On average, the system saves 35.38% of the water, which in turn can save other intertwined resources like time and energy, keeping the efficiency of the irrigation system.

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54.1 Introduction

As a result of both population growth and rising earnings, food demand is expected to keep on rising as well. As per the United Nations' (UN) World Population Prospects: the 2017 Revision, the total world population will grow from 7.8 to 9.8 billion in 2050 [1], resulting in more mouths to feed. Developing countries will account for the vast majority of population growth. Because of this, the required amount of food is expected to touch nearly 3 billion tons by 2050, according to the UN. This increased demand for food required increased and optimal usage of every process in agriculture, one of which is irrigation. Current irrigation systems are mostly manual that causes waste of water, and energy, and are not ideal for optimal yields. Agriculture uses 85% of available freshwater resources worldwide, according to World Bank statistics, and this percentage will continue to grow as a result of population growth and increased food demand. As a result, there is a pressing need to make water management systems reliant on science and innovation, including technological, agronomic, managerial, and institutional advances. We can handle water waste and maximize scientific techniques in irrigation systems by applying technology and innovation, which will significantly improve water usage and efficiency. One of such technologies is the IoT which is booming currently in the agriculture and farming sector in optimizing every step of the process, including irrigation [2–4].

IoT enables us to capture data from various devices called "things" which can be sensors, computers, smartphones, household appliances, or other objects. This information can then be stored in the cloud or web saver and can be retrieved later to improve decision-making. This technology plays an outstanding role in so many fields, and agriculture is not left behind. The IoT framework comprises web-enabled smart devices that use embedded technologies like processors, sensors, and communication hardware to store, transmit, and respond to data collected from their surroundings. Sensor data is exchanged between IoT sensors via linking to an IoT gateway or other edge node, where it is either sent to a server for storage or processed locally. These devices often communicate with one another and take action based on the information they share. The gadgets carry out a fair amount of work without human intervention, but humans may use them to set them up, transmit commands, and retrieve data [5, 6]. The major components of the IoT are shown in Fig. 54.1.

The rapid rise of IoT-based technologies is upgrading virtually every industry, shifting the industry away from statistical to quantitative techniques. In current times, farmers have been utilizing mostly manual irrigation systems through manual control in which the irrigation is performed at a regular interval which leads to improper utilization of water and sacrificing productivity. Through automation, IoT has the ability to make agricultural industry measures more productive by minimizing human interference, which effectively can be called smart agriculture.

A comprehensive study has been carried out in recent years where some of the efficient and effective IoT-based technologies were recommended in the topic of interest [2, 3, 7–22]. In [2], the authors have tried to solve the mentioned issues by developing an IoT-based smart irrigation system using Arduino Uno and Bluetooth technology

Fig. 54.1 Major components of IoT (https://www.rfpage.com/)

by monitoring the soil moisture level. In [4, 9], the authors used NodeMCU and its Wi-Fi module for developing the IoT-based smart irrigation system by monitoring the soil moisture, temperature, humidity, etc. In [16], the authors used an AVR microcontroller and ESP8266 Wi-Fi module for developing the IoT-based smart irrigation system by monitoring not only the soil moisture but also the humidity, light intensity, and temperature. This smart agricultural market is estimated to grow to \$11.23 billion in US (United States) dollars by 2022, as per 2017's Research and Markets Forecast. With an annual growth rate of 20% continuously, the global market size of smart agriculture is forecasted to triple by 2025 to \$15.3 billion (particularly in comparison with just around \$5 billion in 2016). In response to that, the agriculture industry and farmers are already into IoT-based solutions that allow farmers to minimize waste and increase efficiency from the number of fertilizers used to the amount of water made available by the farmer to his crops efficiently, saving the resources like water, energy, etc.

Keeping the discussed issues in mind, the developed soil moisture balancer presented in this paper is intended to overcome the unnecessary water flow into the agricultural lands by alerting the pump control to either turn ON or OFF with respect to the soil dryness or wetness, based on measured soil moisture content and the amount of water usage. The central processing unit of the system also includes a communication gateway such as a Wi-Fi module, to send data to an IoT server in real time, and relay the information to the user's device such as a computer or hand-held devices like a smartphone or tablet for analysis.

Table 54.1 System's components and peripheral devices

Components/devices	ID/remarks
Arduino Uno R3	ATmega328P based
NodeMCU	ESP8266-12E
Water level indicator	P35, floating
Water flow meter	YF-S201, hall-effect
Soil moisture sensor	FC-28
Organic light-emitting diodes (OLED)	0.96″ 12C
Liquid–crystal display (LCD)	16×2 LCD
Relay	LM393, single channel voltage comparator
Pump control	Mini submersible
Breadboard	MB-102, full
Connecting wires	Jumper, MM MF FF

54.2 Methods and Materials

54.2.1 Components and Peripheral Devices

The developed soil moisture balancer system incorporates various electronic devices and components, e.g., an Arduino and a NodeMCU board as the brains of the system, sensors to measure soil moisture, water level, and water flow, a controller to control equipment like the pump, displays to present information, etc., to do its intended function. The total list of required components and tools is provided in Table 54.1.

54.2.2 System Model and Block Diagram

The developed system is comprised of both equipment and computer programs. On the equipment side, 3 (three) types of sensors are utilized to measure soil moisture, water level, and water flow. Subsequently, an Arduino Uno and a NodeMCU are used as the IoT design platforms, where the NodeMCU coordinates with its built-in Wi-Fi module to transfer the data to an IoT server (ThingSpeak). In addition, 2 (two) displays are used to show the results as well. On the programming side, a set of computer codes is written to perform the desired functions. A block diagram is presented in Fig. 54.2 to provide an easy visualization of the entire system. From the diagram, a discrete idea of all the incorporated modules/devices and their responsibilities can be achieved on a macro level. On the input side of the Arduino Uno, there are 2 (two) sensors: soil moisture and water level; and on the output side, there is an LCD display and a relay module. On the input side of the NodeMCU, there is

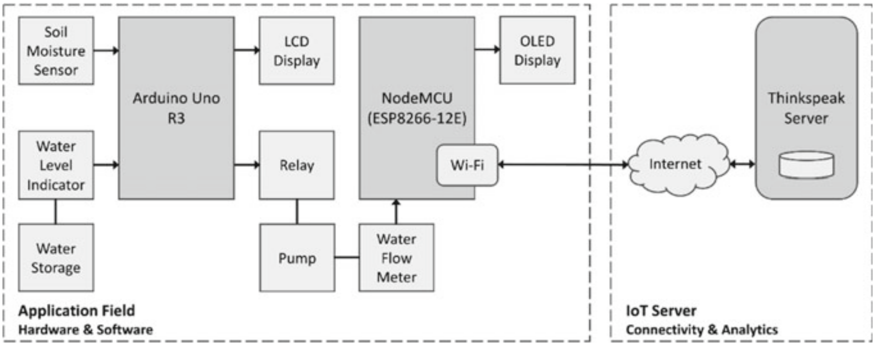

Fig. 54.2 Block diagram of the developed system

a water flow meter; and on the output side, there is an OLED display. The built-in Wi-Fi module of the NodeMCU is used to connect the system to the ThingSpeak server.

54.3 Electronic Circuit/Hardware Interfacing

Arduino Uno R3 and NodeMCU ESP8266-12E are used to make decisions such as turning ON the water pump and sending results to the cloud based on data from sensors. Figure 54.3 shows the schematic of circuit interfacing of the developed system, where the soil moisture and water level sensors are interfaced to the Arduino's A0 and pin-2, respectively, and the relay and LCD display are controlled by pin-3 and pin-4, 5, respectively. The water flow meter is interfaced to NodeMCU's D4, and the OLED display is controlled by D1 and D2, respectively. The complete interfacing is better depicted in Tables 54.2 and 54.3.

54.4 Software Programming and IoT Server Integration

54.4.1 Programming Flowchart

Both Arduino and NodeMCU are microcontroller-based devices. The microcontroller used in an Arduino is ATmega328P from Atmel. The ESP8266 in a NodeMCU is a low-cost Wi-Fi chip that has a microcontroller capability. Therefore, the functionality of an Arduino and NodeMCU depends on the programming that follows the general attributes of Atmega and ESP8266 programming. The Arduino IDE software is used to program both Arduino Uno and NodeMCU. The programming codes that are written for the system in the presented work are described using the flowchart

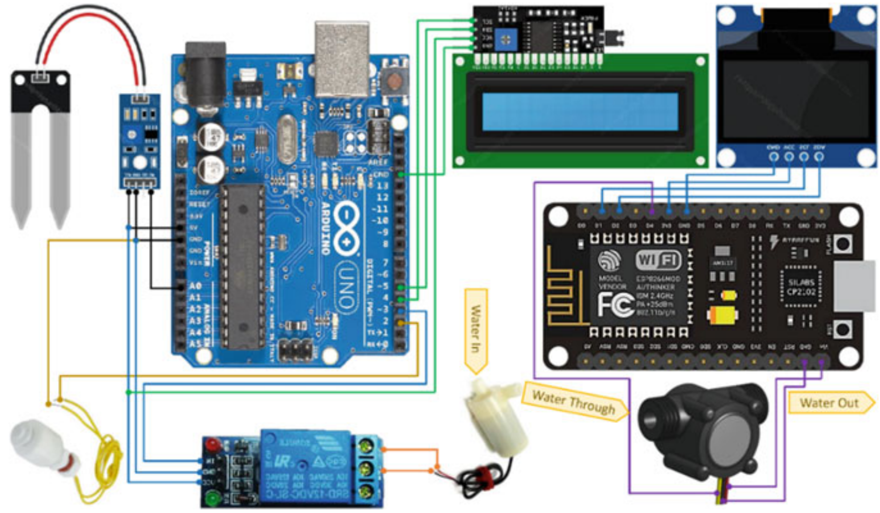

Fig. 54.3 Circuit schematic/hardware interfacing

Table 54.2 Interfacing between Arduino Uno and its components (pin-to-pin)

Arduino Uno	Soil moisture sensor	Water level indicator	LCD display	Relay
GND	GND	GND (−)	GND	GND
VCC (5 V)	VCC		VCC	VCC
Pin-5			SDA	
Pin-4			SCL	
A0	AO (anode)			
Pin-2		VCC (+)		
Pin-3				IN

Table 54.3 Interfacing between NodeMCU and its components (pin-to-pin)

NodeMCU	Water flow meter	OLED display
Vin	Red (VCC)	
GND	Black (GND)	GND
D4	Yellow (hall effect)	
3V3		VCC
D1		SCL
D2		SDA

in Fig. 54.4. According to the flowchart, every time the soil moisture sensor senses dryness the system checks for water availability through the water level indicator and decides whether the water pump should be turned ON or OFF. The system keeps the record of the rate and volume of water flow using the water flow meter and sends the data to the ThingSpeak IoT server.

54.4.2 Sensors and Parameter Setup

Soil Moisture Sensor. The level of the soil moisture sensor changes based on the soil's resistance [23, 24]. The driver LM393 voltage comparator relay is a double differential measuring stick that compares the sensor's tension to a 5 V voltage level. The sensor values range from 0 to 1023; 0 being the wettest state and 1023 being the driest state. Based on the soil attribute the calibration of the soil moisture sensor can be changed in programming, which is done in the following way:

```
if (sensorValue <= 500){ //Soil Value Level Reached
digitalWrite(PumpMotor, HIGH); //Pump OFF
lcd.setCursor(8,1);
lcd.print("PUMP OFF")
```

Water Level Indicator. The water level indicator includes a reed-magnetic switch with floating magnets that leads when water is available. When the Arduino Uno reads the status of the soil moisture using the soil moisture sensor and the soil happens to be dry, then it checks the availability of water in the water storage using the water level sensor. If the water is available then the system notifies with the text "WATER OK" on the LCD screen, then the pump turns ON and automatically turns OFF when an adequate amount of water is supplied. The pump control is driven by a relay circuit. However, when water is unavailable, then the system notifies with a text "NO WATER" on the LCD screen. For any other condition, the pump remains OFF and the status of the moisture and pump will be displayed on the LCD screen.

Water Flow Meter. When the pump control is turned ON, the water passes through the water flow meter. Every revolution of the meter produces an electrical pulse from an inbuilt magnetic hall-effect sensor. Counting the pulses from the sensor's output can be used to calculate the water flow rate. Each pulse contains about 2.25 ml. Though this sensor is the least expensive and one of the best, it is not the most accurate one as the value of water volume fluctuates slightly depending on sensor orientation, fluid pressure, and flow rate. A significant amount of calibration is required to achieve a precision of more than 10%. But for the proof of concept and making the prototype, this sensor is used as it is one of the least expensive ones. Because the pulse signal is a simple square wave, logging it and converting it to liters per minute using the formula below makes it simple [25].

$$\frac{F}{7.5} = Q(\mathrm{L}/\min) \tag{54.1}$$

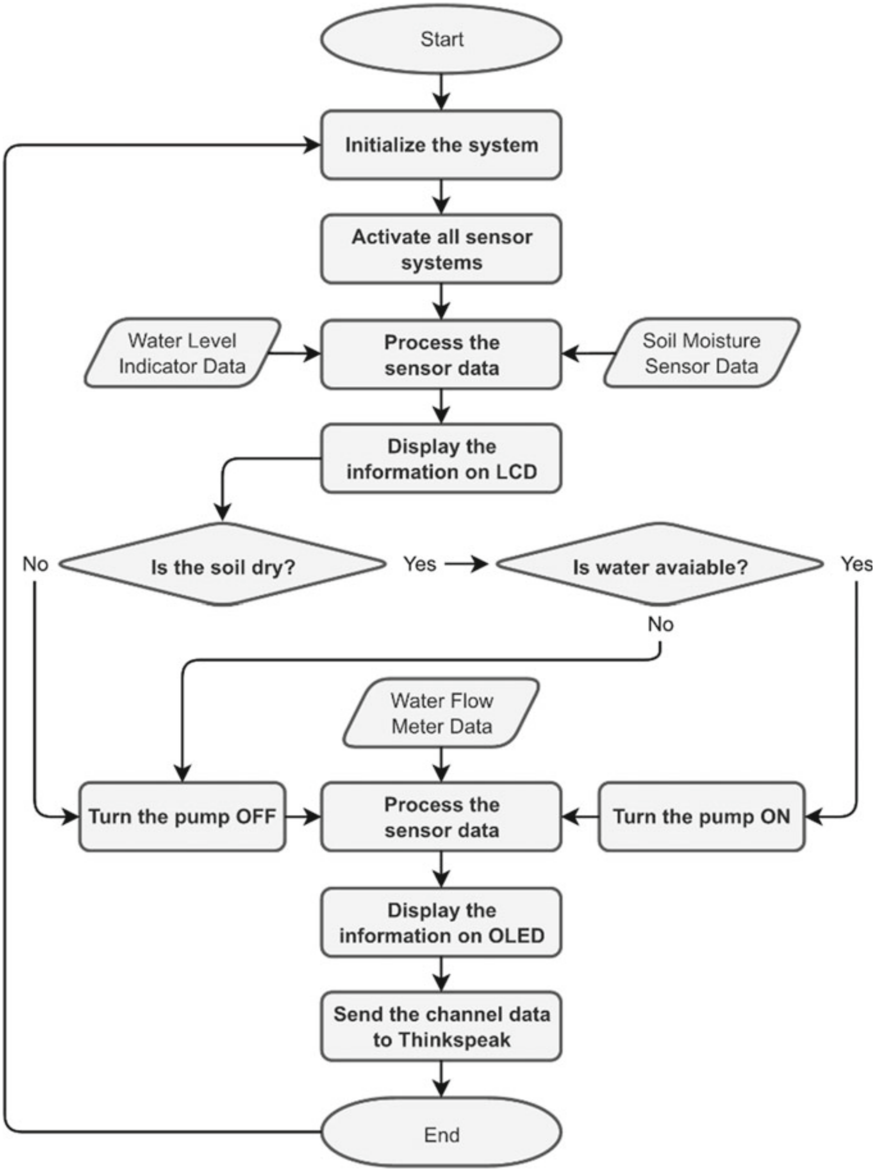

Fig. 54.4 Programming flowchart of the developed system

where F is the pulse frequency in hertz (Hz), and Q is the discharge or water flow rate. The pulse frequency depends on the water speed, and water speed depends on the pressure that drives the water through the pipelines. There is a known and constant cross-sectional area of the pipe, and if the water velocity is known, the water flow rate can be calculated as

$$Q = A \times V\left(\mathrm{m}^3/\mathrm{s}\right) \tag{54.2}$$

where A is the cross-sectional area of the pipe and V is the water velocity. From the previous equation of water flow rate, the volume of water can be calculated as [25]

$$\text{Water volume} = Q \times t(\mathrm{s}) \times \frac{1}{60(\mathrm{s})}(\mathrm{L}) \tag{54.3}$$

$$\text{Water volume} = \frac{F(\text{pulses/s})}{7.5} \times t(\mathrm{s}) \times \frac{1}{60(\mathrm{s})}(\mathrm{L}) \tag{54.4}$$

$$\text{Water volume} = \frac{\text{pulses}}{7.5 \times 60(\mathrm{s})}(\mathrm{L}) \tag{54.5}$$

where t is the time elapsed for water flow in seconds.

54.4.3 Setting Up IoT Server (ThingSpeak)

In order to be called IoT, the end-point systems or devices need to be connected to a cloud server to be able to store data and make analytical decisions. For the work presented in this paper, the popular IoT platform ThingSpeak is chosen. There are some steps to integrate the end device with ThingSpeak. A gist of which is creating channels for different types of data, generating API Keys for each type of data, and incorporating the API Keys in the written code for the end device.

After generating the API keys the incorporation in the written code is done in the following manner. For the proof of concept and demonstration purpose, only one channel creation for the water flow meter is shown (Fig. 54.5).

```
String apiKey = "KBD1JSZTUKCXJ15V";
const char *ssid = "mubarak";
const char *pass = "005kkr″;"
```

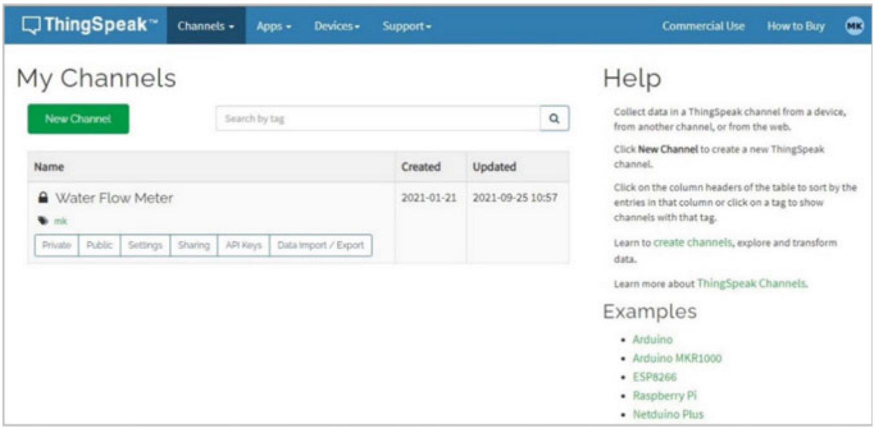

Fig. 54.5 List of the created channel(s)

54.5 Results and Discussion

54.5.1 Prototype Implementation

The developed soil moisture balancer system presented in this paper is practically implemented based on the block diagram and circuit design discussed above using the components and peripheral devices mentioned in Table 54.1. The written programming code based on the flowchart discussed above is burnt on the Arduino Uno and NodeMCU to achieve its functionality. The implemented prototype is created by interfacing all the electronic components using full-size MB-102 breadboards. Almost all the components in the system are running on a 5 V DC supply, except for the OLED screen which takes 3.3 V DC. Figure 54.6 shows the prototype of the practical device with the labeling of its components.

54.5.2 Results from Prototype Testing

In order to test the prototype, the soil moisture sensor is buried inside some dry soil surface (Fig. 7c) carefully keeping the fact in mind that the sensor wirings are not waterproof. For precision sensing, it is recommended to position the sensor near the roots of the plants. The water level indicator is placed in the water storage (tank), and the water flow meter is already connected through the output pipeline. After the power is turned ON, the system worked as designed and programmed by delivering water to the soil. The LCD screen showed the soil moisture sensor, water availability, and pump status (Fig. 7a); and the OLED screen showed the water flow rate and water

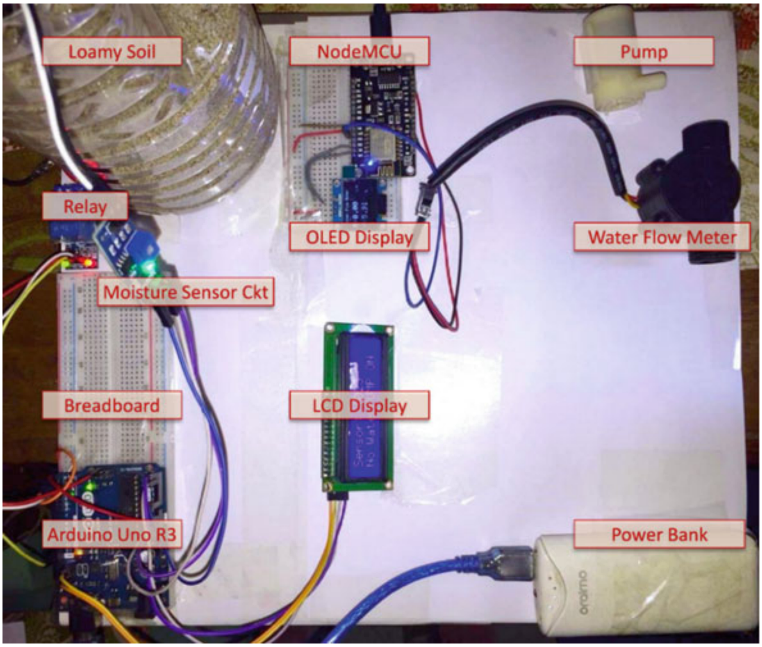

Fig. 54.6 Implemented prototype of the developed system with labeling

volume (Fig. 7b). The IoT server status is also checked and Fig. 54.8 shows that the created channel data (water flow meter) is transferred to the ThingSpeak server.

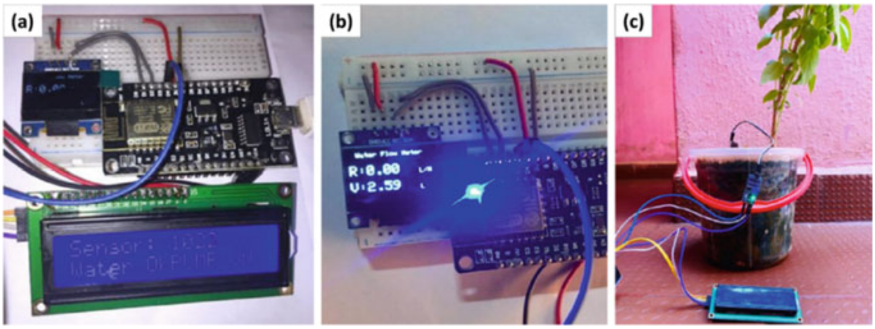

Fig. 54.7 Prototype testing. **a** Soil moisture sensor, water availability, and pump status. **b** Water flow rate and water volume. **c** Calibrating soil moisture sensor for clay soil

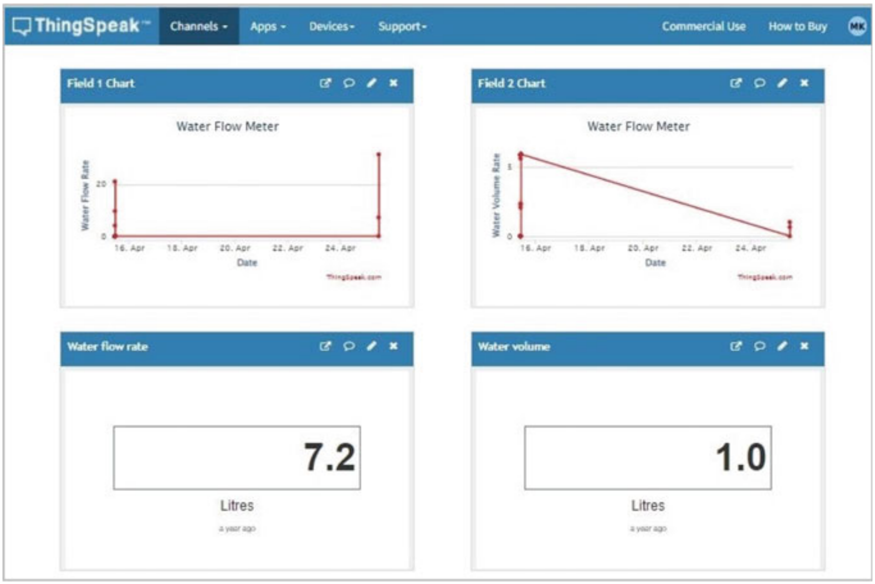

Fig. 54.8 Sensor data is being transferred to the ThingSpeak server

54.5.3 Experimental Results Based on Soil Types

The level of soil moisture varies for different types of soil. So, an experiment is done taking the 3 (three) types of soil (clay, loamy, and sandy) into account by calibrating the soil moisture sensor threshold as per the sensitivity of each soil type to observe how the water consumption by soil varies, with and without using the soil moisture sensor. The obtained experimental results are shown in Tables 54.4 and 54.5.

Table 54.4 Results for variation in water consumption using soil moisture sensor

Soil type	Time	Moisture level (dry condition)	Moisture level (wet condition)	Water volume in liters (L)
Sandy	08:00:03 a.m.	1023	450	1.80
	10:04:08 a.m.	1000	446	1.79
	12:03:00 p.m.	1021	448	1.81
Clay	08:30:28 a.m.	1022	288	1.49
	11:30:08 a.m.	1001	296	1.52
	03:00:06 p.m.	1014	290	1.53
Loamy	09:00:26 a.m.	1021	459	1.70
	11:04:33 a.m.	1010	457	1.67
	01:09:50 p.m.	1020	460	1.71

Table 54.5 Results for variation in water consumption without using soil moisture sensor

Soil type	Time	Water volume in liters (L)
Sandy	08:00:46 a.m. 10:08:18 a.m. 12:01:11 p.m.	2.71 2.95 2.80
Clay	08:39:12 a.m. 12:39:09 a.m. 03:00:18 p.m.	2.30 2.50 2.41
Loamy	09:00:39 a.m. 11:04:10 a.m. 01:05:59 p.m.	2.72 2.21 2.63

54.5.4 Discussion

Averaging the data from Tables 54.4 and 54.5, the differences in water consumption between the cases when the soil moisture sensor is used and not used are calculated and shown in Fig. 54.9. Also, the percentage of water consumption for the case when the soil moisture sensor is used with respect to the case when the sensor is not used are calculated and presented in Table 54.6. According to Table 54.6, using the soil moisture sensor 36.17% (100 − 63.83) of water is saved in the case of sandy soil, 37.08% (100 − 62.92) saved in the case of clay soil, and 32.90% (100 − 67.10) in case of loamy soil.

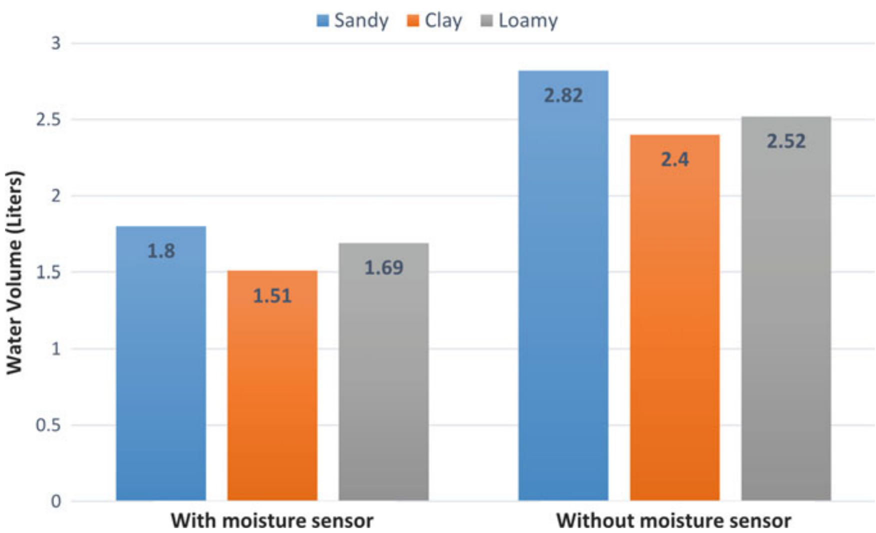

Fig. 54.9 Comparison of water consumption between using soil moisture sensor and without using the sensor

Table 54.6 Percentage of water consumption for using soil moisture sensor with respect to not using the sensor

Soil type	Avg. water volume with sensor (in L)	Avg. water volume without sensor (in L)	% Water consumption with sensor
Sandy	1.80	2.82	63.83
Clay	1.51	2.40	62.92
Loamy	1.69	2.52	67.10

For the proof of concept in the case of incorporating IoT in the developed system, only one sensor's (water flow meter) data is being channeled to the server. But channeling the soil moisture sensor's data would provide a diverse analytical advantage for better decision-making, which is under consideration in the next improvement. In case of testing the developed system for water consumption by 3 (three) types of soil, a 2-L water bottle is used to contain loamy soil, a 2-L and 550-ml plastic buckets are used to contain clay soil and sandy soil, respectively. The resultant data may vary if the sample sizes change.

The work refers to the fact that the methodology used to track the moisture content of the soil here allows agriculturalists to use moisture calculation and automatic irrigation with the potential to eliminate unnecessary irrigation cycles and save a huge amount of water. The developed system is feasible and cost-effective for optimizing the irrigation system in small-scale farms by embedding multiple soil moisture sensors, and probably multiple water pumps depending on the size of the field.

54.6 Conclusion

To address the efficiency of the irrigation system, and save precious resources, the presented system is developed. According to the system, the water releases to the field only when it is required based on the soil moisture level. This is accomplished by sensing the soil moisture using the FC-28 moisture sensor and accordingly controlling the water pump using the LM393 relay controller. This process proceeds only when the storage has enough water, which is determined by the P35 water level indicator. Also, the amount of water being released is calculated by the YF-S201 water flow meter, which gets stored in the IoT server ThingSpeak in real time for producing analytics and fine-tuning future decisions. The prototype of the developed system is tested according to the design and programming. In doing so, it is found that the system saves 36.17% of water in case of sandy soil, 37.08% in case of clay soil, and 32.90% in case of loamy soil. Overall, the system saves 35.38% of the water on average, which in turn can save other intertwined resources like time and energy, increasing the profit margin for farmers. Future scopes of the presented work may involve (i) incorporating humidity, temperature, and other sensors, (ii) introducing cloud controlling, (iii) providing moisture adjustment mechanisms based on crop type, etc.

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