IoT BASED SOIL MOISTURE MANAGEMENT USING CAPACITIVE SENSOR AND USER-FRIENDLY SMARTPHONE APPLICATION

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ระบบอินเตอร์เน็ตของสรรพสิ่งเพื่อจัดการจัดการความชื้นในดิน
ที่ใช้เซนเซอร์ชนิดเปลี่ยนแปลงค่าความจุไฟฟ้าและแอปพลิเคชันบนสมาร์ทโฟน

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ABSTRACT

The Internet of Things (IoT) based system was assembled to monitor the moisture of soils for both indoor and outdoor uses. The SKU:SEN0193 capacitive soil moisture sensor exhibited a linear response to a variation in water volume added to the soil. Microcontroller Arduino NodeMCU was used with ESP8266 Wi-Fi module to transfer the sensing data in real-time, and the soil moisture data was displayed by the Blynk application on a smartphone. When the moisture dropped under the pre-defined threshold, the user was informed via the Line application and able to remotely trigger the irrigation pump.

บทคัดย่อ

ระบบอินเตอร์เน็ตของสรรพสิ่งได้รับการพัฒนาขึ้น เพื่อติดตามค่าความชื้นในดิน สำหรับการใช้งานในร่มและกลางแจ้ง ระบบใช้เซนเซอร์ความชื้นชนิดเปลี่ยนแปลงค่าความจุไฟฟ้ารุ่น SKU:SEN0193 *ที่มีการตอบสนองเป็นเชิงเส้นกับปริมาตรของน้ำที่เติมลงในดิน และไมโครคอนโทรลเลอร์* Arduino NodeMCU *ร่วมกับ* ESP8266 Wi-Fi *โมดูล ส่งข้อมูลที่วัดได้แบบเรียลไทม์ ให้สามารถแสดงข้อมูลความชื้นของดินผ่านแอปพลิเคชัน* Blynk *บนสมาร์ทโฟน ผู้ใช้ระบบจะได้รับการเตือนผ่านแอปพลิเคชัน* Line *เมื่อความชื้นลดลงต่ำกว่าค่าขีดเริ่มที่ตั้งไว้ เพื่อสามารถสั่งปั๊มให้ทำการรดน้ำ*

INTRODUCTION

With the advent of Internet of Things (IoT), smart devices are accessed and connected with others online. Various systems can be remotely monitored by transferring measured data from a wireless sensor network and operated in response to the real-time analysis. There are numerous IoT applications in home automation (*Bheesetti et al., 2021*), industrial automation (*Singholi et al., 2021*), and healthcare (*Indra et al., 2020; Julian et al., 2021*). The applications in precision agriculture have been proposed to increase yields, reduce labour costs and conserve resources. (*Terence and Purushothaman, 2020; Deepa et al., 2021*). The sensing and functioning of devices in such systems are increasingly coordinated by either Raspberry Pi or Arduino UNO board of microcontroller (*Aulin et al., 2019; Barik, 2019; Hashim et al., 2020; Omar et al., 2020; Bheesetti et al., 2021*; *Ito and Kajisa, 2021*). The Arduino microcontrollers are widely deployed in smart farming because it can be customized for specific uses by opensource programming (*Effendi et al., 2020; Hashim et al., 2020; Omar et al., 2020; Ito and Kajisa, 2021*).

To link the hardware to the Internet, the IoT platform that simplifies the building mobile and web applications is vital. An IOS and Android smartphone application in the cloud platform called “Blynk” has been employed to monitor all devices connected to the Raspberry Pi or Arduino modules. Blynk provides various widgets and user-friendly interface to control the connected devices through smartphones.

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Blynk is therefore an automation platform for communicating between different web-based services, applications, and devices. It has been implemented in home automation (*Bheesetti et al., 2021*), street light (*Yusoff et al., 2020*), chicken farming (*Syahrorini et al., 2020*), drainage (*Bhanujyothi et al., 2020*), and water quality monitoring (*Abad et al., 2020*) systems connected to the Internet Wi-Fi. Very recently, the Arduino NodeMCU ESP8266 facilely communicating with a smartphone user via Blynk were used to evaluate the level of waste inside the dustbin (*Maddileti and Kurakula, 2020*).

Of particular relevance to this research is soil moisture monitoring. Accurate and precise measurements of soil moisture are vital to improve crop production and optimize resources. The soil volumetric water content is conventionally measured by means of the gravimetric method and tensiometry. Since the water contents affect the dielectric properties of soils, both resistive and capacitive sensing are viable routes to evaluate the moisture in real-time. Resistive sensors proved effective in low-cost soil moisture monitoring systems, but they are susceptible to systematic errors (*Segundo et al., 2015; Chavanne et al., 2018; Kumar et al., 2021*). Furthermore, commercial capacitive sensors tended to have higher accuracy and precision (*Domínguez-Niño et al., 2019; Adla et al., 2020*). The packed soil between a pair of parallel plates acts the dielectric materials in a capacitor, and the moisture is detected based on changing capacitance and resonant frequency. The SKU:SEN0193 capacitive soil moisture sensor from DFRobot (Shanghai, China) has received much interest recently (*Nagahage et al., 2019; Borah et al., 2020a; Borah et al., 2020b; Placidi et al., 2020; Visconti et al., 2020*). In *Radi et al. (2018)*, it was observed that the moisture reading of this low-cost sensor was not affected by the changes in soil temperature and volume. However, *Nagahage et al. (2019)* suggested that the output from the sensor depended on the soil composition, and soil-specific calibration was demonstrated. In *Placidi et al. (2020)*, the research comprehensively studied the SKU:SEN0193 characteristics and recommended its use in IoT based systems for monitoring a well-defined type of soil.

The objective of this research is to implement the SKU:SEN0193 capacitive sensor in the soil moisture management based on IoT technology. By incorporating Arduino NodeMCU ESP8266 and developing a software platform, sensing data is acquired and viewed remotely on a smartphone. In addition to the soil moisture monitoring, the system also controls an irrigation pump. These automate sensing and remote watering operations are demonstrated for practical uses in agricultural fields, paddies, orchards, as well as urban farming.

MATERIALS AND METHODS

HARDWARE AND SYSTEM DEVELOPMENT

An Arduino microcontroller board (NodeMCU ESP8266) was connected to a capacitive soil moisture sensor (SKU:SEN0193 module v1.2) and a liquid crystal display (LCD). It converted the analog input voltage (0-5 V) from the sensor into digital data. The program was written to adjust the soil moisture percentage from 0 to 100% according to the calibration. The data displayed on the LCD was transferred to a smartphone by linking this moisture sensing system to the Internet Wi-Fi as schematically shown in Fig. 1.

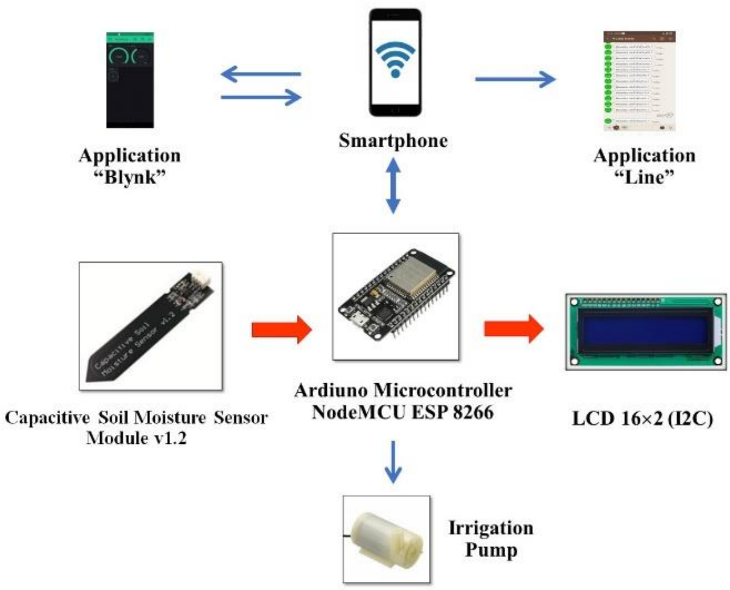

Fig. 1 - Schematic diagram of IoT based soil moisture management system

TEST OF SOIL MOISTURE SENSOR

To demonstrate the sensing operation with packed soils of varying moistures, soils locally acquired from agricultural fields were sieved and then baked in the oven at 150°C for 20 h. In a 100 mL beaker, 65 g of dried soils were filled, and waters of varying volumes up to 32 mL were added. The sensor was installed around the centre of the beaker cross-section at a depth of 3 cm (Fig. 2). The moisture averaged from 5 repeated readings was then plotted as a function of the water content. The beaker was also attached to the water supply from an irrigation pump.

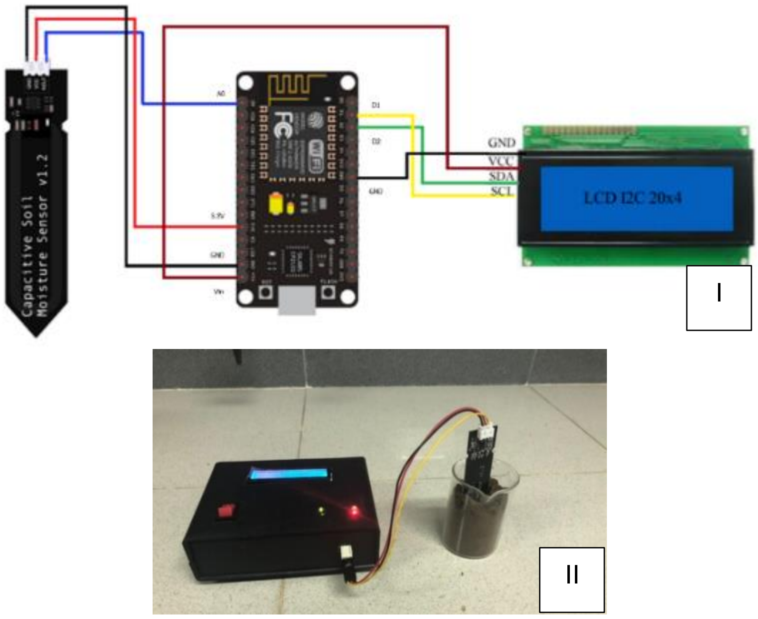

Fig. 2 - Capacitive soil moisture sensor (I) connecting to Arduino board and LCD; (II) probing the packed soil

SOFTWARE DESIGN FOR AUTOMATED MOISTURE MONITORING AND IRRIGATION

The system was developed by taking the electrical signals based on the voltage difference from the SKU:SEN0193 capacitive soil moisture sensor and converted to the moisture level by the Arduino NodeMCU ESP8266. The board was programmed to send the soil moisture to the smartphone and notify the user. Fig. 3 depicts the C programming code to read the soil moisture percentage data and display it on the LCD. The soil moisture data are sent to display on the Blynk application in real-time. The Arduino microcontroller also links the automated irrigation system to a smartphone via the Internet Wi-Fi. If the soil moisture percentage is lower than the pre-defined threshold, the notification message will be sent via the Line application.

The user can execute a command to turn on the irrigation pump via the Blynk application (Fig. 4).

```
//Display moisture level reading from SKU:SEN0193 capacitive sensor
void loop() {
  Serial.print("MOISTURE LEVEL : ");
  value = 1023 - analogRead(sense_Pin);
  lcd.setCursor(10, 0);
  lcd.print(value);
  percent = 1023 - analogRead(sense_Pin);
  percent = (percent / 1023) * 99.89;
  value = value / 10;
  Serial.print(value);
  Serial.print("\t Soil moisture : ");
  Serial.print(percent);
  Serial.println("%");
  delay(3000);
  lcd.setCursor(10, 1);
  lcd.print(percent);
  lcd.setCursor(15,1);
  lcd.print("%");
  delay(100);
}
```

Fig. 3 - The C programming code for collecting the soil moisture data and displaying the reading on the LCD

```
void loop() {
  HumidityValue = 1023 - analogRead (HumiditySensor);
  Serial.print("HumidityValueBlynk :");
  Serial.println (HumidityValueBlynk);
  Serial.println (HumidityValue);
  percent = 1023 - analogRead(HumiditySensor);
  percent = (percent / 1023) * 99.89;
  value = value / 10;
  Blynk.virtualWrite(V0,HumidityValue);
  Blynk.virtualWrite(V3,percent);
. . .
  if (HumidityValue < 350){
     i++;
     HumidityValueBlynk = 0;
     digitalWrite(Pump,ON);
. . .
    Serial.print("PUMP ON");
    Serial.println(i);
    while(i==1){
        Line_Notify(message);
        Serial.println("LINE_Notify");
        i=0;
        delay(10000);
    }
  }
    else {
        i=0;
       HumidityValueBlynk = 1000;
       digitalWrite(Pump, OFF);
       lcd.setCursor(10, 1);
       lcd.print(percent);
       Serial.println("PUMP OFF");
       Serial.println(i);
  }
  …
  Blynk.run();
  …
}
BLYNK_WRITE(V1) {
  int pinValue = param. asInt ();
  Serial.print("V1 Slider value is: ");
  Serial.println(pinValue);
  if (pinValue == 1) {
    digitalWrite (Pump, ON);
    delay(5000);
  }
  else {
    digitalWrite (Pump, OFF);
    delay(5000);
  }
}
```

Fig. 4 - The C programming code for reading the soil moisture data from Arduino, to display via Blynk application and notify the user via Line application, and finally controlling the irrigation pump

RESULTS AND DISCUSSION

From the plot of moisture reading against the variation in water up to 32 ml in Fig. 5, the SKU:SEN0193 capacitive sensor exhibits a linear response to the increase in water content. The linearity obtained in the extended range from 18% to 70% moisture is an advantageous characteristic for practical uses. The standard deviation from 5 repeated measurements, which appeared as error bars in the plot, indicates the precision of the sensing. The largest relative deviation of 4.3% occurs in the case of low water content (5 ml). This precision is comparable to that of a soil moisture meter (Sartorius MA 150) based on the gravimetric method. The performance is consistent with the characterizations of this sensor in the literature (*Borah et al., 2020a; Borah et al., 2020b; Placidi et al., 2020*). From the demonstrations, the SKU:SEN0193 capacitive sensor is fairly robust and applicable for outdoor uses for a period of time. Importantly, the soil-specific calibration is constantly needed to ensure the accuracy of the moisture percentage (*Nagahage et al., 2019*).

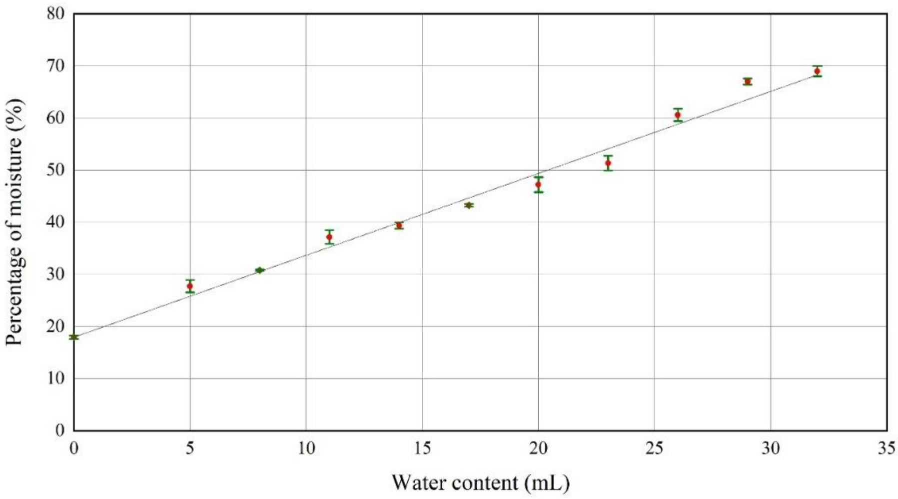

Fig. 5 - Plot of soil moisture against the water content in the packed soil showing the linearity of SKU:SEN0193 sensor

Android applications allow the graphical user interface to receive the data and send commands via the Internet Wi-Fi. Fig. 6(I) shows the smartphone display of soil moisture percentage on the Blynk application, and notifications of the moisture below the threshold of 30% via the Line application are exemplified in Fig. 6(II). As in Fig. 6(III), the irrigation can then be remotely activated by using the Blynk application on any smartphone. Without taking the cost of a smartphone into account, this system costs around 33 USD. The Arduino board constitutes one-third of the cost, whereas the SKU:SEN0193 sensor is available for only a few USD.

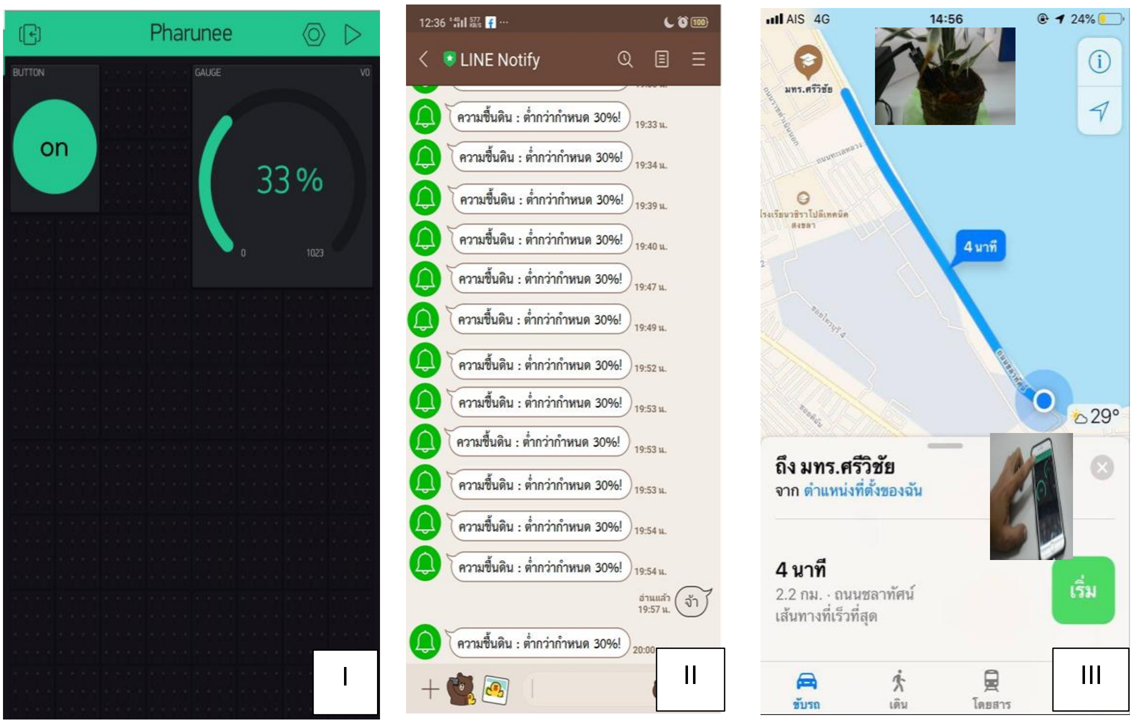

Fig. 6 - Smartphone screenshots of graphical user interface:
I - soil moisture display on the Blynk application; II - message notifications of the low moisture on the Line application; III - remote irrigation

Compared to the earlier systems presented in the literature (*Hashim et al., 2020*), this IoT based system is obviously convenient to be operated by an untrained user because of the exploitation of recent smartphone applications and sensor developments.

As pointed out by (*Omar et al., 2020*), a smartphone platform is user-friendly and advantageous in terms of operational efficiency and productivity in agriculture and farm sectors on any scale (*Effendi et al., 2020*). The Arduino board can be reprogrammable for sensor and feature additions. Multiple sensing nodes are feasible on a limited budget. Other measurements, including temperature and humidity sensing, can be integrated into the system (*Barik, 2019; Kun et al., 2021*), and data can be managed on cloud servers (*Aziz et al., 2019; Hashim et al., 2020*). From the additional information, other operations like automated fertilization were carried out (*Visconti et al., 2020*). This system can be expanded into a soil moisture monitoring station powered by a photovoltaic module (*Ramadan et al., 2018*). Furthermore, it can incorporate weather forecast data and the soil moisture prediction algorithm for irrigation planning (*Goap et al., 2018*).

CONCLUSIONS

By incorporating user-friendly mobile applications and a low-cost capacitive sensor, an IoT based system is demonstrated as a cost-effective and practical route to remotely manage the soil moisture in both agricultural fields and urban farming. A smartphone user is able to monitor the moisture percentage measured by the sensor via the Blynk application and is additionally alerted by the Line application notification whenever the moisture drops below the pre-defined threshold. The irrigation command can then be executed via Internet Wi-Fi. This system can facilely be operated by an untrained user.

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