Australian Journal of Science and Technology

ISSN Number (2208-6404)
Volume 7; Issue 4; December 2023

Original Article

Real-time automatic irrigation system for urban agriculture using GSM module

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ABSTRACT

In Bangladesh, the agricultural systems are followed mainly by conventional methods. However, urban agriculture is increasing continuously to fulfill the demand for fresh vegetables and fruits in Bangladesh. Water scheduling and budgeting are the main critical factors for optimum crop growth. Soil wetness information helps estimate the exact amount and time of watering the crops. The crop needs an optimum and continuous supply of water during vegetative growth. In a busy schedule, most people are too lazy to water the potted plants in their home gardens daily. The main aim of this study was to design and implement a real-time watering system along with constantly storing, analyzing, and reporting real-time data for urban agriculture. A GSM-based watering system and a cloud data logger were developed based on soil moisture content. The circuit design and experiment were conducted in the Precision Agricultural Lab, Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh. We programmed an Arduino Mega board to sense the plant's moisture level and supply the water in a crop structure when required. A SIM was inserted in the GSM module, which received the output data through the GA-6 GSM Module. PLX-DAQ cloud data acquisition tools were programmed and incorporated for storing, analyzing, and monitoring soil data. The soil moisture was calibrated to obtain the threshold value. Results showed the developed system automatically starts and stops watering and supplies the optimum water to the crops based on soil moisture content and soil type. This automated GSM-based real-time watering system will reduce users' time, money, and resources and increase the quality of crops. Therefore, urban and peri-urban users could use the developed method with low cost and easy maintenance.

Keywords: Automated irrigation, cloud data logger, DC pump, GSM, soil moisture

Submitted: 03-09-2023, **Accepted:** 04-11-2023, **Published:** 30-12-2023

INTRODUCTION

Bangladesh has been experiencing a rapid increase in its urban population since its independence in 1971. As a percentage of the total population, the urban population increased from around 8.2% to 38.2% from 1974 to 2020.[1] This rapid urbanization and urban growth are placing massive demand on urban food supply systems. The cities face problems such as a rapid decrease in green space and increased heat island effects.[2] Urban agriculture can reduce the temperature of roofs and the surrounding air, contribute to the overall cooling of a local climate,[3] and help reduce the urban heat island effect.[4] Urban agriculture offers many environmental, social, economic, and health benefits to high-density cities like Dhaka.[5] Urban agriculture allows low-income families to meet their needs for vitamins, minerals, and plant protein by providing daily access to fresh, nutritious fruit and vegetables. Due to the numerous benefits of urban agriculture, around 12% of urban area residents currently practice urban farming.[6] The watering tap is usually on the roof for manual watering activities and rainwater capturing; storm-water management is the primary source in urban areas.[7]

Water is one of the most crucial aspects of properly developing plants and crops. The optimum amount of water is also a factor affecting the crop's rate of growth and yield; the excess or scarcity of water greatly hinders their growth and outcome.[8] Worldwide, about 85% of available freshwater resources are used for agricultural purposes, and this percentage will continue to be dominant because of increasing population growth and food demand.[9] The water required in crops varies spatially and temporally depending on meteorological conditions, crop

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type, and crop growth stage. Spatial variability is associated with soil texture and structure, soil compaction, topographic features, fertility differences, pest distribution, and the types of irrigation systems.[10] An urban garden of high-value crops needs an optimum amount of water, air circulation, fertilizer, and light for proper growth and production. However, people in urban areas need help caring for their gardens and often need to remember to water and fertilize regularly. Moreover, the gardeners sometimes apply more water, and sometimes, the water is late, which causes the crop to dry out.[11] The other drawback of manual watering is that the water supplied to the crop could be more stable. As a result, sometimes, the crops need to receive the optimum amount of water for growth, which hinders their yield; on the other hand, a considerable amount of water is wasted. Hence, it is essential to make strategies based on advanced technology for sustainable water use, including soil structural, crop physiological, managerial, and institutional improvements.

Many approaches have been developed to achieve water savings in various crops based on the canopy temperature distribution of the plant and crop water stress index.[9] Instead, many sensors are available to provide real-time information about the environmental conditions and crop growth parameters.[12] Integrating the technologies with plant physiology and response to water inputs at the different crop growth stages is a significant challenge, if overcome, that could lead to the development of intelligent systems able to emulate the expert decision-making process.[13] Various soil moisture sensors can directly measure soil moisture, including gypsum blocks, capacitance, frequency domain reflectometry, and neutron proof.[14] A soil moisture sensor-based automated irrigation system has been successfully developed in Cymbidium production for efficient irrigation and compared the growth and water use under various substrate conditions[15] and for horticultural crops such as Ocimumbasilicum,[16] Hypericumhidcote,[17] and *Hydrangea macrophylla*[18] enhances crop yield and productivity. Capacitance or frequency domain reflectometry sensors are suggested as suitable soil moisture sensors for the automated irrigation system in nursery and greenhouse production.[19]

There are many advantages found in a complete automation system. However, some weaknesses of the sensor-based systems are observed, including the risk of sensor breakdown[20] and the difficulty of interpreting the sensor data, especially in the case of sprinkler and drip irrigation, where soil water distribution is heterogeneous.[21] Therefore, developing a robust automated technology that could be technologically sound, economically viable, and easy to operate is essential. This study aims to create a microcontroller-based precision level DC pump controlling system with a web-based live-data logger system incorporating capacitive moisture sensors and actuators for watering in an urban garden.

MATERIALS AND METHODS

Description of Overall System

The proposed system was constructed with programmable embedded hardware and a communication module. The capacitive soil moisture sensor was used to precisely control the pump to supply the water needed by the plants. When the system was activated, the entire sensor read the analog value, and the output could be seen in digital form at the controller's serial port. The exact moisture data was determined by calibrating the capacitive moisture sensor connecting with the Arduino. For better control of the system, most miniature components were used. The circuit had been built with an L298N motor driver, an Arduino Uno/Mega, a breadboard, a GSM module, a moisture sensor, and a watering channel connected to a pump. An algorithm had developed when the motor was turned off. Our system could read the exact moisture value as input and perform pump speed and delay time as output. The data logger and GSM module were connected to the pump-controlling circuit. The sensor transmitted the information to the Arduino board, which consisted of ATMEGA328P, and was responsible for automatic pump on/off with a defined speed. Arduino's system condition and pump on/off status were transmitted to the user end via the GSM-GPRS SIM 900A modem. A SIM was inserted with no disturb mode, ensuring an SMS bundle package for establishing user communication. The proposed system diagram is shown in Figure 1.

A program was developed for the Arduino board and added an in-build interfaced sensor, the L298N driving board, to control the pump. A separate Arduino UNO had also been used with the real-time clock (RTC) module for sending data to PLX-DAQ software installed on the PC. The Arduino could interact with the outside world through its input-output pins and used a simplified version of the programming language C/C++, which was run on Arduino IDE.[22] Every digital pin of the Arduino was sinking with 40 mA of current, which could not run a motor directly. A pin interface circuit was needed to drive the motor or pump. The system circuit was built on an electronic breadboard called a solder-less breadboard. Premium breadboard and jumper wires connected all the parts, 10 cm long and ten colors. The wires could be identified as male-to-female jumper cables. An FL-2203 model 12V DC motor was applied for pumping water from the reservoir for the system operation.

System Design and Experimentation

The system was designed and configured according to the soil moisture content. The overall working procedure is shown in Figure 2. Capacitive soil moisture sensors exploit the dielectric contrast between water and soil, where dry soils have a relative permittivity between 2 and 6, and water has a value of roughly 80.[23] This experiment used Arduino IDE to program a microcontroller to read analog signals from

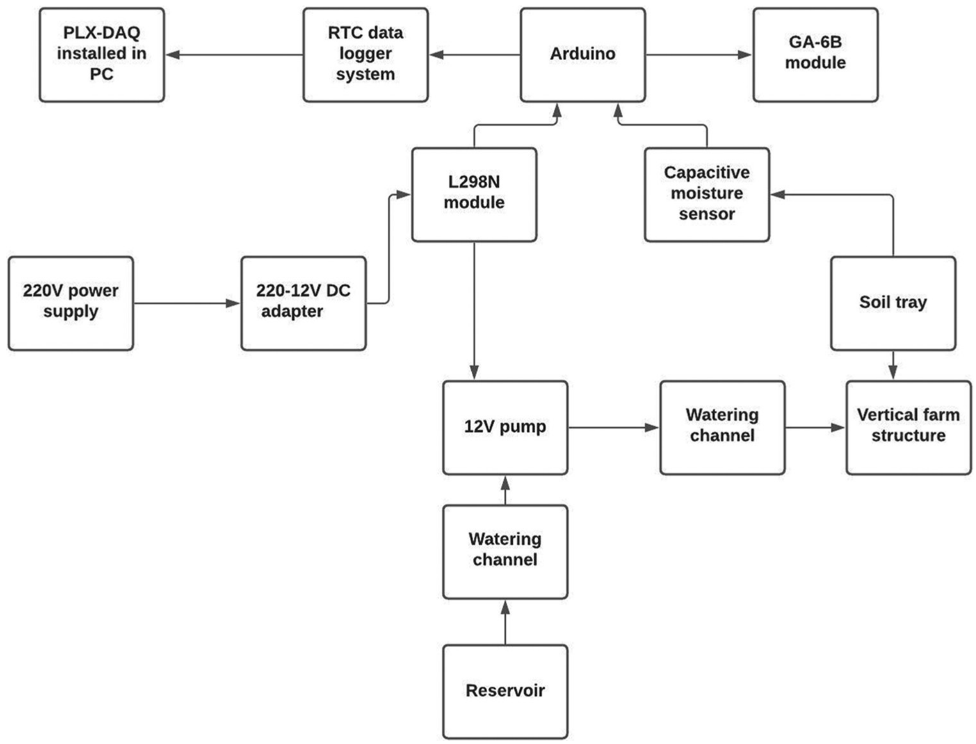

Figure 1: System block diagram

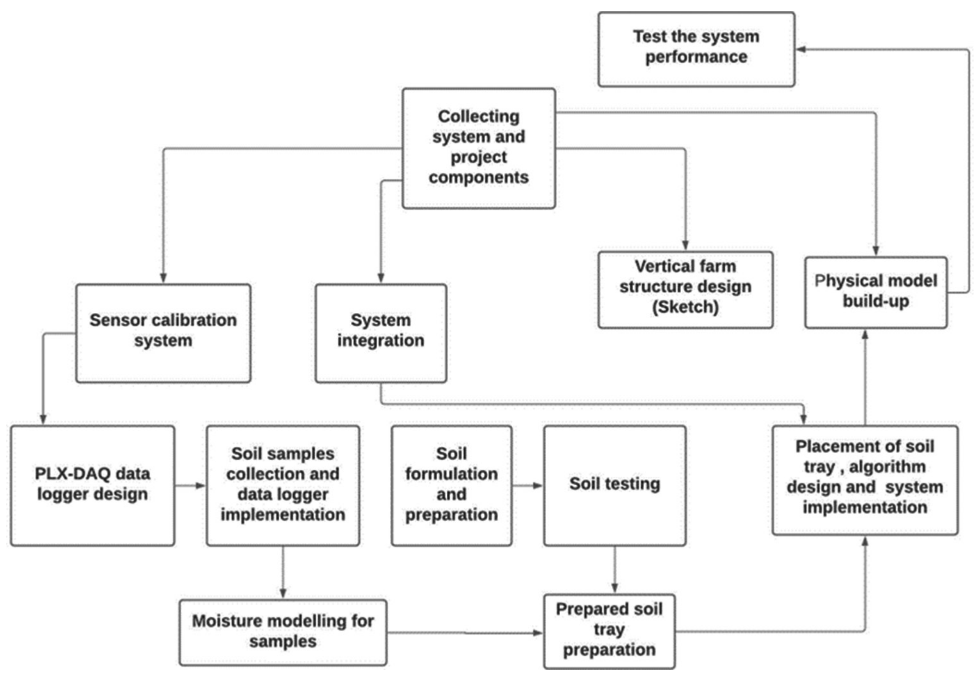

Figure 2: Overall working procedure

the sensor device. Dry and wet soil was operated across a capacitive soil moisture sensor.

Principle of Capacitive Soil Moisture Sensor

The capacitive soil moisture sensor measures soil moisture level by capacitive sensing. This device uses the gravimetric technique to calibrate a capacitive-type electromagnetic sensor. More accuracy can be achieved by using this device in agronomy and botany. The amount of charge of material stored under a given applied electrical potential could be called capacitance. The ratio of charge and potential can be expressed as a capacitance equation.[24]

$$C = \frac{Q}{V}$$

Where C represents capacitance, electrical charge is Q, and an electrical potential is V. The capacitance can be more broadly defined in differential form using Gauss's Law:

$$C = \frac{\oint \varepsilon E.ds}{\int E.dl}$$

Where,
ε represents the dielectric permittivity between the electrodes
E is the electric field
ds and *dl* are the surface and line integrals

By considering uniform charge across the capacitor plate areas and uniform electric field in between the plates of the capacitor the equation of capacitance can be expressed as:

$$C = \frac{\varepsilon EA}{E\delta} = \frac{\varepsilon A}{\delta}$$

Where the capacitance or stored energy is proportional to the dielectric material properties and represents the distance between plates, the common thing is to place the capacitor in series or parallel with other components to read the resonant frequency combined with the inductive, capacitive circuit, which can be expressed as:

$$F = \frac{1}{2\pi\sqrt{LC_t}}$$

Where,

F represents the resonant frequency, L is the inductance of the system, C_t is the total capacitance of the system. The total capacitance based on resonant frequency has a relationship with the approximation of the dielectric constant. The relationship can be written as:[25]

$$\varepsilon = f(F)$$

The high permittivity of the material allows electricity to flow more freely which increases the capacitance and results in a lower value of resonance.

Calibration of Capacitive Soil Moisture Sensor

A different set of soil samples were chosen to determine the soil moisture level. Direct quantification of suitable soil for planting high-value vegetable crops requires soil properties such as soil density and dielectric constant, which is increased with the fertilized soil.[26] The capacitive moisture sensor can measure soil moisture levels using a capacitive sensing technique. The corrosion-resistant material is made its service lifelong.[27] A built-in onboard voltage regulator operates the sensor by connecting three pins' "Gravity" interface. This 15 g weighted sensor device is operated on 5 mA, 3.3 VDC, which gives 3.0V as output.[28] The water content of the soil evaporates within 1 day of the experiment to determine humidity and temperature.[27] Dry soil and pure water were counted as samples for determining the highest and lowest moisture values. The soil moisture content can be calculated as:

$$soil\ moisture = \frac{Weight\ of\ water\ contained\ in\ the\ soil}{Weight\ of\ dry\ soil\ samples}$$

An Arduino-based calibration circuit was developed to measure the collected and prepared soil moisture level. The soil samples were collected from seven different places to determine the required soil type for the growth of the plants. The calibrated soil moisture detection system required UNO ×1, capacitive soil moisture sensor ×1, jumper cable ×3, and Arduino IDE V1.6.5. The function analog Read (0), defined in the calibration code, reads the value as moisture level in analog format and converts it into digital form in the microcontroller. The reading of moisture level depended strongly on how deep the sensor was buried in the soil.[28]

Development of an Algorithm for Controlling DC Motor

The L298 motor driver module was powered on to connect the power adapter. This controlling module had a 2V voltage drop. The VCC and GND pins of the L298 board were associated with power supply pins. The +5V pin of the driver module was connected to the 5V pin of Arduino Mega. A program was written for the mega board to avoid a power latch-up incident when DC power was disconnected. ENA and ENB pins control the speed of the motor connected to the ten pins of Arduino. IN1 and IN2 pins of the driver module were connected consecutively to the 8 and 9 pins of Arduino. These pins were used to control the spinning direction of the motor. When one was HIGH and the other became LOW, the motor was activated with a defined spin and the motor driver pins were figured out, where the OUT1 and OUT2 pins were connected to the positive and negative pins of the pump.[29]

Development of Cloud Data Acquisition System

A Parallax microcontroller data logger system was applied to read the moisture levels for the soil sample and graphically represent the change in moisture levels. A DS3231 RTC module, breadboard, jumper cable, USB (A to B), PC, PLX-DAQ (Parallax data acquisition) software, CR2032 coin cell battery, Arduino, and a capacitive moisture sensor were connected to the data logger system. This software tool (PLX-

DAQ) needs a minimum of 26 data channels for connecting with a microcontroller. A Visual Basic Macro Application was used, which controls a serial port to accept data into Excel. The specific data format has been sent from the controller to the computer serial port. When data arrives, it drops the values into columns in the Excel sheet to analyze the collected data from the soil samples. To overcome security warnings (if macros have been disabled), we have chosen Option > check: Enable this content > OK. The plug-in was tested with MS Office 2007 and 2010 but not with Office 2013. In the code, #include <SPI.h> was used for Serial Peripheral Interface (SPI), which was Pre-Loaded into Arduino. Initialize _ PlxDaq () was declared in the void setup () function, and Write_ PlxDaq () was declared in the void loop () function. The library of RTC module defined as #include <DS3231.h> and DS3231 hardware interface was established by DS3231 RTC (SDA, SCL) where SCL (clock) and SDA (data) pins were connected with Arduino A5 and A4 pins consecutively. The breakout board pins were identified, and a temperature-compensated crystal oscillator chip on the board is connected with the I2C bus, which gives precision level data. The VCC and GND pins of the module were connected to Uno's VCC and GND pins. The SQW line from RTC was connected to the Arduino D2 pin. The RTC was tested before joining the sensor to the Arduino.

Development of Data Transmission System

For robustness of the system according to the demand of urban/semi-urban residents, it needs automated and adequate watering where manual activities do not need to apply. Mobile-enabled information services can overcome the information asymmetry for existing users. The GSM module was interfaced with the output of the system. Using the GSM network, the microcontroller sends a message when the motor is activated and deactivated to the farmer's mobile number. THE GA-6B module is a mini version of the serial GSM development board with a built-in GPRS A6 chip. This small and low-power consumption module (GSM 07.07) communicated to the microcontroller boards through the UART interface. This module could add voice, text, SMS, and data capabilities. The VCC pin of the GSM module was connected with the common VCC pin of the system circuit and provided power to the board. The GND pin was connected with the common GND of the system circuit. UTX and URX are the transmission and receiving pins. The pins were connected to the 4 and 3 pins of the Arduino. In the code, the pins were declared. The working voltage of the board is recommended as 3.5–4.2 VDC. For sending and receiving SMS, the quad-band network uses 850/900/1800/1900 MHZ frequency and TCP/IP protocol.

Programming Flow Diagram of the System

A specific library was declared for serial and sensor communication in the Arduino program interface. The Tx and Rx pins of the GSM module were reported in the program. The sensor pin was declared for reading the live moisture levels, and a determined threshold value was declared for starting the motor. The motor-connected pin was declared high or low if the numerical value of the sensor came down lower than the threshold value. When the system is turned on, it sends the SMS as "System is ready to receive commands." If the motor was activated, the SMS format was declared "Motor Activated," If the motor was deactivated, the command was sent via SMS as "Motor deactivated." An algorithm was developed for regularly monitoring the system that has sent an SMS as "The System is Working Fine." The programming flow diagram is shown in Figure 3.

Soil Preparation for Experimentation

The soil was mixed with 20% khail, 30% cow dung, and 50% Sandy Loam soil for experimentation. The sample soil, hail, and cow dung were weighted separately. The proper mixing process was done using a wooden bar and wooden hammer. The mixed soil was filled into soil trays and weighted soil trays again. For suitable growth conditions, enough water was spread on each soil tray. All samples were kept in a friendly environment with no more than 25°C. The plastic soil tray was 0.4 kg weighted, which could carry 6.8 kg of soil. The soil tray had 4–7 perforations at the lower side for draining the excess water of the soil.

RESULTS AND DISCUSSION

The real-time data logger system stores and determines the sample soil's moisture level. All the sensor data of different soil samples are represented by using PLX-DAQ plug-in software. Successfully programmed the Parallax Data Acquisition tool with system sensors and stored soil data. The data format of the data-logger system was declared in the program.

Moisture Level Determination of Sample Soils

Different soil samples were arranged in a 6.5-inch round plastic container measuring a height of 3.5 inches. We measured the moisture values of eight soil samples along with air and water values (Table 1). The prepared soil was calculated from the rectangular-shaped soil tray. The air moisture level was the highest number, whereas the water moisture level was determined to be the lowest number. Due to the increase in the temperature and humidity, the moisture level degraded when watering started.

The moisture level was graphically represented for 298–300 live data from the live data logger system. Simple data with plots and an interactive bar of PLX-DAQ were used to analyze the results. This experiment emphasized the numerical value of the moisture data and listed (descending) according to the highest value of each sample. Clear visualization of the most significant changes in the sample soil's moisture level was plotted as moisture level versus sample number as shown in Figure 4. Initially, the reading became stable after achieving

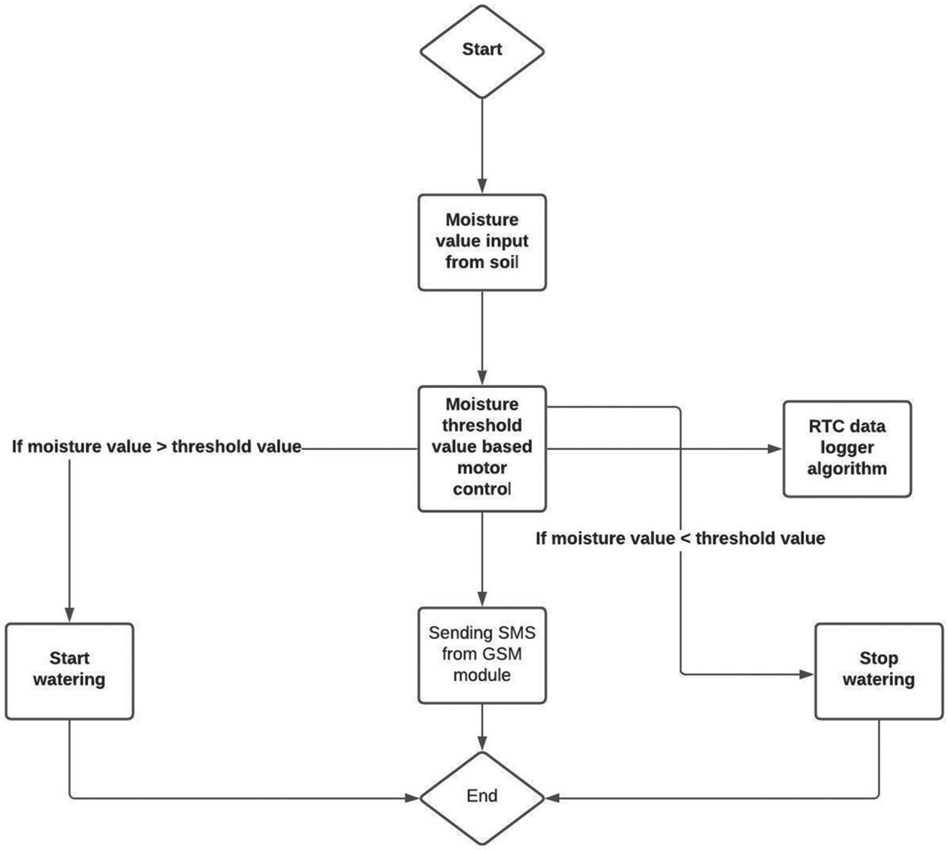

Figure 3: System programming flow diagram

Table 1: Moisture level of different soil samples

Sample type	Moisture value range
Air	824–925
Sandy soil	878–895
Loamy soil (dry)	820–825
Coarse sand (dry)	874–886
Sandy loam (dry)	813–848
Prepared soil (Semi dry)	732–810
Silty soil (semi dry)	764–770
Silty loam (wetted)	699–708
Clay soil (saturated)	599–644
Water	597–634

30–50 values for every sample, and the range was listed considering initial values.

Soil Properties and Their Moisture Level

The soil samples were tested at Humboldt Soil Testing Laboratory, Department of Soil Science, BAU, Mymensingh. The textural class was identified as Sandy soil, Loamy soil (dry), Coarse sand (dry), Sandy loam (dry), Silty soil (semi-dry), Silty loam (wetted), and Clay soil (saturated). Sandy Loam consists of sand soil at 60% sand, 8% silt, and 32% clay. After measuring the moisture level of different soil samples, sandy loam soil was found suitable for indoor crop production. Sandy loam soil was well internal pore spaces, which is effective for nutrient movement and draining the water efficiently. In the range of preferable soil pH, the sandy loam soil's acidity significantly decreased with the increased rate of cow dung, where the optimum pH needed 195 limes. Average Available Water Holding Capacity (AWC) increases by about 0.1 inches per foot for each 1 percent organic matter increase for moderately coarse-textured sandy loam soils. At the same time, the mixture ratio of 50% organic matter with 50% soil in the AWC increased by 5 inches per food. Results are presented in a plot of time versus Moisture level during moisture degradation. About 2000 numbers of repeated data were recorded, and 755 was selected as a threshold value for the system. The collected moisture soil data was also represented in the PLX-DAQ software interface.

System Implementation and Algorithm Development

The program has been declared by downloading Arduino libraries and defining the sensor, motor, and software serial pin. The sensor value is defined as "int sdata1" by char "str."[14] To

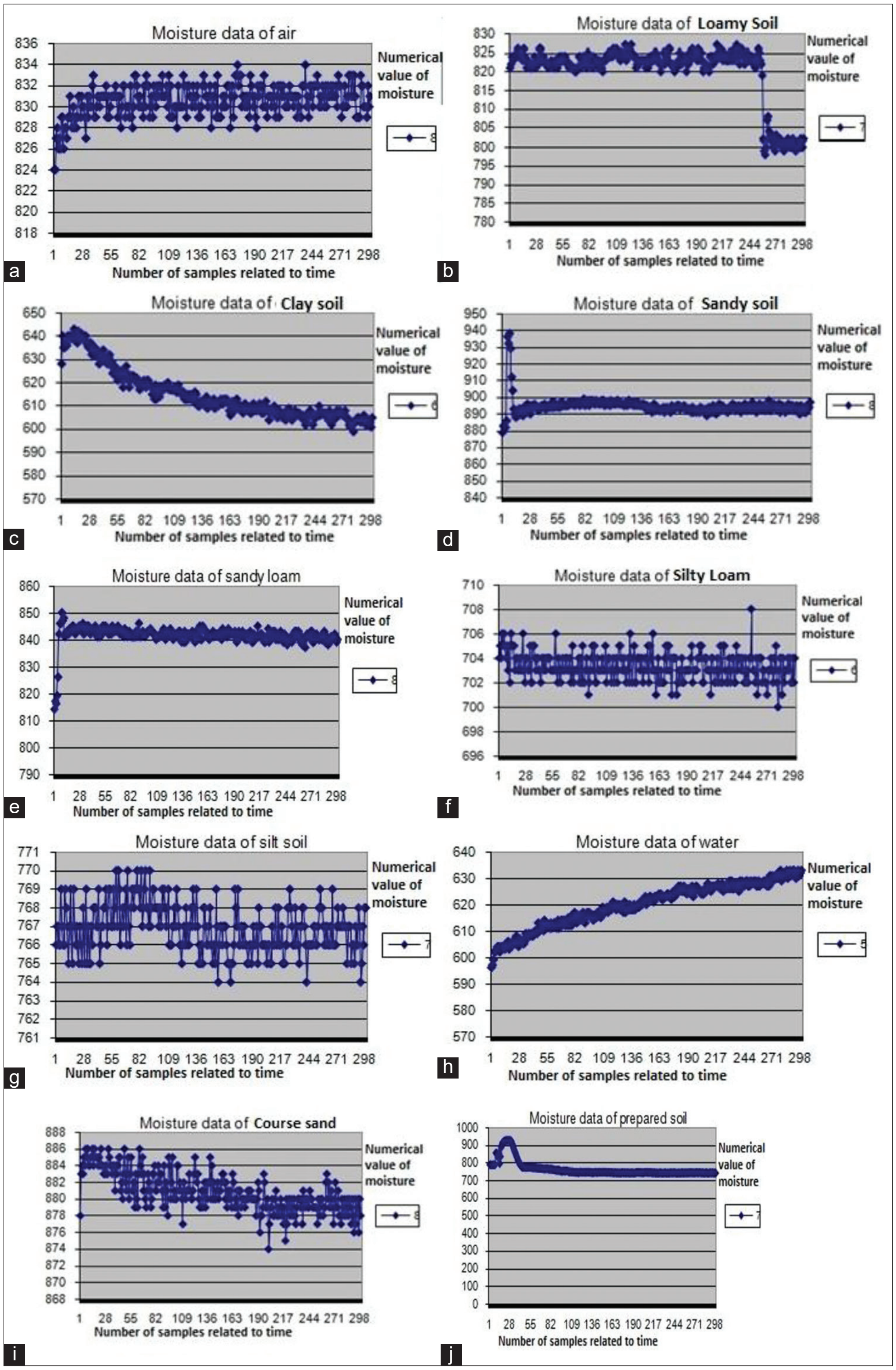

Figure 4: Measurement of soil moisture level in (a) air (b) Loamy soil (c) Clay soil (d) Sandy soil (e) Sandy loam (f) Silty loam (g) Silt soil (h) Water and (i) Coarse sand (j) Prepared soil moisture level

control the motor, define int In1 = 8; int In2 = 9; // to control the motor. In the void setup () function, serial communication was defined as 9600 and sensor value as INPUT and EnA, In1, In2 as output. The AT command of "AT+CNMI=2,2,0,0,0" discarded the old indication and replaced it with the newly received indication. Set the SMS system into text mode by declaring "AT+CMGF=1." The "AT+CMGS" command was responsible for selecting the SMS message format. When the

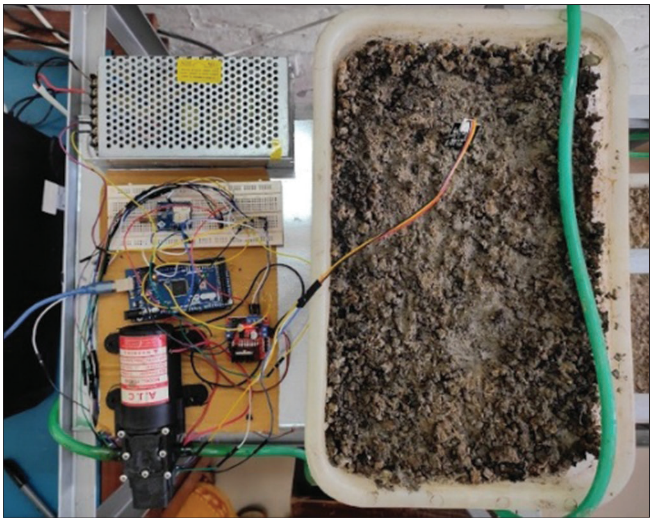

Figure 5: System implementation with soil tray

system woke up, send an SMS as "System is ready to receive commands." Void loop () function contains the main logic to operate the system, which is dependent on the threshold "msvalue." When digital Write (In1, HIGH); digital Write (In2, HIGH), the system send SMS as "Motor Activated." When digital Write (In1, LOW); digital Write (In2, LOW), then the system sends an SMS as "Motor deactivated." A void serial Event () was written in the program as if Serial.find ("/") will read the defined characters and by using void check () function (!(strncmp (str, "motor on," 8))) ensures the motor activated else (!(strncmp (str, "motor off," 9))) ensures motor deactivated. While this regular on/off process was working, then (!(strncmp (str, "test" 4))) sent an SMS as "The System is Working Fine." The physical integrated system is shown in Figure 5.

System Outputs

Two SIM cards were used to monitor the system condition of the motor turned on or off based on the threshold value. The motor was turned off when it was below the threshold value (755), and an SMS was sent to the user as "Motor deactivated." The sensor reads the moisture value, the motor was turned on when it reached the threshold value (755), and an SMS was sent to the user as "Motor activated." The system was run longer in the laboratory to determine the system performance, and the output curve is shown on the serial plotter of the Arduino sketch interface.

CONCLUSION

Urban or rooftop agriculture is increasing continuously to fulfill the demand for fresh vegetables and fruits in Bangladesh. However, watering is a crucial factor in the household garden, which is a labor-intensive task in daily operation. Especially in their busy schedule, most people forget to water the potted plants on their rooftop gardens every day. A soil moisture model-based automated watering system was designed and tested to solve this problem for growing high-value crops in an urban area. Every module has been carefully considered and arranged, resulting in the unit's best operation. PLX-DAQ software was used as a virtual data logger. Six types of soil samples, along with a prepared ideal soil sample, were used to optimize the threshold value. The moisture sensor measures the soil water content (moisture level). The moisture sensor transmits a signal to the microcontroller, converted as numerical values, and stored in PLX-DAQ software. The motor was turned on when it reached the threshold value (755), and an SMS was sent to the user as "Motor activated." The system is expected to help reduce labor and production costs and contribute to sustainable crop production with efficient water and nutrient use.

ACKNOWLEDGMENT

We would like to thank for the permission to the Department of Farm Power and Machinery, BAU, for experimental facilities at the Precision Agriculture laboratory.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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