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Development of an Embedded Moisture Sensing Device for a Distributive Network to Control Irrigation using IoT

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Abstract

Measurement of soil moisture and control of irrigation according to the measured data is crucial in agriculture fields where water scarcity is always a serious issue. For this purpose, a cost-effective distributive network system has been proposed and developed using technology like IoT to control complex irrigation processes. An internet-enabled embedded moisture sensing unit was designed that consists of a capacitive sensor probe and electronic system to process the soil moisture value. The sensor probe was calibrated for six different varieties of soil using the Thermo gravimetric method. The output response is inspiring, with a goodness of fit value of 0.99. Algorithms are developed for irrigation control that operates by a developed web-based application from the control station. The system was implemented at a total cost of 122.37 US dollars and tested in cassava agriculture field for loam soil in Nagaland, India, for 91 days and showed magnificent water saving of up to 95% compared with traditional approaches.

Keywords: Soil moisture; Irrigation control; Distributive network system; capacitive moisture sensor; Embedded moisture sensing unit.

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Introduction

For proper agricultural crop growth in precision or normal farming process, soil moisture plays a crucial role. Maintaining a uniform distribution of water throughout the farmland and measuring moisture content at different levels of soil is quite challenging. But for effective water distribution and minimizing water loss, it is essential to consider the soil property. Since water holding capacity varies with the change of soil type and based on soil type, moisture content varies at different levels and places of agriculture fields. The distributed sensor network system has been more effective in such a scenario. Implementing such systems requires accurate data collection, processing, software design and fast communication.

Over the last two decades, many researchers have been trying to develop a system for optimum water utilization in agriculture. A distributed network system effectively performs the tasks. Based on these two parameters, an algorithm was developed for optimum water use (Gutierrez et al., 2014). An automatically closed loop system in a distributed wireless network to control irrigation is challenging (Yunseop Kim et al., 2008). The system needs proper navigation, sensing, control and transmission. To control such a system programmable logic controller (PLC) is interfaced with the system. All the sensing units are interconnected through a wireless sensor network (WSN) and WiFi technology. The base station's P.C. (Personal Computer) stores an application to monitor and control parameters. Implementation of such an irrigation control system needs proper invigilation and maintenance. Some researchers developed low-cost systems using IoT technology to control irrigation and monitor irrigation-related parameters (Borah et al., 2021). The hybrid system is controlled using a threshold value algorithm programmed into an IoT-enabled controller. Another low-cost irrigation control system is developed around the Node MCU IoT board. The system is designed to control irrigation, detect intruders' presence, and predict which crop type is best for the soil (Chowdary et al., 2019).

Wireless sensor networks play a crucial role in the automated irrigation process (Gokul et al., 2016). Based on wireless sensor network technology, a decision support system (Paucar et al., 2015) was developed for the optimum use of water (Gao et al., 2013). Wireless sensor networks are used effectively to establish communication among sensors and actuators. Gao considered soil moisture content and rate of change of moisture as an input variable for a Fuzzy intelligent system to control the irrigation process.

Traditionally canals are used to distribute water in agricultural fields. Usually, such a canal system has decentralized control. A distributed control network (Rudy et al., 2009) for the canal system was found to be more effective in distributing water. Moreover, some advanced approaches have shown better performance (Balachander et al., 2021) under distributed control networks. The water and control irrigation effectively, different approaches such as neural network-based control systems (Karar et al., 2020), machine learning algorithms (Vij et al., 2020), closed-loop systems (Kim et al., 2009) and the use of specific software tools (Kim et al., 2009) for site-specific irrigation were studied. The performance of such techniques can be further improved with an adequately distributed soil moisture sensing system. The system will become more flexible and effective if the moisture content of the soil can be measured precisely. For that purpose, different techniques such as Ground Penetrating Radar (Huisman et al., 2003), Fiber Optics (Alessi & Prunty, 1986), Neutron Scattering, and Gamma Attenuation (Zazueta & Xin, 1994) have been implemented over the past few decades. The problems with such approaches are a requirement of complex calibration, bulky design, continuous maintenance and high implementation cost. So, such techniques are usually not preferred for traditional agriculture or farming. Capacitive and Time Domain Reflectometry (TDR) based techniques (Rao & Singh, 2011) are used to measure soil water content. Such techniques are based on the dielectric permittivity of the soil (Curtis, 2001). To design the capacitive sensor, probe dielectric permittivity of soil (Campbell, 1990) is greatly influenced. Some research found that the frequency of the input signal (Kizito et al., 2008) to trigger the sensor probe is also greatly influenced by the output response of the capacitive moisture sensor. A soil moisture sensor is presented based on the dielectric properties of soil and found effective at 32 MHz of frequency (Eller & Denoth, 1996).

A unique capacitive soil moisture sensor design unveils (Fu Ching Lee, 2007) that used a plurality of electrodes paired on both sides of the probe. The sensors sense the moisture content based on the change of capacitance due to a change in permittivity. A capacitive soil moisture sensor system with a processor and memory element can read and store data more efficiently (Stephen Charles Davis et al., 2008). For that purpose, the processor needs to be programmed according to a specific algorithm. A complete soil moisture sensor design model is patented (Thomas Runge, et al., 2003). In their design, they used two individual electrodes to get moisture value, a transceiver unit to interrupt an irrigation and a LED (Light Emitting Diode) display to write the moisture value.

Over the last two decades, the fringing field capacitive sensors (McIntosh & Casada, 2008) has been extensively used to measure moisture content in agriculture. Dean et al., (2012) and Mizuguchi et al., (2015) designed fringing field or interdigital capacitive sensors for agricultural commodities. They used Printed Circuit Board (PCB) Technology to fabricate the sensor probe. An impressive goodness-of-fit (R2=0.94) response was reported for the designed sensor probe. A novel interdigital capacitive sensor design is presented to measure soil moisture (Goswami et al., 2018). In their novel configuration, interdigital capacitive sensor layers are on both sides of the FR4 board. The configuration is optimized by considering the electrodes' adjacent gap between the electrode and FR4 thickness.

In this current research work, a low-cost and portable embedded capacitive soil moisture sensing device is designed for a distributed network to control irrigation for cassava agriculture fields. The DNS has four sensing units that are distributed in the agriculture field. All the sensing devices are connected to the control unit through a server. An irrigation control unit that works with sensing devices to control irrigation has been proposed. Communication is established among the sensor nodes, irrigation control unit and control station by using IEEE802.11b (WiFi) standard protocol. For the proper growth of cassava crops, soil moisture plays a crucial role (Olufemi Olayinka et al., 2007). Anyway, cassava plants can grow at a meagre percentage of soil moisture. But for healthy growth, a minimum of 50% moisture needs to be present in the soil for the first three months (Oshunsanya & Nwosu, 2018; Howeler et al., 2013). So, the IoT-enabled distributed network is designed and tested in the cassava field for three months.

A web application is developed using Hypertext Markup Language (HTML), PHP (Hypertext Pre-processor) and JavaScript to control the network, a. The web application is hosted locally to check the performance of the distributed network. The application can communicate in duplex mode to monitor and control soil moisture. To provide internet connectivity, each sensing unit and irrigation control unit is equipped with an ESP-01 module. The complete design of the distributive network and soil moisture sensing unit is discussed in this current work.

Methodology

The conceptual design and flow diagram of DNS to control irrigation in the cassava agriculture field is shown in Figure 1. The DNS stores three central units: embedded moisture sensing unit (MSU), irrigation control unit (ICU) and control station. The control station uses a web application to control irrigation and monitor soil moisture data graphically for a specific soil type. Four different MSUs are distributed throughout the cassava field, and all are connected to the control station through the WiFi network provided by the router. The ICU uses a controller and sprinkler mechanism to control irrigation through a web application. The ICU triggers a water pump based on the command received from the control station/web application to sprinkle water in the cassava field.

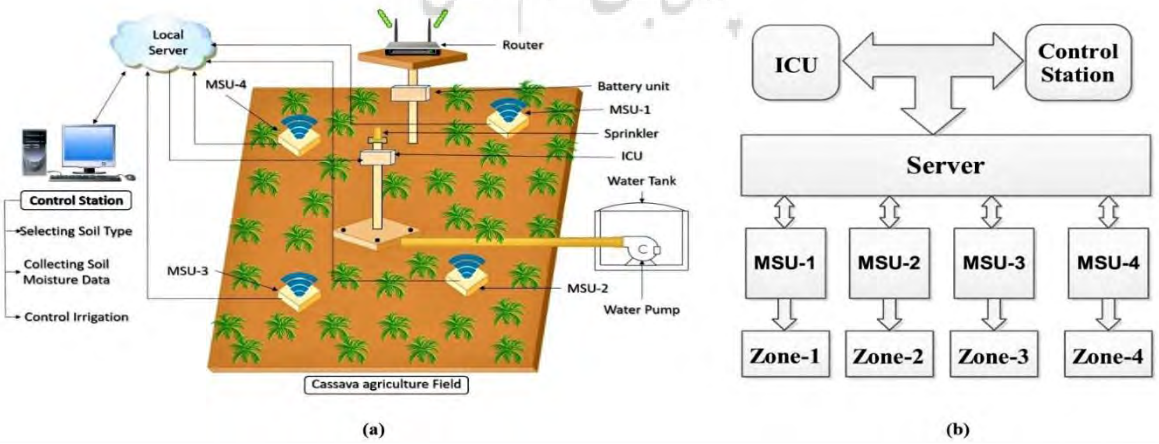


Figure 1. Conceptual design of DNS to control irrigation in cassava agriculture field

Moisture Sensing Unit (MSU)

The embedded MSU comprises an interdigital capacitive sensor probe and an electronic circuit to read moisture values. The details of developing an embedded MSU are discussed below.

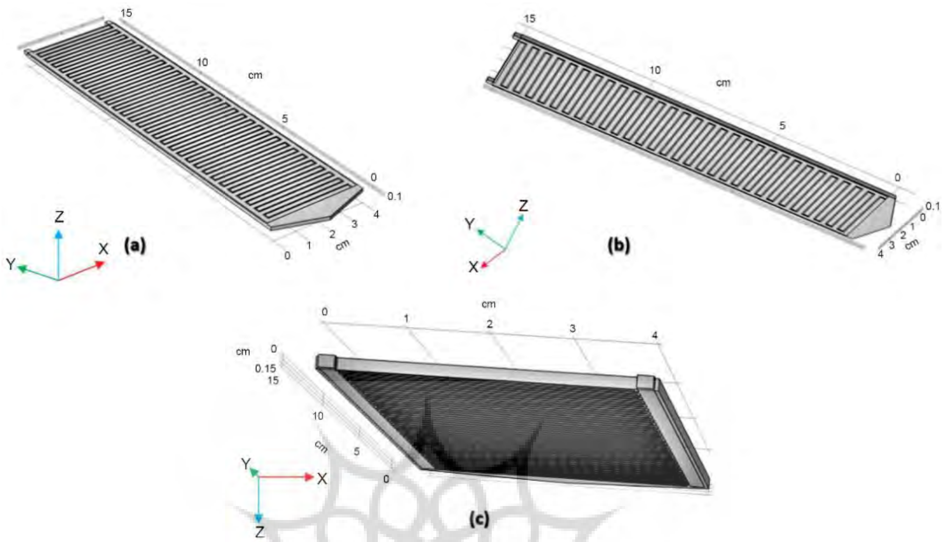


Figure 2. Structure of sensor probe (a) Top view (b) Bottom view (c) Side view

Design of sensor probe: An interdigital capacitive sensor probe is designed with dimensions, as shown in Figure 2 for the MSU. In Figure 2, the detailed structure of the sensor probe is shown from different angles. Introducing an interdigital pattern to design the sensor probe is to improve the resultant capacitance response in a defined area. One end of the sensor probe has a tapered edge that can be easily inserted into the soil.

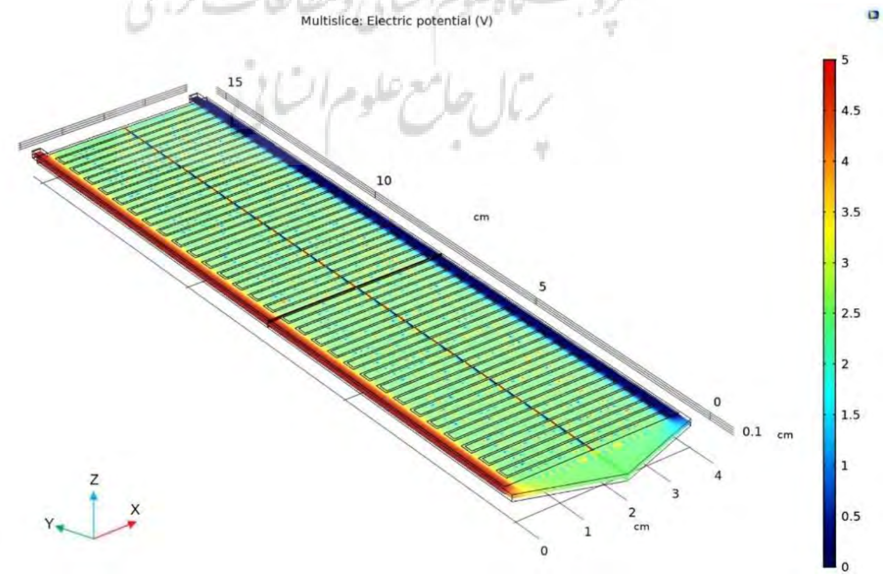


Figure 3. Potential distribution of sensor probe

As shown in Figures 2 (a) and 2 (b), the interdigital pattern is achieved on both sides of the sensor probe. To get a better capacitance response from the sensor probe, the interdigital sensor layers (top and bottom) are connected in parallel. Two opposite polarity electrodes act as a parallel plate capacitor in the interdigital capacitive sensor layers. So, the capacitance of the sensor probe depends on the width of the electrode (i.e area (A) of cross-section), the distance between two opposite polarity electrodes (d) and permittivity (ε) of the material between two opposite polarity electrodes.

COMSOL Multiphysics version 5.4 software tool is used to design the sensor probe. This tool uses the finite element method (FEM) to find the optimum design/structure. The potential distribution of the sensor probe is shown in Figure 3. A uniform potential distribution of 2.5V is observed throughout the probe. In Figure 4, the capacitance response is shown with the permittivity change for the designed sensor probe. The capacitance is found to be increasing proportionally with the increase of permittivity.

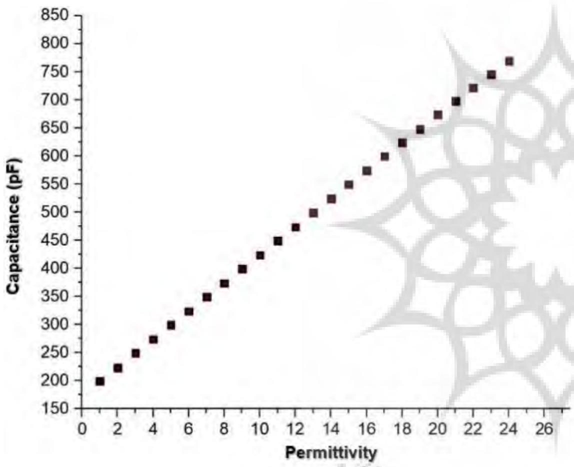


Figure 4. Capacitance vs permittivity

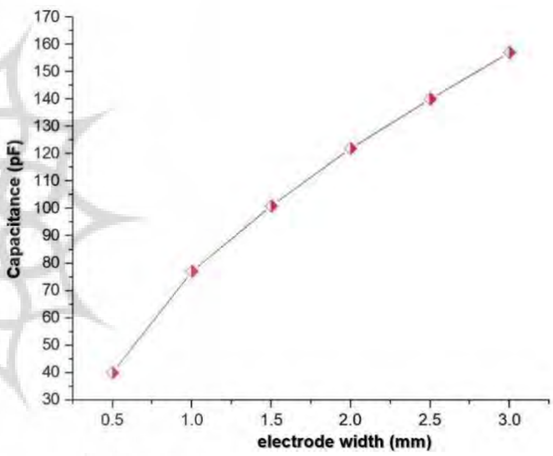


Figure 5. Capacitance vs electrode width

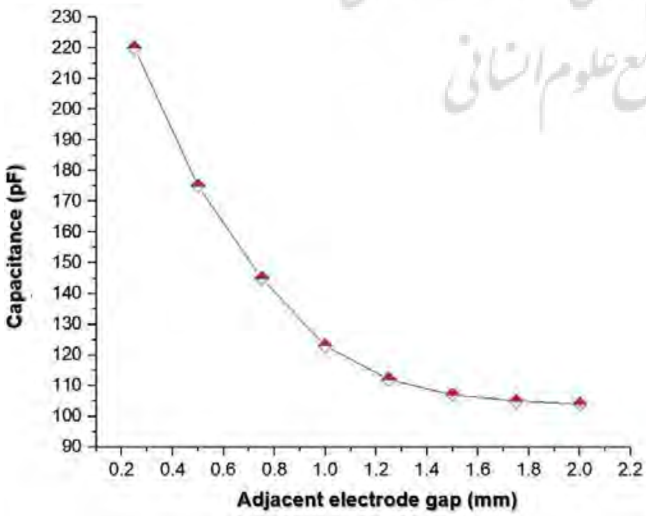


Figure 6. Capacitance vs adjacent electrode gap

Figure 7. Fabricated (a) sensor probe (b) Top view

In Figures 5 and 6, the responses of capacitance with the change of electrode width and adjacent electrode gap have been shown. The capacitance increases with the increment in electrode width and decreases with the increase of the adjacent electrode gap.

Sensor probe fabrication

The designed sensor probe is fabricated using PCB etching technology. Figure 7 shows the fabricated sensor probe's top and bottom views. The layout of the interdigital pattern is designed in Diptrace 3.0.0.2 software. The detailed specification of the PCB used to make the sensor probe is mentioned in Table 1. On both sides of the double-layer PCB, 20 pairs of copper electrodes are placed. A gap of 1 mm is maintained between two adjacent electrodes. The width of each copper electrode is 2 mm, and it has a length of 38 mm. A layer of low dielectric material, epoxy resin, is sprayed over the fabricated sensor probe to prevent any physical damage due to corrosion.

Table 1. Detail specifications of PCB

Property	Specification
Substrate material	FR4
Withstand Voltage	24 V, DC
Resistivity of surface material	0.055 GΩ
Layer material	Glass epoxy Cu- Double sided
FR4 board/PCB thickness	1.5341 mm
Cu layer thickness	0.0341 mm
Dielectric material thickness	1.4659 mm

Electronic system design for embedded MSU

The embedded MSU comprises a microcontroller, capacitive sensor probe, WiFi module, analogue converter circuit, and regulated power sources. The architecture of the electronic system is shown in Figure 8. Each embedded MSU is built around Atmega328P (ATMEL) microcontroller. Atmega328P controller having 8-bit RISC architecture. The standard version comes with 32 K.B. of ROM, 2 K.B. of SRAM and 1 K.B. of EEPROM. The microcontroller generates a square wave signal of 1000 Khz and reads soil moisture value according to Soil Based Moisture (SBM) algorithm. The electronic circuit schematic and flowchart of the SBM algorithm have been respectively shown in Figures 9 and 10. The system is powered by an 11.1V, 2.2 AH lithium-ion battery (SkyCell). The battery has an inbuilt over-current and over-voltage protection circuit with charging and discharging current ratings of 1A and 4.4A, respectively. As shown in Figure 9, two voltage regulators, UA7805CKCT (Texas Instruments) and HT7333A (Digichip) are used along with a few discrete components (capacitors/diodes) to obtain 5V and 3.3V regulated voltage, respectively. 3.3V supply is for ESP-01 (Ai-Thinker) WiFi module. ESP-01 provides internet connectivity to the microcontroller. An external crystal of 16 MHz provides a clock signal to the Atmega328P controller.

The 5V supply is for the microcontroller. The 1000 kHz signal generated by the microcontroller using the timer interrupt is used to excite the capacitive sensor probe. This signal is provided to the capacitive sensor probe through a 10k resistor. A combination of fast switching diode (1N14148) in series with parallel connection of one μF capacitor and 1 MΩ resistor is used to smoothen the signal. The ADC of the microcontroller uses the smoothened signal to get the moisture value. The circuit's parts are assembled in a PCB and placed correctly in a PVC (polyvinyl chloride) box to make it waterproof. Figures 11 (a) and 11 (b) prototype design for MSU with detailed dimensions and the final hardware prototype model are shown. A switch and a LED indicator are also interfaced with the embedded MSU to control the power supply.

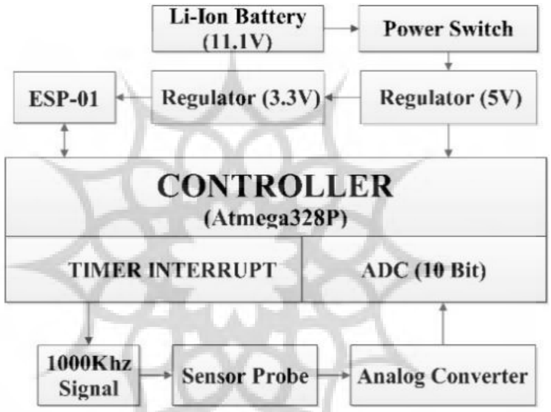


Figure 8. Electronic system architecture for embedded MSU

Some studies show frequency's impact on designing interdigital capacitive sensor probes (Wobschall & Lakshmanan, 2005). In this present work, a function generator is used to apply different frequency signals to analyze the Effect of frequency on the sensor output voltage. Figure 12 shows the Effect of frequency on the sensor output voltage. The minimum and maximum output voltages are taken when the sensor probe is in completely saturated wet soil (100% soil moisture) and parched soil (0% soil moisture), respectively. A maximum voltage range of 1.55V is observed at 1000 kHz of frequency. So, the designed sensor probe is excited precisely with a signal of 1000 kHz. of frequency.

The SBM algorithm mentioned below is developed using a C programming language in AVR Studio version 7.0. The main feature of the SBM algorithm is to find the moisture content for a specific soil using the calibration equations obtained from the linear analysis of voltage responses shown in Table 4. As shown in Figure 10, the algorithm initializes the timer interrupt to generate a signal of 1000 kHz and enables the serial pin to communicate with the control station/web application. The SBM algorithm is programmed to connect with the specified network. Once the MSU connect with the network, the SBM algorithm reads the moisture value. The algorithm chooses a specific calibration equation based on the specific command received from a web application. The calibrated moisture value for the specific soil is sent to the server to interrupt an irrigation process using ICU.

Irrigation Control Unit (ICU)

The internet-enabled ICU is designed to control or schedule irrigation based on the average soil moisture value received from four different MSUs distributed in the cassava agriculture field. The web application governs the control of the ICU. The ICU triggers sprinklers based on the specific command received from the web application.

Electronic system for ICU

The electronic system architecture to design the ICU is shown in Figure 13. A 5V, 5A Single Pole Double Throw (SPDT) relay is interfaced with controller Atmega328P to control the water pump for irrigation.

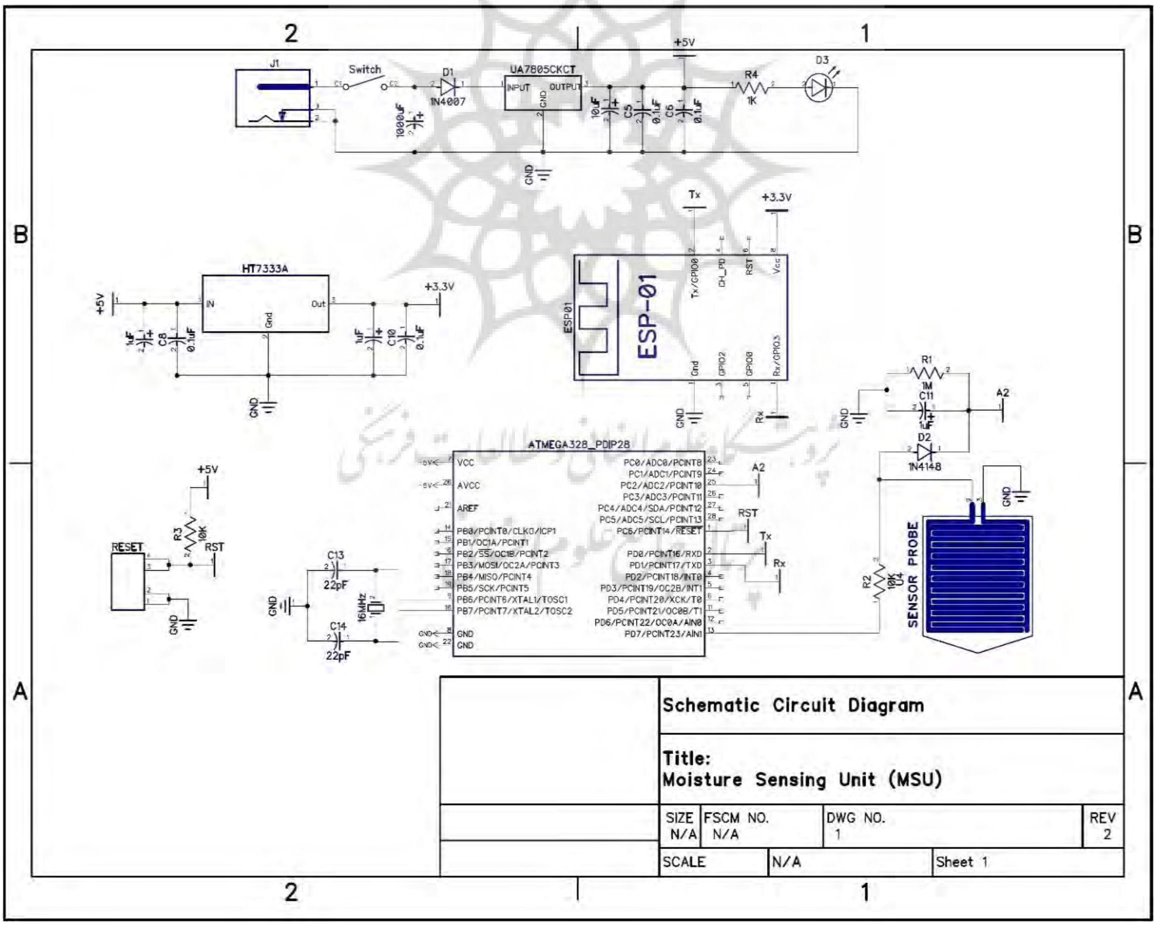


Figure 9. Electronic circuit schematic for embedded MSU

A diode 1N4007 is used across the relay coil to prevent the controller circuit from back EMF. The controller of the ICU is programmed according to Irrigation Based Moisture (IBM) algorithm. The flowchart of the algorithm is shown in Figure 15. The main objective of the IBM algorithm is to trigger a water pump for half an hour to maintain a certain level of soil moisture based on the command received from the web application. The algorithm is developed in AVR Studio version 7.0 using a C programming language. Table 2 shows the detailed parts information and total cost of implementing the DNS.

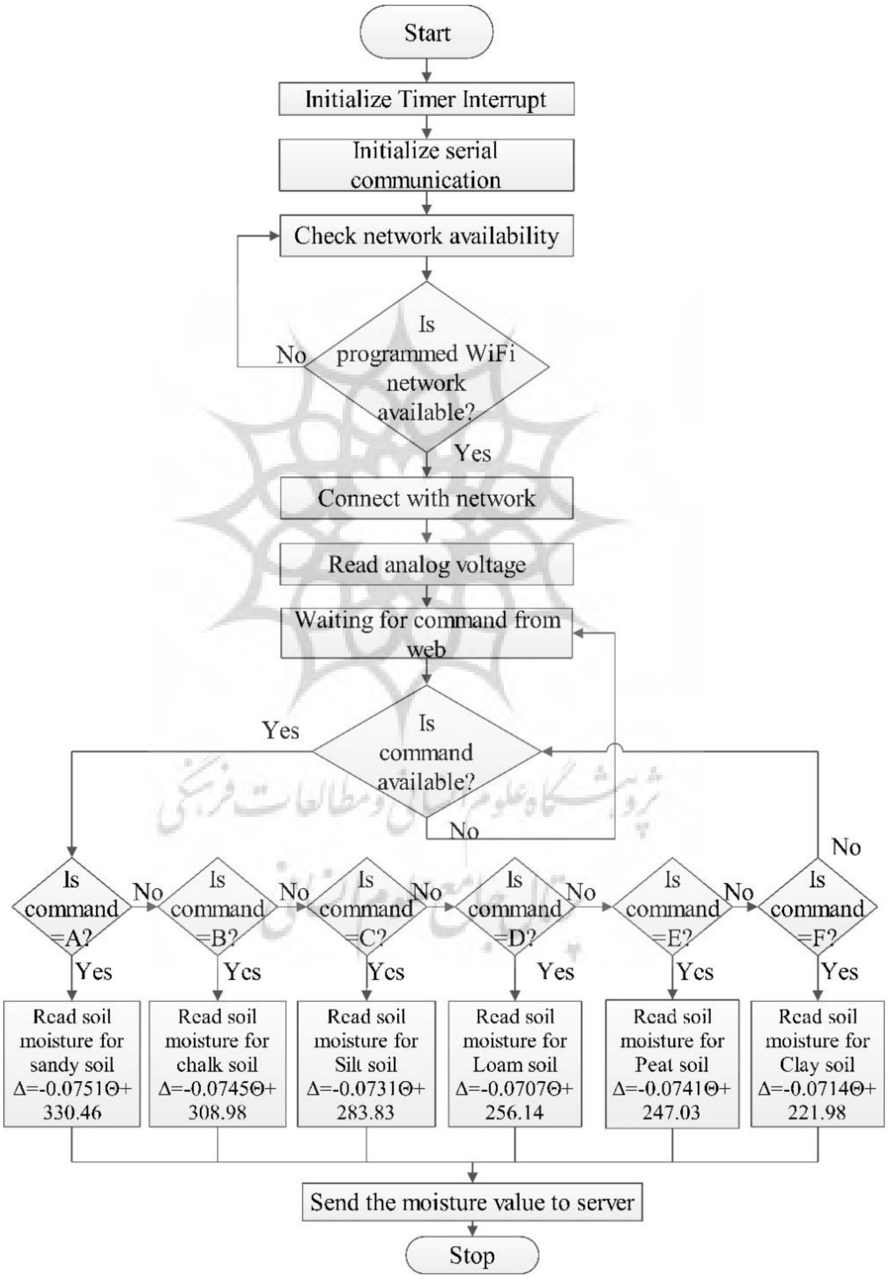
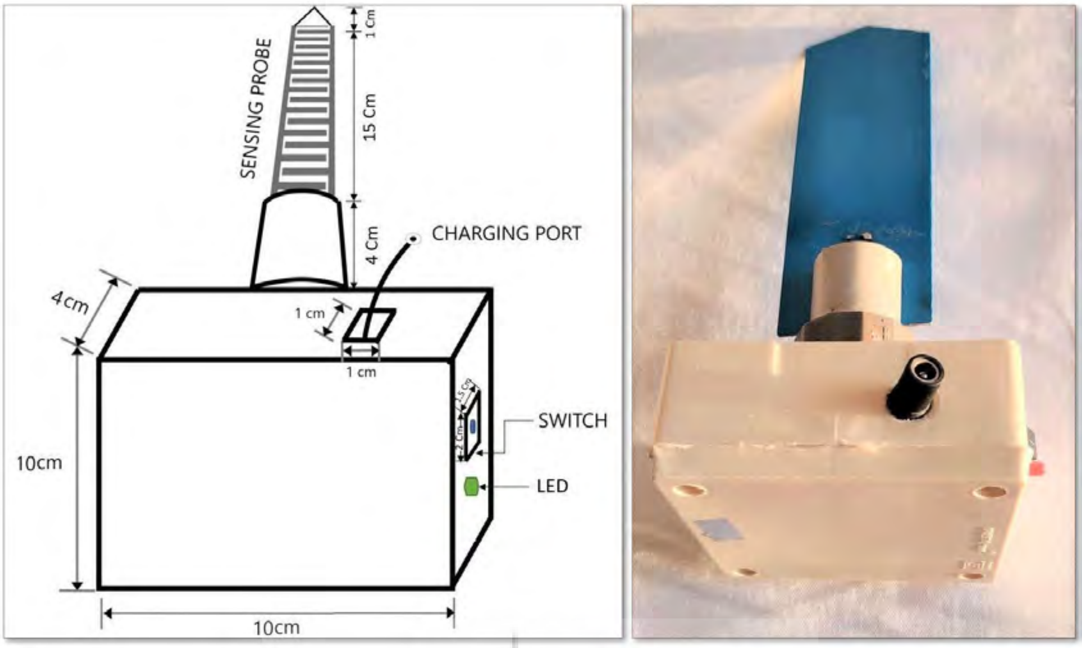


Figure 10. Flow diagram of SBM algorithm



(a) (b)

Figure 11. Moisture Sensing unit (a) Sketch of the prototype design with detail dimension (b) Hardware prototype model

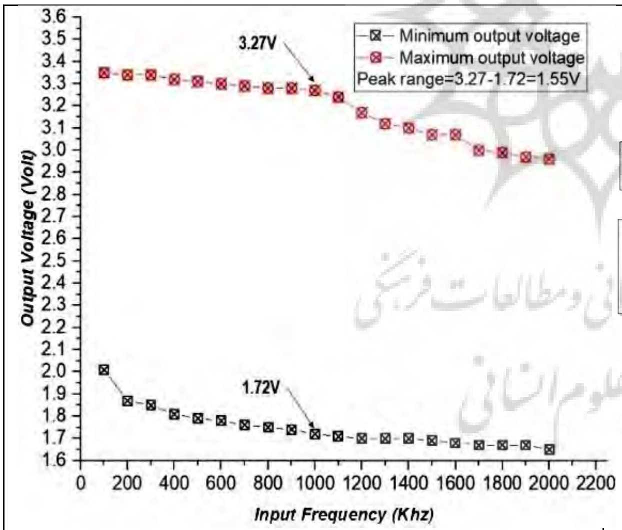


Figure 12. Effect of frequency on the range of output voltage

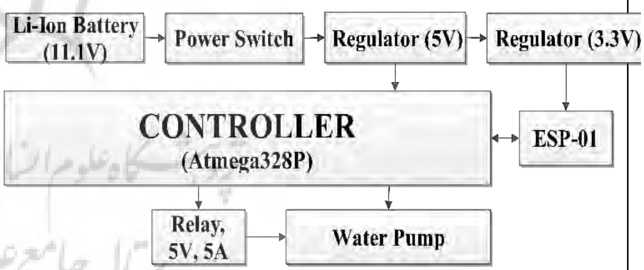


Figure 13. Electronic system architecture for ICU

Web application for DNS

Web application for DNS is developed by using PHP and JavaScript. The web application is used to maintain the database of soil moisture information and for session tracking. This web application helps us to deal with dynamic moisture information. JavaScript (AJAX) enables one to get moisture information without refreshing the web page directly.

The web application is designed to visualize soil moisture information graphically concerning time. The soil moisture information will be displayed, and control irrigation will be accordingly based on the control information parameters. As shown in Figure 16, the control information section can select the soil type since MSUs are calibrated for six different soil types. Two control actions are available to control the irrigation: automatic and manual. The pump triggers automatically based on the threshold moisture value (40%) in automatic control action. The threshold moisture value can be set based on the user's requirement in the manual option. The web application finds the average moisture value received from four different MSUs to control irrigation action. The status of the pump and average moisture (in percentage) can be visualized in the web application.

The web application is designed to send specific commands to get moisture information for a specific soil type. The application sends commands 'A', 'B', 'C', 'D', 'E' and 'F' for sandy soil, chalk soil, silt soil, loam soil, peat soil and clay soil, respectively. Based on the command received by the embedded MSU, it sends the concerned soil moisture value. Web application sends command 'T' based on the set value of soil moisture to trigger ICU to control irrigation.

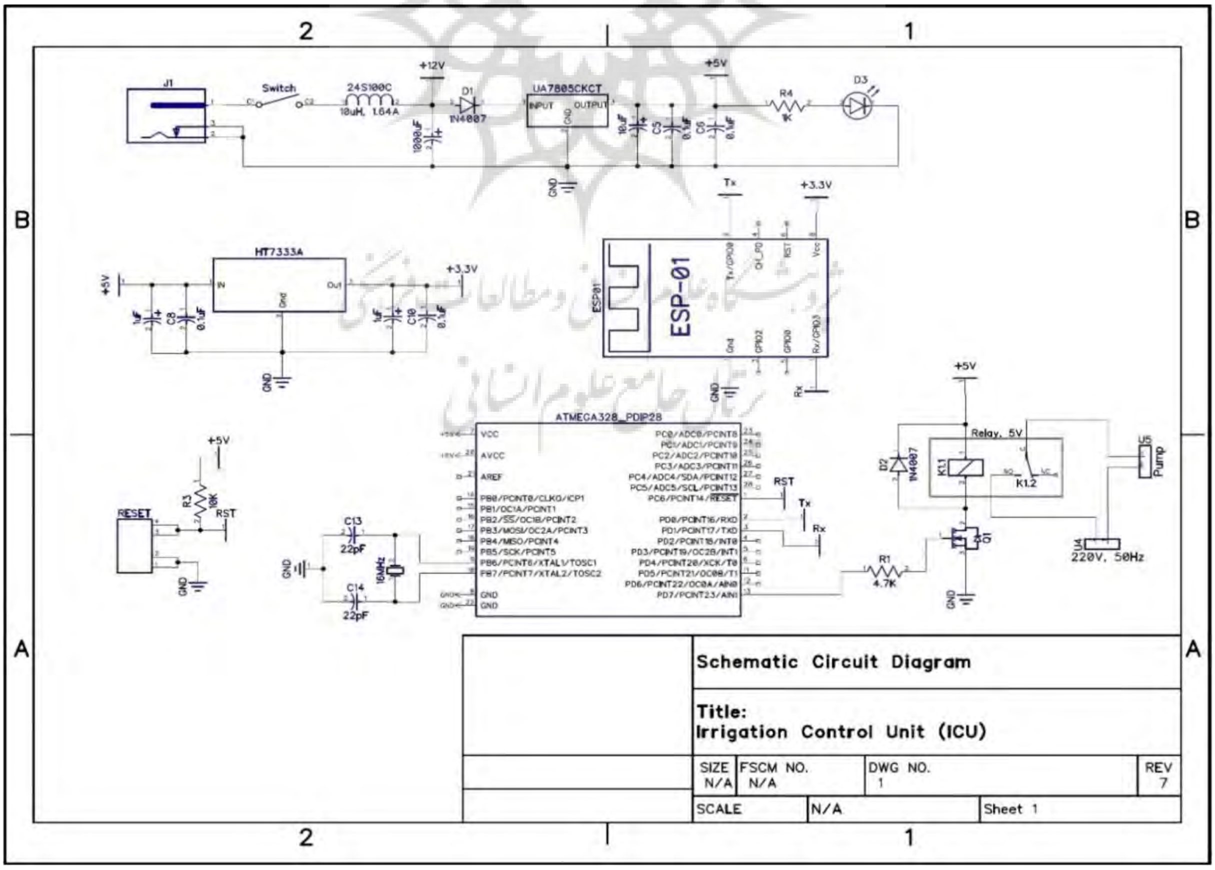


Figure 14. Electronic system architecture for ICU

The web application is hosted locally to monitor and control DNS; thus, all Internet-enabled devices (MSU, ICU, control station) are connected to the same local area network. The field testing of the DNS in the cassava agriculture field is shown in Figure 17 with details part information.

Results and Discussion

The water-holding capacity of soil varies with the soil properties/type. It greatly depends on soil texture, soil density and aggregate stability. Particles of soil having less surface area can hold water for more duration of time as compared with the particles having more surface area.

Table 2. Detailed parts information used to build the DNS

Circuit Details	Components used	Component ID	Manufacturer	Quantity	Price/piece (□)	Total (□)
Moisture Sensing Unit (MSU)	5V Regulator	UA7805CKCT	Texas Instrument	4	61.62	246.48
	3.3V Regulator	HT7333A	Digchip	4	37.00	148
	Diode	1N4148TR	On Semiconductor	4	10.63	42.52
	Microcontroller	ATmega328P-DIP	Atmel	4	239.00	956
	WiFi Module	ESP-01	Ai-Thinker	4	199.00	796
	Li-Ion battery	RKI-2733	SkyCell	4	790.00	3160
	Miscellaneous (Resistors, Capacitors, DC Socket, Double layer Cu PCB, Switch, LED, Crystal-16MHz, Wires, Diode etc.)	-----	-----	----	450.00	450.00
Irrigation Control Unit (ICU)	5V Regulator	UA7805CKCT	Texas Instrument	1	61.62	61.62
	3.3V Regulator	HT7333A	Digchip	1	37.00	37.00
	Relay	HF33F	Hongfa	1	73.10	73.10
	Microcontroller	ATmega328P-DIP	Atmel	1	239.00	239.00
	WiFi Module	ESP-01	Ai-Thinker	1	199.00	199.00
	Li-Ion battery	RKI-2733	SkyCell	1	790.00	790.00
	Miscellaneous (Resistors, Capacitors, DC Socket, MOSFET, Switch, LED, Crystal-16MHz, Wires, Diode, Inductor etc.)	-----	-----	---	450.00	450.00

Others	PVC pipe, PVC box, Water Pipe, Terminal block, flexible wires, Enclosure box, Adapter	-----	-----	---	1500.00	1500.00
				Total Amount in INR		9148.72
				Total Amount in US$		**122.37**

So, the designed capacitive soil moisture sensor probe is calibrated for six different types of soil that exist in different agricultural commodities. Six different types of soil samples, namely clay soil, peat soil, loam soil, silt soil, chalk soil and sandy soil, are collected and calibrated using the thermogravimetric method. In Figure 18 and Figure 19, respectively, we have shown the observed capacitance and voltage responses for the designed sensor probe.

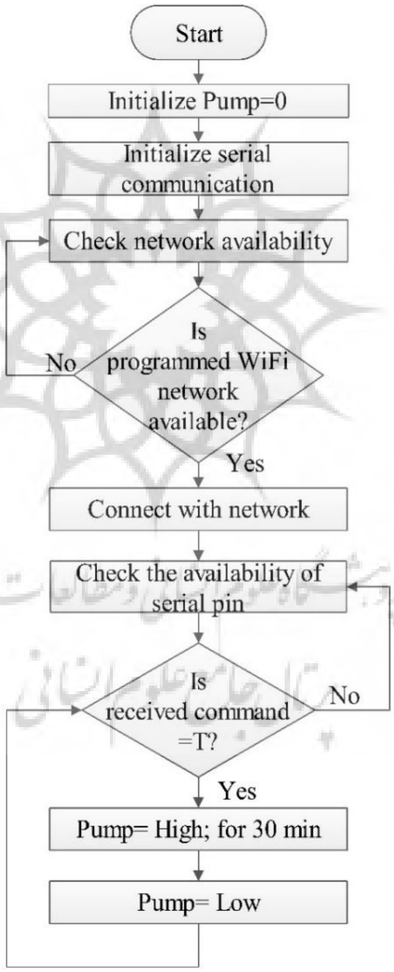


Figure 15. Flowchart of irrigation-based moisture (IBM) algorithm

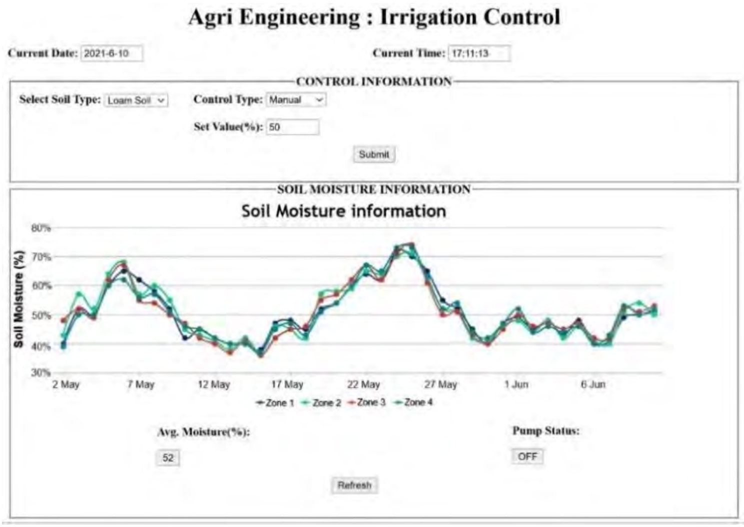


Figure 16. Screenshot of Web application panel to visualize and control irrigation

A linear analysis is also done for the observed capacitance and voltage responses, respectively, shown in Tables 3 and 4. The derived calibrated equations for clay soil, peat soil, loam soil, silt soil, chalk soil and sandy soil are shown respectively from Equations 1 to 6. All the equations are derived in slope-intercept form.

$$\Delta=-0.0714\Theta+221.98 \quad (1)$$

$$\Delta=-0.0741\Theta+247.03 \quad (2)$$

$$\Delta=-0.0707\Theta+256.14 \quad (3)$$

$$\Delta=-0.0731\Theta+283.83 \quad (4)$$

$$\Delta=-0.0745\Theta+308.98 \quad (5)$$

$$\Delta=-0.0751\Theta+330.46 \quad (6)$$

Here, Δ & Θ represent soil moisture (in %) and voltage (in mV).

A comparison of the presented wireless distributed network system with the existing distributed network system to control irrigation is shown in Table 5. Different researchers approached unique techniques to deploy sensor nodes in the agricultural field to set up distributed networks. WSN technology, such as Bluetooth, ZigBee etc., to collect information from the distributed sensor nodes and controls irrigation using algorithms (Kim et al., 2009; Gutierrez et al., 2014). Collecting and coordinating information with the control station in a distributive network system is challenging and expensive. But with the advent of technology like IoT, collecting and coordinating information is no more expensive. In this reported work, the DNS is developed to collect and coordinate data with the control station efficiently. All the deployed sensor nodes collect field data using the SBM algorithm and send it to the control station for processing and control irrigation with the support of a web application and ICU that operates under the IBM algorithm. The cost involved to make each MSU and ICU are 23.90 US dollars and 24.7 US dollars, respectively. The total cost of implementation is only 122.37 US dollars, much less than the two mentioned existing wireless distributed network systems for irrigation control. The system is tested for three months (since monitoring water content is crucial for the first three months in cassava plants) in Nagaland, India and found very effective in saving water.

For precise monitoring of soil moisture and hence to provide better control of the irrigation process, a capacitive soil moisture sensor probe is designed and developed. Table 6 shows a comparative analysis of the designed sensor probe with the existing capacitive moisture sensors. The moisture sensor reported in this paper shows a better output response than the reported capacitive sensors (Mizuguchi et al., 2015; Nagahage et al., 2019). The better output response is found in the goodness of fit (0.99). The sensor probe is calibrated for six different types of soil available in different agricultural commodities that provide flexibility to the DNS to implement in different agriculture regions.

Table 3. Linear analysis of capacitance responses for six different soils

Soil type	Goodness of fit	Slope	Intercept
Sandy	0.99501	15.8869 ± 0.45952	160.08333 ± 19.22302
Chalk	0.99812	15.67619 ± 0.27743	175.33333 ± 11.60585
Silt	0.99934	16.19286 ± 0.17012	164.5 ± 7.11652
Loam	0.9976	16.31905 ± 0.32684	170.08333 ± 13.6727
Peat	0.99839	16.14286 ± 0.2643	187.5 ± 11.05631
Clay	0.99781	16.84286 ± 0.32234	194.5 ± 13.48426

Table 4. Linear analysis of voltage responses for six different soils

Soil type	Goodness of fit	Slope	Intercept
Sandy	0.99801	-13.29405 ± 0.24224	4400.91667 ± 10.13357
Chalk	0.9981	-13.39405 ± 0.23836	4145.41667 ± 9.97123
Silt	0.99444	-13.6119 ± 0.41545	3882.41667 ± 17.37936
Loam	0.99198	-14.03214 ± 0.51496	3619.25 ± 21.54217
Peat	0.99131	-13.38333 ± 0.51149	3330.91667 ± 21.39709
Clay	0.99558	-13.94405 ± 0.3791	3106.91667 ± 15.85903

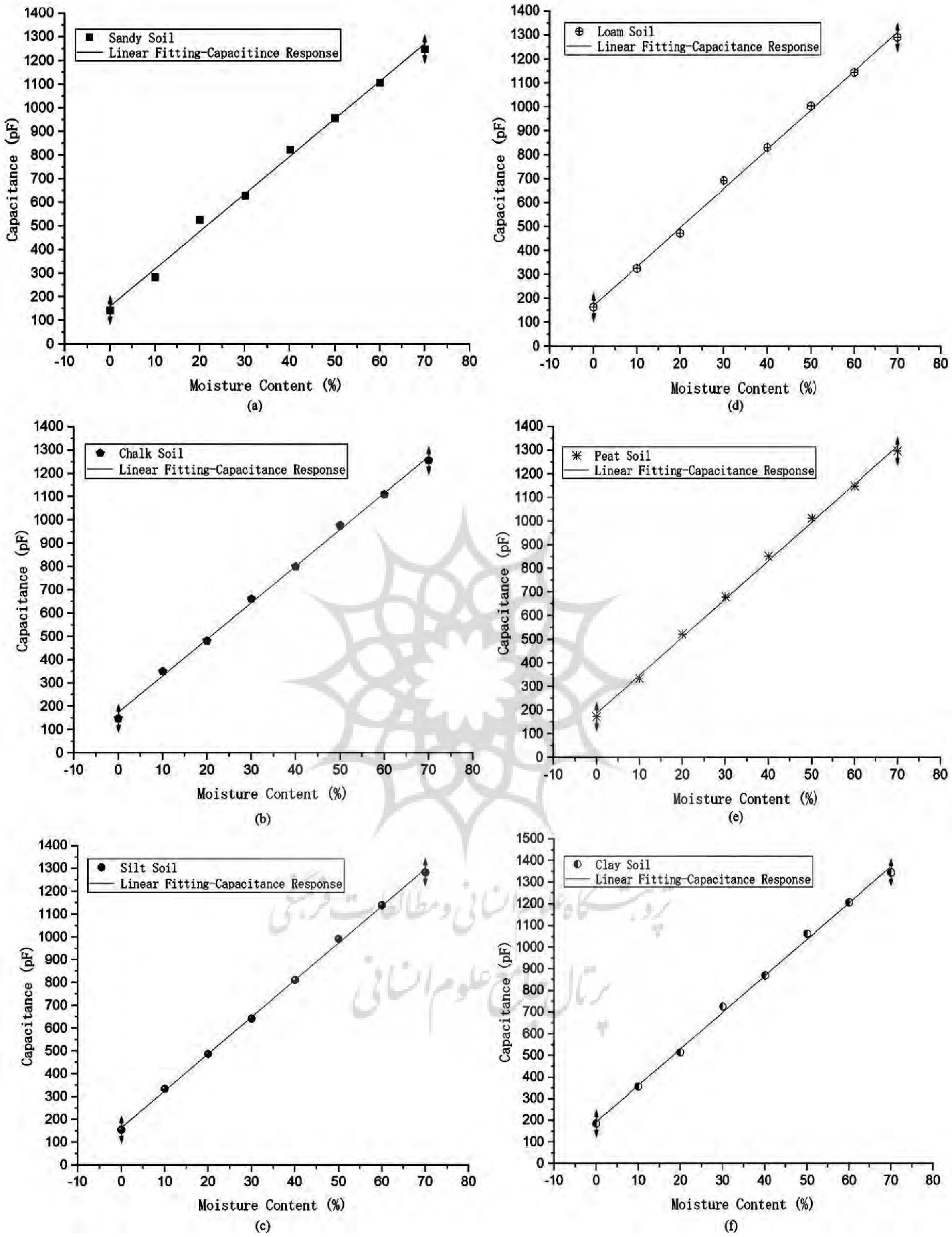


Figure 18. Capacitance responses vs moisture content (a) sandy soil, (b) Chalk soil (c) silt soil, (d) Loam soil, (e) peat soil and (f) clay soil

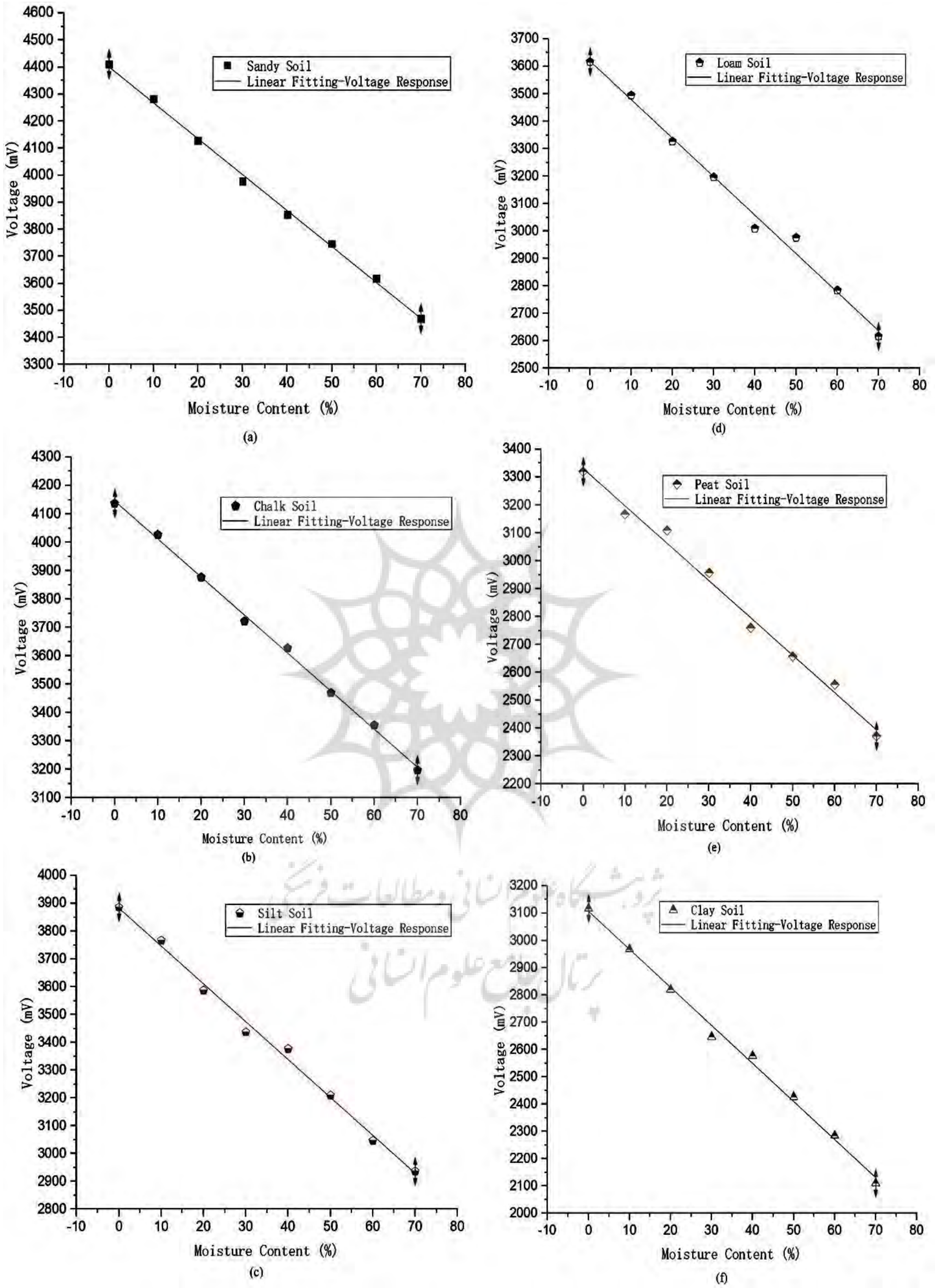


Figure 19. Voltage responses vs moisture content (a) sandy soil, (b) Chalk soil (c) silt soil, (d) Loam soil, (e) peat soil and (f) clay soil

Table 5. Comparison of the distributive sensor network with the existing distributive network for irrigation control

Reported Work	Algorithm/Techniques	Implementation cost	Result	Summary
Kim et al., (2009)	A site-specific irrigation control mechanism is used by collecting all the field information to control irrigation.	More than 1000 US$.	The distributed wireless sensor network is tested in the winter season for 110 days. All the field data like soil moisture, soil temperature, air temperature, humidity, precipitation, wind speed/direction and solar radiation are monitored to control irrigation in a better way.	A distributed wireless sensor network is developed that consists of different wireless field sensors, a weather station, a control station and a base station. The base station has wireless in-field sensing and control software (WISC) for monitoring and controlling irrigation.
Gutierrez et. al., (2014)	A threshold value algorithm is implemented based on the temperature and soil moisture value to control irrigation.	Cost of each WSU and WIU are 100US$ and 1800US$, respectively.	The irrigation control system is implemented in the sage field for 136 days and can save up to 90% water compared to traditional methods.	A wireless sensor network consisting of WIU and WSU controls irrigation. WSU consists of a soil moisture sensor and a temperature sensor. Irrigation is interrupted based on the threshold value of sensor data.
Current Reported Work	Soil Base Moisture (SBM) and Irrigation Based Moisture (IBM) algorithms are used for irrigation control.	The total cost involved 122.37US$.	The DNS is tested in a cassava field for 91 days and found it can save up to 95% of water as compared with the other traditional methods of supplying water	An MSU is designed and calibrated for six different soil types to control DNS irrigation. All the MSUs are connected via a WiFi network to a web-based application. An ICU is developed based on the web application's command to control irrigation.

Table 6. Comparison of design of capacitive moisture sensor with existing capacitive moisture sensors

Reported Work	Description of the sensor probe	Result	Calibration function	Summary
Mizuguchi et. al., (2015)	Two different interdigital capacitive sensor models are reported here, one having a dimension of 236mm×67mm and the other having a dimension of 10×20cm.	The response of sensors output is recorded and found 0.94 coefficient of determination value for data.	The gravimetric method is adopted to find the water content in the soil.	The response of the sensor is recorded by adding drops of water to the surface of the sensor probe
Nagahage et. al., (2019)	A capacitive soil moisture sensor probe is reported with dimensions 9.8cm×23cm	The sensor's response is compared with a standard SM-200 sensor, and a goodness of fit value of 0.98 is obtained.	A soil-specific calibrated function is reported to find the soil moisture.	The sensor probe is tested in organic-rich soil
Current Reported Work	The sensor probe reported here has a dimension of 15cm×4cm with an interdigital capacitive sensor layer on both sides of the PCB.	The sensor probe is calibrated using the thermogravimetric method and finds an average of 0.99 goodness of fit values for the voltage and capacitance responses for six different soil types.	Moisture content is found using the SBM algorithm that used derived calibration equations from the voltage responses.	The sensor probe is calibrated for clay, peat, loam, silt, chalk, and sandy soil.

Conclusion

A cost-effective distributive network system is designed and developed to monitor and control irrigation in the cassava agriculture field in Nagaland, India. The distributive network can collect soil moisture data based on the availability of soil type. The DNS is tested for loam soil, and the system was found to be very efficient in saving up to 95% water compared to traditional practices. A compact wireless embedded MSU and ICU are developed respectively to monitor soil moisture and control irrigation. The embedded MSU is equipped with an interdigital capacitive sensor probe calibrated for six different categories of soil. The thermogravimetric method and response of the designed sensor probe are very reliable as it shows a goodness of fit value of 0.99. Two algorithms, SBM and IBM, are developed and implemented in real-time to control the irrigation process to operate the DNS smoothly. A web-based application is also developed for the DNS for smooth control and monitoring of the overall process.

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Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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