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# DEVELOPMENT OF AN AUTOMATED DRIP IRRIGATION SYSTEM USING SOIL MOISTURE SENSOR

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***Abstract:*** Irrigation has been a major boost to agricultural practices but significant amount of water is still wasted due to poor irrigation application and scheduling. To optimize the use of available water, there is a need to improve irrigation systems using internet of things (IoT) approach. In this study, an Arduino board, microcontroller, soil moisture sensors, battery, relay module, soil, and 12V solenoid valve were used and connected together through a wireless communication network (NRF24L01 wireless transceiver module) and a cloud platform (Blynk) for storing data. The system was tested for a period of four weeks. During the period of testing, the system observed eighteen automatically scheduled irrigation events. Simple descriptive statistical analysis of soil moisture data revealed mean values; 37.09, 35.68, 37.05, and 39.26 in weeks 1, 2, 3, and 4 respectively, and mean average of 37.27. Weeks 3 & 4 displayed higher average soil moisture content (38.15) compared to weeks 1 & 2 (36.39), this is due to recorded rainfall in the study area in weeks 3 and 4. Soil moisture content ranged between $66.30 m^3m^{-3}$–$16.00 m^3m^{-3}$ with standard deviation of ±8.25.

The Analysis of Variance (ANOVA) test confirmed this difference to be statistically significant (p-value=0.001), suggesting potential factors (soil type, sensor type, depth of insertion, etc.) influencing soil moisture over time.
The system achieved 55.25% water saving when compared to manual method of irrigation. More study should be done in integrating stable network connections (Wi-Fi) and solar systems to power the system without fail.

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***Key words***: *soil moisture, sensors, IoT, automated irrigation, crop water requirement*

## INTRODUCTION

Planting is carried out by the farmers only when there is optimum moisture in the soil, since crop performance depends on the early establishment by utilizing available moisture [1]. Various studies [2,3] have reported that soil moisture content is mainly dependent on soil water recharge by rains and other alternate sources like irrigation. Thus plants that develop their canopy rapidly have the advantage of enhancing the effective use of water by reducing moisture loss due to evaporation [1].

Water is one of the most precious resources on the earth, it is therefore imperative to measure, control and preserve for sustainable agricultural production and healthy living [4]. The severe global competition for food and water is due to the effect of increase in world's population and climate change. This has increased the interest on how to achieve optimal use of scarce resources such as water using precision irrigation aimed at increasing food production and water saving [5]. Agriculture plays a vital role in the growth of the country's economy. There are a lot of modern technologies to make agricultural work very easy. Due to the shortage of water in most areas of the world, the watering process is one of the most important and critical processes in modern farming [6]. Hence, there is a need for automatic, intelligent, and smart systems that can make smart utilization of the available amount of water to feed plants for maximum time of farming, reduction of drudgery, stress and improvement in farm yield, and ease of farming, [7].

In manual based irrigation system, intense man power is required for irrigation and water management is not utilized properly. In addition, manual-based irrigation system leads to improper water allocation since labor is not automated at the right time. All these factors impact the growth rate, seed quality and productivity of crops negatively [8]. In order to negate such problems, there is a need to develop an automated irrigation system by using the knowledge acquired in soil-water plant relationship. This study proposes to develop an automated irrigation system enhanced with soil moisture content sensor, which will aid efficient and effective irrigation and irrigation scheduling of farmlands. The most significant advantage of this automated irrigation system is that the right amount of water is supplied and stopped automatically at the right time, to the right depth in the soil for crops when the right crop water requirement (CWR) is achieved, and when the soil moisture content has reached its required volume. The study covers only the use of moisture sensor to determine the irrigation and irrigation schedule of the automatic irrigation system. Other parameters; temperature, humidity, etc. are not covered in this study.

## MATERIALS AND METHODS

### Study Area

The project was implemented in the Greenhouse at Latitude 5°2'32.81"N and Longitude 7°58'33.03"E which is within the boundary of the Faculty of Engineering, University of Uyo permanent site, Uyo, Nigeria. Uyo is in the tropical rainforest belt of Nigeria, between latitude 5°5'2.288" N and 4°52'32.477" N, longitude 7°47'25.785" E and 8°0'54.393" E. The climate of Uyo is generally humid because of its proximity to the sea.

Based on its geographical location, the climate of Akwa Ibom State can be described as a tropical rainy nature which experiences lots of rainfall with high temperatures. The maximum humidity is reported in July, while the lowest is recorded in January. Average yearly temperature ranges between 26°C and 29°C, while mean annual rainfall ranges from 2.000mm to 3.000mm [9]. The Greenhouse was built in 2020 as a part of the TETFUND demonstration farm project in the University of Uyo. Major activity in the Greenhouse is greenhouse farming.
A drip irrigation system was already installed on a 10 x 5m Greenhouse spaced at 0.5m. The drip irrigation system consisted of 1m High-density polyethylene (HDPE) laterals with twenty emitters spaced at 0.2m. The experimental data was collected from August 28th to September 25th, 2023, resulting in 672 data sets for the soil moisture content.

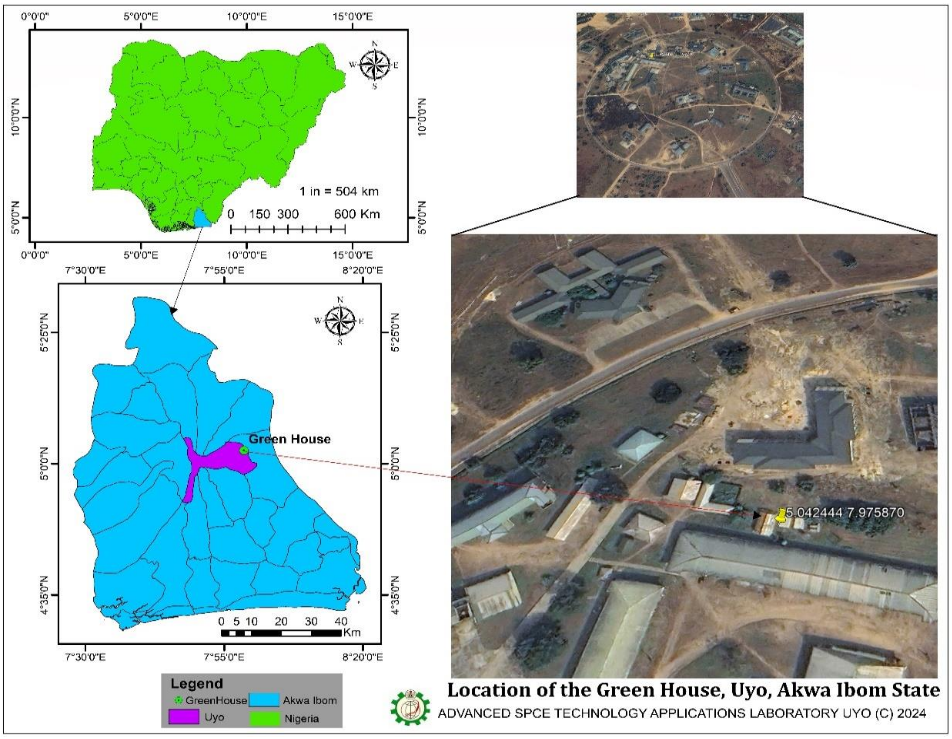


Fig.1. GIS Map of Akwa-Ibom state showing the Greenhouse, [10].

**Materials Used**

The following materials were used during the course of this work.
Soil sample for collection of soil for analysis: ESP8266 Microcontroller, NRF24L01 Wireless Transceiver Module, Soil moisture sensor, Relay Module, Battery/BMS, 12V Solenoid Valve, Blynk Platform.

**Esp8266 Microcontroller**

The Esp8266 microcontroller was selected as the central control unit for the irrigation system. It offers built-in Wi-Fi connectivity, control signals for activating or deactivating the solenoid valve through the relay, and sends data recorded by the sensor to an IoT platform (Blynk) wirelessly.

Fig. 2. Esp8266 Microcontroller

The Esp8266 microcontroller was programmed to serve as the central control unit of the irrigation system. It is designed to operate efficiently with low power consumption. This is a critical consideration for battery-powered applications, ensuring that the central control board can function for extended periods without frequent recharging or replacement of batteries.

**Soil Moisture Sensor**

The soil moisture sensor module was used to detect the moisture of the soil. It uses dielectric constant or contact, electrical resistance, with neutrons as a proxy for moisture.

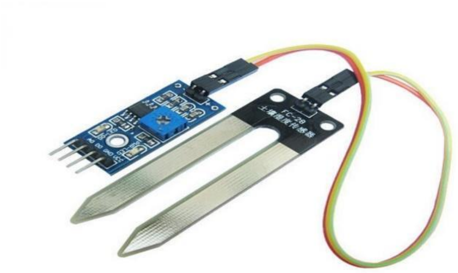

Fig.3. Soil Moisture Sensor

It measured the volumetric content of water inside the soil and produced the moisture level as output. The sensor sent analog signals to the ESP8266 based on the measurement, which is converted to a digital signal by the ESP8266.

**Blynk Platform**

Blynk is a platform developed for Internet of things. Blynk helps us to control the hardware remotely. It displays the sensor data, stores it, and also represents the data in graphical format.

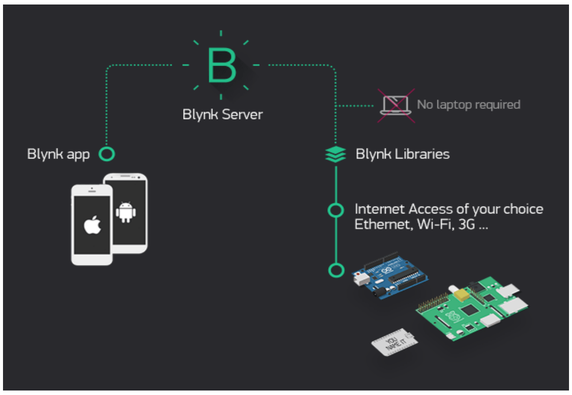

Fig.4. System architecture (Blynk Platform)

- Blynk App- In this you are able to interface your projects. Along with that you are to assign the pin numbers.
- Blynk Server- Blynk server is mainly used for the communication between the hardware and the smartphone.
- Blynk libraries- It helps us to enable communication with the server and process all incoming and outgoing commands between the all the popular hardware platforms.

**Battery and Battery Management System (BMS)**
The combination of the battery and Battery Management System (BMS) is crucial for maintaining uninterrupted operation of the central control board. The 2P3S configuration enhances power supply longevity, allowing the system to function for extended periods without frequent recharging. The series configuration ensures stable voltage levels required by the control board.

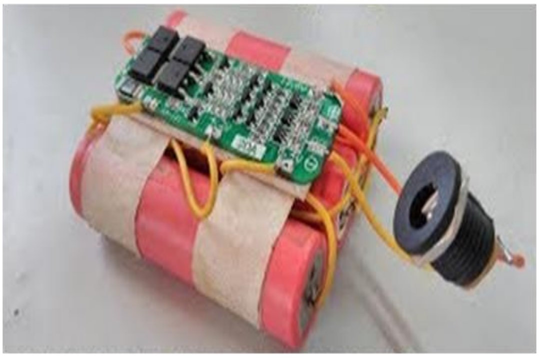
Fig.5. Battery and BMS

The BMS actively monitors each cell, promoting even charging and discharging to prevent overcharging or over-discharging, thereby preserving battery life. Additionally, the BMS incorporates safety features to guard against potential hazards like short circuits and thermal issues, bolstering the overall safety of the system.

This integration of the battery and BMS enables autonomous system operation for extended durations, making it suitable for deployment in environments lacking a continuous power source.

**NRF24L01 Wireless Transceiver**

The NRF24L01 wireless transceiver module (Fig.6.) plays a pivotal role in establishing communication between the central control board and the wireless soil moisture sensors. This module operates in the 2.4 GHz ISM band and employs the Enhanced ShockBurst (ESB) communication protocol for efficient data transmission [11].

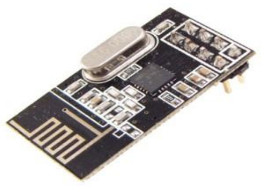

Fig. 6. NRF24L01 Wireless Transceiver

Fig.7. Relay Module

**Relay Module**

A relay (Fig.7.) is a simple electrically controlled switch. By sending a signal from the ESP8266, we can turn the switch on and supply a 24V AC to the solenoid valve and open and close it.

**12V Solenoid Valve**

The 12V solenoid valve (Fig.8.) is responsible for actuating the relay module and pump for automatic irrigation. It is an electrically controlled valve. This valve is shown in Figure 8. A solenoid is an electric coil with a movable magnetic core. Applying an electric current to this coil creates a magnetic field, which moves the core and allows water to flow. If the current is cut off, the valve closes, and the water flow stops, [11].

Fig.8. Solenoid valve

**Methods**

**Soil Analysis**

Soil texture analysis was performed using Hydrometric method, [15]. The USDA particle size classes viz. sand (2.0–0.05 mm), silt (0.05–0.002 mm) and clay (<0.002 mm), were used when classifying the textural classes. Soil organic carbon (SOC) was determined by the Walkley-Black oxidation method, [12]. Total nitrogen (TN) was determined using the Kjeldahl digestion method, [13] and Available Phosphorous (Av-P) was determined using Olsen's extraction method, [14]. Available potassium (Av-K) and the exchangeable bases ($Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$) were measured by atomic absorption spectrophotometer, [15]. The Cation Exchange Capacity (CEC) was determined by extraction with Ammonium acetate method, [16] and soil pH was determined by potentiometric Methods at a 1:2.5 soil-to water ratio.

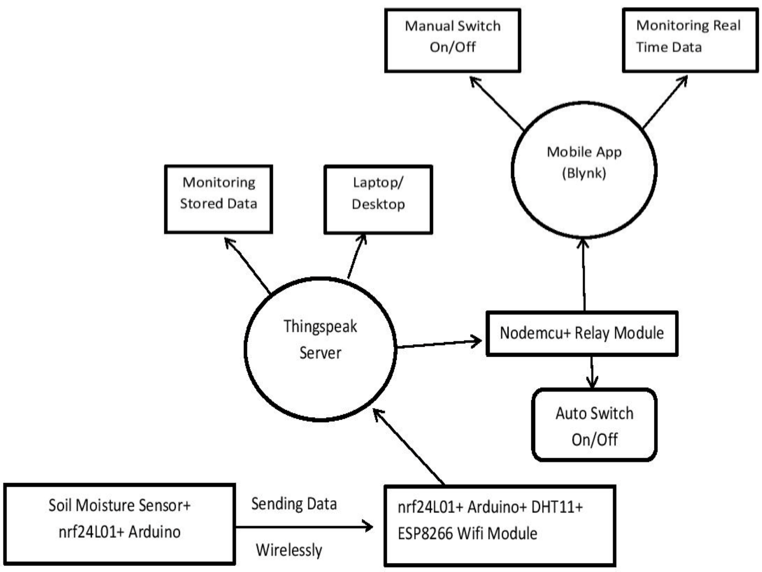


Fig.9. Automatic Irrigation System architecture

**Calibration of soil moisture sensor**

In the experimental field, soil moisture sensors were tested and installed. Before installation in the field, soil moisture sensors were calibrated. Moisture values were recorded every two hours between 8:00 am and 6:00 pm. The oven-dry method was also used to determine soil moisture content. For real-time data from soil moisture sensors, an account on Blynk.cloud was created.

The moisture sensor in the soil were positioned near one of the drippers. According to [17], soil moisture sensors should be placed at the top of the active root system, relative to drippers and the bottom of the root system; in every case studied, 11 cm between the drip line and 10 cm beneath the surface of the soil was deemed to be the most suitable position.

**Primary Tests in the Laboratory**

The initial tests were conducted in the lab to test the moisture sensor, temperature sensor, air humidity sensor, water flow sensor, solenoid valve, and firmware. The system was powered using a power supply. Using the relay, the ESP8266 was able to control the solenoid valve. With a loud click noise, we were able to know when the valve was opened or closed. The soil moisture sensor was calibrated by first reading the value of the sensor in the air and then placing the probe in a glass of water and re-reading the value.

After calibrating the moisture sensor, it was confirmed that the ESP8266, moisture sensor, and valve worked well together. To do so, the valve was programmed to open if the ESP8266 was not in the cup of water, then the cup was replaced with a potted plant, re-calibrated the moisture sensor with the soil [18], and repeated the experiments.

## RESULTS AND DISCUSSION

**Soil Physical and Chemical Properties**

Results of soil physical and chemical properties at 15cm depth are shown in Table 1 and 2 respectively. The particle size distribution of the soils was dominated by the sand fractions. Texture of the surface soils was generally loamy sand (Table 1). Texture of the surface soils was generally loamy sand. The textural composition of soil is highly influenced by parent material, [19].

Table 1. Physical Properties of Soil

| Sample | Depth (cm) | Sand % | Silt % | Clay % |
|---|---|---|---|---|
| Plot A | 15 | 83.13 | 4.31 | 12.56 |
| Greenhouse (Control) | 15 | 84.77 | 4.31 | 10.44 |

The textural class for the plot A and the control were Loamy sand. The high percentage sand observed in all the land use patterns could be attributed to the geology of the area. The geology of the area is coastal plain sands which are characterized by sandy soils over a wide expanse of land [20].

Generally, pH was slightly acidic with a value of 5.53 recorded in plot A, and strongly acidic in the control (3.77). This acidity influences the available phosphorus in the soil (88.044mg/kg). Also, the value of 7.91cmol/kg for ECEC was recorded in plot A and 8.92cmol/kg in the control at similar depths (Table 2). Plot A had total nitrogen content of 0.08% at 15 cm soil depth; the control had a value of total nitrogen (0.06%). The total nitrogen (TN) also correlated positively with organic matter and ECEC (Table 2). The result of the present study agrees with the findings of [21] who attributed the decrease in total nitrogen with increasing depth to declining humus with depth.

Table 2. Soil Chemical Properties

| Chemical Properties | Plot A | Control |
|---|---|---|
| Ph | 5.53 | 3.77 |
| EC ds/m | 0.10 | 0.05 |
| OC % | 1.80 | 1.30 |
| Org. M % | 3.12 | 2.25 |
| TN % | 0.08 | 0.06 |
| AV.P mg/kg | 43.355 | 88.044 |
| K cmol/kg | 0.09 | 0.17 |
| Cacmol/kg | 1.80 | 2.40 |
| Na cmol/kg | 0.19 | 0.09 |
| Mg cmol/kg | 1.20 | 1.45 |
| EA cmol/kg | 4.36 | 5.67 |
| ECEC cmol/kg | 7.91 | 8.92 |
| BS % | 42.7 | 36.2 |

**Soil Moisture Sensor Performance evaluation**

Soil moisture sensor was installed 0.1m in a Loamy sand soil to help in irrigation control based on soil moisture content. This device used Internet of Things technology to automate irrigation without the need of human interference. Soil moisture sensor continuously tracked soil moisture levels in the Green house. The wireless soil moisture sensors proved to be highly effective in their operational capacity. They successfully transmitted data wirelessly to the ESP 8266′ s configured Wi-Fi module, if the moisture level falls below the pre-defined value; it triggered the water pump and irrigates the field. The measured variables were continuously recorded automatically and sent to the Blynk cloud based server.

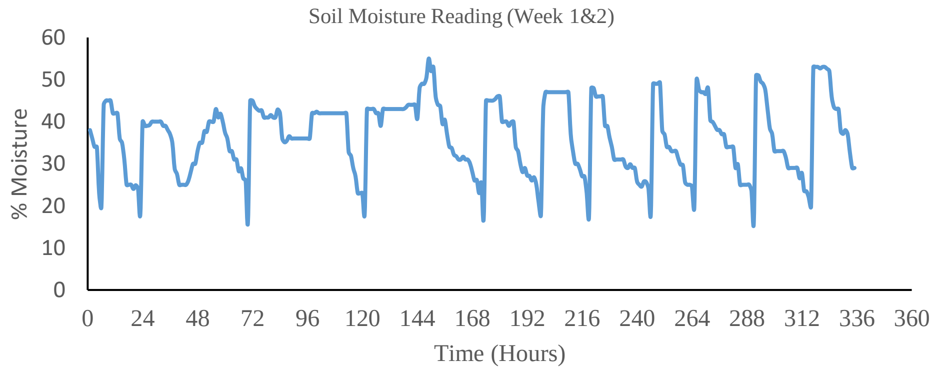


Fig.10. Moisture sensor reading (week 1&2)

The irrigation data were collected over one month and plotted the soil moisture content graph (Figures 10 and 11). The soil was considered to be dry if the moisture reading goes below 20% moisture content, then the ESP8266 opened the solenoid valve to irrigate the field. The soil was considered semi wet between 21 and 29% moisture content, wet if the reading was between 30 and 45%, and very wet if the reading was between 46 and 60%.

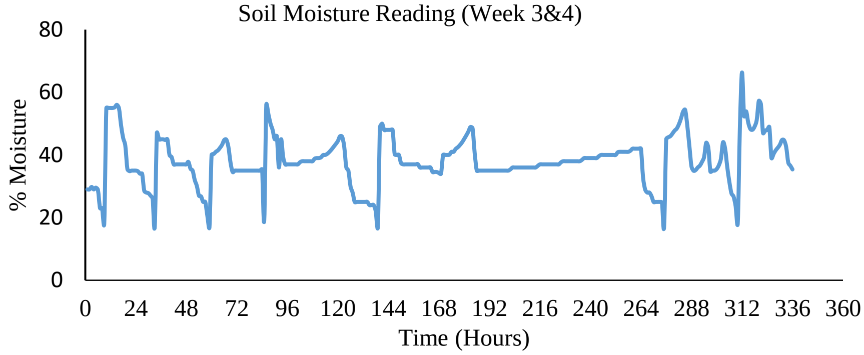


Fig.11. Soil moisture readings (week 3&4)

**Irrigation Management**

The system was tested to determine water flow rate through drippers. The water from the drippers was collected using a bottle for ten minutes and measured it in a graduated cylinder. The tests were replicated multiple times.

Table 3. Measured flow rate of drippers

| Test Number | Flow Rate of Each Dripper (L/h) | Total Flow Rate of Twenty Drippers (L/h) |
|---|---|---|
| 1 | 0.93 | 18.6 |
| 2 | 0.81 | 16.2 |
| 3 | 0.89 | 17.8 |
| 4 | 0.85 | 17 |
| 5 | 0.87 | 17.4 |
| Average | 0.87 | 17.4 |

The average flow rate of the drippers was determined to be 0.87 L per hour and 17.4L per hour for the twenty drippers in the greenhouse (Table 3). This indicates a reduced quantity of water applied to the crop compared to manual irrigation. From figures 10 and 11, we can see that the irrigation was scheduled eighteen times an hour each during the four weeks' period.

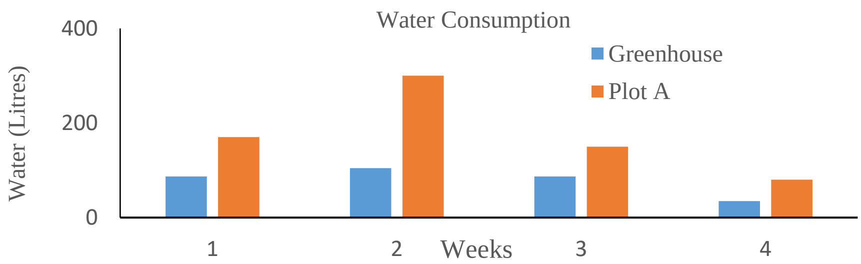


Fig.12. Water Consumption

Each dripper watered a plant for an hour five times in the first week, six times in the second week, five times in the third week, and two times in the fourth week.

The irrigation scheduling was done based on the relay information from the soil moisture sensors. It can also be deduced from Fig. 12, that the moisture sensor enhanced automatic irrigation system was able to achieve 55.25% water saving when compared to manual method of irrigation. Other researchers [22,23] have found consistent results confirming water savings up to 35–65% than standard flood and manual irrigation systems.

**Statistical Analysis**

Simple descriptive statistical analysis of soil moisture data revealed mean values; 37.09, 35.68, 37.05, and 39.26 in weeks 1, 2, 3, and 4 respectively, and mean average of 37.27. Soil moisture content ranged between 66.30$m^3m^{-3}$–16.00$m^3m^{-3}$ with standard deviation of ±8.25. The average moisture content across weeks 1 and 2 (36.39%) was slightly lower compared to weeks 3 and 4 (38.15%) as a result of recorded rainfall in the study area in weeks 3 and 4. The soil moisture data collected over the four-week period was statistically analyzed using a one-way Analysis of Variance (ANOVA) to determine if there were significant differences in soil moisture content throughout the period of the experiment. The one-way ANOVA confirmed our initial observation from the descriptive statistics; there's a statistically significant difference (p-value = 0.001) in the moisture content between the four monitoring weeks, suggesting potential factors (soil type, sensor type, depth of insertion, etc.) influencing soil moisture over time, and at least one week having a moisture content that is statistically different from the others.

Table 4. Weekly Soil Moisture Content Statistics

| Week | Mean Moisture Content (%) | Standard Deviation (%) | Variance (%) |
|---|---|---|---|
| Week 1 | 37.093109 | 7.403929708 | 54.81817511 |
| Week 2 | 35.681081 | 9.657899982 | 93.27503207 |
| Week 3 | 37.050619 | 8.330377998 | 69.39519759 |
| Week 4 | 39.245597 | 7.056324529 | 49.79171586 |

Table 5. ANOVA results for soil moisture content

| SUMMARY | | | | |
|---|---|---|---|---|
| Groups | Count/Hours | Sum | Average | Variance |
| Week 1 | 169 | 6268.73544 | 37.0931091 | 54.8181751 |
| Week 2 | 168 | 5994.42157 | 35.6810808 | 93.2750321 |
| Week 3 | 168 | 6224.50402 | 37.0506192 | 69.3951976 |
| Week 4 | 168 | 6593.26021 | 39.2455965 | 49.7917159 |

| ANOVA | | | | | | |
|---|---|---|---|---|---|---|
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 1093.21332 | 3 | 364.404441 | 5.45498561 | 0.00104155 | 2.61821785 |
| Within Groups | 44690.5983 | 669 | 66.8020902 | | | |

The observed difference between the four weeks testing period suggests the sensor's responsiveness to varying moisture levels and the system's ability to adjust irrigation accordingly. The standard deviation and variance values indicate some natural fluctuations in moisture content even within designated irrigation cycles, reflecting the dynamic nature of soil moisture.

## CONCLUSION AND RECOMMENDATIONS

**Conclusion**

Water is a limited resource in the world and agriculture is a primary market. Therefore, a sustainable and economic approach is to be adopted for efficient agricultural practice and irrigation scheduling. The use of soil moisture sensors helps farmers with irrigation scheduling by providing information about when to water the crops. The development of wireless sensor applications in agriculture makes it possible to increase efficiency, productivity and profitability of farming operations as well as the maximum crop yield with minimum use of irrigation water.

The Automatic Irrigation System using Soil Moisture Sensor has been developed and tested successfully and found to function automatically. The system was able to execute the pre-established irrigation schedule without human intervention. Also, the effectiveness of the moisture sensor enhanced irrigation system is contingent upon the quality of internet connectivity. This is due to the system being operated by internet connection (wireless).

**Recommendations**

Despite the good results obtained in this study, some aspects of the system which should further be improved upon include:

- Automatic assessment of the representativeness of the soil moisture sensors and the integration of a sensor that automatically characterizes the water stress of the plant.
- Exploring some portability options and solar energy systems. Integrating pH sensors, etc.

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## RAZVOJ AUTOMATSKOG SISTEMA ZA NAVODNJAVANJE KAPANJEM PRIMENOM SENZORA VLAŽNOSTI ZEMLJIŠTA

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**Apstrakt.** Navodnjavanje je veliki podsticaj u poljoprivrednoj proizvodnji, ali značajna količina vode i dalje se potroši zbog loše primene i rasporeda navodnjavanja. Da bi se optimizovala upotreba dostupne vode, postoji potreba da se poboljšaju sistemi za navodnjavanje korišćenjem i pristupom Internet tehnologijama (IoT).
U ovoj studiji, primenjen je Arduino tip osnovne ploče, mikrokontroler, senzori vlage u zemljištu, baterija, relejni modul, i 12V solenoidni relejni ventil, koji su zajedno povezani preko bežične komunikacione mreže (NRF24L01 bežični primopredajni modul) u platformu-oblak (Blink), zbog prikupljanja i skladištenje podataka.
Sistem je testiran u periodu od četiri nedelje. Tokom perioda testiranja, sistem je kontrolisao osamnaest (18) automatski određenih mernih mesta za navodnjavanje.
Jednostavna deskriptivna statistička analiza podataka o vlažnosti zemljišta prikazuje srednje vrednosti; 37,09; 35,68; 37,05 i 39,26 u nedeljama 1, 2, 3 i 4 respektivno, i srednji prosek od 37,27.
Nedelje 3 i 4 su pokazale veći prosečan sadržaj vlage u zemljištu (38,15) u poređenju sa nedeljama 1 i 2 (36,39), što je zbog zabeleženih padavina u oblasti istraživanja u 3 i 4 nedelji ispitivanja.
Sadržaj vlage u zemljištu kretao se od 66.30$m^3m^{-3}$ do 16.00$m^3m^{-3}$ sa standardnom devijacijom od ±8,25.
Analiza varijanse (ANOVA) je potvrdila da je ova razlika statistički značajna (p-vrednost = 0,001), što ukazuje na potencijalne faktore (tip zemljišta, tip senzora, dubina postavljanja, itd.) koji utiču na vlažnost zemljišta tokom vremena.
Sistem je postigao 55,25% uštede vode u poređenju sa ručnim načinom navodnjavanja. Treba uraditi više studija o integraciji stabilnih mrežnih veza (Wi-Fi) i solarnih sistema za napajanje sistema bez greške.

***Ključne reči:*** *Vlaga u zemljištu, senzori, IoT, automatizovano navodnjavanje, potreba useva za vodom*

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