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Sensor-Based Variable Rate Technology (VRT) as a Tool to Determine Water Saturation of Various Soils in Farming for Improved Irrigation

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Abstract

Food sustainability is vital to a nation's food security. Sustained food production is a pointer to development through increased Gross Domestic Product (GDP) on food exportation. However, to achieve food security, farming must be aided by technology that can ensure farming at all seasons and without ceasing. Over the years, irrigation farming has proven to be a veritable technology that can be used to meet the food needs of a nation. However, irrigation has opened up a great concern about water shortages due to the amount of world fresh water that goes into irrigation, hence, there is a need to introduce techniques that will optimize and conserve water in irrigation while guaranteeing adequate food production. This research explores the use of sensor-based variable rate technology to vary dispensed irrigation water based on varying soil types and water retention capacities. In this research, 5 grams of Sandy, Loamy and Clay Soils were used with Soil Moisture Sensors (SMS) in each soil sample. In addition, 12V DC pumps and relay were used with a microcontroller to develop the control box for the irrigation system. Software (Firmware) was designed to control the sensors, microcontroller and other gadgets in the research. The research shows that it takes less than 5 seconds for the sandy soil to reach the upper threshold value of the SMS which implies its water saturation point and 7.6 secs and 13.2 secs for the loamy and clay soils, respectively. The system shows good potential for preventing water run-off which is a major challenge in an uncontrolled irrigation system.

Keywords: Soil Moisture Sensor, Variable Rate Technology, Microcontrollers, Food Sustainability, Food Security, DC Pumps

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Introduction

Crop farming in agriculture has been an age-long tradition that has evolved over-time from the Stone Age to the mechanized and now automated state of farming. In Nigeria, the National Bureau of Statistics reported that agriculture contributed 19.63% to the nominal GDP in the first quarter of 2023. This makes agriculture a major non-oil contributor to the nation's GDP. Also, Statistica an online statistic dataset reported that from 2013-2022, agriculture employed 37.99% of the nation's workforce, thus making agriculture a major employer of labour in the country.

However, as the population of the world is expected to increase by 30% by the year 2030 (Osama, 2013) and at an annual increase of 78 million, the world population is further estimated to reach 8.9 billion by the year 2050 with 95% of this population increase coming from developing countries which include Nigeria (Nwokoye, 2018). This projected world population increase has put a great demand on food production on the world at large and Nigeria in particular with a projected annual increase of 3.2% on her population (Nwokoye, 2018). This projected population and the demand for food had been the bedrock of concerted efforts made towards improving crop farming through irrigation to enhance food security. The advancement in irrigation has sustained farming and accelerated development mostly within rural areas where farming is predominately their occupation (Alausa & Ogunyinka, 2018; Ogunyinka & Onwuasoanya, 2018).

For irrigation to be effective, water is essential in large quantities, but the Food and Agriculture Organization (FAO) stated that 70% of the world's fresh-water withdrawal is done by agriculture, it further stated that the percentage of freshwater withdrawal can reach as high as 95% in developing countries, thus making it compete with other domestic, industrial and environmental needs of water. Other works of literature estimated agriculture as consuming 85% of fresh water available for human use (Isik, et.al, 2017; Mehta & Pandey, 2016). These statistics call for efforts to ensure the efficient use of water resources that is fast becoming scares (Surendran, et.al, 2015; Guttierrez et.al, 2014).

To meet up with this increasing food demand farming needs to be done on a very large scale which involves a large span of land that could incorporate various soil types on the farm. For efficient and improved irrigation the water saturation point of the varying soil types must be determined to ensure irrigation is done on each soil type based on its saturation, this will ensure over or under-irrigation of the crops and improve water conservation.

Using Variable Rate Technology, an irrigation technique that allows water dispersing in irrigation based on the use of sensors or GPS to enhance and optimize water conversation. Using the Sensor-Based Variable rate Technology this paper tends to determine the saturation point of three types of soil in farming; Clay, Lomy and Sandy soils by incorporating soil moisture sensors in each soil sample and setting a lower and upper threshold of soil sensors to determine the level the pump will be triggered for water pumping and when the pump will stop once at the upper threshold. These show a varying time of reaching saturation point for the different soil.

Smart irrigation systems based on Variable Rate Technology (VRT), have emerged as sustainable solutions to address the challenges of water conservation and enhance agricultural water management. With the use of VRT, several research geared towards water optimization and enhancement of irrigation had been concluded by various researchers with the results showing good improvement in irrigation practices in large-scale farming.

In the work of Vellidis et al., 2016, a dynamic Variable Rate Irrigation (VRI) control system is introduced, emphasizing the critical aspect of adaptability in irrigation practices. The study significantly advances our comprehension of real-time data utilization for dynamic adjustments in irrigation rates. By addressing spatial variability in soil and crop characteristics, the authors highlight the potential of VRT to revolutionize irrigation precision. The dynamic nature of VRI, as proposed represents a paradigm shift in irrigation practices.

The adaptability to real-time conditions offers a promising solution to the challenges posed by variations in soil characteristics and crop requirements. This adaptability is crucial in optimizing water use and improving overall agricultural efficiency. Munir et al. 2018, explore the integration of Internet of Things (IoT) technologies into a smart irrigation system designed for tunnel farming. The study emphasizes not only water conservation but also considerations for smart energy consumption. The interdisciplinary approach adopted in this research underscores the synergy between technology and resource management in the context of smart irrigation.

The integration of IoT technologies is a significant leap forward in the realm of smart irrigation. The work highlights the potential of IoT to enhance both water and energy efficiency in agriculture. This holistic approach aligns with the broader goals of sustainable and resource-efficient farming practices (Davis et al., 2019).

Parthasarathy's work, although not explicitly centered on Variable Rate Technology, provides foundational insights into intelligent irrigation practices. This study, conducted in 2016, contributes to the broader understanding of components and functionalities crucial for the successful implementation of smart irrigation systems.

The foundational insights from Parthasarathy's study are invaluable for framing the broader context of smart irrigation. While VRT might not be the central focus, the study likely addresses fundamental aspects of data-driven and automated irrigation, forming the bedrock for subsequent advancements in precision irrigation techniques.

Darshna et al. 2015, make a significant contribution to literature, expanding the knowledge base in the field of smart irrigation systems. The 2015 study, although not specifically discussing Variable Rate Technology, adds to the understanding of essential components and functionalities for the successful implementation of smart irrigation systems.

The expansion of the knowledge base by Darshna et al; 2015. is crucial in grasping the multifaceted aspects of smart irrigation. As the technological landscape evolves, these foundational studies become pivotal in informing subsequent research directions and innovations in smart irrigation practices.

An investigation into irrigation scheduling for rice using Variable Rate Irrigation (VRI) sheds light on the need to adapt irrigation practices to specific crop requirements. This study provides valuable insights into the application of Variable Rate Technology in a crop-specific context, showcasing its potential to enhance water-use efficiency in rice cultivation (Vories et al.’ 2017). The application of VRT in rice cultivation, as explored by Vories et al., 2017 signifies a targeted approach to precision irrigation. By tailoring irrigation practices to the specific needs of crops, this study addresses one of the fundamental challenges in smart agriculture ensuring optimal water use while maintaining or improving crop productivity.

In a study by Davis & Dukes, 2015 a methodological insight into the successful implementation of smart irrigation controllers were given. The study, while not directly focused on VRT, offers valuable guidelines and considerations for designing and deploying intelligent irrigation systems. Such insights can be instrumental in integrating Variable Rate Technology into smart irrigation systems (Davis & Dukes, 2015).

The methodological insights presented by Davis and Dukes lay the groundwork for the practical implementation of smart irrigation systems. Even without a specific focus on VRT, the study likely addresses key considerations in designing automated and data-driven irrigation systems, forming a basis for the incorporation of VRT in subsequent developments.

Methodology

VRT Design Implementation

System Design

The Sensor- Based VRT used in this research comprises of Hardware module and Software development to drive the hardware. As depicted in Fig.1, the hardware comprises of the components needed Soil Data Collection, System Control Unit, and Irrigation Trigger Unit. Each unit of the hardware is made up of sensors, microcontroller and components shown in Fig. 2. Similarly, the software involves the development of firmware that handles soil data collection, data aggregation and triggering of the pump. As shown in Fig.3, the block diagram represents each section of the system software.

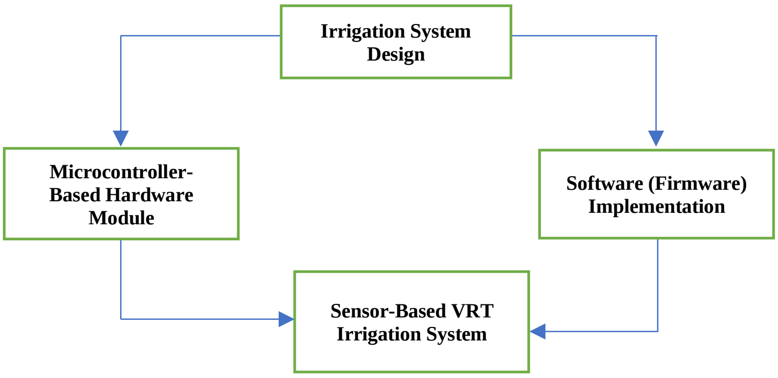

Figure 1: Sensor-Based VRT System Design

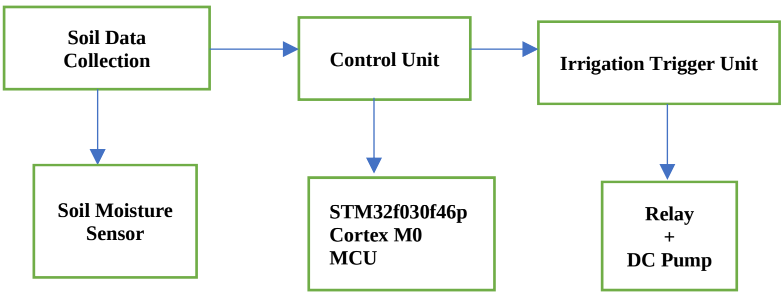

Figure 3: Hardware Setup

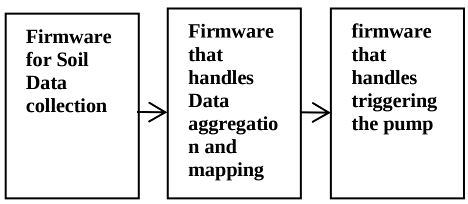

Figure 2: Software (Firmware) Implementation

System Implementation

Hardware Implementation.

The implementation consists of several essential components used in the research. These components are STM32f030f46p Cortex M0 MCU, Soil moisture sensor and 12v DC pump, 12v DC power supply, relay module, buck converter module etc.

As depicted in Fig. 4, the buck converter module is powered from a 12V DC supply source which in turn steps down the voltage to supply 5V to the Microcontroller unit (MCU), relays and Soil Moisture sensors.

The supply pins of the soil moisture sensor are connected to the analog general purpose input/output (gpio) pins of the MCU and its power pins (Vcc and GND) to the buck converter. The Relays have a diode connected in between the coils. The cathode of the coils is connected to the 5V Vcc supply while the anode end is connected to a switching transistor (BC 547).

The anode of the diode is connected to the collector, the emitter is connected to ground and the base is connected to ground through a 1Kohm resistor to one of the digital gpio pins of the MCU for control.

The soil moisture sensors were connected to the microcontroller via flexible wires for data communication and power. The buttons are connected through 10 ohms pull-up resistors to the microcontroller. The relays, pump, and buzzar were also connected through flexible 0.5mm wires and jst connectors to the microcontroller.

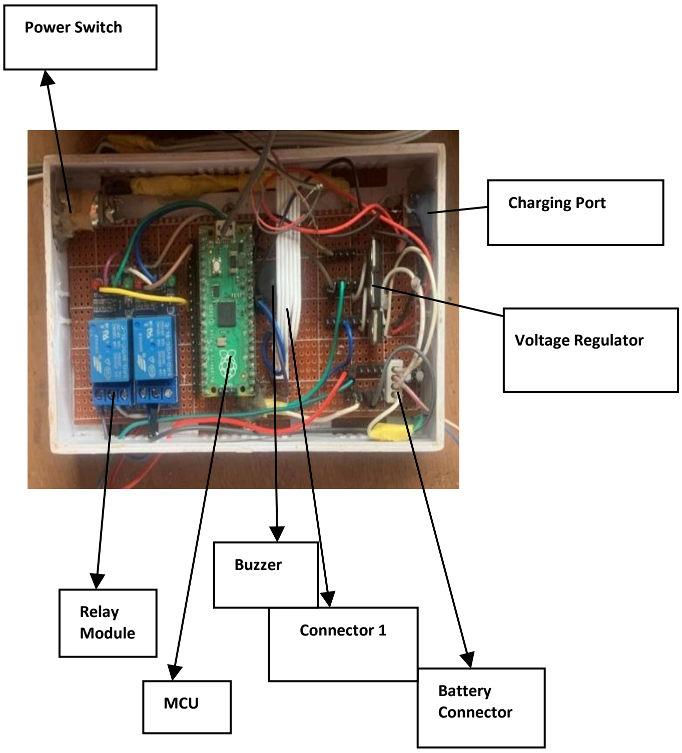

Figure 4: Hardware Implementation

Software Implementation

The firmware design is achieved using embedded software development programming languages including C, C++, and the Arduino framework utilizing the Platform IO IDE and VS code. The firmware design will follow the toll of creating Object-Oriented Programs to handle all the functionalities required to effect sensing, control, communications and actuation (triggering the irrigation system). That completes the project of a smart irrigation system using variable rate technology.

The Final System Setup

The final system setup of the sensor-based VRT system was assembled as shown in Fig. 5. The control box was made into a 6x3 adaptable box. This box houses the control unit circuitry, allowing the sensors and pumps to connect to it for control. The control box is placed on a flat wooden surface board alongside sample containers for various soil samples. Also Onboard is a water reservoir container from which the pump sources its irrigation water.

System Working Operation

The working operation of the system, as depicted by the flowchart in Fig. 6 at start-up will initialize all the hardware components connected (sensors and pumps) to the controller. At the press of a button corresponding to each soil moisture sensor (SMS) in each soil type, the SMS corresponding to that button is activated to take and report current soil moisture data to the microcontroller. The reading of each SMS is now aggregated and compared with the SMS threshold values preset within the firmware. Once the SMS reading is less than the lower threshold value of any soil type, the pump is activated to pump water to that soil type. Otherwise, the system continues to compare readings till there is a need for irrigation. The system compares the threshold level after 5 secs of pumping. Once the moisture level is equal to the upper threshold value of any or all the soil samples, the water supply to that soil type is cut-off while pumping continues for another 5 secs to other soil type below the upper threshold value. This cycle continues until all soil samples reaches their different upper threshold value and varying time intervals.

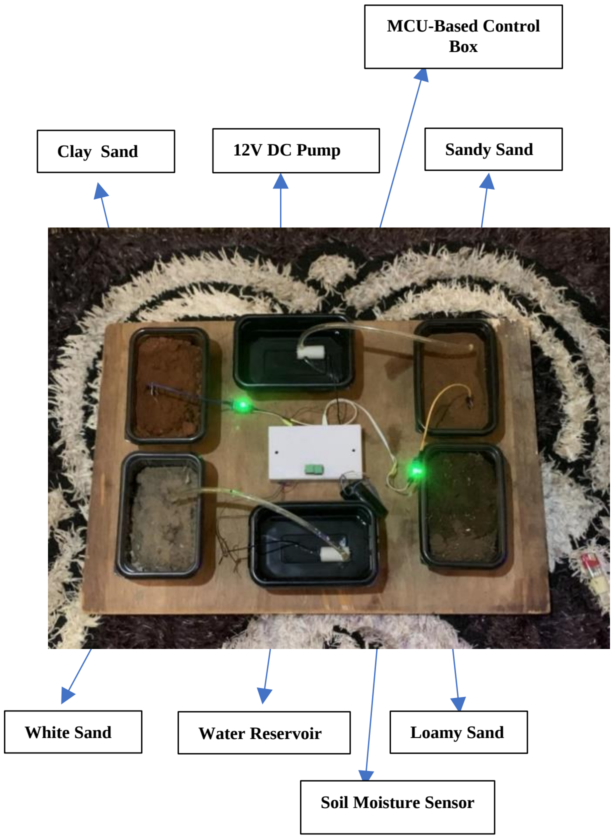

Figure 5: Final System Setup

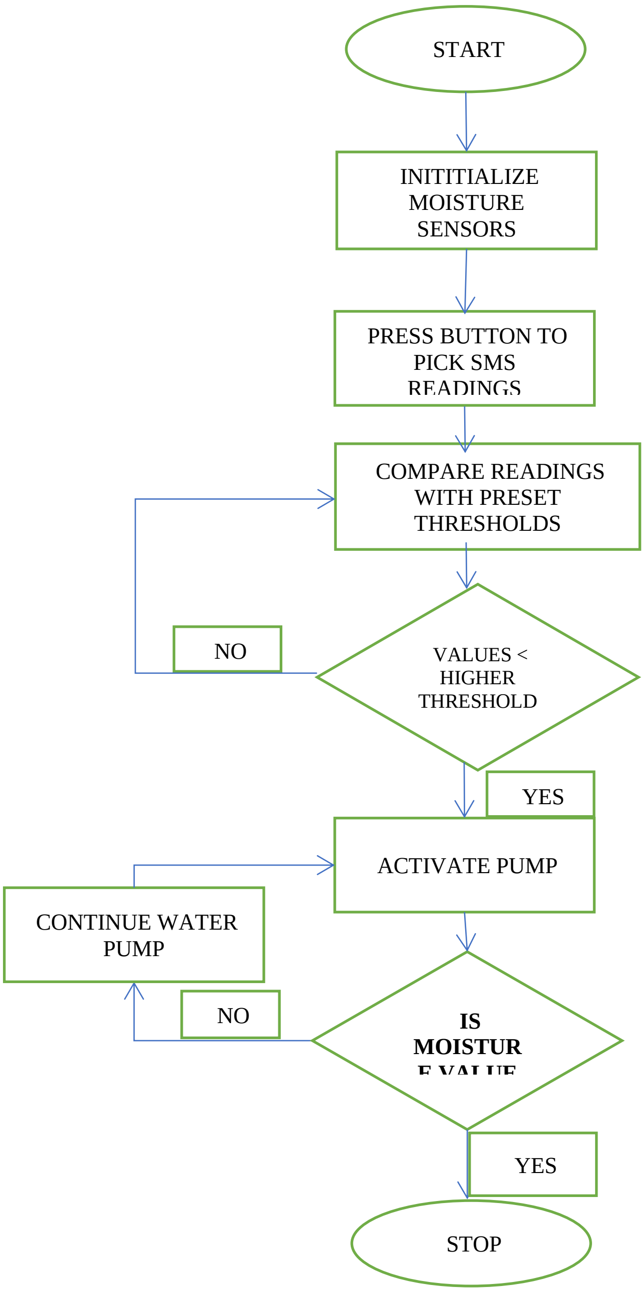

Figure 7: Flowchart Showing the Operation of the VRT Irrigation System

Conclusion

Irrigation has proven to be a method of ensuring the food security of every nation as it allows farmers to plant without ceasing and in all seasons. However, like every technology, irrigation has proven to be a huge drain on the world's water resources, thus the reason for several research (Davis & Dukes, 2015; Doris, 2024, Darshna et.al., 2015) on water conservation in irrigation farming.

The implementation of VRT technology in irrigation has further revealed methods of optimizing and enhancing water conservation in irrigation. This research shows that with varying soil types within farmland, water can be further conserved by dispensing water according to soil type and the soil water retention capacity. It was revealed that varying soil types requires varying volumes of water, and that irrigation can be planned to vary water dispersing

Figure 6:Flow Chart Showing System Working Operation

according to soil type thereby preventing water run-off that could have happened on certain soil types within the farm that have lesser water retention capacity. The implementation of this irrigation system will further conserve water, save costs and ensure increased food production.

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