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EXPERIMENTAL STUDY OF AN AUTOMATIC IRRIGATION SYSTEM ON SENSING SOIL MOISTURE CONTENT, TEMPERATURE AND NPK LEVEL

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ABSTRACT

This research focused on the experimental study and development of an automatic irrigation system capable of sensing soil moisture content, temperature, and NPK (Nitrogen, Phosphorus, and Potassium) levels for efficient agricultural water and nutrient management. The study was motivated by the need to reduce water wastage, improve crop productivity, and minimize human involvement in irrigation practices, especially in developing countries where traditional irrigation methods are still predominant. The developed system integrates soil moisture sensors, temperature sensors, NPK sensors, a microcontroller-based control unit, relays, solenoid valves, and a water pumping mechanism to automate irrigation and nutrient application processes. The system continuously monitors soil conditions and responds intelligently by supplying the required quantity of water and nutrients whenever the soil parameters fall below preset limits. The control unit was implemented using an ATmega328P microcontroller programmed through the Arduino platform, while the sensing unit provided real-time feedback on soil moisture, ambient temperature, and nutrient status. Tests were carried out on different soil samples to evaluate the performance and responsiveness of the system. The results showed that the system effectively detected variations in soil moisture, temperature, and nutrient deficiencies, and automatically regulated water and nutrient supply accordingly. The system also successfully suspended irrigation during excessive temperature conditions to prevent water loss through evaporation and inefficient irrigation practices. The study concluded that the developed automatic irrigation system is efficient, reliable, affordable, and suitable for sustainable agricultural practices. The system preserved soil structure, reduced unnecessary water application, minimized nutrient leaching, and enhanced proper crop growth under varying environmental conditions. The research therefore demonstrates a cost-effective approach to smart irrigation management that can improve agricultural productivity and support peasant farmers, particularly in developing nations such as Nigeria.

Keywords: Automatic irrigation system, soil moisture sensor, temperature sensor, NPK sensor, microcontroller.

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I. INTRODUCTION

Irrigation is the process of applying controlled amount of water to the crops artificially to fulfill their soil water requirements. For some soils that are too loose, nutrients may be provided to the crops through irrigation. Irrigation is mostly practiced in areas where average seasonal rainfall rate may seem ample but the rains are frequently unevenly distributed or areas where soils have low water holding capacities. In these areas, traditional rain-fed agriculture makes agriculture a high-risk enterprise. The water for irrigation can come from wells, ponds, lakes, canals, tube-wells and even dams.

History has it that several millennia ago, nomadic tribes were able to settle in more stable communities with assurance of annual crop productivity because they relied on irrigation. At that time, irrigation was rudimentary, consisting of ponding water in basins enclosed by low earthen dikes, after which, research revealed that the earliest societies to rely successfully on irrigation were located in four major river basins: the Nile in Egypt around 6,000 B.C.E., the Tigris and Euphrates in Mesopotamia about 4,000 B.C.E., the Yellow River in China around 3,000 B.C.E, and the Indus in India approximately 2,500 B.C.E. In Mexico and South America, irrigation was practiced by the Maya and Inca civilizations more than 2,000 years ago. Kuros, (1984) and (National Geographic, 2017) stated that a hundred feet below the mysterious pits, a narrow tunnel carries water from a distant aquifer to farms and villages that wouldn't exist without it. These underground aqueducts, called qanats, are 3,000-year-old marvels of engineering, many of which are still in use throughout Iran. More so, using Earthen dams to store surface water were first constructed in the second and third centuries in Japan to irrigate rice. In Central Europe, irrigation was documented as early as the third century C.E. as noted by Csekö and Hayde, (2004). In North America, irrigation is known to have existed among Native Americans of the southwest as early as 1200 B.C.E. Early Spanish explorers found evidence of irrigation canals and diversion points along rivers. The Spaniards introduced new irrigation methods and irrigated crops such as grapes, fruits, vegetables, olives, wheat, and barley. As in other areas of the world, irrigation made it possible for Native Americans to develop settlements and enjoy a more secure food source (Gulhati, 1973). Up to that time most irrigation works were small systems. Irrigation began to expand in many countries in the nineteenth century and took on new dimensions in terms of the amounts and methods of water diversion and management. The first barrages, short diversion dams, were built in the Nile Delta in about 1850. About the same time in India, several irrigation canal systems were constructed. The Lower Chanab Canal in Pakistan was the first canal system intended strictly for arid land not previously cultivated. In 1847 Mormon colonies began irrigating in Utah. Their efforts expanded into California, Nevada, Idaho, Wyoming, Arizona, New Mexico, and Canada. German immigrants started an irrigation colony in Anaheim, California, in 1857, and an irrigation colony was started in 1870 at Greeley, Colorado. Today, irrigation systems use reservoirs, tanks, and wells to supply water for crops. Reservoirs include aquifers, basins that collect snowmelt, lakes, and basins created by dams. Canals or pipelines carry the water from reservoirs to fields. Canals and pipelines, just like the ancient Roman aqueducts, often rely on the force of gravity. Pumps may also move water from reservoirs to fields. As practiced in many places, however, (Eisenhauer, Martin, Heeren, & Hoffman, 2021) noted that irrigation is still based largely on traditional methods which fail to measure and optimize the supply of water to satisfy plant water demands. Unmeasured irrigation tends to waste water, nutrients, and energy, and may cause soil degradation by waterlogging, erosion, and salination. The vital task of assuring adequate global food production must include a concerted effort to modernize irrigation systems and improve water management. These improved techniques will help achieve sustainable and efficient production while protecting the environment. New systems must be based on sound principles and designs to optimize

irrigation in relation to essential inputs and operations while guaranteeing sustainability of irrigated agriculture. Water and soil must be recognized as vital, precious, and vulnerable resources and managed accordingly.

The method employed is to continuously monitor the soil moisture and nutrient level to decide whether irrigation is needed, and how much water and nutrient is needed in the soil. A pumping mechanism is used to deliver the needed amount of water to the soil. The work can be grouped into four subsystems namely; power supply, sensing unit, control unit and pumping subsystems which make up the automatic irrigation control system. A moisture sensor will be constructed to model the electrical resistance of the soil, a regulated 12 volts power supply unit will be constructed to power the system, the control circuit will be implemented using microcontroller and the pumping subsystem will consist of a submersible low-noise micro water pump that will be constructed using a small dc-operated motor. System response tests will be carried out to determine the time taken for the system to irrigate potted samples of different soil types having different levels of dryness and deficiencies. The results obtained showed that sandy soils require less water than loamy soils and clay soils require the most water for irrigation.

Objectives of the Study

The main objectives of this research work includes:

- To control watering of crops using microcontroller-based irrigation system
- To apply nutrients to the soil based on the plant requirements.

Other objectives include: To know the quantity and quality of water to apply to the soil, and also the exact quantity of nutrient required.

II Literature Review

Irrigation as the artificial application of water to the land for various purposes, which may include crop cultivation, re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall, replenishments and maintenance of landscapes has different ways of applying it. CDC, (2016) noted that the application depend on how the water is distributed throughout the field. Some common types of irrigation systems include:

Surface irrigation where water is distributed over and across land by gravity and as such, no mechanical pump is needed.

Localized irrigation. In this type, water is distributed under low pressure, through a piped network and applied to each plant.

Drip irrigation on its own is a type of localized irrigation in which drops of water are delivered at or near the root of plants. In this type of irrigation, evaporation and runoff are minimized.

Sprinkler type of irrigation, water is distributed by overhead high-pressure sprinklers or guns from a central location in the field or from sprinklers on moving platforms.

Center pivot irrigation also, water is distributed by a system of sprinklers that move on wheeled tower in a circular pattern and its common in flat areas.

Lateral move irrigation type involves distributing of water through a series of pipes, each with a wheel and a set of sprinklers, which are rotated either by hand or with a purpose-built mechanism. The sprinklers move a certain distance across the field and then need to have the

water hose reconnected for the next distance. This system tends to be less expensive but requires more labor than others.

Sub-irrigation is a type of irrigation where water is distributed across land by raising the water table, through a system of pumping stations, canals, gates, and ditches. This type of irrigation is most effective in areas with high water tables.

Manual irrigation. It involves w**a**ter been distributed across land through manual labor and watering cans. This system is very labor intensive. With the invention of sensors and transducers, such as soil moisture sensors and transducers, the real–time soil moisture status can be electronically monitored and same information can be used to determine the water and nutrient requirements of the soil through actuator induced irrigation. Different approaches have been undertaken to manage irrigation using electronics. Evidence to that are the works of Banerjee and Singhal (2010) where they proposed a method for the control of temperature and relative humidity inside a poly house using a microcontroller. In the proposed method the greenhouse controller senses the change in temperature and relative humidity with the help of input sensors and process the output to take appropriate control action. The proposed system is a low cost and user-friendly system with high stability and reliability. Another work on this, is the work of (Dondapati &. Rajulu, 2012; Aderemi A. Atayero and Adeyemi S. Alatishe, 2015). They proposed a method in which the microclimatic parameters are monitored round the clock for cultivation of specific plant species which could maximize their production over the whole crop growth season and to eliminate the difficulties involved in the system by reducing human intervention to the best possible extent. When any of the climatic parameters crossed a safety threshold which had to be maintained to protect the crops, the sensors sensed the change and the microcontroller after having read this change then performed the specified actions through the use of relays until the strayed-out parameter has been brought back to its optimum level. The use of a microcontroller made the set-up low-cost and effective nevertheless. Morris (2006) surveyed some low-cost soil moisture monitoring tools and methods, including new generation of sophisticated and user-friendly electronic device and explained the process of water detention by soil. Prathyusha and Chaitanya (2012) mention that microcontroller based drip irrigation system which proves to be a real time feedback control system, monitors and controls all the activities of drip irrigation system efficiently. They also reported that using this system one can save the water and manpower to improve production and ultimately profit.

III MATERIALS AND METHODS

Materials

The developed circuit consists of several components/materials which includes, a power supply section through which regulated D.C. supply is provided for energizing the circuit, a microcontroller, soil moisture sensor, NPK sensor, temperature sensor, locally-made water sensor, relays, water pump, solenoid valves, two-way switches, variable resistors, connectors for power supply etc.

The Power Supply Unit

The power supply unit has the part that supplies 220V from the solar powered system. This is used in running the pump. The other part supplies 12V D.C. And 5V D.C. for the microcontroller through some rectifying circuits.

The Sensing Unit

This unit is responsible for the detection of the presence of the physical parameters and converting same to electrical form for processing. The physical parameters of interest are the soil moisture, soil nutrient, the ambient temperature and the presence of water in the tank. It will consist of the soil moisture sensor, NPK sensor and liquid level sensor. The Water Switch was used for the liquid level sensing.

The Soil Moisture Sensor

The soil moisture sensor used in this circuit was purchased from Amazon. Its voltage output is proportional to the quantity of water in the soil. There is no data-sheet available for it and all information about it is given on Amazon's site. Its specified supply voltage is from 3.3V to 5V and with this supply, it gives an output voltage of between 0V to 2.3V for the full range of complete dryness to submersion in water. Its rating for maximum operating current is 15mA. The transducer is buried in the soil near the root zone of the crops for accurate monitoring. Its output is fed into the ADC input of the microcontroller.

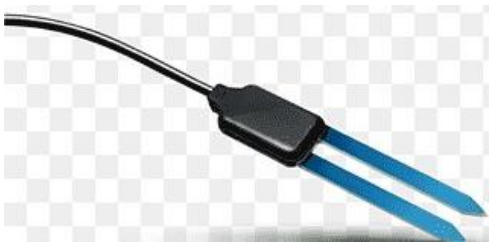


Figure 1: Soil Moisture Sensor

The Temperature Sensor

The temperature sensor used in this circuit is the LM35 temperature transducer. It is a precision temperature transducer with a linear voltage output over the range of -55^{o}C to 150^{o}C. Its favorable property is its linearity and step-wise sensitivity. It has a sensitivity of 0.01V/^{o}C starting from 0^{o}C hence its temperature can easily be calculated. The output of the transducer is applied to the ADC segment of the microcontroller for processing.



Figure 2: Temperature Sensor

The NPK Sensor

Nitrogen (N), Phosphorus (P) and Potassium (K) are three elements that are essential for plant growth and development. Determining their concentrations in soil can help farmers determine the nutritional status of their crops. Soil NPK sensor is a device that is used to measure the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in soil. It can detect and send soil nitrogen (N), phosphorus (P) and potassium (K) data to a connected microcontroller. The soil NPK sensor has high precision, fast response, stable output and less affected by soil salt content. It is suitable for all kinds of soil and can be buried in the soil for a long time, resistant to long-term electrolysis, corrosion, vacuum filling and it is waterproof. The device can be connected directly to the MCU through the 485-interface chip.



Figure 3: NPK Sensor

The Water Switch

The water switch is a locally made sensor. It is constructed using a Vero board. It is simply an open circuit formed by a **g**roup of conductors separated by a little spacing to give room for water running through it to bridge it. If a voltage is applied to the switch, it is found to be short- circuited when water flows through it. We can therefore say it takes either of two states relative to voltage across its terminals - on or off - hence the name "switch". It is with this property that we are able to control the water filling of the tank.

The Solenoid Valves

A solenoid valve is an electrically controlled valve. The valve features a solenoid, which is an electric coil with a movable ferromagnetic core (plunger) in its center. In the rest position, the plunger closes off a small orifice. An electric current through the coil creates a magnetic field. The magnetic field exerts an upwards force on the plunger opening the orifice. A 2-way solenoid valve has two ports, an inlet and an outlet. Flow direction is critical to ensure proper operation, so there is typically an arrow indicating the flow direction. A 2-way valve is used to open or close the orifice.



Figure 4: Solenoid Valve

The Control Unit

This unit is basically where the control of the whole system takes place. It consists of a ATmega328P 16MHz microchip which is the central hardware component of the system and is programmed using the Arduino programming board. Based on the ATmega328P 16MHz microchip, this board features 14 digital input/output pins, 6 analog pins, and an ICSP (In-Circuit Serial Programming) header, and is able to provide up to 5V to the components connected to it.

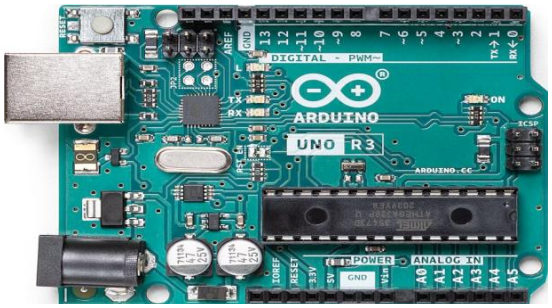


Figure 5: ATmega328P based Arduino Board

The Display Unit

The display unit is simply an output unit used for the purpose giving the user required information. The display unit is a simple 16x4 LCD module. This means it has sixteen columns and four rows. Each column can represent only a single character. The device can display the ASCII alphanumeric characters, some Japanese characters, and some symbols. The information to be displayed are the current soil moisture - on a percent base of which submersion in water is a 100% and in dry air is 0%, the lower limit soil moisture, the upper limit soil moisture, the current temperature, the state of the system (whether irrigating, or filling the tank) etc. The LCD screen is powered by a 5V supply voltage, and has back-light to enable the user to see the character that may be displayed on the screen where external light may be insufficient. The contrast of the display can also be controlled using a simple potentiometer or variable resistor with the sweep terminal connected to the VEE pin of the LCD screen. When the device is used in the 4-bit mode, the pins D0, D1, D2 and D3 are left unconnected, while D4, D5, D6 and D7 are connected to corresponding output pins of the microcontroller.



Figure 6: Liquid Crystal Display Module

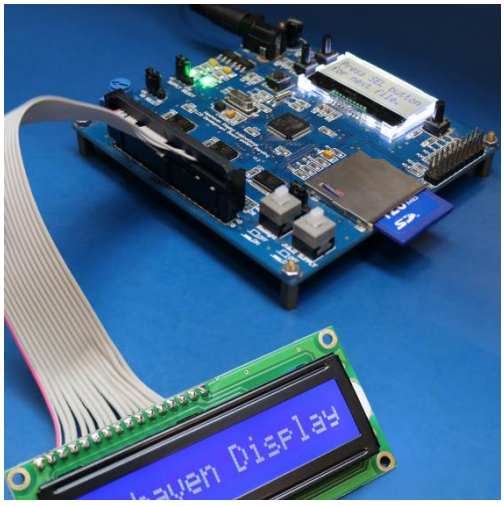


Figure 7: Way of Connecting LCD Module to Arduino Board

The software

The microcontrollers can be programmed using the C and C++ programming languages (Embedded C), using a standard API which is also known as the Arduino Programming Language.

The Actuators

The actuators used in this work consist of the solenoid valves, electric water pump and all the relay switches used to energize and de-energize them.

Methods

The experimental study on automatic irrigation system was developed. Taking into considerations are portability, corrosiveness, toughness to weather parameters, quick response, easy for installation and fixation of the sensors. The system is a simple circuit developed to control an irrigation scheme on a farmland. It is designed to manage irrigation based on response to the real-time status of the soil moisture and nutrient content and will cause them to always be in a certain range suitable for proper crop development. The architecture of the system was divided into two subsections/methods based on function carried out. These are:

1. The irrigation controller method and
2. The water-storage controller method.

The Water and Nutrient Irrigation System

This section of the device performs the action of irrigation management. It does so by monitoring the moisture content of the soil continuously and comparing the values with two set reference values-the upper-limit and lower-limit moisture content values- and then inducing corresponding actions required. Provision is made through control knobs for the user to set these values as so desired. When the soil moisture content goes below the lower-limit value set by the user, the system observes this and begins irrigation action. The land section will be irrigated until the soil moisture level reaches the upper limit value set by the user. At this point irrigation action will cease until the soil moisture level is observed to fall below the lower limit value again. In this way, the soil moisture is kept within the desired range suitable for optimal growth of the crops and water is only supplied, as the crop requires. Also included on the system is the temperature sensing and controlling functions. When the temperature function is activated, the soil temperature will be continuously monitored and whenever the temperature is observed by the system to exceed a certain preset temperature value, the irrigation action is terminated if it is in operation or else it will be prevented from commencing if it is required to do so (i.e., if the soil moisture level falls below the lower limit of soil moisture). Consequently, the temperature sensing operation has a higher priority over the soil moisture-based irrigation operation. The temperature value, over which this operation occurs, is set in the firmware program code to represent the average afternoon temperature of (36°C), which is considered unsuitable for irrigation by some users. What this means is that once the afternoon temperature is reached, irrigation action is suspended (even if the soil moisture level is below the lower limit) until the temperature falls below this set value - in the evening. Irrigation action will be resumed at this point, until afternoon temperature is reached the next afternoon. In this mode of operation, the soil will only experience stress due to absence of water, if ever, in the short period of the afternoon hence the optimal conditioning of the soil is scarcely compromised. This is an adaptive and optional function and is included for users who work with the principle of not irrigating under the high temperatures commonly obtained in the afternoons. It is made optional. It can be activated (if required by the user) or deactivated. Equally as part of the system is the nutrient application function. The system is equipped with the NPK sensor which when activated, will continuously be monitoring the soil nutrient level. Irrigation when done excessively causes the movement of nutrients to the lower lands due to gravity. It is more rapid in the rain forest zone due to the high rain rate especially at the peak of the wet season. This nutrient sensing function will probe the soil and determines the nutrient level and compares it with what the system considers as deficiency, then apply the particular nutrient gradually until it gets to the desired level. With this, the irrigation operation will not lead to soil leaching.

The Nutrient and Water-Storage Level Monitoring System

The system also includes the option of filling up a nutrient and water storage medium (i.e., tank) used in the irrigation scheme and monitoring their quantities to ensure that it does not go below a certain set levels (lower limit) by commencing filling action of the storage medium as soon as it falls below this level. It then refills the medium until the levels reach another set levels (upper limit) at its full capacities. At this point, the filling action is terminated. It will again resume the filling as soon as the levels fall below the lower limit and the cycle would continue. This feature is made optional as well and can be activated - if desired by the user - or deactivated if the user does not require it.

IV. RESULTS AND DISCUSSIONS

At the end of the experimental research, the temperature of the soil was detected using the temperature sensor. This provided a clear knowledge when to apply water or not, to the soil. The moisture content level of the tested soil was detected with the aid of the soil moisture sensor, giving an insight of whether there is need for water application to the soil or not. Considering the need for water application, the water application was done and regulated by sprinkling water and stopping the sprinkling at the point of saturation of the soil.

The entire experimental setup was able to detect the soil nitrogen, potassium and phosphorus content of the soil and adjust it by applying the desired amount of it to the soil.

V. CONCLUSION

The experimental setup preserved our soil structure and kept our plants to be absorbing nutrients, not the runoff water. The irrigation system performed up to expectation as plants fared well under severe environmental condition. The experimentally designed irrigation system is easy to operate, efficient and affordable most especially for peasant farmers in developing countries like Nigeria who may find other methods of agricultural practice quite expensive. This work has elucidated a cost-effective means of controlling/regulating temperature and water application in farming generally, which if adopted will reduce the high rate of crop destruction encountered during planting, hence increase in income generated for farmers.

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