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Soil Moisture Based Irrigation Control System for Rice Cropping Using Wireless Sensor Network

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Abstract
Recent advances in information and communication technology (ICT) and wireless sensor networks have made new trends to merge in irrigation practice. Irrigation practice has been considered to be one of the most water consumers in the world today. Proper management of water irrigation is more needed now for sustainable productivity and improvement of water use efficiency of rice crop. Studies show that the appropriate level of water contribute to the quality of rice grains and affects the incidence of pests and diseases, weed population and availability of nutrients in the soil hence the need for efficient and automated irrigation systems, which can irrigate plants to a desired level and supply those plants with just the amount of water required for normal uptake plant growth. The paper presents an automated irrigation system based on supervisory control and wireless communication. Monitoring and control of water level in the rice cropping irrigation which represents an important input on water conservation and improved efficiency in rice production is realised. The benefit of this design is extended to fertilizer and/ or chemical applications.

Key Words: *Irrigation, soil moisture, wireless sensor network, Control System Efficiency, Water.*

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I. Introduction

Water is a basic component of all known life on Earth. Water can both sustain life in correct quantities and threaten life when it is not available or overabundant. Water as a result is a very precious natural resource that must not be wasted. If too much water is applied the problems arise consisting of runoff, erosion, waste of water and deceased plant life. If too little water is applied different problems arise such as turf burnout. The idea of irrigation is not new. Irrigation stems as far back as the Egyptians and probably further in unrecorded history. Even the idea of automated irrigation is not new, mankind has figured out how to irrigate large areas of foliage through the use of automated and drop irrigation systems. The key in irrigation is strives to correct balance for optimal plant life with optimal use of water. In the developing world for an instance, water allocated to irrigation exceeds 69% of water resources [1]. In view of increased domestic competition for resources and the need for larger agricultural production to ensure food security, such a fraction is unsustainable. Therefore, future water security can be guaranteed by a considerable increase of the water use efficiency. The concept of using soil water sensor to evaluate irrigation scheduling is a well-known concept and has become a common practice since the introduction of dielectric (TDR, FDR) soil water sensors. Since many sensors and controllers are involved in this and each controller performs an individual schedule which is set and reprogrammed on a regular basis, the cost for investment, installing wiring , maintenance, data-handling and use is becoming bottleneck, hence the need for new improved and cost-effective monitoring and control system. The use of wireless sensor networks (wsn) on irrigation system could save a lot of installation and management cost and would add value to technical, environmental and economical overall performance of irrigation system. It would however, provides nearly unlimited installation flexibility for sensors and increased network robustness [2].

II. Basic Irrigation Control Concept

There are two basic irrigation control strategies: open loop control systems and closed loop control systems. The difference between these is that closed loop control systems have feedback from sensors, make decisions and apply decisions to the irrigation system. On the other hand, open loop control systems apply a preset action, as is done with irrigation timers. Since the controller is the brain behind irrigation control system, the type of controller used determines the irrigation control system

III. Open Loop Control System

Open loop control systems use irrigation duration or applied volume for control purpose. In this type of controller, the basic control parameters are how often and how long is the irrigation water to be applied. This type of system is based on a pre-defined control concept, with no feedback from the controlled object. The user sets the time to start, the time to end and the time to pause intervals and the watering periods. These parameters are pre-set for the entire session as thus:

- How long the irrigation session should last
- How often the irrigation period should repeat itself and
- How much water, fertilizer, and/or chemical be used in the irrigation session.

No Checking Is Done To Know Whether Right Amount Of Water Is Used Or Not. Open Control Loop System Is Said To Be Time-Driven. Therefore, The Open-Loop Controller Uses A Periodic Irrigation Policy [3]. In This Policy, The Irrigation Is Based On The Relevant Amount Of Water That Must Be Given Periodically (A Large Amount Once In Few Days, Or Fractions On Each Day). The Experts Claim That Periodic Irrigation With Large Amounts Is Better Because It Washes The Soil Free Of Chemicals And Creates A Better Balanced Soil Chemically [4]. Open Loop Control Systems Have The Advantages That They Are Low Cost, Readily Available, And Many Variations Of The Devices Are Manufactured With Different Degrees Of Flexibility Related To The Number Of Stations And Schedule Specification. This Type Of Irrigation Control System, Though Relatively Simple And Cheap But In Most Cases Does Not Provide The Optimal Solution To Irrigation Problem. However, They Do Not Respond Automatically To Environmental And Climatic Changes And Require Frequent Resetting To Achieve High Levels Of Irrigation Efficiency.

IV. Close Loop Control System

These Are Based On A Combination Of Pre-Defined Control Concept (Feed-Forward) And Feedback From The Controlled Object. In This Type Of Controller, There Is A Feedback Of The Necessary Data To Determine The Amount Of Water Needed For Irrigation. There Are Several Parameters That Should Influence The Decision Of How Much Water To Use In The Irrigation Process. Some Of These Parameters Are Fixed For The Session And Are Of An Agricultural Nature (Such As The Kind Of Plants, Kind Of Soil, Stage Of Growth Etc) And Some Of Them Are Vary And Should Be Measured During The Irrigation Process. These Parameters Are Of A Physical Nature (Such As Temperature, Soil Moisture, Air Humidity, Soil Humidity Wind Speed, Radiation Etc). So, When These Conditions Change, The Amount Of Water Being Used For The Irrigation Should Change [5]. Controller Receives Feedback From One Or More Sensors In The Field , That Continuously Provide Updated Data To The Controller About The Parameters That Are Influenced By The System Behavior (Such As Soil Moisture Level, Temperature, Wind Speed Etc). According To The Measurements Provided By The Sensors And The Pre- Programmed Parameters (Such As The Kind Of Plant, Kind Of Soil Etc), The Controller Decides On How Far To Open The Water Valve. It Is Important To Note That In This System, State Of The System Is Compared Against A Desired State And A Decision Based On This Comparison Is Made Whether Irrigation Should Be Applied Or Not. Closed Loop Controllers For Irrigation Systems Base Their Irrigation Decisions On:

- Monitoring the state variables
- Comparing the state variables with the desired variables or target state.
- Deciding what actions are necessary to change the state of the system.
- Carrying out the necessary actions.

Closed control loop system is event-driven and hence responds automatically to climatic and environmental changes thereby achieving high level of irrigation efficiency.

V. Material And Methodology

Design Of Irrigation Controller

Figure 1 depicts the block diagram of the irrigation controller embedded in the system model. As can be seen, the controller is operated in three interrelated stages.

 Desired soil input: This block shows the set point parameters (both climatic & soil conditions) that plant require to for optimum productivity.

 The input variables: In this stage, there are key physical parameters that would influence the decision of how much water, nutrient, and/or chemical used in the irrigation process (i.e. temperature and soil moisture)

 The control stage: In this stage the desires inputs are compared with the measured variable inputs following the comparison, a dynamic decision is made regarding the amount of water to be added to the soil.

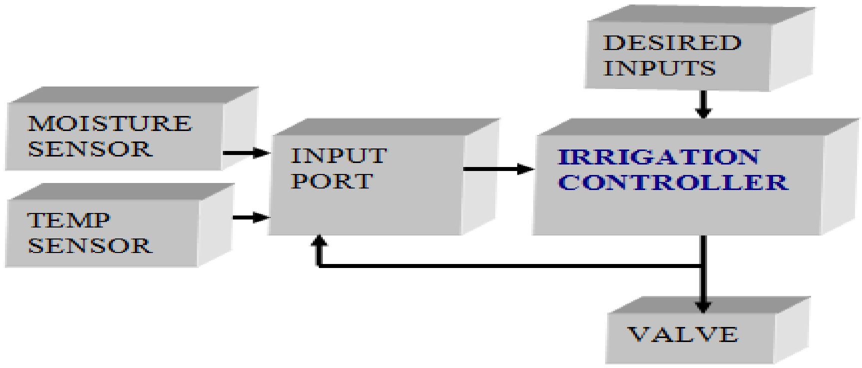

Fig.1 Block diagram overview of irrigation controller

VI. Soil Moisture Sensor

The concept is for an appropriate amount of irrigation to occur when needed to maintain adequate soil moisture levels. The soil moisture is the ratio of the volume of water in the soil to the volume of void space between the soil particles, and is reported as a percentage value. This system should operate on the principle that a preset irrigation quantity is applied when the measured soil moisture level drops to a threshold set point by the user. Soil moisture sensor acquires soil moisture data. The output sensor value is an analogue data is within the range of 0- 5v DC for 0 -100% and is converted to digital data by ADC. The value of ADC input which comes from the sensor is stored in a 10-bit register

VII. Temperature Sensor

The temperature sensor voltage output varies with temperature at 10mv/^{o}C which means that at 100^{o}C the voltage is 1000mv.The system should only switch on water pump at temperature 35^{o}C and above even if other conditions are met. So the voltage input at that temperature is calculated thus $V_{min} = (V_s/T) \times t$, where V_{min}=voltage for irrigation to start, V_s= voltage at 100^{o}C, T=100^{o}C, t=temperature for irrigation to start. V_{min} = 1000mv/100^{o}C x35^{o}C =350mv. This voltage (350mv) is converted to digital voltage by analogue to digital converter before feeding it into the controller input port.

7.1 A/D Interface

The electrical signals resulting from the sensors are converted to digital data. This is done through specialized hardware referred to as the Analogue-to-Digital (A/D) interface. Discrete signals resulting from switch closures and threshold measurements are converted to 0 and 1. Continuous electrical (analogue) signals produced by the sensors signals are converted to a number related to the level of the sensed variable. The accuracy of the conversion is affected by the resolution of the conversion equipment. In general, the higher the resolution, the better the accuracy

7.2 Software

The controller monitors and derives the logical portions. The controller is programmed using C^{++} to enhance flexibility in writing codes. The flowchart of this software is shown in figure 2. After power-up, the base station unit (or controller) sends address data from sensor unit. If the controller matches the sensor data, it evaluates the moisture data. If it requires, the position of valve can be changed. Afterwards, the controller sends address data for getting new sensor value. The sensor unit (SU) measures the soil moisture after receiving it from base station unit (BSU) and sends the data. The valve unit (VU) changes the position (on or off) after receiving the data from BSU thereby determining which zone is to be irrigated.

The pseudocodes are as follows:
a. initialize the system
b. read the temperature
c. check the soil moisture
d. compare soil moisture with desired soil moisture
d. switch on the pump if less than
e. switch to next zone, if present zone is ok

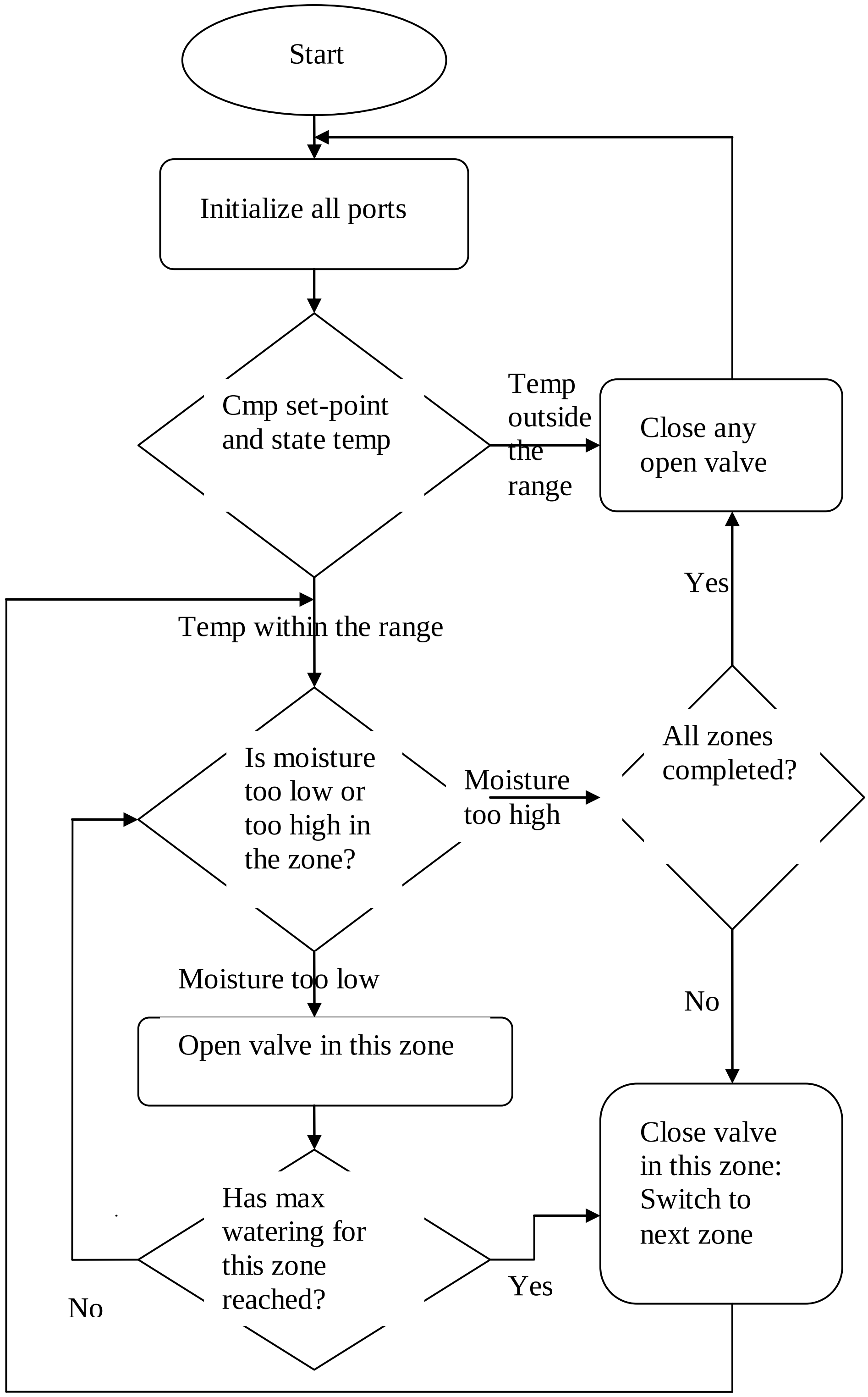

Fig 2 Flowchart for the code used to irrigate zones

VIII. Wireless Sensor Network (Wsn) Node Requirement

Each wireless device also known as NODE has one or more sensors integrated in it. In addition to sensors, a node is also equipped with transceiver (transmitter and receiver), actuators, analogue-to-digital and/or digital-to-analogue converters, microcomputer and battery. The sensors cooperatively continuously monitor soil data (soil moisture) and whether data (temperature). The actuator provides the control function desired (i.e. A switch that turns a motor on or off). The transceiver (transmitter and receiver), is used for wireless communication with other nodes or directly with gateway. The transceiver modulates and transmits, receives and demodulates digital data. The gateway in the transceiver is responsible for transmitting sensor data from sensor patch to remote base station. The microcontroller reads the sensor data and, after processing and formatting, outputs the data to the wireless transceiver. The microcontroller is also responsible for any control command directed to the actuator. It is worthy to note that the controller is rugged, flexible, and easily programmable and above all energy efficient.

8.2 System Control Strategy

Soil moisture and climatic temperature are the key physical parameters that influence the decision of when and how long should this irrigation process occur. However, the soil characteristics and the type of crop are the fixed input parameters that form the basis for determining desired values (or set-point). When these parameters change, the amount of water used for the irrigation also change. The system is realized in three modules or units. There are Sensor Unit (SU), Base Station Unit (BSU), and Valve Unit (VU). Soil moisture is seen in sensor unit which sends data of soil moisture to base station unit. The Base Station Unit evaluates the data received from SU. The BSU is the master device that is programmed to read and evaluate sensor data, control valve in Valve Unit, communicate other units and hence decide which irrigation zone is to be watered. On the other hand, the project comprises three major levels of communication. The lowest level is the communication of field devices (sensors) with a controller. Wireless communication is used at this level. The second level is the wired communication between the controller and the actuators (electronic drives for pumps). The logic control of drives is implemented in the controller based on the information from sensors. The third level is between the controller and. operator's GSM phone. This mode of communication is also wireless. Flowchart for the code used to irrigate the zones is shown in fig 2

8.3 Site Description

The irrigation landscape is mapped into two zones (zone A and zone B). Zone A represents clay soil while zone B represents sandy soil. Prototype is built on two container crops representing the two zones while the full implementation of the project is to be sited at Onuebonyi-Echara Ikwo L.G.A. of Ebonyi State, Nigeria. This region is responsible for more than 50% of rice production in Ebonyi State. The land is bounded in North by Ebonyi River and South by Obubra River, Cross-River State, Nigeria. The area is about 2km away from Ebonyi State Modern Rice Milling Cluster. The climate of the region is temperate with average temperature of 28^0C at rainy season and 34^0C at dry season. The characteristics of soil composition, the climatic factors, and cultivated rice crop are taken into account to determine the set-point parameters of the irrigation system.

8.4 Experiment to Determine the Rate of Soil Moisture Infiltration

Experiment is carried out between zone A, (clay soil) and zone B (sandy soil) to determine their respective soil moisture infiltration rate and moisture retentive capacity. The soil moisture sensor node consists of the sensor interface and signal conditioning circuits. The sensor is derived by a 200 kHz square wave. The frequency changes according to the moisture value. The output of the sensor indicates the level of the soil. The moisture level scale is between 0 to 3.5v indicating 0 to 100% moisture. Both zones were allowed to dry to moisture content value of 2.5%. Thereafter, they were irrigated for about 9mins and the percentage soil moisture values were obtained in every interval of a minute. The graph of fig 3 shows the plot of rising moisture value of zone A and B with time (min) ; fig 4 shows the decrease in their soil moisture contents with time (hours) after the ten-minute irrigation period; while fig 5 shows decrease in water level in the reservoir during the irrigation period.

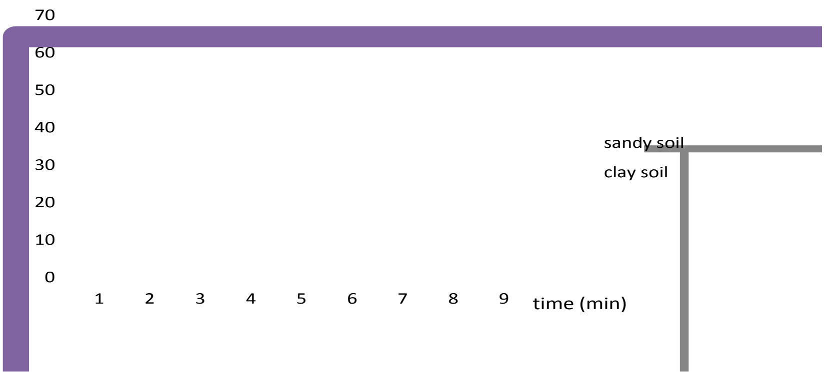

Fig 3 Increase in soil moisture content with time during irrigation period

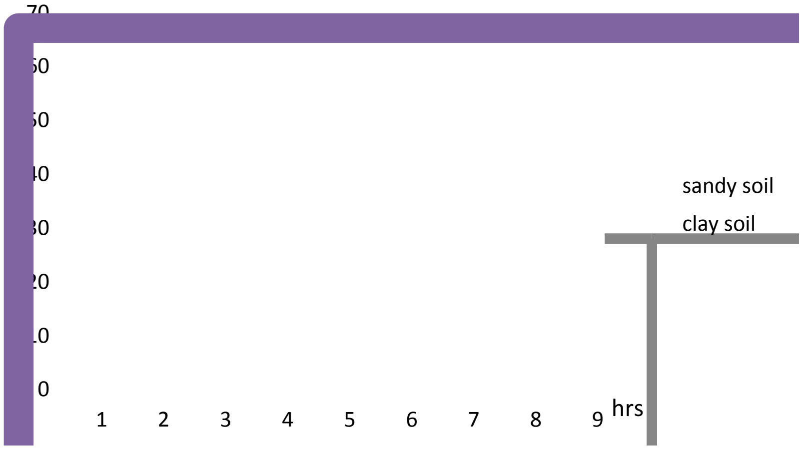

Fig 4 Decrease in soil moisture content with time after the irrigation

Fig 5 Decrease in water level in the reservoir with time during the irrigation period

8.5 Field Trial Test

The objective of field testing of the prototype is to validate the performance of the system in the actual usage system. Three trial runs that present three different scenarios were achieved. In the first scenario, both zones (A and B) required watering, zone A is set to a relatively small value for the desired moisture content, while zone B is set to desired moisture content of 100 percent. When zone A activates, the supplied moisture was enough to shut off zone A in a few seconds and the system switches to zone B. However, zone B remains running for the entire one-minute interval, because the 100 percent desired moisture content is never achieved. In the second trial runs, zone A does not activate anymore, because the moisture content in the soil is still high enough from the previously supplied amount of water. Zone B activates immediately and again remains active for the entire time, because it is virtually impossible to reach 100% soil moisture content. In the last trial runs, the system simply stays shut off because the temperature set-point limit is set very tightly between 45^0c and 50^0c. The system will only activate if the temperature falls between these two values. Because it was approximately 10^0 c outside system during the trial run, the system did not irrigate either the zone. This illustrates shut-off for the system during undesirable temperature conditions.

IX. Discussion Of Results

The type of soil (i.e. sandy, clay etc) can determine the rate of water infiltration and water retentive capacity in the soil. It is largely influenced through soil aggregates, structure and texture. Soils that have stable strong aggregates as granular or blocky soil texture have a higher infiltration rate than soils that have weak, massive, or plate like structure. From the experiment above, a sandy soil has a higher infiltration rate than a clayey soil. From the result, it can be concluded that water standing on gravely or coarse sandy soil percolates into the soil so rapidly that the water surface may be lowered several millimetres within a few minutes while on fine textured clay soils, it may collect and stand on soil seemingly with very little infiltration for quite longer period. The result equally demonstrates that irrespective of soil type, the infiltration rate is generally higher when soil is initially dry and decreases as the soil becomes wet as illustrated in the graphs above. However, this infiltration rate is a function of soil moisture content or amount of water in the soil. Invariably, soil moisture content is one of the key parameters that determine when, where and otherwise how long irrigation should occur. Therefore, a thorough understanding of field infiltration is essential needed for efficient design, management and operation of irrigation control systems.On the other hand, the field trial test helps us to validate the performance of the system: All units including temperature sensor circuitry, wireless sensor network circuitry, pipes, valves, controller, relay circuitry functioned as expected after the system was built; System switching from zone A to zone B and system running off at correct times (i.e. when desired soil moisture content is reached and when temperature is outside the range) attests the prototype verification a success.

X. Conclusion

The work presented in this paper has demonstrated ability to automatically control irrigation based on the soil moisture content using wireless sensor network (WSN). The system technique has provided more supervision and control than in traditional system of continuous flooding. Available equipment especially soil moisture monitoring device provided needed information to the irrigation management control system. This irrigation control system is of benefit for efficient water management integration for decision making process with controls as a viable option for determining when and where to irrigate and how much water to apply. The developed system gives a framework for further research on the quality of rice production through the intersection of historical water level data and whether data. The control system has met all the desired objectives.

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