Affordable Microcontroller-Controlled Home Irrigation System for Urban Farmers in Nigeria

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Abstract- Nigeria is a nation of an estimated 200 million people. The pre-colonial era was largely characterized by rural activities. Farming, though relatively subsistent, was the major means of livelihood. As civilization started taking the centre stage, more people sought modern ways of living via formal education they received in schools. This migration leading to urbanization has brought about growth in urban poverty and food insecurity. To mitigate this challenge, an attractive means of easy farming, irrespective of space size, with the aim of conserving water resources using an intelligent irrigation system based on microcontroller is developed to assist farmers in urban centres across Nigeria. This category of farmers produce, process, and sell food and other products within and around cities and town thereby encouraging people to contribute their quota to the reduction of scarcity of food and conservation of water in the country. This work is therefore an add-on technology to the practice of urban farming which is fast becoming popular in Nigeria. The developed model of this microcontroller-controlled irrigation system is cheap in terms of procurement, maintenance, and running compared to conventional irrigation technology. PIC16F877A is the microcontroller that was used for the control processes programmed with ‘Flowcode’ flowchart basics. The performance is tested, and compared with the performance of the conventional irrigation system using Proteus VSM environment which gives an improved performance over the existing conventional irrigation system and also saves energy.

I. INTRODUCTION

Urban farming has gradually become an integral part of our socio-cultural life in Nigeria. More and more people are utilizing available space or vacant plots to practise farming with the aim of supporting their family and sell the excess, if available, to others. The challenge of food security and urban poverty could be tackled if urban farmers are well encouraged with appropriate technology [1]. The use of water as one of the key ingredients of farming cannot be overemphasized. In early times, people have long sought for ways to maximize water usage in agriculture practices by minimizing the amount of water wastage in the course of sustaining a reasonable level of soil moisture content during crop production. The simple purpose of this practice is to increase crop yield. In arid regions like Northern Nigeria, farmers aim at getting water on the land and holding it there for as long as possible until when needed which helps a great deal in minimizing the effects of drought which slows down crop yielding capacity.

All these practices thus led to a study called irrigation management. Irrigation simply means the artificial application of water to land or soil to assist in the growing of agricultural crops, maintenance of landscapes and vegetation of disturbed soils in dry areas and during periods of inadequate rainfall [2]. Despite the fact that about 82 million hectares out of Nigeria’s total land area of about 91 million hectares were found to be arable, only 42% are currently being utilized for farming [3]. The question that readily comes to mind is what the remaining land areas are being used for?
According to World Bank Indicators of 2014, rural population was put at 53.06 percent of the total population. This shows that 46.94 percent are city dwellers who are mostly active between the ages of 18 and 35 [4]. It therefore becomes important to encourage as many as possible number of city dwellers in the country to start practising farming in their homes to complement the already shortened supply of food products using a cheaper means to conserve water presently being wasted away in Nigerian cities. This work therefore presents a twin-advantaged solution to assist and encourage urban farmers to boost food productions within a confined space using a microcontroller-controlled irrigation system as well as provide a means of putting to good use the wasting city waters.

The use of programmable integrated circuits (PICs) would help the entire home irrigation technology to be fully automated. If the setup is programmed properly, automatic irrigation systems would be cheaper and help to conserve water. However, the savings from automatic irrigation systems could go beyond that. Conventional irrigation targets plant roots with no significant degree of precision. In contrast, microcontroller-controlled irrigation system is programmed to discharge more precise amount of water within a targeted area which promotes water conservation. The remaining part of the work includes; literature review, fundamental model design, testing and discussion, as well as conclusion.

II. LITERATURE REVIEW

This review focuses on improvements made in precision agriculture and does not cover in entirety prescription agriculture which requires real time knowledge regarding the processes which are limiting production at any time in all areas of the field [5,6]. It is therefore supplementary equipment to urban farming practice in order to improve yield and overall food production.

Urban agriculture has become a popular topic for metropolitan areas to engage in on a program and policy level. It is touted as a means of promoting public health and economic development, building social capital, and repurposing unused land. Food policy councils and other groups that seek to position urban agriculture to policy makers often struggle with how to frame the benefits of and potential problems with urban agriculture. Urban farmers are also constrained by land tenure insecurity, erratic water access and inadequate inputs for optimizing plot productivity and ambivalent application of urban legislative frameworks [7]. These are challenges which this work also tends to mitigate especially as to satisfy the various goals of urban farming such as food security, education, and community building [8, 9].

In the conventional automated irrigation system, water is simply supplied artificially to the soil from a reservoir making use of sensors and microcontrollers that collects data parameters from the soil such as moisture content and uses this information to implement the flow of water through a pump to the sprinkler to create a rain-like effect on the plants. Now, a newer method of using microcontrollers for the control of temperature and relative humidity inside a poly house has been investigated [10]. In the proposed method, the green house controller senses the change in temperature and relative humidity with the help of input sensors and processes the output to take appropriate control action. The proposed system is low cost and a user friendly system with high stability and reliability.
Further experiments conducted show that once an automated irrigation system is set up and verified to be in proper working conditions, only a fortnight observation may be required for such systems [11]. Hence the use of programmable microcontrollers in automated irrigation systems play an important role in effective irrigation management. For instance, the effectiveness of using automated irrigation system on wheat crops has shown that the use of fully automated water sprinkler with the appropriate programming supports precision farming as water being supplied to plants is proportional to the change in temperature, humidity as well as soil moisture content.

On medium and large scale farming, drip irrigation is the most water efficient system available to water garden. Some systems are so efficient that they only allow a few litres of water per hour to fall into the soil and the best way to water the plants at ground level where they need it the most. Installing an irrigation system such as sprinkler or drip system without automation has always been a difficult and frustrating problem for homeowners, contractors and growers alike. This is due to cost and high end technology on which their functionality depend [12]. With the right controller, the right amount of water will be able to apply, at the right time, for optimum plant growth. Thus, valves may be easily automated by using controllers and solenoids. This decision support-irrigation method removes the need for workmanship for flooding irrigation as well as drip irrigation but there are still rooms for improvements [13].

Another critical device that would determine the efficiency of the irrigation system is the use of sensors that have been classified according to the type of energy transfer that they detect. Soil moisture measurements provide useful information for agriculture, such as grape growers, soil stability monitoring, dam monitoring and construction activities [14]. Recent irrigation system using a ZigBee-based technology have been investigated with the use of a single-chip on microcontrollers equipped with wireless transceivers for smart home automation because of their built-in resources, low power consumption, size affordability and durability [15].

III. FUNDAMENTAL MODEL DESIGN

There are basically two types of automated irrigation systems, the open loop and closed loop systems. Open loop irrigation systems involves a user defined specification for irrigation control, thus the design of the system is done in such a way that the user of the system decides when the sprinkler is activated usually pushing a button whereas, closed loop irrigation systems makes use of sensors which collect data from the soil and the plants to discharge water to the soil. In closed loop sprinkler irrigation, feedback information is used to implement new process such that the system is responsive to change with respect to the present conditions. That is, the system responds in real time intelligently.
Mathematically, this closed loop system is represented by:

\[ \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)} \]  

(1)

Where:

\( C(s) \) is the Laplace transform of the output quantity.

\( R(s) \) is the Laplace transform of the input quantity.

\( G(s) \) is the Laplace transform of the actuator-Controlled Sprinkler.

\( H(s) \) is the Laplace transform of the sensor-based output quantity.

This closed loop irrigation control system automatically discharge water to the targeted area if the set required conditions such as; the amount of water in the soil, soil temperature and humidity level have all been met.

A. Water Flow Rate: The flow rate design is as shown in fig. 1.
In order to achieve the required flow rate, Bernoulli equation which supports energy conservation in flowing fluids is considered. Due to the effect of gravitational pull on overhead tank water to the ground, water flowing from the valve attached to the tank would have a velocity of flow directly proportional to the height of the tank as well as the pressure. Hence, water pressure is generated with the weight of water itself.

From Bernoulli’s principle,

\[
P/\rho g + V^2/2g + Z = \text{constant} \tag{2}
\]

\[
P + 1/2\rho V^2 + \rho gZ = \text{constant} \tag{3}
\]

Where:
- \( P \) = pressure
- \( \rho \) = density of water
- \( V \) = velocity of flow
- \( Z \) = height of water from ground level
- \( g \) = acceleration due to gravity

The relationship between the flow conditions of water in the reservoir tank A and the discharge pipe B is given by Bernoulli’s expression:

\[
P_A + 1/2\rho V_A^2 + \rho gZ_A = P_B + 1/2\rho V_B^2 + \rho gZ_B \tag{4}
\]

Since \( P_A = P_B = \) atmospheric pressure

\[
1/2\rho V_A^2 + \rho gZ_A = 1/2\rho V_B^2 + \rho gZ_B \tag{5}
\]

Since density of water is constant for both ends, we have:

\[
1/2V_A^2 + gZ_A = 1/2V_B^2 + gZ_B \tag{6}
\]

and there is no velocity of flow in the tank. Then:

\[
Z_A = 1/2V_B^2 + gZ_B \tag{7}
\]

\[
V_B^2/2g = Z_A - Z_1 \tag{8}
\]

Where
Thus the velocity of the sprinkler nozzle is given by:

\[ v_s = \sqrt{2gH} \]  \hspace{2cm} (10)

and the discharge from the nozzle is given by:

\[ Q = AV_s \]  \hspace{2cm} (11)

where

- \( Q \) = discharge from the nozzle
- \( A \) = Area of the discharge nozzle
- \( V_s \) = velocity of flow of water from the nozzle.

**B. The Home Irrigation Model**

![Diagram of the home irrigation system](image)

**Figure 2. Model of the home irrigation system**

A - Electrical control unit.
B - Sensors evenly placed on the soil in the base plate.
C - The sprinkler nozzle.
D - Transparent ceramic casing enclosing the system.
E - High radiation intensity light bulb.
F - The base plate holding the soil.

The microcontroller controlled irrigation model is shown in fig. 2. It comprises of six vital section such as; A which houses the electrical control unit, B contains sensors placed in the soil sample, C which has the sprinkler nozzle attached, D is the ceramic casing which houses the entire system, E is the light ray source which replicates the source of light energy needed by the plant, and F which is the base plate the hold the soil.
C. Operational Flowchart

The operation of the system is contained in the operational flowchart shown in fig. 3. Sensors are the main components that determine the effectiveness of the irrigation model. So, good quality sensors are incorporated for optimal performance.

![Image of operational flowchart](image)

IV. TESTING AND DISCUSSION

To ensure that the system is in proper working condition, the temperature sensor is placed close to an electric bulb representing sunlight.

For conventional irrigation system, at steady-state operational condition, the sensors give normal atmospheric temperature reading shown in table 1.

<table>
<thead>
<tr>
<th>S/N</th>
<th>SENSORS</th>
<th>TEMPERATURE READINGS (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>T1</td>
<td>25</td>
</tr>
<tr>
<td>2.</td>
<td>T2</td>
<td>27</td>
</tr>
<tr>
<td>3.</td>
<td>T3</td>
<td>24</td>
</tr>
<tr>
<td>4.</td>
<td>T4</td>
<td>24</td>
</tr>
</tbody>
</table>

It is also observed that the soil weight reduces faster with increase in length of time of soil’s exposure to sunlight due to evaporation. Therefore, soil weight drop with increase in time is investigated to determine intervals of
sprinkler operation. These results are shown in table 2 when the sprinkler operates conventionally, that is, without the microcontroller.

Table 2
Soil weight variation at different temperature when sprinkler operates without a microcontroller

<table>
<thead>
<tr>
<th>S/N</th>
<th>Weight Loss (kg)</th>
<th>Temperature of sensor (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>0.86</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>0.69</td>
<td>22</td>
</tr>
</tbody>
</table>

The relationship between the soil weight loss and the change in temperature when the sprinkler operates without a microcontroller is shown in fig. 4.

Figure 4. Graph of soil weight against temperature for conventional sprinkler system

Also, soil weight variation at different temperature for a microcontroller-controlled sprinkler is displayed in table 3.

Table 3
Soil weight variation at different temperature for a microcontroller controlled sprinkler

<table>
<thead>
<tr>
<th>S/N</th>
<th>Weight Loss (kg)</th>
<th>Temperature of sensor (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.7</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>0.72</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>0.88</td>
<td>25</td>
</tr>
</tbody>
</table>
The operational values of soil weight and temperature for a microcontroller controlled sprinkler is shown in fig. 5.

![Figure 5. Graph of soil weight against temperature for a microcontroller controlled sprinkler](image)

The combination of fig. 4 and 5 is displayed in fig. 6.

![Figure 6. Comparison between a microcontroller-controlled irrigation system and conventional irrigation system](image)

**Discussion**

The rate of soil weight loss is faster in a conventional irrigation system with a sharp rise in soil weight loss against increase in temperature while the rate of soil weight loss is gradual for a microcontroller controlled irrigation system. The slight fluctuation in the rise and fall of values of soil weight loss with every increase in temperature are due to the fact that signals coming from the different sensors do not reach the microprocessor at the same time. As the heating element is placed close to any of the temperature sensors, a gradual rise in temperature is observed. This indicates an operational independency of each sensor thus the sensors can be
placed at several strategic positions in the soil for a targeted area temperature sensing application. Further look at the performances of both irrigation systems shows that microcontroller-controlled irrigation system saves energy as energy demand is smooth and slower unlike the conventional irrigation system whose energy demand is higher at throughout its operation. The implication of this is that, sprinkler motor operates more often in conventional irrigation system compared with the intermittent operation of the microcontroller-controlled irrigation system.

As could be seen from figure 6, 24°C is the critical temperature where a sharp change in soil weight loss occurs for both conventional irrigation system and the microcontroller-controlled irrigation system before reaching a peak soil weight drop of 0.9kg for conventional irrigation system and 0.87kg for microcontroller-controlled irrigation system. The sprinkler automatically picks up for microcontroller-controlled irrigation system when the output signal falls below the set references in line with equation (1). This makes the operation unique in terms of farm space and water resources management.

V. CONCLUSION

This developed irrigation system is smart and works in real time with the assistance of the incorporated microcontroller which intelligently analyzes variables such as soil temperature and moisture content to operate sprinkler valve appropriately during water discharge operation. The performance of this device is faster than the conventional manually controlled irrigation system prevalent in the market. This developed model is cheap, efficient, saves energy and made with readily available components thus making it accessible to all and sundry unlike the conventional irrigation system. Water conservation is greatly encouraged and urban farmers are encouraged to start its usage to boost food production, processing, and sales across homes in Nigerian urban centres as well as save energy. Urban food shortage and poverty also reduces in turn and vacant plots would be put to a meaningful use with the application of this microcontroller-controlled irrigation system. Thus, the application of this novel irrigation device serves as a useful add-on to the practice of fast rising field of urban farming as manpower and cost of operation are greatly reduced. Household are therefore encouraged to take up, in a simpler manner, the practice of farming with their little space available. Meanwhile, this model could still be improved for medium and large scale farming operations with increase in operational capacity and reach using locally available materials in Nigeria.

REFERENCES


DOI: 10.5897/JASD2014.0302


DOI: 10.1109/ICCSPA.2015.7081305