Design and Implementation of a Microcontroller-Based Hydroponic System

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ABSTRACT
Fresh vegetables in the daily diet have been linked to improved gastrointestinal health, clear vision, and a lower risk of heart disease, stroke, chronic diseases including diabetes, and several types of cancer. It consist of essential nutrient for a well-balanced diets since they supply vitamins, minerals, dietary fiber, and phytochemicals, and to this end, it is recommended that lots of it should be consumed. Despite the fact that hydroponic foods are highly nutritious and pest-free, they are difficult to grow since they demand continual care to maintain the proper conditions for the plants and knowledge of the hydroponic system. This paper is targeted at designing, constructing and installing a microcontroller-based control approach of growing green vegetables for individual and commercial consumption and all year-round by the teeming population in the country. This microcontroller-based approach eliminates the major setback being experienced by manual hydroponic systems whereby great attention is required for optimal result. The system is such that the microcontroller (ATMega328P) is connected to various sensing circuits (sensors) which monitors, measures parameters such as pH level, turbidity of the solution, nutrient temperature and nutrient level for stable nutrient composition. All the sensors were designed and provided on a printed circuit board called the Hydroponic circuit board. Results show that the system is capable to control device by displaying message on LCD and triggering an alarm on when pH is low and when the turbidity becomes very high.
Keywords: Microcontroller-based, Hydroponic, Circuit board, Sensing circuits, Green-vegetables

I.   INTRODUCTION
Hydroponics is a technology for growing plants in nutrient solutions (water containing fertilizers) without the soil or without the use of artificial medium (e.g. vermiculite, rock wool, perlite, sawdust, etc) to provide mechanical support [1]. It must be borne in mind that the soil merely provides support not the actual food/nutrients for plant roots. The food/nutrient comes from other materials mixed in the soil such as compost, broken down plant waste or fertilizers [2]. Due to the fact that hydroponic systems lack media to store water and nutrients, water culture systems need a continuous flow of nutrients to prevent drying out the plant roots. Hydroponic production is not organic because artificial nutrients are always used and plants are not grown in soil.

Hydroponic systems can be liquid or aggregate. Liquid hydroponic systems have no supporting medium for the plant roots while aggregate systems have a solid medium of support. Hydroponic systems are further categorized as open (i.e. once the nutrient solution is delivered to the plant roots and it is not reused) or closed i.e. surplus solution is recovered, replenished, and recycled &[2]. Hydroponic growing (as opposed to soil growing) allows the grower to control the nutrient levels for his plants directly as mineral nutrients are dissolved in water and fed directly to the plants' root system. Because of the higher control over nutrients, hydroponically grown plants generally have a much higher yield than similar plants grown in soil. In addition, pests and diseases are easier to get rid of and problems associated with weeding are eliminated [3].

Hydroponic systems are used all year-round both indoors and outdoors for growing plants like lettuce, spinach, tomato, cucumbers, herbs (basil, thyme, mint, etc), strawberries, peppers, potatoes, Cabbage, green beans, vegetables, etc. To grow plants in a hydroponic system, it is important to maintain the condition required for the plants to grow. Due to advancement in technology, smarter and automatic approach, use of Microcontroller (an 8-bit ATMEGA328 AVR microcontroller) may be adopted[4]. The pH meter for measuring the pH of the solution, Electrical conductivity meter for calculating the Total Dissolved Solids in the solution, a thermometer for measuring temperature

and the water level sensor are connected to the microcontroller. The microcontroller gets the value from respective sensor, converts it to digital value using an inbuilt Analog to Digital Converter and processes the value to control the DC pumps which pumps nutrients, acids and water to the nutrient solution [5].

II. LITERATURE REVIEW

Diet/food, to a large extent, determines the overall health, productivity and longevity of individuals. However, food security has been a major issue globally and specifically in Nigeria in recent times. The case of threatening food insecurity in Nigeria can be traced to many reasons and the major one being the issue of open grazing by herdsmen which has led to many farmers abandoning their farmlands and running for safety. The option left for individuals is to seek alternative means of farming. Soilless culture, otherwise known as hydroponic is a new method to achieve food security. In soilless cultures, plants do not really need soil but they need to be supplied with minerals (macronutrients and micronutrients) such as Nitrogen(N), Potassium (K), Phosphorous (P), Calcium (Ca), Magnesium(Mg), Sulphur (S), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc(Zn), Molybdenum (Mo), Boron (B), Chlorine (Cl) and vitamins. Also, they need water, light, carbon dioxide and oxygen at their root.

Several studies on hydroponic system technique have been published, hydroponic systems are believed to be more advantageous than conventional soil farming. Some of the advantages are (Department of Agriculture, Forestry and Fisheries, South Africa, 2011): Crops can be grown at any place even at places when the soil is infertile or unsuitable e.g. deserts. There is a better nutrient control.Faster growth rate with increased crop yield. Ituses less water than soil grown crops and saves space Reduction in soil-related pests and insects. No weeding is required during growing stage. It is also fair and balanced to mention the disadvantages associated with hydroponic systems as [6]: Initial cost could be higher than soil farming. Additional knowledge on the required nutrient content, method of nutrient application, etc is needed. It requires constant monitoring if the system is not automated possibly by means of microcontrollers. Vulnerability to power outages if steady power source is not provided.

There are different types of hydroponic systems based on the manner nutrients are supplied to the system and the most commonly used ones shall be described below [6][7]. WICK: Here, nutrient solution is drawn up to plant roots through a wick in the growing media. The wick is the connecting part between the plant and nutrient solution in the reservoir. It is the simplest form of hydroponic system that does not need pumps or electricity and is applied in small scale hydroponic systems. 2. DEEP WATER CULTURE: Plant is suspended in platforms (growing substrates) above the nutrient solution in the reservoir. The roots are submerged in the water culture. Since the plants are floating and continuously in contact with the nutrient solution, there is no risk of damage to plants in the event of power outage or stoppage of the pump.It is used either in small scale or large scale hydroponics for plants like lettuce, strawberries and herbs. 3. EBB & FLOW: This type uses a pump to temporarily flood grow tray/substrate (e.g. rock wool substrate, Styrofoam/Floral foam substrate, honeycomb substrate, Perlite, Vermiculite, etc) with nutrient solution and then drains solutions back into the reservoir i.e. the pump is switched on and off (perhaps 20 mins ON, 10 mins OFF) to flood the grow tray periodically using a timer. Set timer varies with size and type of plants, temperature, humidity and growing medium. Applicable for growing seedlings, small plants and cuttings. 4. DRIP: This makes use of timer controlled submersible pump placed in a separate reservoir. Nutrient solution is dripped directly into the base of each plant with drip lines located at the stem of each plant. The nutrients filter down to the plant roots and are passed back to the reservoir. 5. NUTRIENT FILM TECHNIQUE: This method is often used for commercial purposes and it is good for crops to be harvested in a short time. Nutrient solution is a constant flow, hence no timer is required. Highly oxygenated nutrient solution is pumped from the reservoir to the grow tray and recycled back to the reservoir. The recycling is possible by building the grow tray with sufficient slope to allow the solution trickle down the tray and not flood the tray. The technique is well suited for plants that have small roots. 6. AEROPONICS: This is the most technologically advanced hydroponic system in which plants are suspended with roots hanging below and plants' roots are sprayed with nutrient-rich water. Nutrient solution is pumped from the reservoir where a second higher-pressured pump mists solution over the roots. Advanced timer is required that needs to mist more often since each mist provides less than other items. Nutrient solution moved around making it more oxygenated allowing plants to grow faster. This method is mainly used for starting large crops of seedlings, transplants and cuttings.

Agriculture without soil dates back to several hundred years BC since the civilization of ancient Egypt, China and other cultures. However, the earliest published work on growing terrestrial plants without soil was the 1627 book, Sylva Sylvanum by Sir Francis Bacon referred to as the father of Scientific method. In 1666, Robert Boyle, an Irish scientist described the first experiments on growing plants with their roots submerged in water. John Woodward published his water culture experiments with spearmint in 1699 and found that plants in less-pure water sources grew better than plants in distilled water [8]. The first proposal for a commercial and modern water culture system was made in 1929 by Professor William Frederick Gericke of the University of California at Beckeley. The term hydroponics was coined by Gericke in 1937 to describe the growing of crops with their roots in a liquid medium. Moreover, in 1940, Gericke wrote the book, Complete Guide to Soilless Gardening. Between 1939 and 1945 (World War II), US army fed troops stationed in Pacific Islands using hydroponics. In the 1960s, Allen Cooper of England developed the nutrient Film technique. In recent decades, many companies and agencies are sponsoring various researches on soilless agriculture so as to ensure global food security. This work is expected to create more awareness about hydroponics in Nigeria [9].The STM32-based hydroponics nutrient mixing system that automatically creates hydroponic nutrient solution in accordance with each plant's specific nutrient formula by employing a different dosing pump for each fertilizer concentrate[4][10]

III. METHODOLOGY AND MATERIALS

The controller employed in this study was the ATMega328P, which has a variety of functionalities that are suited for designing and implementing hydroponic systems.In the implementation of the system two things were primarily taken into consideration: The hardware and software modules design.The Atmega328 microcontroller is an 8-bit AVR microprocessor with RISC architecture. It has the needed amount of GPIO pins that can communicate effectively.

The pH meter detects the pH of the solution, a turbidity sensor measure the density of turbid water and the concentration of foreign matter, a temperature sensor monitor the temperature of the solution, 16×4 LCD Character display were connected to monitor the system,buzzer alarm for notification and a water level sensor that is connected to relay and pumpare also connected to the microcontroller. The block diagram for the system operation is shown in Fig. 1. The microcontroller receives the value from the sensor, transforms it to digital using an Analog to Digital Converter, and then processes it to control the submersible pump that pumps nutrients every three hour to ensure proper circulation of nutrient into the system growing medium. It also communicates with the user by presenting the system's status on the LCD and notifying the owner with alarm. The hydroponic medium was made up 1" and 3" PVC pipes with 64 pots connected together for proper nutrient flow Fig. 2.
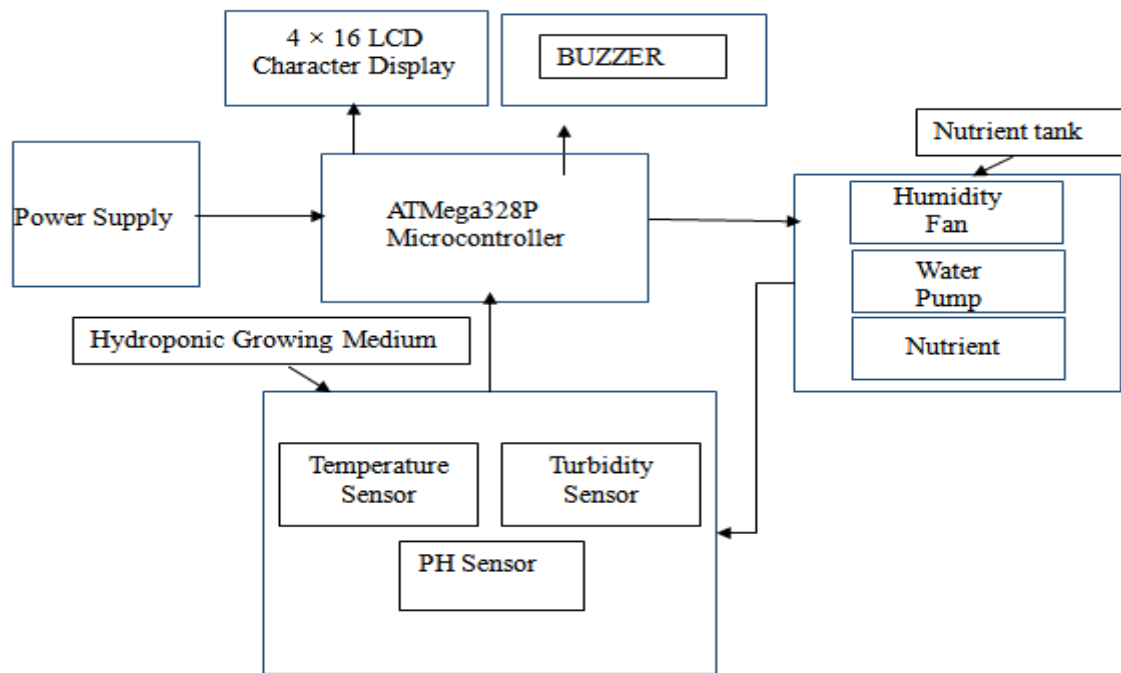
Fig. 1: Block diagram for the system operation

Fig. 2: Image of hydroponic growing medium

Fig. 3: Hydroponic System Hardware Layout

The solubility of several elements varies depending on the pH level. The pH range for producing vegetables in hydroponics is between 6.0 to 7.0 for vegetable plants. The pH changes when the plant absorbs nutrients from the fluid. Plants emit hydrogen ions into the nutrition in return for the ions of elements they require. They do this to keep the electrical system neutral, Photosynthesis produces hydrogen ions for the plants. Hydronium ions are formed when hydrogen ions react with water, raising the pH of the water. To ensure the solubility of all the elements in the nutrients, acids such as phosphoric acid must be added to the nutrient solution. The device detects variations in the pH of the solution and displays. A variety of things influence the pH and turbidity change in the solution. As a result, if the pH of the nutritional solution is critically low, a message as in fig. "ph level is critical" will display on the LCD requesting for change of the nutrient solution. Likewise, if the turbidity is high the system displays "Change Solution" The buzzer alarm is also ON. The proposed system assist in ensuring the water and nutrient in the reservoir and hydroponic growing medium is continuously maintained through the display on the LCD and buzzer alarm with level control which triggers valve to control flow into or out from the reservoir. Fig 3 depicts the hardware layout of the hydroponic system.

THE MONITORING SYSTEM
The Atmege328's was used. A 16MHz crystal oscillator was also used by the Atmege328. Fig 4 depicts the system circuit arrangement and Table 1.

Also depicts the pins connection of the components.
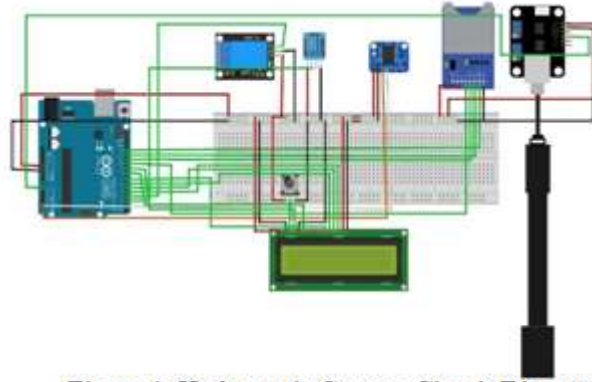Hydroponic Hardware Configuration

Figure 4: Hydroponic System Circuit Diagram

Table 1: Pin Configuration of the Component

LCD 16*4 PINS	ARDUINO UNO	DHT	ARDUINO UNO
VCC	5V	VCC	5V
GND	GND	GND	GND
RS	PIN 9	DATA	PIN 2
RW	GND		
E	PIN 8		
D4	PIN 7	SD MODULE	ARDUINO UNO
D5	PIN6	VCC	5V
D6	PIN5	GND	GND
D7	PIN4	CS	10
A	5V	MOSI	11
K	GND	SCK	12
		MISO	13
RTC MODULE	ARDUINO UNO	5V RELAY	ARDUINO UNO
VCC	5V	VCC	5V
GND	GND	GND	GND
SCL	A5	IN	PIN3
SDA	A4		
PH SENSOR	ARDUINO UNO		
VCC	5V		
GND	GND		
PO	A0		

Hydroponic software design

To control the microcontroller on the Arduino chip after finishing the design and hardware setup, you'll need a set of instructions (or a program). The Arduino IDE's built-in C language was used to construct the software. The ATmega328 microcontroller receives the instructions (codes) after they have been created in the Arduino IDE, built, and uploaded. Fig. 5 displays the code used in this project.

Fig. 5: Proram Code

4.1 PRESENTATION OF RESULT

As a result of this research, a successful controlled hydroponic system was designed and constructed. Eight parts make up the system: a power source, a CPU, a PH sensor, a temperature sensor, a turbidity sensor, a water level sensor, an LCD display, and an alarm (Buzzer). Before being soldered, each of these parts was examined on the circuit board to make sure they were in good working order. The entire system was tested over a period of time while the module was being configured, with the PH sensor detecting the PH of the solution, the temperature sensor detecting the temperature in the storage container so that the temperature remains normal, the turbidity sensor detecting water quality, the water level sensor maintaining the nutrient, and the water flowing into the growing medium. The ATmega328 controller's analog input connection was used to communicate the analog signal value from the sensors. Seven weeks were used to test the entire system while growing the vegetable in Fig. 5a. As shown in Figs. 5b and 5c, respectively, the pH and turbidity sensors detect low pH and high turbidity and provide the analog signal value to the ATmega328 controller through its analog input connection. The alarm was set off after the microcontroller examined the signals and printed "Attention ph level is Critical" and "Change Solution" on the LCD.
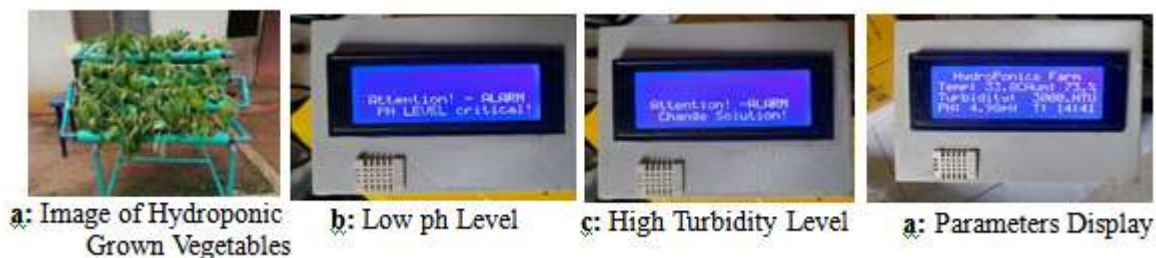

a: Image of Hydroponic Grown Vegetables   b: Low ph Level   c: High Turbidity Level   a: Parameters Display

Fig. 5: Complete Hydroponic System

IV. DISCUSSION OF RESULT

The entire system is composed of the Microcontroller Circuit, Power Supply, pH sensor, turbidity sensor, temperature sensor, water level control, and Buzzer. The power supply provides energy to the Atmega328. The ph and turbidity

Sensor measures and detects any change in the growing medium, and as soon as the system's pH falls below 6 or the turbidity increases significantly, the sensor's output drops. When the microcontroller notices this, the LED and buzzer are activated. The microcontroller keeps sending the Display Module the messages "Change Solution" for high turbidity and "ph is Critical" for low ph values. The full mechanism showing the status of the entire system is shown in Fig. 5d.

V.   CONCLUSION

A hydroponic controlled system that can measure and detect the PH value, turbidity of the nutrient, and nutrient level for growing fresh vegetables was successfully developed using the ATmega323 microcontroller. Other plants may also be grown using the technique. The usage of a GSM Module to convey the message to the user's cell phone through SMS may be explored in further research on this topic. Finally, a GSM-based system will be employed to monitor and regulate data in greater detail and in real-time, where the entire system and addition of nutritional solution are automated.

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