Development of an Affordable Bluetooth-based Measuring System to Analyze Water Quality for Hydroponic Plants

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Abstract-- **Hydroponic farming is a modern method of farming that involves growing crops and plants in an artificially maintained water-medium, without the use of soil. It is said to be the future of agriculture since it has been showing great promise over the past few years. This system consists of the essential sensors such as pH sensor and a waterproof temperature sensor to measure water quality, an Arduino Microcontroller and a Bluetooth module that is used to connect the entire system to a phone. The data from the sensors is processed by the Arduino Microcontroller and the code running the system sends this sensor data to an android phone via a low-cost, low-energy Bluetooth module. This data can then be seen and recorded on the android phone in an open source application that was created particularly for this project, keeping in mind the need of simplicity.**

Keywords-- **Android Application, Arduino Microcontroller, Bluetooth Module, Hydroponics, Local Network System, pH Sensor, Temperature Sensor, Water Quality.**

I.INTRODUCTION

Our modern society today has never consumed food in quantities as large as it does today and the one of the obvious implications of that are there is a shortage of food because of the ever so unpredictable climate and growing demand. One of the most promising techniques for tackling the problem of global hunger and food shortage is by growing food crops using a a new technology called 'Hydroponics'[1], i.e. growing plants without soil in a water-based growing medium that supplies all the necessary nutrients to the roots of the plant while maintaining an optimal environment for the plant to efficiently consume those nutrients. The primary benefit of hydroponic farming is that this technique utilizes much less resources such as water, artificial nutrients and, most importantly, time when compared to conventional farming techniques of the same plants/crops. In order to grow crops/plants hydroponically, the water which is used as a growth medium for the plant needs to be at its most optimum configuration. Therefore, it must be analyzed for essential parameters such as pH temperature, turbidity, dissolved oxygen, electrical conductivity, etc. to determine what changes need to be made to the water and by how much. This technology is not common-place and is therefore, very expensive and sophisticated to operate. For India to embrace hydroponic techniques for farming conveniently, certain level of automation and simplicity of design is needed in order to aid farmers with less or no technical expertise, or even basic education, to make full use of this technique. This system has been designed and developed taking into consideration such individuals and hence uses affordable hardware, local-network connectivity and simple interfaces to measure, manage and store plant data. The further sections of this paper describe in detail the System Architecture, the components and the resulting data obtained using this device.

II.SYSTEM

Great emphasis was put on making the device as affordable and accessible as possible. The device mentioned here costs INR 2100 to build, including both sensors, Arduino Microcontroller and HC-05 Bluetooth module[2]. Whereas in the current market, the cost of a discrete pH sensor ranges from INR 2000 to 5000 and that of a discrete temperature sensor ranges from INR 200 to 500.

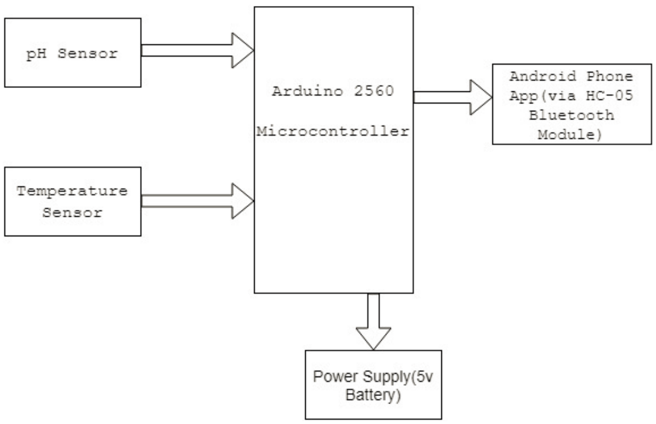


Fig. 1)Overall Layout of the System

The block diagram is meant to present a clear picture of how the system works to monitor water quality in real time.

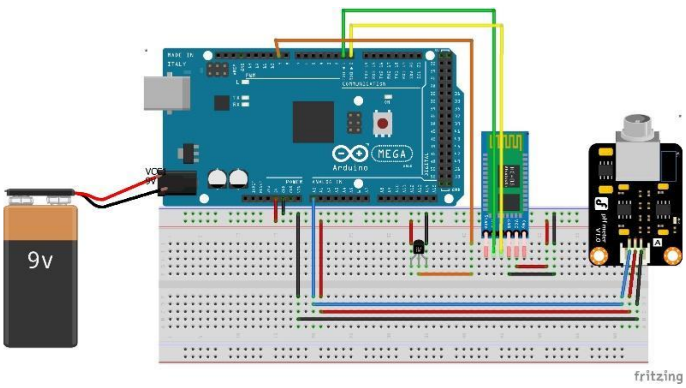


Fig. 2)Schematic the Device

Every component of the system is described below:

A. pH Sensor-

In order to make the first prototype and to make the system affordable, the most essential sensors were chosen. pH of a solution, in this case the water that is used to grow the plant hydroponically, is the measure of the acidity or alkalinity of the solution(water). The pH scale is a logarithmic scale whose range is from 0-14 with a neutral point at 7.0. Below 7.0 the water is said to be acidic and above that, alkaline. The pH sensor used in this system runs on 5v power supply and relays data to the Arduino via a special interface module that connects the ionized pH probe and the Arduino microcontroller[3]. Upon rigorously testing the digital pH sensor along with the smartphone, the accuracy of the sensor was found to be promising. With an acceptable tolerance of ±2.903%[4].

Fig. 3)pH probe

Fig. 4)pH probe-to-Arduino interface module

The pH sensor was calibrated to measure accurate values using a pH 4.0 (Phthalate) buffer Solution and a pH 7.0 (Phosphate) Buffer Solution. The ideal pH for most hydroponic applications is between 5.8 and 6.2 pH.

Equation for pH Calculation:

$$pH = pK_a + \log(\frac{[A^-]}{[HA]})$$

Equation 1)Henderson-Hassellbalch Equation for Calculation of pH

1) The Method Used for Testing Accuracy of the Digital pH Sensor:

Step i. The pH probe-to-Arduino interface module was connected to the Arduino microcontroller as per the schematics given later in this document and the

Arduino microcontroller was connected to the Android Smartphone via the HC-05 Bluetooth module.

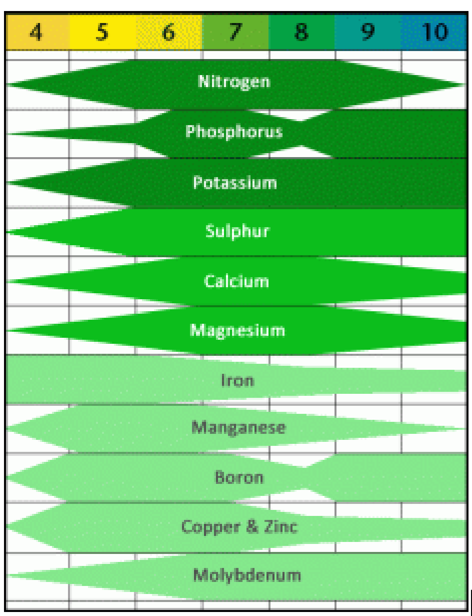
Step ii. The pH probe was calibrated to the correct pH reference values using industrial-grade pH Buffer Solutions of pH 4.0 and pH 7.0.

Step iii. After calibration, the pH probe was tested against a solution having a known pH and the data was displayed onto the Smartphone, on its application.

Step iv. The data that was received differed from the actual pH of the solution by ±2.903 %.

2) *Effect of pH of Water on the Growth of Hydroponic Plants and the Need to Measure/Monitor it:*

If the pH of a solution is not within the correct range the plant will not have the ability to absorb some of the essential elements required for proper plant growth. All plants have a particular pH range, which will produce healthy growth, and this level will vary from plant to plant, but most plants prefer a slightly acidic growing environment (5.8 to 6.2), although most plants can survive in an environment with pH values between 5.0 and 7.0[5].



[5]

Fig. 5)*Chart to represent different elements in different pH values of water*

Plants grown in acidic environments can experience a variety of symptoms, including Aluminum (Al), Hydrogen (H), and/or Manganese (Mn) toxicity, as well as nutrient deficiencies of Calcium (Ca) and Magnesium (Mg).

Conversely, in alkaline environments Molybdenum (Mo) and macronutrients (except for Phosphorus) availability increases, but Phosphorus (P), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu) and Cobalt (Co) levels are reduced and may adversely affect plant growth.

From the chart, it can be inferred that each element can become more and less available to the plants as pH changes. If the pH of the water-medium is out of the desired range, one or more of the essential elements will become unavailable to the plant, causing nutrient deficiencies, which will result in slow growth rates, and poor yields.

B. *Temperature Sensor-*

Water temperature is an essential parameter for optimum growth of the hydroponic plants. The DS18B20 is a waterproof digital temperature sensor which has a sensing range from -55˚C to +125˚C.

Fig. 6)DS18B20 Waterproof Temperature Sensor with connections

1) *The Importance of Temperature Data for Optimum Cultivation of Hydroponic Plants:*

In all systems, hydroponic water temperature is critical. The ideal water temperature for hydroponics is between 18˚C and 26˚C. Hydroponic water researchers have found the nutrient solution to be most effective if it is kept between 18˚C and 26˚C. Experts agree that the ideal water temperature for hydroponics is the same as the nutrient solution temperature. If the water added to the nutrient solution is the same temperature as the nutrient solution itself, the plant roots will not suffer any sudden temperature shifts.

Hydroponic water temperature and nutrient solution temperature can be regulated by using aquarium heaters[6].

C. *Arduino Microcontroller-*

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

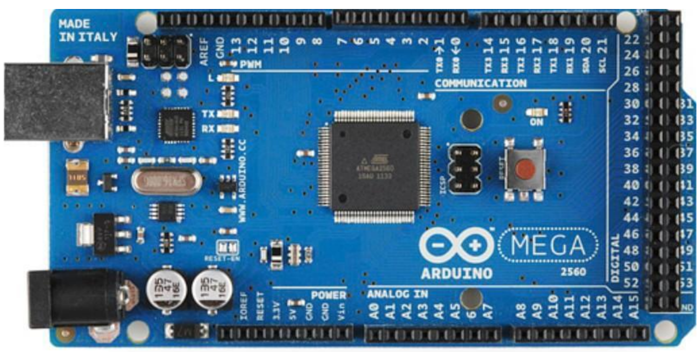


*Fig. 7)*Arduino MEGA 2560 Microcontroller

The Arduino MEGA 2560 microcontroller [7] is the main processor of the entire system. It takes analog input data from the sensors in the form of electrical signals in the range of 0v to 5v and translates this data using the equations and algorithms with which it has been programmed. The Arduino IDE, based on Embedded C, was used to write the code for the microcontroller [8].

After taking in the data from the sensors, the Arduino microcontroller relays this data to an android application via the HC-05 Bluetooth device. More information about the HC-05 Bluetooth module and the android application is given below.

D. *HC-05 Bluetooth Module-*

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. The HC-05 Bluetooth Module can be used in a Master or Slave configuration, making it a great solution for wireless communication. This serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate)3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature).

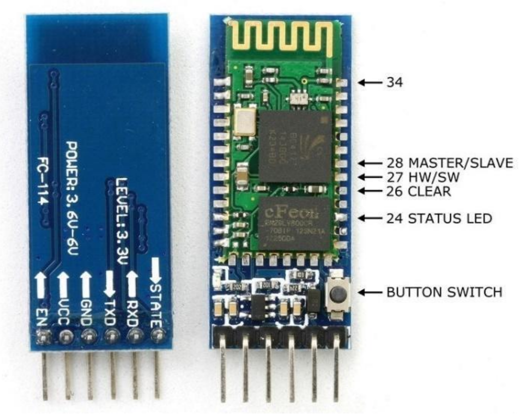


*Fig. 8)*HC-05 Bluetooth Module with pin-out

1) *Purpose of Using this Module:*

The primary intention of this project is to provide hydroponic farmers and enthusiasts access to affordable, locally-connected and easy-to-use-and-maintain hardware as well as software[9]. Initially, the idea of this system was conceived to utilize IoT(Internet of Things) technologies but upon doing a side-by-side comparison of the ESP8266 WiFi module, that is typically used for its IoT features, and the HC-05 Bluetooth module the following inferences were made[10]:

i. It is simpler for the Arduino microcontroller to interface with the HC-05 bluetooth module and the data transfer is much smoother as compared to the WiFi module.
ii. The hardware for a WiFi connection on the Arduino is much more expensive than that for a Bluetooth connection. Since, it is not very economical for a farmer to setup, install and maintain a WiFi system in his/her farm, a Bluetooth connection is the preferred choice.
iii. The HC-05 module is very efficient in data transfer and hence utilizes much less energy as compared to a WiFi module.
iv. Using a local network such as a Bluetooth system aids data security.

E. *Android Application-*

The android application is the most important feature of the system as it serves as an interface between the user and the system. It was designed using MIT AppInventor Software which is an Open Source drag-and-drop block-based android application development software[11]. The interface of the application is designed to be simple and user-friendly. A screenshot of the application is shown below.

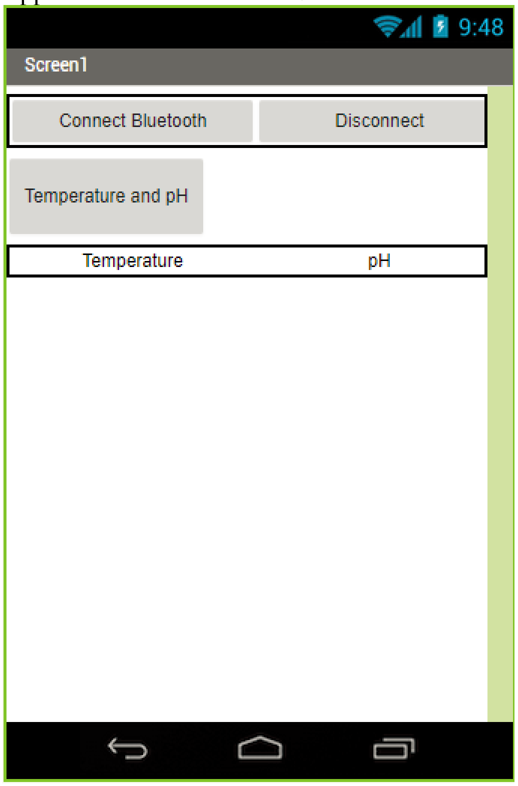


*Fig. 9)*A screenshot of the Android Application made specifically for this device

*Fig. 10)*The drop-down menu of bluetooth connections available to the smartphone, in the Android application

i. **'Connect Bluetooth' Button:** It gives a drop-down list of all the available Bluetooth devices to pair the smartphone with the HC-05 Bluetooth module.

ii. **'Disconnect' Button:** It disconnects the smartphone from the HC-05 Bluetooth module.

iii. **'Temperature and pH' Button:** It sends a cue to the HC-05 module over Bluetooth to read analog sensor data from the sensors. The Arduino then processes this request by collecting and translating the data as per the algorithms and equations written in the Arduino code. This data is then packed in package and then sent over to the HC-05 Bluetooth module which relays it to the smartphone.

iv. **'Temperature' label:** The Temperature label displays the temperature of the water.

v. **'pH' label:** The pH label displays the pH of the water.

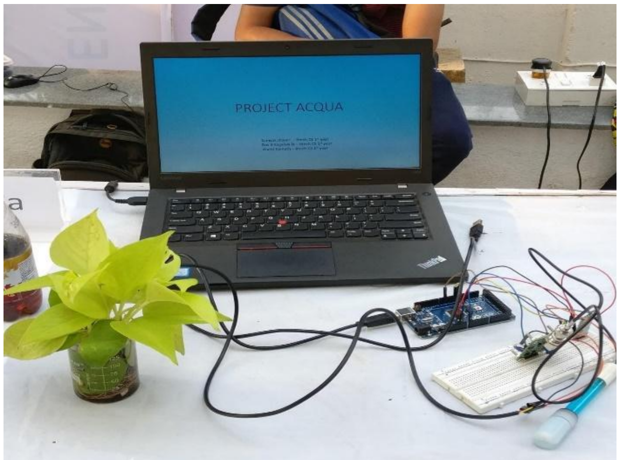


Fig. 11)The System Architecture

IV.RESULT AND DISCUSSION

The device was tested multiple times under various conditions. The sensors were connected to the Arduino microcontroller which was in-turn connected to an Android smartphone over Bluetooth, via the HC-05 Bluetooth Module. After calibrating the pH sensor probe with 4.0 and 7.0 pH Buffer solutions, some samples of water that could be used to grow plants hydroponically were tested using the system. The data was then displayed on the smartphone as well as on the screen.

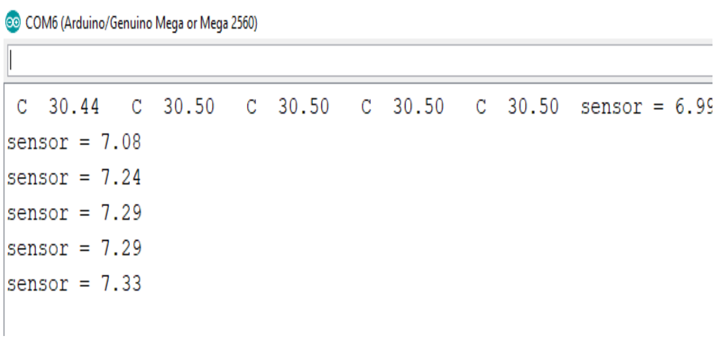


Fig. 12)Temperature and pH data readings of Water sample 1

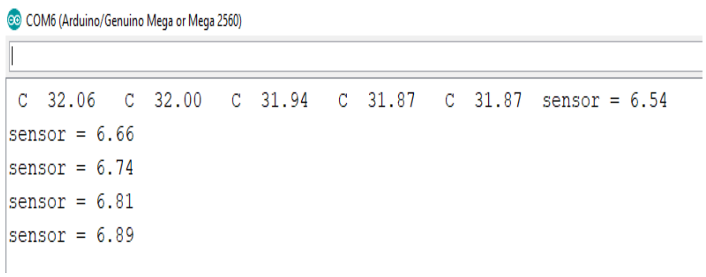


Fig. 13)Temperature and pH data readings on Water sample 2

V.CONCLUSION

Using Open-Source tools such as the Arduino Microcontroller and the MIT AppInventor Software made the development of this device affordable and cost-effective. Since this device uses low-energy Bluetooth as a connection between the sensors-processor and the smartphone, it is energy efficient and also helps make the device cheaper. The simplicity of the hardware as well as software programmed in this device make it easy-to-use and convenient for less-educated farmers to operate it and thus, reduce the complexity of monitoring water quality.

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