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Building indigenous smart hydroponic farm as lessons from an academic experiment--A review article

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Abstract Growing population is creating seriously concerns regarding availability of adequate food supplies. There is continuous pressure on agricultural technology stake holders to come up with cheaper and more efficient techniques that can be applied at scale. Hydroponics is one of the advanced plants growing techniques. This is an alternate agricultural technique based on soil-less methods with the promise of solving food shortage problem. There is needed to create expertise in modern farming methods. Hydroponic technology is gaining traction in Pakistan. Several farms have been developed in different areas of Pakistan. However, such systems suffer from different problems. The primary problem with contemporary efforts to build such farms is used the imported materials. This makes the cost prohibitively high. These farms are devoided any modern control and communicated the mechanism thus completely relied on manual methods. This paper describes our efforts to design and develop a smart Hydroponic system using only locally available materials, and also explains the lessons learned to provide a new guideines for farmers/researchers interested in this domain.

Keywords: Hydroponics, Nutrient film technique, Smart systems

Introduction

World population is growing steadily. Pakistan's population is growing at a rate faster than that of the world. Pakistan is expected to become fourth most populous country of the world in 2030. On the other hand, cultivable area is not expanding accordingly. In such scenario, alternate agricultural methods are needed to solve the problem. One such method is Hydroponic based controlled environment agriculture. Hydroponic is the method of growing plants without soil. Plants have their roots in water rather than in dirt. The basic premise behind the hydroponics is to allow the plants roots to come in direct contact with the nutrient solution, while also having access to oxygen, which is essential for proper growth. The technology is built on the premise that soil provides the mere structure, not necessarily the actual food itself, for plant

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roots. The food comes from the other materials mixed in the soil. So if we mix those nutrients in water, and provide it to the roots of plant, then it will easily grow. Plants grown hydroponically can actually grow faster and healthier than plants in soil because they do not have to fight soil borne diseasesIn many ways, growing plants hydroponically is simpler than growing plants in soil. Plants need food, water and air. When we break it down to those three things, it becomes simple to give plants only what they need. Hydroponics greatly increases the rate of growth in plants. Plants will grow bigger and faster because they do not have to work as hard to obtain nutrients. Hydroponics will also use less water than soil based plants because the system is enclosed, which results in less evaporation. As a result, per acre yield of Hydroponics systems is much higher than traditional agriculture (Jensen, 2013). Other advantages include less use of pesticides (Aravind and Sasipriya, 2018). These systems however require continuous monitoring for good yields (Springer, 2013) so that all the parameters are maintained within required ranges (Bugbee, 2004).

Hydroponics based systems are being practiced worldwide for a long time and becoming more popular lately (Orsini *et al.*, 2010). Hydroponic farms are being used in urban environment such as in Stockholm, Sweden (Martin and Molin, 2019). Vegetables grown using such systems are perceived by customers as nutritious and healthy (Gole *et al.*, 2020). In addition to basic Hydroponic systems, hybrid techniques like Aquaponics are also being practiced worldwide (Diver and Rinehart, 2000). These farms are increasingly applied smart technologies which make use of sensors, wireless communications, data collection and artificial intelligence (Ibayashi *et al.*, 2016). As a result, the farm acts like an autonomous system. Hydroponic systems are now gaining traction in Pakistan. Academic as well commercial farms have been developed at several locations, for example BARI (Chakwal), Faisalabad, Sahiwal, Sukkur, Karachi and Quetta to mention a few. These projects have been built using imported material, making the cost prohibitively high. Additionally, these farms mostly are manual and do not employ any intelligent, automated technique to operate and maintain the farm.

In this paper, we presented our efforts to design a hydroponics system completely based on material available in the local market. We further described our efforts to convert the farm into a smart farm by automating the irrigation, cooling and ventilation based on data collected remotely from the farm through sensors. We also presented the lessons learned during this project.

Hydroponics basics

Hydroponic systems use soil-less methods for agriculture. A variety of techniques are used in practice (McDonald, 2016).

Wick growing system: Wicking is a passive system, meaning it has no moving parts. Nutrients are moved from reservoir to plants roots by a wick or string (Sharma *et al.,* 2018). Plants can be housed in the variety of growing mediums. Due to their simplicity, wick systems are great option for growing smaller plants. The downside to wick system can be inefficient if not set up properly. Using the wrong wicking material will distribute nutrients unevenly resulting in poor plant growth or even death.

Deep water culture: Deep water culture system is the simplest of all active hydroponic systems. It is also known as Reservoir method. In this system, the roots are suspended in a nutrient solution (Sharma *et al.,* 2018). An aquarium air pump oxygenates the nutrient solution; this keeps the roots of plants from drowning. An air pump supplies air to stone that bubbles the nutrient solution and supplies oxygen to the roots of plants. This system is ideally suited for water-hungry plants but is not so well suited for more long-lived plants such as tomatoes.

Nutrient film technique: Nutrient Film Technique (NFT) system has a constant flow of nutrient solution, so no timer required for submersible pump. The nutrient solution is pumped into the growing tray and flows over the roots of plants (Graves, 1983). When the solution reaches the end of the growing tray, it drops back into the main reservoir, and is sent back to the beginning of the system again making it a recirculating system, thus reducing waste. There is usually no growing medium other than air which saves the expense of replacing medium after every crop. The main disadvantage of NFT that is the pump stops working or power goes out, the roots will dry out quickly and plants will die.

Ebb and flow (flood and drain): The ebb and flow system are worked by temporarily flooding, the grow in trays with nutrient solution and then draining the solution back into the reservoir (Buwalda *et al.,* 1993). This action is normally done with a submerged pump, which connected to a timer. When the timer turns the pump on, it floods the entire tray and pots holding the plants. When the timer is off, the water drains back into the reservoir siphoning oxygen back into the pots. The basic components of Ebb and Flow system are plant tray, reservoir and submersible pump.

Dutch bucket hydroponics system: It is also known as Bato Bucket System. It uses buckets as core of this growing method. Dutch Bucket (Vásquez and Vásquez, 2017) which is the variation of Ebb and Flow method. It differs in the way it looks, but still operates on the same principle. The nutrients are forced onto the bucket then automatically drained back to the reservoir, or it can drain out of the system without returning to reservoir, at regular intervals. The buckets must contain the growing media to keep moisture, aeration as well as supporting plants to stand upright. If we do not want the nutrients to return to reservoir, we can get drain out of the system. This is called flow-to-waste.

Drip growing system: Drip systems are one of the most widely used types of hydroponics systems around the world. They are simple to operate on large scale, making them ideal for commercial growers. Plants are cultivated in the growing media. The operation is simple, a timer control and the submersed pump. The timer turns the pump on to release nutrient solution onto the base of each plant via drip lines. A recovery drip system uses nutrients a bit more efficiently, as excess solution is reused (Sharma *et al.,* 2018). Non-recovery Drip system does not collect the excess solution and needs to get more precise timer, so that watering cycles can be adjusted to ensure that the plants uptake enough nutrient solution and runoff is kept to a minimum.

Aeroponic srowing System: This system is the most highly technology and complex system, but also yields the biggest and fastest growth. The growing medium is primarily air. The roots hang in the air are misted with nutrient solution (McDonald, 2016). The mistings are usually done every few minutes because the roots are exposed to the air like NFT system, the roots will dry out rapidly, if the misting cycles are interrupted. A timer is used to control the nutrient pump, ensuring that the plants are properly misted with the nutrient solution every few minutes. Unlike other systems, aeroponic systems expose plant roots to a lot more oxygen. Therefore the plants yielded the greatest results in the least amount of time.

The farm

Outer structure: We have built a small-scale farm with an area of 20x14 square feet with a semi-circle roof. Outer frame of the farm is erected by welding zinc plated iron pipes of diameter ¾ inches. The frame is erected over an already available concrete base. A thick plastic sheet was spreaded in farm floor to avoid any contamination from the ground. This initial frame is shown in Figure 1. The frame is covered by a clear polyethene sheet sourced from local market. This type of greenhouse is considered best for cultivating and growing vegetables, flowers or other plants in garden.

Internal design: Inside the farm, several subsystems are deployed to implement Nutrient Film Technique (NFT). These subsystems include NFT and cooling subsystem. All these systems are described below and shown in Figure 2a and Figure 2b in actual implementation inside the farm.

The NFT subsystem is composed of many components which each is described as follows: Growing tray: Twelve feet long main pipe of 3 inches diameter are used as growing tray. After each 8 inches, a hole is created 66 mm

(2.6 inches) diameter for growing crops. The hole distance depends on the type of crop. A 9 mm hole is created at the nutrient water entering side of main pipe, and a 25mm hole is created at the water exit side of the pipe. A total of what is it? pipes are installed over three stands of size 8x3x2 ft. Each stand has four growing trays. Nutrient Reservoir: A 5 gallon capacity plastic canister is used as nutrient reservoir. The canister is filled with nutrient solution. Original canister is modified to support both the irrigation line and the return of nutrients. Continuous nutrients flow to irrigation line is enabled by using a small pump, described next. Water pump: A 2m head pressure water pump is used for pumping nutrient water into growing trays. Head pressure is chosen by looking the specifications of drips and irrigation line. Irrigation line: A 13ft long pipe having diameter 30mm is used as irrigation line. There are twelve 9mm drips connected between irrigation line and trays for transferring water and nutrients into the growing trays. Nutrients return pipe: at exit side of trays, a returning pipe of 60mm diameter is connected with trays via 25mm pipes for returning nutrient water back into the reservoir.

Maintaining temperature is a necessary requirement in hydroponic systems. There are different ways to do in our farm, we have used a combination of wet wall and exhaust fans. Wet wall is deployed closely to growing trays at the back of the farm. A porous pipe is placed over wet walls. This pipe is connected with a water reservoir. Water leaks through pores and passes through wet walls. Air movement through wet wall creates cooling effect. Waste water drips in the container placed below the wet wall and stored in the reservoir. Two exhaust fans are installed on the front to further facilitate the cooling process.

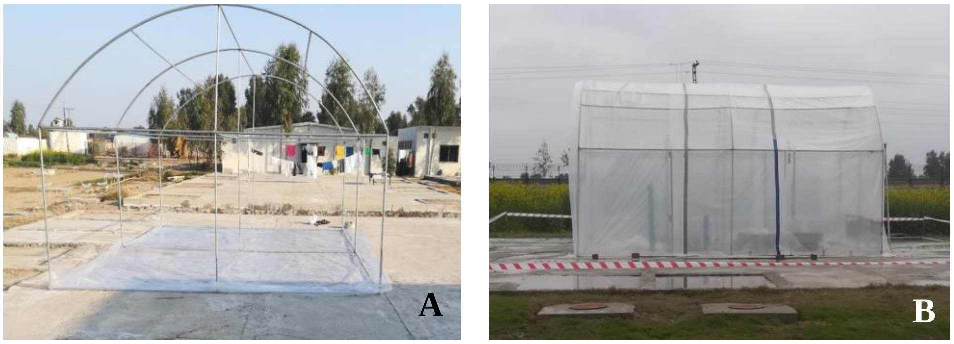

Figure 1. Basic structure

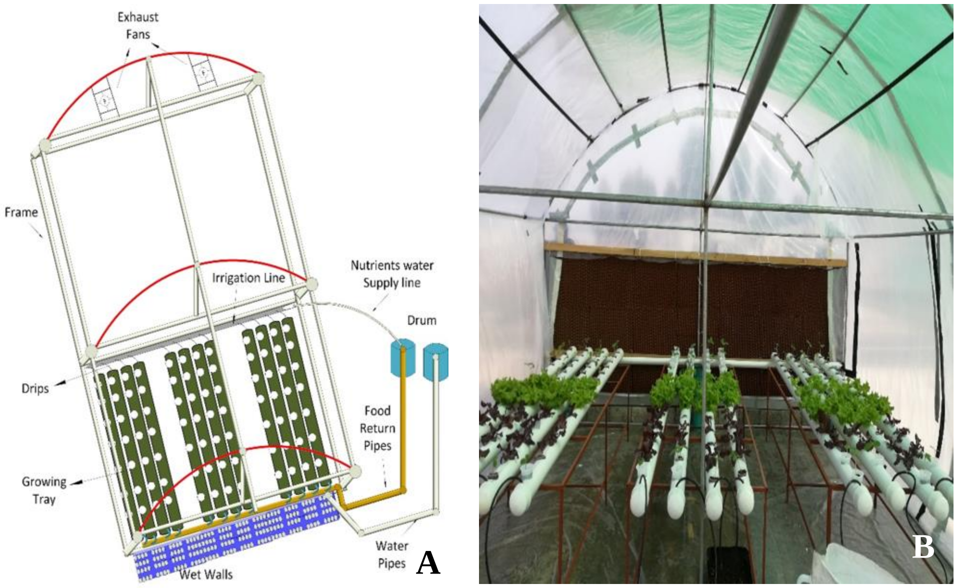

Figure 2. Internal design and implementation

Making it smart

The development of farm resulted in fully functional hydroponic system. Vegetables have been grown successfully. However, it requires constant human monitoring and intervention. An ideal smart hydroponic farm should be able to manage the temperature and steady supply of nutrients autonomously. It must be intelligent enough to decide when cooling mechanism should be activated and when to be stopped. Similarly, it must be able to create nutrient solution as per plant needs autonomously. First step towards this ideal is the ability to obtain farm data remotely. Some other similar efforts (Hidayanti *et al*., 2020) have been reported recently, however the systems developed by them is not described in detail.

To achieve this, we have equipped the farm with four NodeMCU boards (NodeMCU). These boards have different sensors and actuators, programmed to do specific tasks. Three of these boards contain sensors for data collection and one board is responsible for controlling the actuators. Completely data collection system includes set of software components running on remote computers. In this section, we describe the hardware components in detail. Some of the hardware used is also depicted in Figure 3.

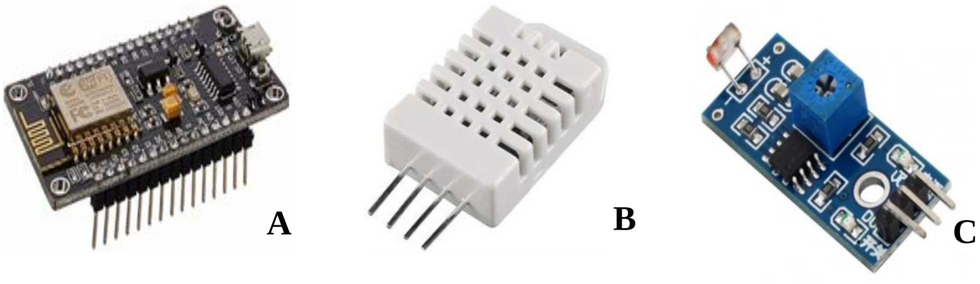

Figure 3. Various sensors

Sensors nodes are made of Arduino-programmable ESP8266 based NodeMCU boards connected to three different types of sensors, for monitoring different ambient variables. These sensors include: ambient temperature and relative humidity sensor (DHT22), water temperature sensor (DS18B20) and light sensor (LDR). NodeMCU development board is featured with Wi-Fi capability, analog pin, digital pins and serial communication protocols. It is an open source LUA based firmware developed for ESP8266 Wi-Fi chip. Since it is an open source platform, the hardware design is open for edit/modify/build.DHT22, also known as RHT03, is a low cost humidity and temperature sensor with a single wire digital interface. It’s a 3.3-5.5V input powered digital sensor module. DHT22 uses a thermistor along with a capacitive humidity sensor to measure the temperature and humidity of surrounding air. It communicates through a single wire and sends the reading it through a digital signal on the digital data pin. It can measure 0 to 100% relative humidity with +- 2% error and -40 to 80 degree ambient temperature with +-0.5% error (DHT22 Datasheet). DS18B20 is a one-wire, waterproof, 3-5.5V powered, temperature sensor that can measure temperature from -55 to +125 degree. No external components are needed. It can communicate with any digital pin. Thermometer resolution is user-selectable from 9 to 12-bits. It converts temperature to 12-bits digital word in 750ms. LDR is a 3.3V-5V powered Photoresistor (Light Dependent Resistor) module, which gives the light “value” in terms of resistance: higher the light, lesser would be the resistance. It is read by an analog pin and gives the value between 0 and 1024.Multiple of these sensor modules are connected to different NodeMCU boards, which are programmed to read these sensors after pre-defined time intervals and send the data to servers over the Wi-Fi network, through network sockets.

Actuator node: Like sensor nodes, these are NodeMCU based nodes which connected to actuators (fans, pumps, etc.) through relays. These are programmed to receive certain instructions as bytes strings over the network and toggle pins corresponding to command. Actuator node has a basic socket server running on it on port 5111. Commands are sent to the actuator node by Command center node. Command center n ode is also an on farm device. It is different from other on farm devices in several aspects. It is a raspberry Pi (RaspberryPi, 2002) running custom built software that a) continuously receives data from sensor nodes, b) sends the data to permanent storage after some basic analysis and c) forwards commands to actuator nodes. To achieve these objectives, several software components work together.

Server script keeps listening continuously. After receiving the data string from any sensor node, it parses the data, identifies the node its coming from and then stores the data in respective log file. Each data record consists of different fields. First two fields are date and time of data recording, followed by a variable number of key-value pairs. These key-value pairs include device/location identification within the farm and values of different sensors.

Another continuously running script on Command Center Node is instructor script: it reads the log file every half an hour and takes all the values that were entered in last 30 minutes. It, then, takes the average of corresponding data entries to get the overall climatic conditions of the farm. A strict climate model is programmed in the instructor script, which keeps track of life cycle of the crop. Data coming from the farm is compared with this climate model to take decision about actuators. Respective commands are, then, sent to the actuating nodes.

Both of these scripts run on Raspberry Pi and they are added as start-up scripts, so whenever the devices boots, manually or heedlessly, these scripts start working.

Permanent data storage at AWS Cloud

Amazon Web Services cloud stores the data which is sent by server and it also looks for any anomaly in the pattern to detect any failure in the system or any unresponsive node; in such case it sends notification to user through email and mobile message.

Experiments and data collection

The system was tested in a real, controlled hydroponics farm by growing lettuce, mint, cucumber, tomato and basil, over the period of three months from their seeding/sapling stage to fruiting age. Plants were grown in net pots while net pots were placed in holes created on growing tray.

After a bunch of iterations and improvements, the system worked perfectly for this time period. The farm practically ran on-it-own during this period. The system was taught climatic requirements of red and green lettuce, and it followed it perfectly, keeping the conditions in ideal range by lettuce.

Since the system was being monitored continuously, ambient characteristics such as temperature, humidity and light were collected regularly. This data can provide interesting insights. For example, ambient characteristics inside the farm at any given time may not be the same throughout the farm; instead different parts may exhibit different values. This can affect the plant growth. Figure 4 shows a plot of temperature values collected periodically in a day through two different sensors placed at two different points in the farm. This graph shows number of things; a) It shows that cooling mechanism is at work, and b) temperature difference between two points can be as high as 2C^{o}.

For three months, nutrients and water was delivered timely and right amount and actuators were manipulated perfectly to keep humidity and temperature in desired range. Different stages of plants actually grown can be seen in Figure 5.

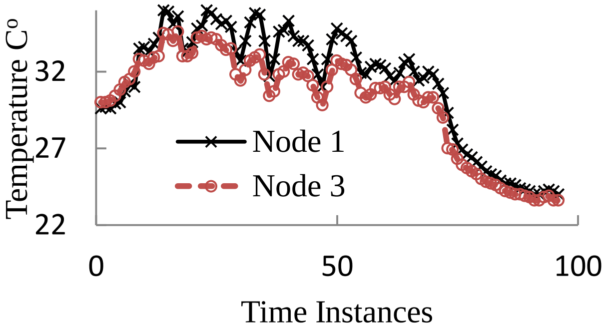

Figure 4. Temperature values from different sensors

Figure 5. Plant growth stages

Cost details

Total cost of this project was under 250,000/- PKR. Approximate breakdown of major costs involved are described below:

Farm skeleton: 35000
NFT Trays & Stands: 25000
NFT Irrigation Mechanism: 20000
Wet Walls and Exhausts: 20000
Sensors and Communications: 25000
Growing medium and Nutrients: 10000

Since the project is carried out at a remote place, shipping/travelling is a major cost. Human resource cost is considered to be zero since all the engineers/developers worked on the project without any remuneration for completion of their degree requirements. Software development cost is also considered to be null for the same reason.

The total cost of the setup was around 2,00,000/- PKR (less than 1500 US$.) The cost included material to erect the structure, construction, hardware devices and seeds. A similar work reported recently (Olubanjo and Alade, 2020) that a typical hydropinc farm costs around 25,00,000/- Naira (more than 6000 US$). Further more, their design does not make use of any smart devices.

The reduction in cost was achieved since we used a commonly available plastic sheet. Further, the farm was covered by combining several pieces of sheets. As a result, the farm became vulnerable to strong winds. We recommend using thicker plastic sheets and without any joints. This also suggests considering wind factor while choosing location for the farm.

We learned that temperature values may vary with respect to height inside the farm. This should be considered while planning wet wall placement in the farm. A similar recently reported work (Hidayanti *et al.*, 2020) describes relationship of pH and the temperature through data obtained using sensing IoT devices. However, the work does not describe costs involved the design and development of the system.

Conclusion and future directions

The work carried out under this project has helped us to understand how actual hydroponic systems can be developed using locally available material. We have successfully demonstrated that leafy vegetables can be grown in such a setup even in relatively hot areas of Pakistan. Further, we were able to install and use several different sensors inside the farm to make it semi-automatic. This work can now be used to study in detail, different aspects of hydroponic systems. For instance, different experiments can be carried out to study the impact of different ratios of nutrients for different vegetables.

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