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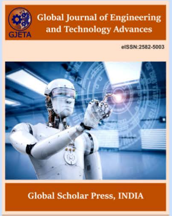

(Research Article)

Farming with the utilization of IoT

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Abstract

The use of IoT in farming has enabled plants to get precise amounts of water, nutrients, sunlight and heat. Historically planting has always been in soil but SiO_2 is not consumed. Plants given mechanical support will grow with their roots in a container of nutritious water. Such hydroponics can achieve 30-50% faster growth, with less space/output, utilizing 1000% less water. Light can either be from the sun penetrating greenhouses or from LEDs. Such systems have enabled the tiny country of Netherlands to become the second largest exporter of food in the world. This must be the solution to supply food to an ever-increasing population of humans. In this research done in 2021, tomato plants were grown in coco pit mixed with perlite in four Dutch buckets with an automated irrigation system. The output plants were compared with control grown in the soil in clay pots. The temperature, moisture, pH and EC were monitored. Data from two sensors were exported to a laptop over Bluetooth. The usage of solar panels to power the system was also studied. The overall results indicate 34 - 67% better characteristics for the plants grown with this technique compared to the control grown in normal soil.

Keywords: IoT; Hydroponics; Drip irrigation; Wick irrigation; Photovoltaic power

1. Introduction

Water, nutrients, sunlight (UV) and temperature (infrared) must be fed to plants in the exact amount. For example, too much water will cause the plants to drown and too little will cause them to wilt; the same precision is needed for the nutrients, sunlight and heat. One of the main food sources for plants is red light of frequency range 400-480 THz (not heat or infrared light of frequency 300-400 THz). But plants do need heat because it survives best between 18-29°C. For best, growth plants need cooler temperatures at night of 16-20 °C [1,2,3].

IoT has thus far been used to monitor and control the water (automated sprinkler system), fertilizer, temperature, humidity, warehouse monitoring for pest and fire hazard, drones to spray fertilizer and communication to harvester machines [4,5].

One option to solve the food scarcity is to increase investments in greenhouses for which a glaring example is the Netherlands but also notably in India, the USA, Japan, Germany and China [6,7]. The greenhouses of the Netherlands operate 24X7 with controlled environments. Temperature and light are precisely controlled and are totally unrelated to the outside environment. In fact, many in the Netherlands call their farming, "Precision farming" [8]. Pests are absent in this relatively sterile environment and human workers work inside wearing coveralls. Many utilize LED light because it is perfectly controllable to provide the exact wavelength of light which can even change the taste and texture to suit

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different customers. Many farms are vertical, thereby finally moving humanity away from the two-dimensional farming done for most of history. Three-dimensional farming can produce immensely more produce / acre [9].

A second approach to solve the food crisis is the encouragement for people to be vegetarians. An interesting fact proven by the likes of chains such as Mc Donald, KFC and Pizza Hut is that the various races of humans around the globe have a similar craving for the taste of food [10]. If this similar taste can be incorporated for vegetarian foods, the world can reduce waste and environmental pollution to a large extent. Taste is what humans crave for which can be satisfied by more investments in labs to provide vegetarian food with the taste of meats since a high percentage of humans crave for the meat taste. This has already been worked upon by the likes of Beyond Meat company. Putting it in numbers, to make 1 kg of beef takes 2.24 kg of corn and 2850L of water (5.24kg of water; density of water is 1 kg/m^3). The corn and water have a mass of 17.24kg. Therefore, there is a 17:1 ratio in mass from farm to meat. A typical beef meal which is about the size of a deck of cards and weighs 0.19kg takes 3.2kg of corn (10 ears of corn) plus three one-liter bottles while a typical human can only consume a maximum of two ears of corn plus one one-liter bottle of water. Basically, the human consuming beef is consuming a mass that is 500% more [11,12,13].

A third avenue to tackle the food crisis is that plants should be left to grow naturally all over the earth and machines should be developed to appropriately process them. Imagine a world where a human go out of his / her home and plucks any vegetation and put it in a machine that detects what it is and cooks it appropriately. Some of these plants have been growing in certain regions of earth for millions of years and have therefore evolved resistance to pests, disease and environmental factors. And since most plants have the nutrients needed to satisfy human needs, this is theoretically possible [14].

A fourth avenue to solve the food problem is that of the richer sections of humanity throwing away food. All homes need a grinder to turn all these into fertilizer since grinded food can decompose much easier than the whole food. Also throwing whole vegetables, fruits, and carbohydrates on the backyards of homes do not look good aesthetically and the slow decomposition will produce longer periods of bad smell. It must be noted that this cannot be done with meat according to the EPA (Environment Protection Agency of the USA) because it can attract rats, diseases and emit a strong smell for the humans nearby [15, 16].

2. Literature review

Figure 1 The left plant was pulled out of a roof gutter and the right lettuce was grown using hydroponics

The advantage of hydroponics over field farming is that it does not face the problems associated with soil erosion, food borne illness and chemical use as fertilizer and pesticides [17]. Fig. 1, left image is a plant which has grown thus far without soil; it was pulled out of a roof gutter. The extra-long roots are an adaptation to acquire as much water as possible whenever it rains. The right image of Fig. 1 is a lettuce plant for sale in a food shop indicating the ever-increasing awareness of hydroponics by humanity [18].

The top thinkers in the world who are building a depressing scenario for the future of humanity in terms of food supply are not observing the example of the Netherlands which has a land area of only 41,543 km^2 which is currently the second largest exporter of food in the world after the USA [19,20].

The primary nutrients plants need are carbon, hydrogen, nitrogen, oxygen, phosphorus, and potassium. The secondary nutrients needed are calcium, magnesium, and sulfur. Plants also need trace amounts of boron, chlorine, copper, iron, manganese, molybdenum, and zinc. A few plants need cobalt, nickel, silicon, sodium, and vanadium [21,22]. Plants absorb almost all the needed nutrients via the roots except carbon which is absorbed via the stomata of leaf pores.

Plants cannot directly consume inorganic compounds like dung or other bio-waste. These need to be broken down into inorganic ions via bacterial action before it can be absorbed by the plants. This process is called mineralization. In other words, plants only consume positively charged ions (cations) or negatively charged ions (anions). Fungi enable plants to absorb phosphorus because it increases the size of roots thereby providing more surface area of contact with the soil [23].

Hydroponics is sometimes done with artificial mediums like sand, gravel, vermiculite, rockwool, perlite, peat moss, coir, or sawdust. These materials provide mechanical support for the plant plus enable retention of nutrients over longer periods [24]. Most hydroponics systems recycle the nutrient rich water. The only reason for not recycling is that water quality is of prime importance in hydroponics. There have been cases where contaminated water destroyed whole hydroponic farms. Therefore, sensors must be monitored carefully and if humans cannot do the monitoring continuously AI (artificial intelligence) software must be written to perform the activity of monitoring and taking appropriate reactions [25].

3. Material and methods

In this research, the first of the four options discussed in the introduction to solve the food crisis was worked upon. Tomato plants were grown and monitored using an Arduino microcontroller and sensors and their growth was measured using KQC (key quality characteristics). The sensors used are listed in Table 1. The tomato plant used in the experiment was the Lycopersicon esculentum which is a tomato variety which produces cherry sized tomatoes. Initially the experimental plants were grown in a medium of coco peat and perlite and the control plants were grown in normal soil in small containers as a nursery. After approximately 20 days, the plants were transplanted into the Dutch containers and clay pots which had normal soil. The plants were transplanted on the 5th of September 2021.

The main objective is to set up the cheapest possible hydroponic systems because obviously some of the fully closed loop systems adopted in advanced countries are too expensive to be utilized by most of humanity. The system designed and built in this work is not enclosed. There have been similar farms which utilize innovative protocols to avoid the biggest problem of open systems which is pest control.

Table 1 List of sensors used

Water level sensor	pH meter
Temperature sensor	Electrical conductivity (EC)

Among these are biorational products which are chemicals released by animals affecting the physiology of other species. Then there are insect growth regulators (IGRs) which are synthetic insect hormones which can prevent insects from reaching maturity by interfering with the molting process or the process of shedding the outer layer of their body and building new ones as they increase in size. Next is non-toxic heat treatments such as Rentokil's Entotherm which dehydrates the insects from the inside. This kills insects, eggs, larva at temperatures of 56-60°C. Then there is CRISPR or gene editing which regulates the key genes that controls fertility and sex discrimination of insects [26].

A prototype shown in Fig. 3 was designed and built. Two irrigation systems were used: firstly the top orange pipe carries water to the plants via the black tubing and blue drippers shown in Fig. 4 right image. The water will flow down the Dutch bucket through the coconut husk and perlite medium to the bottom of the Dutch bucket where wicks are placed to help water move out to the outgoing orange pipe shown in Fig. 4 left image. A secondary drain off using wick going to leachate collectors was later built because some to the water at the very bottom of the Dutch container was not draining off; this wick was sized 100 X 0.5 cm. Fig. 5 left image is the microcontroller used and the right image is a picture of how the phone app written for this research using MIT App Inventor to monitor the sensors looks [27].

Four Dutch containers were filled with around 500 grams of coco peat mixed with perlite in the ratio 1:3. Coco peat is resistant to diseases, does not decompose and has a high-water retention rate. The function of the perlite is to increase the drainage of excess water and therefore prevent roots from drowning as they have a lack of O_2 being soaked in water. With perlite, the O_2 absorption increases to 98%. Perlite is analogous to a sponge with air pockets allowing it to retain higher water and nutrients. Both these mediums have a neutral pH which make it easier to later control the nutrients supplied to the plants.

The experiment was conducted where an equatorial climate of Kuching, Malaysia prevails. Planting from seedling was conducted from the end of the dry season in August and replanting into the Dutch containers was initiated in September which was the start of the wet season. The dry and wet season mentioned above only affects the temperature since the experiment was placed just at the edge of a shed. Around 5.7 L were added to the reservoir and nutrient was added to the solution slowly once a day until the electrical conductivity (EC) was around 1.5 mS/cm (milliSiemens per linear centimeter) and then it would be maintained at this EC level. The EC should range between 1.2-1.6 mS/cm during vegetative stage and 1.6-2.4 mS/cm during flowering stage [28].

The prototype was built as shown in Fig. 3 where it could be seen that the piping (9) used was the orange hose due to its malleability. This orange hose was built to enable recycling the water plus nutrients; it goes from the maroon reservoir to the four Dutch containers and back to the maroon reservoir. Fig. 4 left image the orange pipe making a loop from the bottom of the Dutch containers back to the maroon reservoir. Fig. 4 right image is how a black T plastic fitting is used to puncture the orange pipe and a black tubing ends up in the blue dripper to enable ease of water flow exactly at the point where the plants are in the Dutch containers. The black T fittings have three holes, one of which was blocked by pushing in a black tubing and folding it and then kept folded with a cable tie.

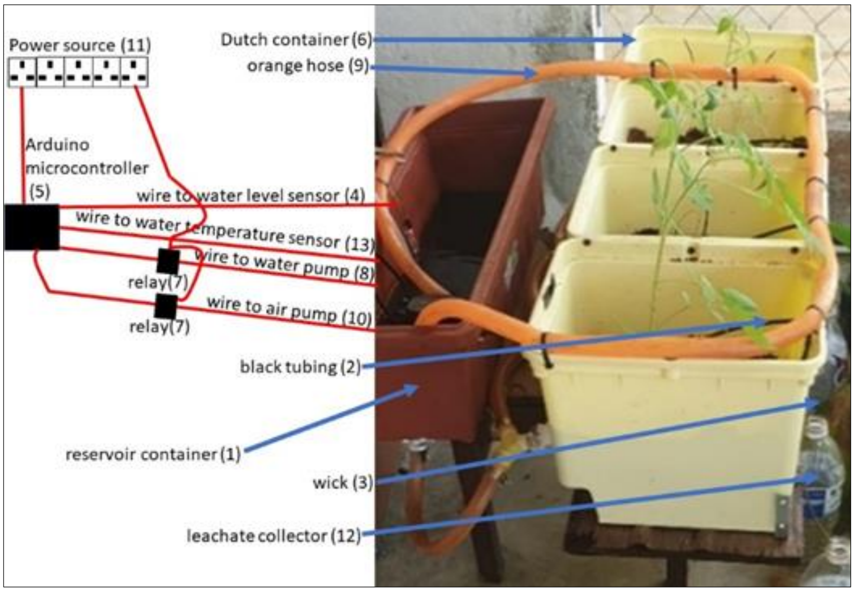

Figure 3 The setup used to grow the tomato plants

Figure 4 The connection of the orange hose. The right image shows the piercing of the orange pipe with connector and the black pipe which goes to the plant

A 45W water pump circulates water in the orange pipes but the software instructs it to switch on for only 5 mins / 24 hrs at 6am, recycling water from the maroon reservoir to the plants and back to the reservoir. An additional 1.6 L of water is poured into the reservoir (1 in Fig. 3) at 12 a.m. every day. As can be seen in Fig. 3, water is collected at the bottom of the Dutch containers (6), back to orange pipes (10) and back to the reservoir (1). This can happen because the bottom of the Dutch container is placed vertically above the reservoir.

The orange pipe (10) was connected to the bottom of the reservoir tank using T-connectors. At the bottom of each Dutch container is a flannel wick with a width of 1.5 cm and length 30 cm which will hasten the water to flow out. An earlier experiment was done to study the rate of wick irrigation by filling the reservoir with 5.7 L of water and a timer was used to time the outflow. The sensors and the water pump were controlled using an Arduino Uno (5) microcontroller.

The code was written using Arduino Integrated Development Environment (IDE) which was used to interact with the Arduino board. The electrode water level sensor (4) was used to determine how high the transpiration rate is to initiate the pump at the right time. Fig. 6 is the chart of water level versus time. The pump was controlled with a relay (7) which gets signals from the Arduino microcontroller. The data from the sensors were obtained every 5 minutes because if a quicker span of time was used the Arduino microcontroller would be overloaded with data and data overload is one of the biggest problems with IoT; old data purging must be a feature of IoT software. The water level sensor was also used to trigger the operator to refill the maroon reservoir whenever the water level was low. A low power (2 W) air pump (10) was used to pump air into the water of the reservoir for 24hrs X 365 days to aerate it, ensuring sufficient O_2 within the water. A temperature sensor (13) was also used to determine the reliability of an air pump because a daytime temperature below 32.2^{o}C is not suitable for this variety of tomato plants [29]. The chart of temperature versus time is shown as Fig. 7. Sarawak, Malaysia has an ambient temperature of 21-32^{o}C but temperatures below 25^{o}C are only reached around 6am. The temperature sensor was also used to ensure that the water would only be delivered to the plants through the water pump if the temperature was below 30^{o}C. The microcontroller system utilizes the real time clock (RTC) to function [30].

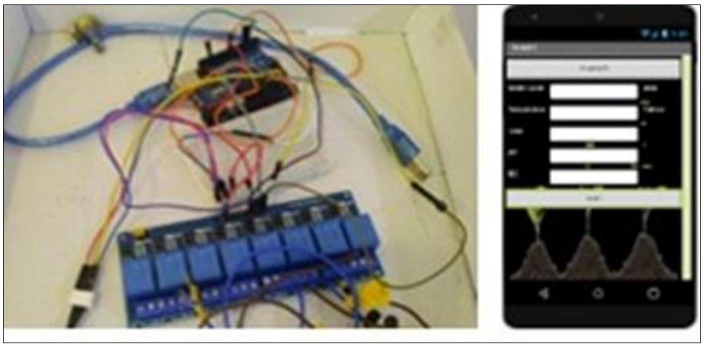

Figure 5 The microcontroller (Arduino) and relays used. The right image is the phone app screen to monitor the sensors

The phone app developed as shown in Fig. 5 on the right image keeps track of five parameters, namely: (1) water level, (2) temperature, (3) time, (4) pH and (5) EC level. This phone app pulls information from the Arduino board through a HC-05 Bluetooth component which enables the phone to be placed 15’ away. The phone app collects the data from the sensors and sends it via Bluetooth to the phone which automatically stores the data in Google Doc Excel in Google Drive. A button on the phone screen was used to input readings from the pH sensor and the EC sensors since these were manually read. The application was also used to send a notification when the water in the reservoir tank was below the 1.0 V readings of the water level sensor.

4. Results and discussion

It was discovered that the transpiration rate through wick irrigation of the plants would increase during the no-sunlight hours as shown in Fig. 6 where the blue chart is the actual data and the black line indicates the trend at the three time periods. The data came from the water level sensor placed within the reservoir. There was a steeper decline in transpiration rate observed at night. The reason for this is that as plants do not engage in photosynthesis at night so the water absorption is less. Right after the sunlight hours there seems to be a greater need for water as if to quench thirst and this absorption decreases after 12am. This period would be ideal for the drip system to be initiated to ensure maximum productivity would be done by the water pump to provide the plants with water and nutrients while diluting the salt accumulation within the medium. At five a.m., the software in the Arduino microcontroller will instruct the initiation of the water pump based on the RTC (Real Time Clock) sensor used after checking that the water temperature was above 30^{o} C. Based on the calculation done, the rate of solution provided by the dripper would be 0.167 mL/s. The pump would only be operated for a maximum of five minutes at 6 a.m. as its main purpose would be to remove salt accumulation within the medium. Within these five minutes, each plant would receive 50 mL of solution which was pointed directly to the root area allowing for a higher absorption rate of solution.

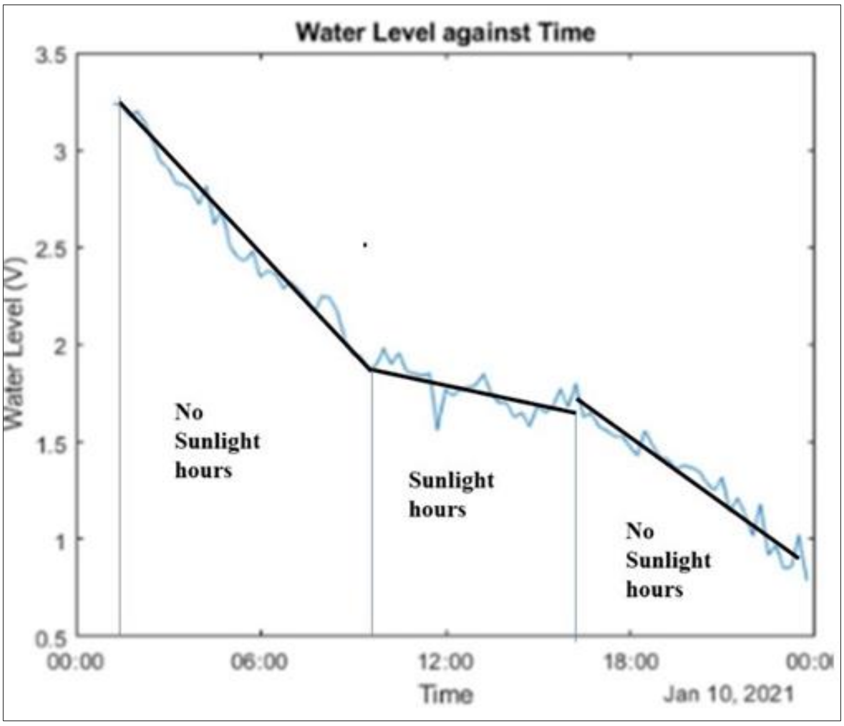

Figure 6 Graph of Water Level against Time

The volume within the maroon reservoir was 5.7 L and the length of the wick was 30 cm and the width was 1.5 cm. The capillary rate was around 0.03125 mL/s for each bucket. Over a span of 24 hrs, the liquid provided to the plants was around 2.7 L. The loss of water was determined by measuring the amount of water provided within the reservoir and deducting the water collected in the leachate bottles and this was determined to be 2.2 L for the four pots. This indicated that the average water absorbed was 0.55 L (2.2 L / 4) for each pot over a period of 12 hrs minus a little gone via evaporation. It must be noted that evaporation in such a porous environment of perlite is negligible. It could also be observed that the pots with larger plants have less liquid within the leachate bottles. This indicates that the consumption of water is higher by the bigger plants. Literature indicates that this variety of tomato plants in Malaysia require a minimum of 0.5 L per day to grow well versus 0.55 L in this experiment [29,31]. The system used was quite efficient in providing the required liquids for the plants. Water from the leachate container is taken and poured back into the maroon reservoir once in 24 hrs at 12 a.m.

The aerator decreased the water temperature within the maroon reservoir providing a suitable water temperature for the plants. The aerator provides air bubbles within the water which will increase evaporation and therefore decrease the water temperature. This is shown in Fig. 7 where the blue chart which is the water temperature is much lower than the orange chart which is the atmospheric temperature. Based on the chart, it can be observed that the highest temperature of the solution within the reservoir was 29° C which was optimal for the growth of the tomato plant. Fig. 7 also shows that it could be determined that over the 24-hr period the aerator decreased the water temperature by an average of 1.82° C. This was quite a significant decrease with a small 2 W aerator pump.

Monitoring of the pH and EC levels of the system was done using a pH meter and an EC meter manually. The results were tabulated and shown in Table 2. From the data it can be observed that the leachate pH was below 6 which was slightly too acidic for the plants but the pH of the water in the maroon reservoir remained at an average pH 6.8. The magnesium salt foliar to increase alkalinity was sprayed onto the plants once in two weeks if the pH in the maroon reservoir reached dangerously low levels. The magnesium salts were used sparingly as too much magnesium salts would lead to higher salt accumulation within the solution which would cause the plants to wilt. From the data shown in Table 2, over these five days the pH did not reach below the recommended levels thus the magnesium foliar was not required up to this point of time.

The overall results of the experiment were determined by measuring the KQC (key quality characteristics) which are the size of the leaves, the height of the stems of plants grown in the experimental setup as well as the normal clay pots on 17th November 2021 which was 74 days after the transplantation. Both experimental and control plants have not started flowering. The KQC data of the plants are tabulated in Table 3. The data indicate a 34 - 67% improvement in KQC for the experimental setup.

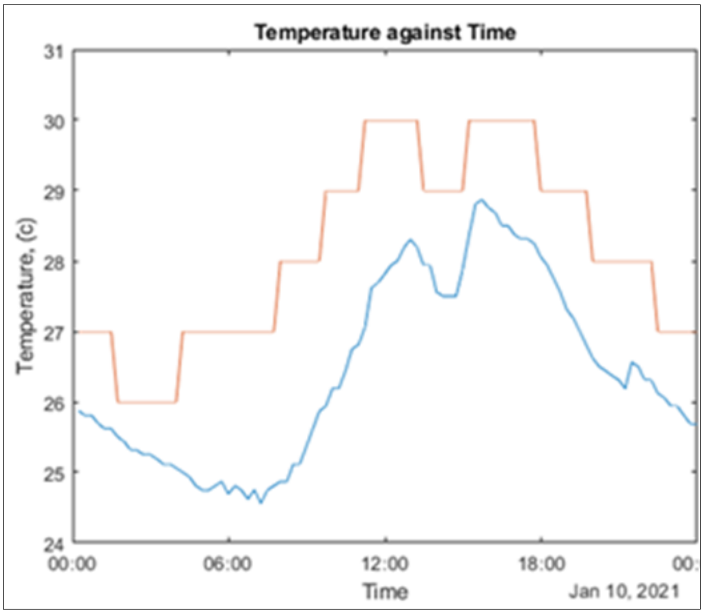

Figure 7 Graph of Temperature against Time

Table 2 Table of EC and pH data

Date	Reservoir EC (mS/cm)	Reservoir (pH)	Leachate (pH)
10/10/2021	1.387	6.71	5.93
11/10/2021	1.393	6.53	5.99
12/10/2021	1.395	6.69	5.92
13/10/2021	1.420	6.83	6.03
14/10/2021	1.417	6.95	5.94
15/10/2021	1.438	6.82	5.96

Table 3 Growth comparison

Type of medium	Leaf length (cm)	Leaf width (cm)	Number of twigs per plant	Number of leaves per plant	Shoot height (cm)
Soil	5.50	2.10	6.00	39.00	39.05
Coco peat and perlite	7.90	4.20	10.00	76.00	55.20
Difference (%)	35.82	66.67	50.00	64.35	34.27

To improve the prototype to make it suitable to be used even in the rural areas in Sarawak, the power source should be from solar panels and the design for this is shown in Fig. 12. This was necessary as within rural areas the power lines have a high probability of being damaged due to wild animals such as squirrels, snakes or falling trees. This unstable power in the irrigation for the plant would result in lower production by the tomato plants. The data for Fig. 8 was taken with a 10 W photovoltaic panel for five days during June which was one of the driest periods (least clouds to shadow the panels) in equatorial Kuching, Malaysia. One of the data sets was excluded due to heavy downpour. The solar panel used was rated by the manufacturer as 20V. But based on the graph, the range of voltage obtained from it was 12V to 22.5V; average 20.30V. The peak voltage was observed at around 13:45 hrs. The efficiency of the panels reduces after this period due to overheating of the panels and the reduction of the intensity of the sun causing a standard deviation of 2.12V [32]. As the solar panel shown above was quite reliable, using solar to power the system would be possible. Based on the power consumption of the water pump, aerator and the Arduino system, the photovoltaic system design was proposed. The water pump would only be used for a maximum of 5 min / 24 hrs as its main purpose was to remove the salt accumulation within the medium. Thus, the system had a total power consumption of 5.807W as shown in the calculation below (2).

$$\text{Power of Water Pump} = 45\text{W} \times \frac{5\text{ min}}{60\text{ min}} = 3.75\text{W-------(1)}$$

$$\text{Power of Aerator} = 2\text{ W}$$

$$\text{Power of Arduino System} = 0.057\text{ W}$$

$$\text{Total Load Power} = 3.75\text{W}+2\text{W}+0.057\text{W} = 5.807\text{W------(2)}$$

Electrical storage could be used to increase the response to demand and prevent an elevated load peak. The battery rating proposed was 12V, 150mAh.

$$\text{Battery Power Rating} = 12\text{V} \times 26\text{Ah} = 312\text{Wh----(3)}$$

$$\text{Maximum hours usage} = 312\text{Wh} / 5.807\text{W} \approx 53\text{ hours-(4)}$$

Kuching, Sarawak, Malaysia has days with very heavy downpours where there was no sunshine. One battery would provide a grace period for ≈ 2 days and 5 hours (4) of power for the system. The charging current (5) of a battery which was normally one tenth of the battery rating was required to determine the number of solar panels (7) required to power the system (6).

$$\text{Charging current} = \frac{1}{10} \times 26\text{ Ah} = 2.6\text{ A-------------------(5)}$$

$$\text{Power of the battery} = \text{VI(Charging Current)}$$

$$\text{P} = 12\text{V} \times 2.6\text{ A} = 31.2\text{ Watts------------------------------(6)}$$

$$\text{No. of Panels} = \text{Battery Power} \div \text{Panel Power Rating}$$

$$\text{Number of Solar Panels} = 31.2\text{ W} \div 10\text{ W} = 3.12 \approx 4\text{ Solar Panels---(7)}$$

As the equipment used for the system all uses AC while the power produced by the solar panel is DC, an inverter will be needed to convert DC to AC. The rating of the inverter (8) required for the system should be 25% greater than the total load.

$$\text{Inverter Power Rating} = \frac{125}{100} \times 5.807\text{W} = 7.26\text{ W-(8)}$$

Based on the calculation, an inverter greater or equal to 8W should be used for this system. The inverter would have a 12 V direct current input and 240V alternating current output. Since a 100 W power inverter is easier to find in the market, that is proposed for this system. A 3A charge controller will be recommended as the battery's charging current was 2.6A. The charging controller would ensure that the maximum charging current received by the battery would be 3A which would prevent overcharging of the battery. Based on the calculation and overall deduction on the types of equipment which could power the hydroponic system, a circuit diagram was drawn as shown in Fig. 9. The solar panels will be connected in parallel since the inverter is 20V and more in parallel provides more mAh.

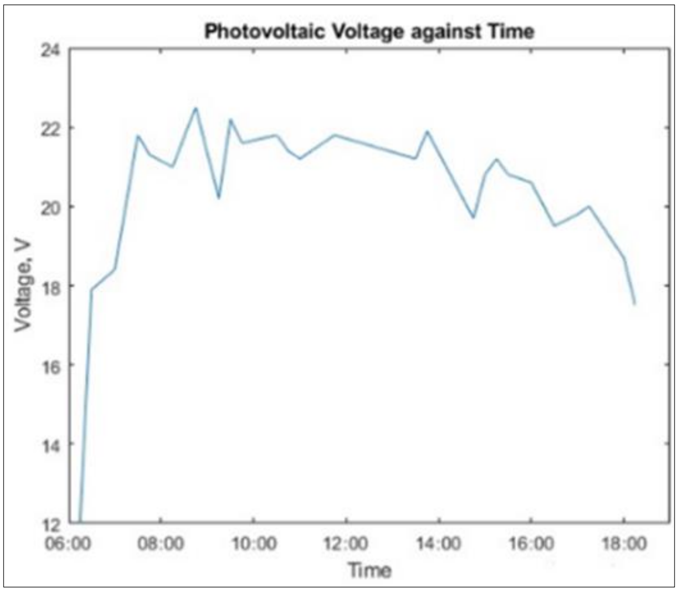

Figure 8 Graph of Photovoltaic Voltage against Time

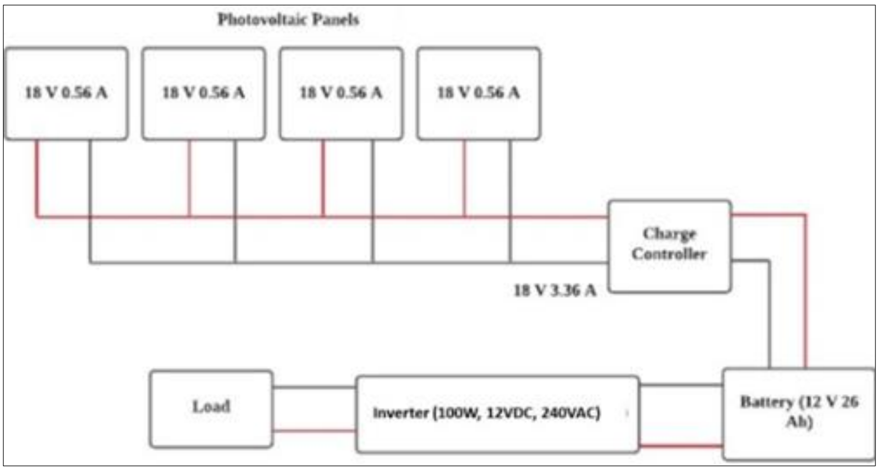

Figure 9 Photovoltaic System Design

5. Conclusion

This research has proven that the usage of IoT can help in the productivity of farming. Tomato plants were grown with experimental methods and compared to the plants grown in normal soil in clay pots. The main results are shown in Table 3 which indicate that for the KQC chosen, the percentage improvement of the tomato plants in the experimental setup is 34-67% better than the control, growing in normal soil.

Four sensors were used to measure the water level, temperature, pH and EC. For the first two, data collection was automatically taken using an Arduino microcontroller and the data from the EC and pH sensors were keyed in manually once a day. The data from the temperature and water level sensor was sent wirelessly (via Bluetooth) over to an application in a phone placed 15’ away and the data is stored in a Google Doc Excel file which is later accessed with a laptop in another location. A user-friendly phone app was also developed to provide the data of the growing conditions instantly to a farmer.

Based on the data of the temperature and water level sensors, the microcontroller was programmed to automatically provide nutrients and water to the plants through drip irrigation for a period of five minutes at 6 a.m. The water and nutrient solution were provided to the plants continuously and it was determined that within a span of 12 hrs the water retained within the medium was 0.55 L and the consumption of the plants plus evaporation was 1.6 L which was refilled once a day at 12 a.m. As the water provided through the wick subirrigation could be controlled by determining the rate of capillary rise, this sub-irrigation method would be suitable for rural areas where power availability is low. The sensors require only a little power while the 45 W water pump was only used for 5 mins per day at 6 a.m. and the air pump which pumps 24 X 365 is only 2W; it is quite impressive that this relatively cheap pump can run continuously for such long period, thanks to their developments resulting from the worldwide interest in keeping fishes in homes. Therefore, the overall system uses very little power. Reviews by some is the fact that most of the system is made of plastic which is a health hazard, but all the parts used in this work have silicone equivalent which is chemically neutral to the human body and can be equated to growing in soil or SiO_2.

The solar power panel system designed for the system was of low power tapping capacity and not capable of powering the whole system, but this can be improved by utilizing more solar panels.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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