The use of IoT to solve Farming Problems

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***Abstract*— As with every other field, IoT is moving into farming, providing plants with the right amount of water, nutrients, sunlight and heat. Though historically planting has always been in soil, they do not consume SiO_2. Water and nutrients can be supplied if the roots are in a container of water and the plants are provided mechanical support; such hydroponics have achieved 30-50% faster growth, utilizing much less space/output, using 1000% less water and light either from the sun through greenhouses or from LEDs. Such systems have enabled the tiny country of Netherlands to become the second largest exporter of food in the world. If such technologies are exported, the world will be free from the ever-worrisome food crisis. For this research, tomato plants were grown in a coco pit mixed with perlite in four Dutch buckets and compared to the control plants grown in pots left in the prevailing environment outside and watered daily. The variables monitored are moisture, temperature, pH and nutrient levels. Data from sensors were sent to a laptop over Bluetooth. The usage of solar panels to power the system was also studied. The result indicates a 34 - 67% better characteristics for the plants grown with the modern techniques compared to the control.**

Keywords*— Hydroponics, IoT, drip irrigation, wick irrigation, photovoltaic energy.

I. Introduction

Plants will grow well if water, nutrients, sunlight (UV) and temperature (infrared) are fed to plants in the exact amount. Too much water will cause the plants to drown and too little will make them wilt; the same precision is needed for the nutrients, sunlight and heat. Among the main food sources for plants is red light of frequency range 400-480 THz but not heat or infrared light which has a frequency of 300-400 THz. But some of the later frequency is needed because plants survive best between 18-29^{o}C during the day and cooler temperatures of 16-20^{o}C at night.

For hydroponics, IoT has thus far been used extensively to provide a precise amount of water (automated sprinkler system), fertilizer and temperature. In agricultural warehouses or storage, IoT is used for monitoring for pest and fire hazard. Drones operated with IoT are used to spray fertilizer and provide data and communication for harvester machines.

There are many top thinkers who forecast a depressing future where a lack of food for the ever-increasing population converges with farmlands that are contaminated due to the over usage of fertilizers and pesticides. The outflow from these farmlands have contaminated many rivers, resulting in a lack of water supply for farms located downstream. Many studies report these same facts [1,2,3,4].

But most of humanity is turning a blind eye to these problems, thinking that if food is still available in supermarkets albeit at an ever-increasing price, it is alright. The apathy to solve the food crisis for the world by projecting the trajectory of the food situation for the sake of their own descendants is immense; there is a general lack of conscience. In reality what is keeping the food shelves full in supermarkets is the advances in freight systems whether with ships or air-cargo. This has pushed the problems of farmlands away from the general human conscience. Another reality is that one of the biggest sources of O_2 and biodiversity (which has vast medicinal value) for earth, the Amazon is being leveled to sustain the demand for food [5,6]. But the recent war in Ukraine has one positive outcome in that it has brought back the problems of food scarcity to the mainstream media (MSM). The few thinkers who study the overall situation are suggesting insane ideas like population reduction which is just like a person who cannot get into a door deciding to cut off his head to enter it.

One option to solve the food scarcity problem is to increase investments in high tech greenhouses for which the Netherlands is a glaring example. But it is also extensively being done in India, the USA, Japan, Germany and China [7]. These greenhouses operate 24X7 with controlled environments. Temperature, light and nutrients are precisely supplied and are totally unrelated to the outside environment which enables year-round farming. Many in the Netherlands call their farming “Precision farming” [8]. The greenhouses are in a sterile environment without any pests. Human workers work inside in coveralls and perhaps in cleanroom bunny suits as in high-tech chip manufacturing in the near future. LED lights are preferred because they are almost perfectly controllable; enabling plants to receive the exact wavelength of light which can even change the taste and texture to suit specific customers. The plants are cultivated vertically thereby finally moving humanity away from the two-dimensional farming done for most of history, thereby vastly improving produce / acre [9].

Another avenue for solving the food crisis is a fact proven by large food chains such as Mc Donald, KFC and Pizza Huts which is that the various races of humans around the globe have a similar craving for taste of food. A physicist, Riccardo Sabatini stated that if human genetics is printed it will take up 262,000 pages and only 500 of those pages are unique to any individual. That means only 0.19% (remember it as 0.2%) of a human’s gene is different from another human [10]. If this similar taste can be incorporated in vegetarian foods which has already been done to a high degree, the world can reduce waste and environmental pollution to a large extent. > 50% of the climate change of earth is caused by the two million animals killed every week to feed the seven billion humans. To put it numerically, to make 1 kg of beef takes 2.24kg of corn and 2850L of water (5.24kg of water where density of water is 1 kg/m^3) = 17.24kg of mass. Therefore, consuming beef causes a 17:1 ratio in mass from farm to food for humans. A typical beef meal of 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 of water. 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 utilizing 500% more mass of food than a vegetarian. Therefore, the encouragement of humans to be vegetarian is one avenue to solve the food crisis. Taste is what humans crave for and this can be satisfied by more investments in labs to provide vegetarian food with the taste of meats. This is currently being done by the likes of Beyond Meat company [11,12,13].

A third route to tackle the food crisis is that plants should be left to grow naturally all over the earth and science should be used to develop recipes to cook them appropriately such that humans can consume them. This is because the plants growing in a region have been doing so for millions of years and has developed natural immunity to the local pests and disease. This is possible because most plants have the nutrients needed to satisfy the basic human needs [14].

A fourth route of solving the food problem is to utilize the big throwing away of unconsumed food by the richer sections of society. It should be encouraged that these homes have grinders to turn all the waste food into fertilizer since grinded food can decompose much easier than the whole food with their much greater surface area. Throwing un-grinded vegetables, fruits or carbohydrates in backyards of homes does not look or smell good. However, 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].

II. LITERATURE REVIEW

Hydroponics do not face the problems associated with soil erosion, food borne illness and chemical use of fertilizer and pesticides [17]. But it is vital that parameters of the liquid below the plants be monitored precisely since the traveling of improper chemicals, bacteria, fungus or viruses is much faster in hydroponics.

Fig. 1. This plant was pulled out of a roof gutter.

Fig. 1 is an example plant which was grown thus far without soil. It was pulled out of a roof gutter, depicting the extra-long roots developed to acquire as much water as possible whenever it rains. Fig. 2 is a lettuce plant, for sale which was grown thus far without soil which indicates an ever-increasing awareness of hydroponics by humanity.

An increasing acreage of farmland is being damaged due to the overuse of fertilizer and pesticides causing an insufficient supply of clean water supply. Rivers are today being contaminated with fertilizers and pesticides [18, 19]. But the Netherlands which has a land area of only 41,543 km² is currently the second largest exporter of food on earth after the USA [20]. Comparatively, Sarawak, Malaysia is just one of Malaysia's 13 states (albeit the largest) has three times the land area at 124,450 km² [21]. But most of humanity on earth cannot even point out Malaysia on the world map, therefore many less would be able to point out the Netherlands on the world map, though she is much more famous for various historic reasons. Therefore, if the farming technologies of the Netherlands are implemented in more countries, the food shortages for humanity will be solved.

Fig. 2. Lettuce being grown without soil.

The nutrients plants need are carbon, hydrogen, nitrogen, oxygen, phosphorus, and potassium. The secondary nutrients needed are calcium, magnesium, and sulfur. They also need micro amounts of boron, chlorine, copper, iron, manganese, molybdenum, and zinc. There are a few plants that need cobalt, nickel, silicon, sodium, and vanadium [22].

All nutrients get into plants via their root except carbon which is absorbed via their stomata. Plant do not absorb organic compounds like dung; they depend on microbes to break them down into inorganic compounds before it can be absorbed. This process is called mineralization; in other words, plants only consume anions and cations [23]. Plants also depend on fungi to increase the size of the root, providing an increased surface area to absorb phosphorus [23].

Hydroponics is not always where plants are suspended mechanically in liquids, artificial mediums like sand, gravel, vermiculite, rockwool, perlite, peat moss, coir, or sawdust are sometimes used. Other than mechanical support these materials provide nutrients over longer periods [24].

Hydroponics are not always closed loop; open loop is sometimes used though a minority because of the worry that the liquids may carry much faster all the microorganisms that can also attack the whole farm very fast. Optimally a future development is to send the liquid into various containers where tiny fishes consume the known bad microorganisms.

With an increasing adoption of AI (artificial intelligence) the control of the liquid medium can be more precise [25].

Another aspect of planting is that they cannot be overfed with water because the roots will drown as they become unable to absorb O_2 when surrounded by water. Therefore pumping air and stirring of the water is done in greenhouses. Basically, growing takes lots of intelligence and is best done with proper AI. In on-land farms, irrigation can achieve 40% efficiency while with hydroponics, 75-95% efficiency can be achieved thereby conserving water [26].

III. METHODOLOGY

Of the four methodologies mentioned in the introduction, the first one was studied in this research. Four tomato plants were grown in four Dutch buckets and an Arduino microcontroller and sensors were used to monitor and control the planting. The sensors used are listed in Table 1. Another four tomato plants were grown in normal soil in pots and left out in the open environment as a control. Selected (key quality characteristics) were used to determine the quality of the experimental plants versus the control plants. This experimental setup did not use an enclosed greenhouse. The main idea was to perform IoT monitoring and irrigation with the most economical resources. The fully enclosed setups developed in the Netherlands are too expensive and technology intensive to solve the immediate food needs for most of humanity. Since the experimental setup was in the open, the pest control protocols discovered so far need to be incorporated when the system is scaled up. Among these are biorational products which are secreted by animals which disturb the physiology of other animals. Insect growth regulators (IGRs) which are synthetic insect hormones has been developed to affect the physiology of the pests, these can hamper the insects' ability to mature by interfering with the shedding of the outer layer of their body as it increases in size, this is also known as the molting process. Other methods employed are dehydrating the insects, eggs or larva from inside with up to 56-60^{o}C which is the process used by Rentokil's Entoterm. CRISPR or gene editing is also done where key genes that control the fertility and sex determination of insects are interfered with [26].

The prototype built is shown in Fig. 3. The top orange pipes (9) carry water from the maroon reservoir (1) and from this comes out black tubings which end as blue dippers as shown in Fig. 4 right image. The orange hose (9) was chosen due to its malleability. The orange hose goes from the maroon reservoir to the four Dutch buckets and back to the reservoir. Fig. 4 left image indicates how the water comes out from the bottom of the Dutch buckets. At the top of the Dutch buckets, the orange hose is punctured with a T shaped black plastic fitting with one part of the T blocked with a black tubing folded and cable tied. To the other end of the T is connected a black tubing whose other end is a blue dipper placed near the plant. The water will flow down the Dutch bucket through coconut husk and perlite medium to the bottom of the tank where wicks were placed to help water move out back to the orange outgoing pipes shown in Fig. 4 left image. This wick has a dimension of: length=30cm, width=1.5cm. Because some of the water at the bottom of the Dutch buckets was not draining off, a secondary wick was placed at this point to help drain off the liquid into leachate collectors. This wick had a dimension of 100 X 0.5 cm. An earlier study was done to determine the rate of dripping of water using the wick to the leachate containers.

An air pump oxidizes the liquid in the maroon holding tank 24 X 7 X 365. The air pump (10) uses only 2W.

$$2W\ X\ 24\ X7\ X\ 365 = 122640WH = 123KwH$$

$$123kwH\ X\frac{0.35}{4.5} = \$9.5\ per\ year$$

The tomato plant used is named Lycopersicon esculentum which is a tomato variety which produces cherry sized tomatoes. The plants were initially grown in a plastic container with many holes which was designed to grow nursery plants. 20 days later on 5th Sep. 2021 they were transplanted into the Dutch buckets for the experimental plants and clay pots with normal soil for the control plants.

TABLE I. LIST OF SENSORS USED:

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

Fig. 5 left image shows the microcontroller and relays used and the right image shows how the data appears on a phone screen. The app used to develop this specific phone screen is MIT App Inventor [27].

In the Dutch buckets are filled 500g of coco peat mixed with perlite in the ratio of 1:3. Coco peat was chosen because of its resistance to disease and ability to remain undecomposed for long periods. It also has a high water retention ability. 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 access to O_2 since they are soaked in water. Farmers also add perlite to soil to reduce compaction in clay soil. Both perlite and coco peat have a neutral pH making it easier to provide a precise pH for the plant as nutrients are added.

The experiment and control were grown in the equatorial climate of Kuching, Malaysia (1.6 degrees above equator). The planting of the seedling in the nursery was done at the end of the dry season in August and transplanted into the Dutch buckets in September which is the start of the wet season. Kuching gets six times more rain than most of the Northern hemisphere consisting of the USA, Europe, China and Japan. The dry and wet season affects the temperature of the plants in the experiment since the rain does not fall into the experimental setup. The setup was placed at the edge of a shed. 5.7 L of water was added to the maroon reservoir daily. Nutrients were added to the reservoir till the EC (electrical conductivity) reaches 1.5 mS/cm (milliSiemens per linear centimeter). This plant needs an EC ranging from 1.2-1.6 mS/cm during the vegetative stage and 1.6-2.4mS/cm during the flowering stage [28].

The recycling of the liquid happens at 6 a.m. each morning for 5 mins / 24 hrs with a 45W water pump which circulates water in the orange pipes. An additional 1.6 L of water is poured into the reservoir at 12 a.m. The bottom of the Dutch buckets is placed vertically above the reservoir which enables gravity flow of water. At the bottom of the Dutch buckets the orange pipe is connected with Y shaped yellow connectors. A wick mentioned previously is placed from the Dutch buckets and leads to the Y shaped yellow connectors.

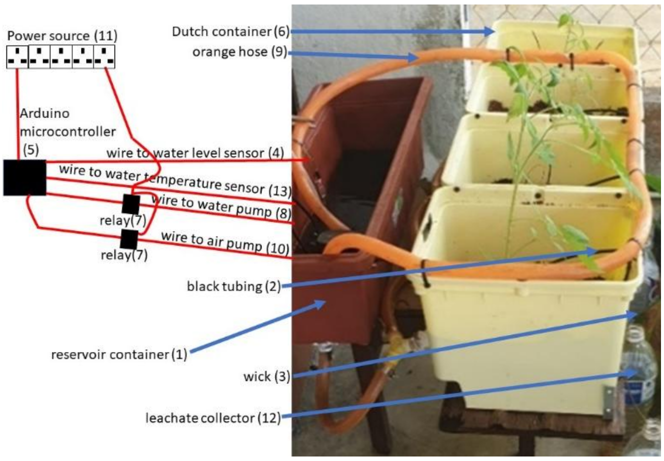

Fig. 3. The setup used to grow the tomato plants

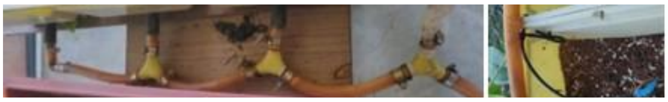

Fig. 4. The connection of the orange hose. The right image shows the piercing of the orange pipe with connector and the black pipe which goes to the plant

The water pump was controlled with the microcontroller (5) and the sensor data is also collected with the microcontroller. The microcontroller software is called Arduino Integrated Environment (IDE). The electrode water level sensor (4) was used to determine the water level in the reservoir. The water pump and air pumps (aerator) are controlled by the microcontroller via relays (7).

Fig. 6 is the chart of water level versus time. Data from the sensor is recorded every five minutes. If a quicker span was used the microcontroller could be overloaded with data. Data overload is one of the biggest problems in IoT systems; old data must be purged. A temperature sensor (13) was also used to determine the reliability of the air pump. The temperature must be above 32.3^{o}C is not suitable for this variety of tomato plant [29]. Fig. 7 is the chart of temperature versus time. Kuching has an ambient temperature of 21-32^{o}C but mostly above 25^{o}C. Temperatures below 25^{o}C are only reached around 6am just before the sun rises. The microcontroller utilizes the real time clock (RTC) to compute the time of the day [30].

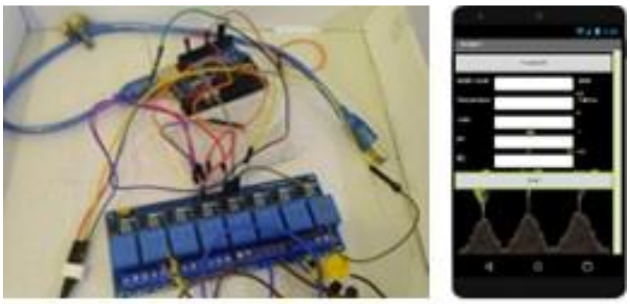

Fig. 5. The microcontroller (Arduino) and relays used. The right image is the phone app screen to monitor the sensors.

The phone app developed is shown as Fig. 5 right image. This screen keeps track of five parameters namely the (1) water level, (2) temperature, (3) time (4) pH and (5) EC level. This phone obtains data from the microcontroller through a HC-05 Bluetooth device. This enables the phone to be placed 15' away from the microcontroller. From the phone, data is programmed to be stored automatically in a Google Doc Excel spreadsheet in Google Drive. A button on a phone was programmed to input the readings from the pH and EC sensors since this data is manually read. The app was also programmed to send a notification when water in the reservoir was below 1V reading of the water level sensor.

IV. RESULTS

The results indicate that the transpiration rate through the wick irrigation of the plants increases during the no-sunlight hours as shown in Fig. 6. Here the blue chart is the actual data and the black line is the trend during the three distinctive time periods. This data is from the water levels in the reservoir. There is a steeper decline of transpiration rate during the night hours as if the plants were sleeping where they do not engage in photosynthesis. Right after dawn, the water intake increases as if it is breakfast time. And this thirst for water decreases after 12 p.m. This is when the pump is started to ensure maximum productivity by providing the plants with water and nutrients while also diluting the accumulation of salts within the medium. A calculation showed that the dripper provides 0.167 mL/s. As mentioned previously the pump is switched on for five minutes at 6 a.m. and its main purpose is to remove the salt accumulation within the medium. In these five minutes each plant would receive 50mL of solution.

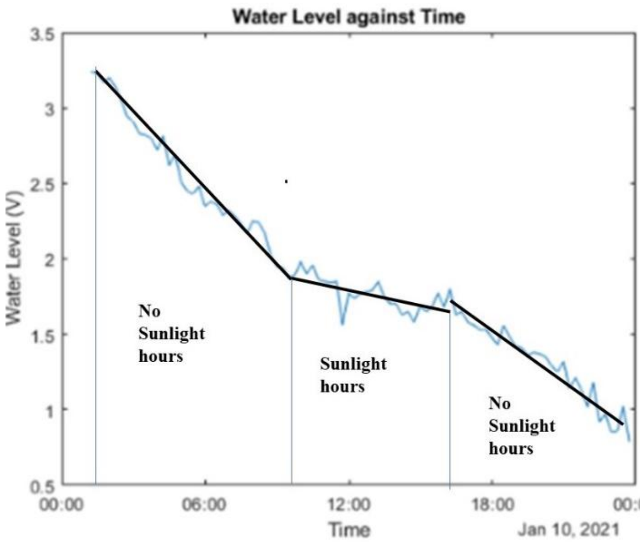

Fig. 6. Graph of Water Level against Time

The maroon reservoir had a volume of 5.7 L. The capillary rate was 0.03125mL/s per Dutch bucket. The liquid supplied to the four plants was 2.7 L over a period of 24 hrs. The loss of liquid over 24 hrs was 2.2 L for the Dutch buckets which was determined by measuring the liquid provided to the reservoir and deducting the liquid collected in the leachate bottles. This means the average liquid absorbed was 0.55L (2.2L / 4) for each pot over a period of 12 hrs minus a little gone via evaporation. The evaporation is very low in such a porous environment of perlite. It can also be observed from the liquid collected in the leachate bottles that there is a higher consumption of water by larger plants. Literature review indicated that this variety of tomato plants requires a minimum of 0.5 L of liquid per day for proper growth versus 0.55 L in this experiment [29]. Liquid connected in the leachate container was poured back into the maroon reservoir once in 24 hrs at 12 a.m.

The aerator has two functions, namely decreasing the temperature within the maroon reservoir as well as decreasing the temperature of water. The air bubbles increase evaporation thereby decreasing the temperature of the liquid. Fig. 7 depicts the water temperature as the blue chart and the orange chart as the atmospheric temperature. The blue chart is much lower than the orange chart meaning the water temperature is much lower than the atmospheric temperature indicating that the evaporation process which was enhanced by the air bubbles is effective in drawing out heat from the liquid. The chart also indicates that the aerator decreased the liquid temperature by 1.82°C over a 24-hr period which is quite a significant decrease for a 2W aerator pump. The chart also shows that the highest temperature of the reservoir is 29°C which meets the literature specified optimal temperature for this variety of tomato plant.

The pH and EC levels of the liquid was done manually using a pH and EC meter. The results of which are in Table 2. From this data it can be observed that the leachate pH was below 6 meaning it was too acidic for the plants but the pH of the liquid in the reservoir remained at an average of 6.8. To achieve this Mg salt was sprayed sparingly into the reservoir. If too much is sprayed, the plant will wilt due to too much salt absorption. The data in Table 2 indicates that over these five days the pH did not reach below the recommended levels thus the Mg foliar was not required.

The main result of the experiment is to measure the KQC (key quality characteristics) of the plants which are the size of the leaves and heights of the stems. The plants grown in the Dutch buckets were compared to the control plants grown in normal soil in pots. This measurement was done on 17th November 2021 which was 74 days after transplanting. Both experimental and control plants did not start flowering. The KQC data are tabulated in Table 3. Overall, there was a 34-67% improvement in KQC for the experimental setup.

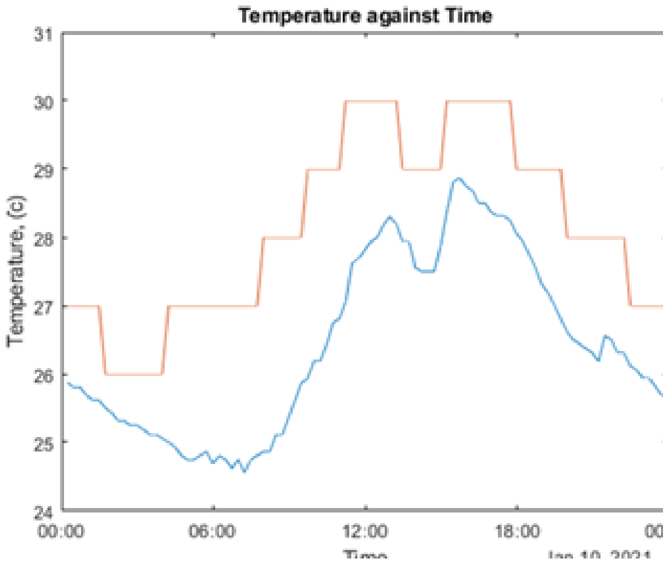

Fig. 7. Graph of Temperature against Time

TABLE II. 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 III. 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

The final thing worked upon was to power the whole system with solar panels. This is necessary since in some rural regions of Sarawak, there is no electric supply or the incoming lines are frequently damaged by wild animals, such as squirrels, snakes or falling trees. Even a day of no power from the grid have an impact on the health of the plants. The schematic for the solar panel setup is shown in Fig. 12. The photovoltaic data for Fig. 8 was taken over a period of five days in the month of June with a 10W photovoltaic panel. June is the driest month of the year in equatorial Kuching which implies the least cloud cover to block sunlight. One day's data was taken out due to heavy rains. The solar panel was rated by the manufacturer at 20V but based on the graph, the range of voltage was 12 to 22.5V which means an average $\bar{x}$=20.3V and a standard deviation σ =2.12V [32]. The peak voltage was around 13:45 hrs and the efficiency of the panels decreased due to overheating of the panels. This explains why huge PV projects attempted in desert countries failed. A place like Southwest Australia is optimum for solar panels where there are minimal no clouds as well as low ambient temperatures. The power consumption of the water pump, the aerator and the microcontroller is 5.807W as shown by the calculation below:

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

Power of Aerator = 2 W

Power of Arduino System = 0.057 W

Total Load Power = 3.75W+2W+0.057W =5.807W (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.

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

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

Kuching, Malaysia has days with very heavy downpours where there was no sunshine for up to a week. One battery would provide backup power for ≈ 2 days and 5 hours (4) of power for the system. Since the charging current (5) of a battery need to be one tenth of the battery rating, the number of solar panels required (7) to power the system (6) is as follows:

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

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

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

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

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

The aerator pump as well as the water pump and phone charger to power the microcontroller uses AC while the supply from the solar panel is DC. Therefore, an inverter (8) is needed. The power rating for this inverter should be 25% greater than the total load. An inverter of 8W is sufficient. It should have 12V DC input and an output of 240V AC. But since 100W inverters are available in the market, that can be used.

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

A 3A charge controller will be required because the battery's charging current was 2.6A. The charge controller would ensure that the maximum charging current is received by the battery (which is 3A) and prevent overcharging of the battery which will cause the battery to heat up.

The schematic for the solar PV system for the system is shown in Fig. 9. The solar panels will be connected in parallel since the inverter is 20V and more in parallel provides more mAh.

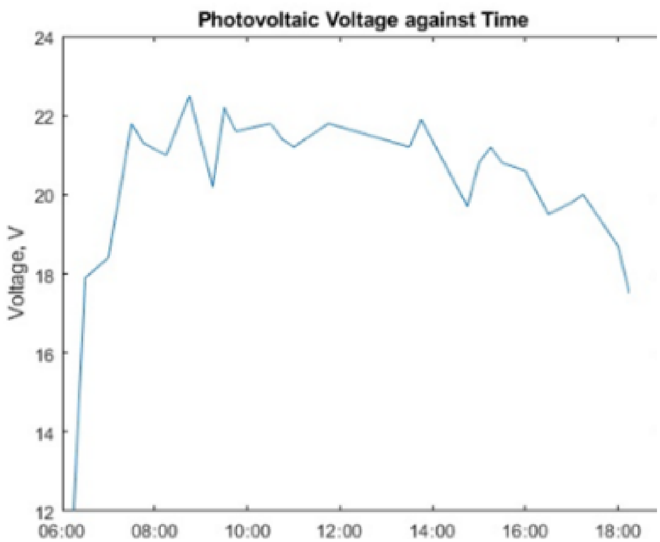

Fig. 8. Graph of Photovoltaic Voltage against Time.

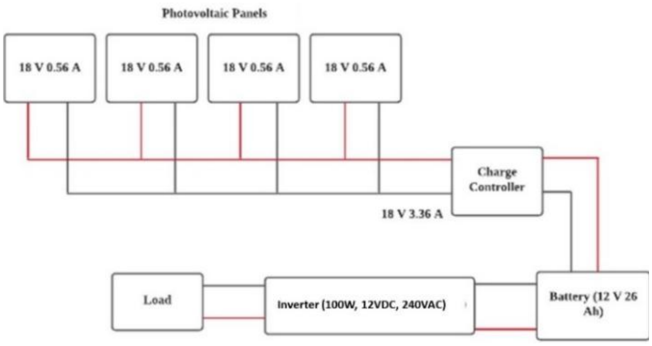

Fig. 9. Photovoltaic System Design

V. Conclusion

This research has proven that the usage of IoT can improve the quality of food grown both in terms of material usage as well as the output of the plants. The experiment tomato plants had better food value than the control ones grown in normal soil in clay pots. Table 3 shows the main results which indicates that for the chosen KQC, the experimental plants had 34-67% better characteristics.

Four sensors were used to monitor the plants which are the water level, temperature, pH and EC. For the first two data was automatically taken and sent to the microcontroller and the next two were manually inputted once a day. The data for the temperature and water level sensors was wirelessly sent over Bluetooth to an app which was designed and built on a smartphone. The smartphone was placed 15' away from which data was stored in Google Cloud in a Google Doc Excel spreadsheet. This data was later accessed with a laptop in another location.

Drip irrigation was provided automatically for the experimental plants every morning at 6 a.m. The refilling of water was done manually at 12 p.m. daily. Water and nutrients were continuously monitored to meet the literature review suggested numbers. The water retained in the medium was 0.55L. The consumption of the plants plus the little evaporation of the plants was 1.6L.

As for power consumption, the 45 W water pump used to perform irrigation was started only once a day at 6 a.m. for a duration of 5 minutes. The air pump is quite incredible in that it ran for 24 hrs X 365 days and uses only 2W. This is quite impressive for the cheap price for it. This is thanks to the high demand for it worldwide by those who rear fishes in home aquariums.

Some reviewers may highlight that the whole system was built with plastic parts which will lead to microplastics entering plants and reducing root growth and water and nutrient intake. But all parts used in this experiment have silicon equivalents thereby making them equivalent to growing in SiO_2.

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