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Design and Implementation of Lab Scale Automated Solar Powered Irrigation and Fertigation System

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Abstract: In Brunei, natural oil and gas contributes to about 99% in the generation of electricity and about 88% to the country revenue. Since Brunei is heavily dependent on a non-renewable energy, potential exhaustion of oil and gas reserves pose a challenge to the country, especially with continuous increase of energy consumption in order to meet the population demand. Additionally, Brunei has ambition to improve its agriculture sector. Implementations of PV systems in local agricultural sectors can also help improving the country revenue by increasing yield and reducing costs from electricity consumption. In this paper, we present design and practical implementation of fully automated solar powered irrigation and fertigation system. Ultrasonic sensors and moisture sensors are used to detect the state of the tank and the soil. The whole system is controlled with a microcontroller and a wireless monitoring system with mobile application is designed. The operation of the system was tested and the performance was acceptable.

Keywords: Solar powered, irrigation, fertigation

1. Introduction

Since the 20th century, oil and gas still remain as the main sources in electricity generation. The world energy consumption continues to grow annually especially due to the increase in world population which results in an increase of oil and gas consumption in order to meet the escalating population demand. On the other hand, generating electricity from fossil fuel could affect the ecosystem adversely. Brunei has a high potential of solar energy which can be utilized to reduce the fossil fuel consumption. Brunei has plan to increase its agricultural production. Solar energy can be used as the main energy source in the agricultural sector. Furthermore, the additional implementation of PV systems in agricultural farms, such as for automatic irrigation systems, can improve productivity of agricultural sectors and further help in the increase of the country's revenue.

According to the ministry of primary resources and tourism, the major contributors to the growth of the GDP as well as export and economic diversification in Brunei Darussalam are the primary resources, manufacturing sectors and agriculture and Agri-food [1]. To further enhance its economic contribution to the GDP and ensure the security and sustainability of the national food supply, much significance has been placed on the development of agriculture and Agri-food sectors. Data obtained from the Agricultural and Agri-food statistics of Brunei Darussalam from 2017 states that the land developed for agricultural use in Brunei Darussalam is 7225.14 ha whereby about 40% of this land is used for livestock farming and the remaining land of about 4267.32 ha was used for crop production. The statistics also shows that there are 822 livestock farmers, 433 crop farmers and 390 Agri-food entrepreneurs which gives a total of 5545 Agriculture and Agri-food farmers and entrepreneurs in the country. Furthermore, the recorded agriculture labour force added up to a total of 7685 persons with 1753 people working in livestock, 2057 people in crops and 3875 people

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in the Agri-food department [1]. It was also found that the livestock sector has a higher retail value of $199.81 million as compared to both the crop sector at only $59.65 million and Agri-food process which has an output value of $120.19 million. Hence the different sectors mentioned contribute to the total agriculture output at 53%, 16% and 31% respectively [1].

The implementation of solar energy for agriculture practices are also becoming more common in Brunei such as the installation of small solar PV for an aquaponic greenhouse owned by one of the Institute of Brunei Technical Education (IBTE) campuses. These automatic control systems provide plants with precise irrigation and fertilization using less power. From this, Brunei may be able achieve its 2035 national vision to enhance the agricultural sector by increasing yields and improving farming methods. PV systems were also installed in a secluded chicken farm in Pengkalan Batu. The local farmers initially had to hatch and raise their chickens in their home before transporting them to the farm as there were no access to electricity on the farm. The 500 Wp solar PV system allows the farm to power several incubators and small electronics which helps improve the productivity and revenue. Agricultural area is commonly located in the countryside or rural areas which are isolated from the main cities. Due to this, some of the farmers might not have proper access to the local electrical grid and are forced to generate their own electricity through diesel generator which might be expensive. Therefore, one possible solution to counter this is by implementing standalone PV system [2].

Implementation of low cost sensors in irrigation systems allows soil moisture levels as well as temperature and humidity to be monitored while still being accessible and affordable for even poor farmers. This is best used in areas with scarce water supplies which must be used in limited quantities. These systems usually use LCD to display the measured values and relays that control the microcontrollers for motor to pump water to the plants [3]. An automated sensor based system brings much significance to modern farming as plants are only watered when required. This reduces costs of water consumption and avoids wastage as compared to traditional irrigation techniques where farms are watered at regular techniques which has possibility of leaching fertilizers below the root zone, soil erosion and pollution of nearby water supplies [4]. Recently, the solar powered automated irrigation and fertigation systems have attracted a lot of attention due to their reliability, water saving, energy saving and automation. For further readings the readers can refer to [5-11] and the references therein.

The paper presents a low cost solution for automated solar powered farming. In the next sections, the energy situation in Brunei is briefly reviewed. Then the irrigation and fertigation processes are briefly explained. The system design is explained in section 4. Finally, the results and the conclusion are presented.

2. The Energy Situation in Brunei

Brunei Darussalam has a total area of 5,765 square kilometres with about 60 percent of the country's GDP generated by the energy sector. In 2013, the country's total final energy consumption (TFEC) totalled to approximately 0.92 Mtoe. As shown in Table 1, the highest energy consumption sectors are the transport sector followed by commercial and residential (Others Sector) and industrial sector [12].

Table 1 - Energy supply and consumption 2013 (Mtoe)

Supply and Consumption	**Oil**	**Gas**	**Electricity**	**Total**
Primary Energy Supplies				
Indigenous Production	8.01	10.45	-	18.46
Net Import and Others	-7.31	-8.28	-	-15.59
Total Primary Energy Supply	**0.70**	**2.17**	**-**	**2.87**
				Final Energy Consumption
Industrial Sector	0.15	-	0.02	0.17
Transport Sector	0.45	-	-	0.45
Others Sector[1]	0.02	0.02	0.25	0.29
Non-Energy	0.01	-	-	0.01
Total Final Energy Consumption	**0.63**	**0.02**	**0.27**	**0.92**

Mtoe = million tons of oil equivalent.
Note: Heating Values conversion factor of for natural gas: 1 TJ = 0.02388 Ktoe is based on IEA conversion factors.
Source: IEA and IEEJ, 2016.

Brunei has high potential of solar energy. The solar radiation in Brunei Darussalam is shown in Figure 1. The solar radiation is in the range between 4.7 to 5.8 KWh/m^2 per day which is considered as high level globally. The irradiation is obtained using different sources which are NASA, by estimation, and measured data. The estimated values are higher than the measured and NASA data, whereas both the measured and the data from NASA are approximately equal. However, all data values are realistic since they are within the reasonable global range of the irradiation. In this paper, the NASA data are used to design the PV system due to its reliability and its regular updates as well as the flexibility to access the irradiation history from previous years up to date.

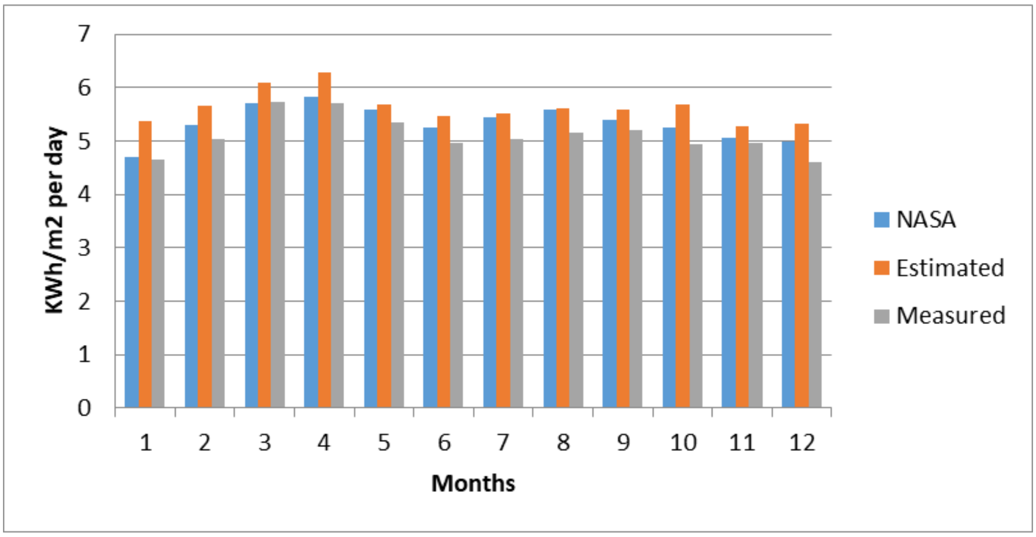

Fig. 1 - The solar radiation in Brunei

3. The Irrigation and Fertigation

Irrigation is a method of controlling the use of water given to plants at a specific time in order to ensure the growth of agricultural crops, maintaining scenery and helps to revive soil in dry areas and during drought [13]. There are many types of irrigation methods, which includes surface irrigation, overhead irrigation, drip irrigation, sub-surface irrigation, sprinkler irrigation and micro irrigation [13]. Focusing on the drip irrigation, it is considered as the most efficient water saving technique in which the rate of evaporation and runoff water are reduced and the main target is concentrated to the root of the plant [14]. Usually in irrigation, motors used are either diesel generator or electric motor, which can create pollution, the solution for this is by using solar energy. Some irrigation areas use gravity for the water to flow, but the disadvantage of this is that it cannot be controlled.

Fertigation is a system where fertilizers are injected through drip irrigation system and delivers the mixture of water and plant nutrients to plants in specific quantities and at specific time [15]. In order to determine the optimum ratio of water and plant nutrients, specific types of sensors are used, such as the pH level sensor and soil moisture sensor. Sensors are very important in automatic fertigation, since they are used to monitor and measure the plants condition [14].

Irrigation and fertigation can be controlled in two different ways, open loop system and closed loop system. In open loop system, the controller will have no feedback from the controlled object, hence sensors will not be used. Irrigation and fertigation will be performed periodically at specific time interval set by the user. Although open loop system is considered cheap, it does not provide the best solution in irrigation and fertigation, therefore closed loop system is introduced. In a closed loop system, the controller will have a feedback signals by using a sensor. During normal operation, the sensor will be used to monitor the control objects, in this case the plants. For example, if the soil moisture or soil acidity level is too low, the sensors will send a signal to the controller to indicate the plants needs to be supplied with water and fertilizer [15]. Many improvements have been made in the agricultural sectors to ease farmers and increase yields. Once such method is the introduction of automatic irrigation and fertigation systems as well as implementation of PV power to these systems.

4. System Design

The design of the system is divided into three parts which are the PV system design, irrigation system and fertigation systems design. The solar powered irrigation and fertigation system is shown in Figure 2. In PV system design, optimum battery and current are calculated depending on the daily load consumption and the solar radiation data in Brunei. The angle of inclination of the solar panel was also taken into consideration for optimum absorption of solar energy.

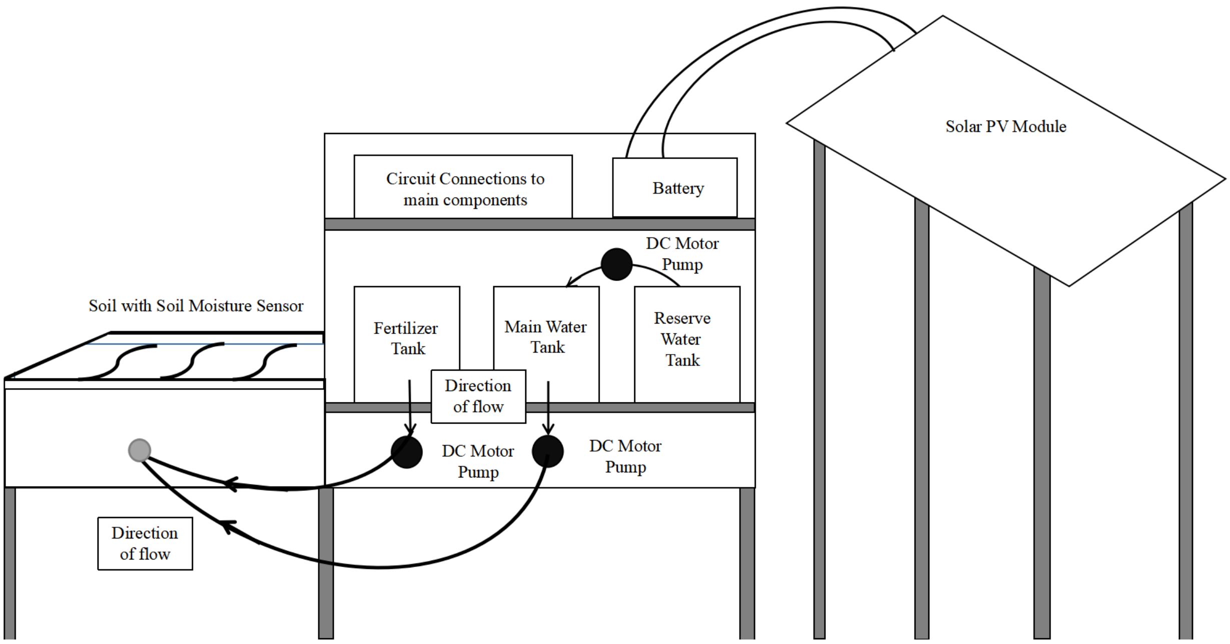

Fig. 2 - The solar powered automated irrigation and feritigation system

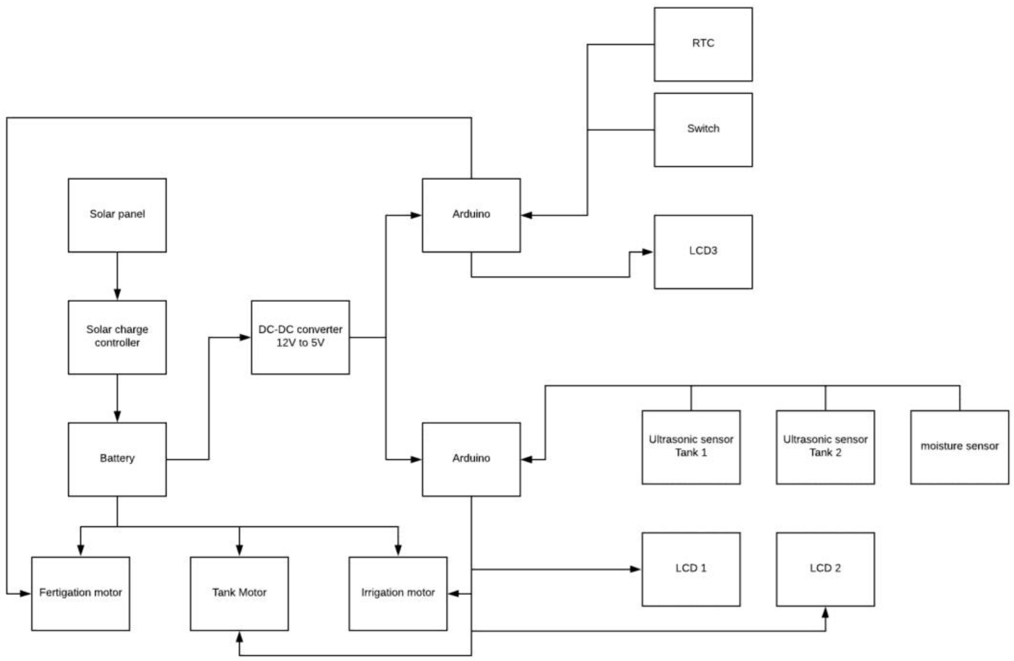

Fig. 3 - The solar powered automated irrigation and feritigation system

The fertigation and irrigation systems are designed to have two different tanks which are used to store water for the irrigation and fertilizer. Each tank is equipped with ultrasonic sensors to monitor the tank level and display it on LCD. Both of the systems use the dripping method by making use of a DC water pump to supply water and fertilizer into the plants. HC-SR04 ultrasonic sensors are used to measure the water levels of the water tanks to ensure that there is sufficient water for irrigation. Typically, an ultrasonic sensor uses a single transducer to transmit a pulse and to receive the echo of the pulse reflected back [16]. The irrigation system is designed as a closed loop system, where soil moisture sensor is used in the feedback. The soil moisture sensor would constantly monitor the soil for 24 hours. If the soil is too dry, the sensor will send a signal to the controller. The controller will then trigger the activation of the dc water pump so that the plant was supplied with water until the moisture level is high again. YL-69 moisture sensor is an electrical resistance sensor. It is set up by two pieces i.e. the electronic board and the probe. This soil moisture sensor reads the soil moisture content around it. The probe is made up of two electrodes. The soil moisture was determined based on the current that is passed through the soil and the resistance to the current in the soil. If the soil water content is high, the resistance of the soil will be low, thus more current will pass through and the output voltage of the sensor decreases and vice versa. This soil moisture sensor reads the soil moisture content around it and for a large area more moisture sensors need to be installed. The probe is made up of two electrodes. The soil moisture was determined based on the current that is passed through the soil and the resistance to the current in the soil. If the soil water content is high, the resistance of the soil will be low, thus more current will pass through and the output voltage of the sensor decreases and vice versa. Unlike the irrigation system, the fertigation system is designed as an open loop system, since no sensor is used. The fertilizer would be injected into the plants at specific time of interval, for example once a week. This was achieved by making use of RTC module. Additionally, a Bluetooth module was connected to allow remote monitoring of the systems showing the percentage level of water and fertilizer in their respective tanks as well as the soil moisture level. A stand-alone PV system is used as the main power supply, with a battery as a backup if no sunlight is available. The controller of the irrigation and fertigation system is an Arduino microcontroller. The complete system diagram is shown in Figure 3, and the flowchart of the system operation is shown in Figure 4.

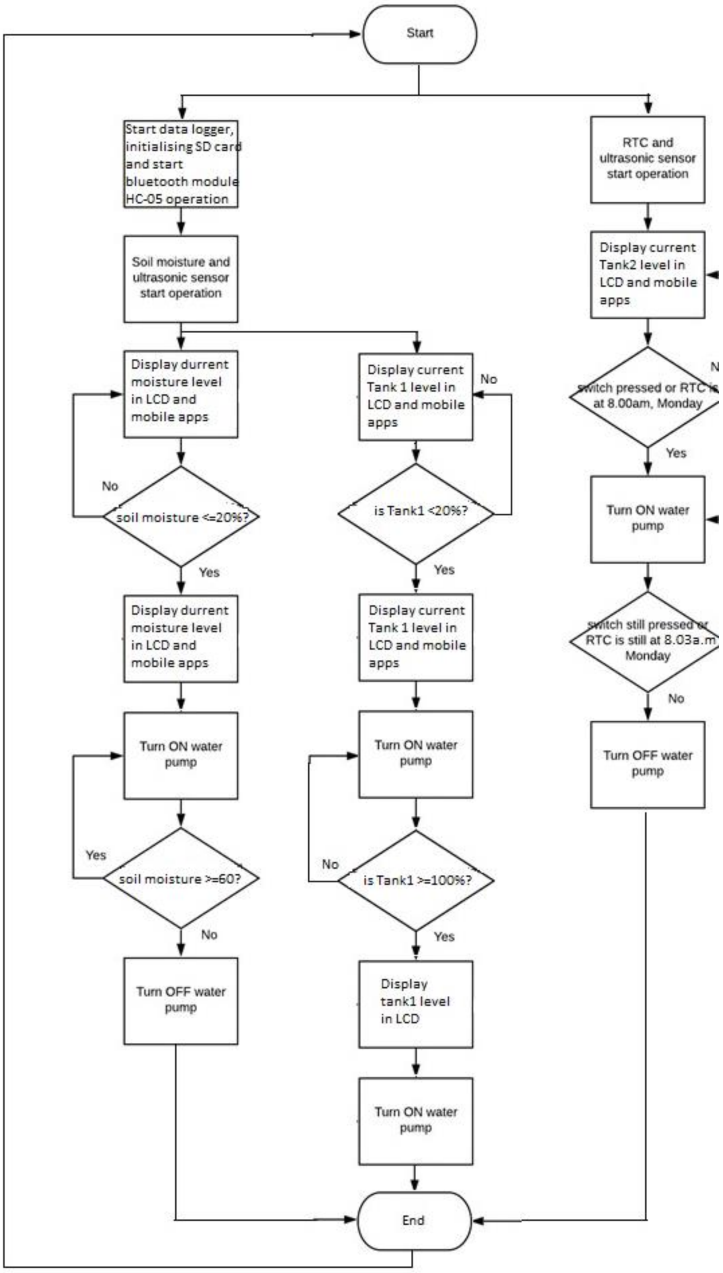

Fig. 4 - The solar powered automated irrigation and feritigation system

Ultrasonic sensor is placed on top of the irrigation and fertigation tank, measuring the height for both tanks which will later be used as level sensor for the tank system. The maximum heights of the tanks are 28 cm and 24 cm for irrigation and fertigation tank respectively. Calibration was made to both ultrasonic sensors by limiting the maximum range it can measured, in which in irrigation tank, the ultrasonic will only give an output reading from 0 to 25 cm while for the fertigation tank, the ultrasonic sensor will only give an output reading from 0 to 21 cm. Both tanks were divided into 10 divisions, representing 0% to 100% with an increment of 10% for each steps to indicate the water level of the tank. The schematic of the ultrasonic calibration is shown in Figure 5.

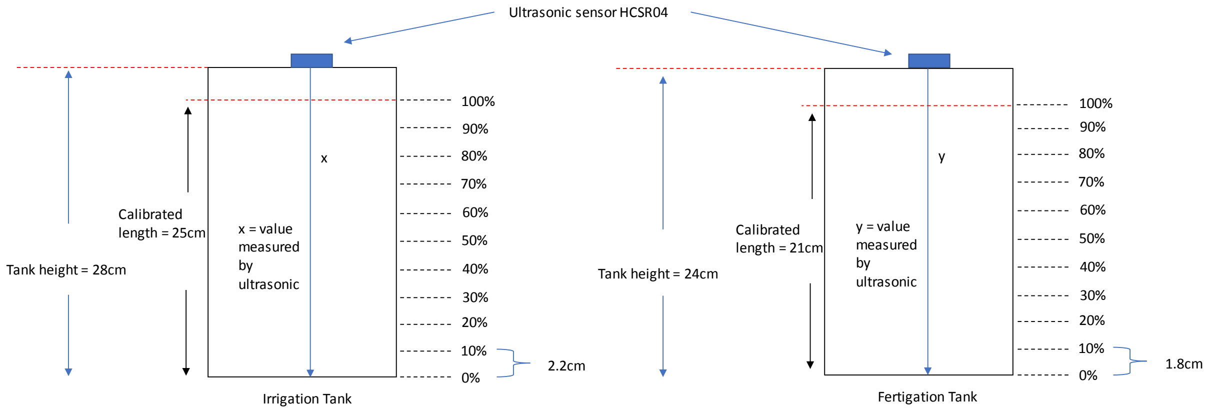

Fig. 5 - Ultrasonic sensors calibration

To design the PV system properly, the electricity needs of the system should be estimated. The different load used in the system are given in Table 2. From Table 2 the daily load consumption is 25 Wh. The required storage for the system for one day is:

$$C_R = \frac{D}{V_b} \tag{1}$$

Where C_R is the required capacity, D is the daily consumption and V_b is the battery voltage. The required storage for one day is then 2,069 Ah. In a worst-case scenario i.e. no sunshine for 2-3 days, the capacity of the battery should be approximately 6 Ah. The battery chosen for this project has a capacity 7.2 Ah. The average solar radiation in Brunei is 5.09 kWh/m^2. The current can be calculated using the mean solar radiation and considering 95% battery efficiency and 90% dust accumulation, the required current can be calculated as:

$$I_{PV} = \frac{D}{R \cdot \eta_{battery} \cdot \alpha} \tag{2}$$

Where I_{PV} is the PV panel current, R is the average radiation, α is the dust accumulation factor, and $\eta_{battery}$ is the battery efficiency. Using the given data, the optimum current of the PV panel is between 0.478 A – 1.127 A.

Table 2 - Daily load consumption

Load	Quantity	Power Rating (W)	Total Power (W)	Working hour (per day	Daily Watthour (Wh)
LCD 16x2	3	0.006	0.012	24	0.288
Soil moisture sensor	1	0.1	0.1	24	2.4
Ultrasonic sensor	2	0.075	0.15	24	3.6
12V DC water pump	1	5	5	0.033	0.165
12V DC water pump	1	5	5	0.0667	0.3335
12V DC water pump	1	3.6	3.6	0.083	0.2988
RTC module	1	0.0015	0.0015	24	0.036
HC-05 Bluetooth module	1	0.288	0.288	24	6.912
Arduino	2	0.225	0.45	24	10.8
total					24.8333

The overall system is shown in Figure 6. A plastic basin was used which contains about 5 cm of soil which is irrigated using drip system. Small holes were drilled equally distanced from each other on the hose pipes which are then laid on top of the soil as seen in the Figure 7. Due to uneven drilling of the water hose, some of the holes were facing upwards instead of towards the soil which instead creates a kind of sprinkler system as shown in Figure 8. Flooding of the soil might cause plants to suffocate and die, hence, this must be avoided which is done by drilling the bottom of the basin. However, it was found that this design is not enough to prevent flooding especially when there is an overflow during irrigation. Thus, more holes were drilled at the sides of the basin and the plastic basin was elevated to allow excess water to leak out shown in Figure 9.

Fig. 6 - The automated solar powered irrigation and fertigation system

Fig. 7 - Top view of soil area with drip system and moisture sensor

Fig. 8 - Water flowing out of water hose for irrigation

Fig. 9 - Additional level with drilled hole to avoid flooding

5. Results

Before the sensors are used in the system, the values of the sensor based on water content in the soil were tested. The results obtained from the test was used to determine the threshold value for the moisture sensor for the irrigation system. For the test, approximately 153 cm^3 of soil was used. The soil used was the typical soil found in Brunei Darussalam. The soil was left to dry for three days to ensure that there is no water content in the soil. The raw reading of the moisture content was recorded. Water was then added to the soil in steps and the sensor values were recorded. Figure 10 shows the relationship between the sensor reading with respect to the soil moisture content. Wireless monitoring of the system was available using a mobile application which allows users to monitor the water and fertilizer levels in the tank as well as the moisture levels in the soil. The mobile application was set-up and built using the online apps inventor known as MIT ai2 apps inventor. In setting up the connection between the HC-05 bluetooth module, an android compatible phone was needed. The advantage of remote monitoring system is the user can monitor the current status of tank and farm remotely. As can be seen from the Figure 11, the values shown in the LCD are exactly the same as that in the mobile application. However, it was found that there might be slight delays in the mobile application at times especially when the distance from the system is too far. The system was tested for three days and the results are shown in Figures 12-14.

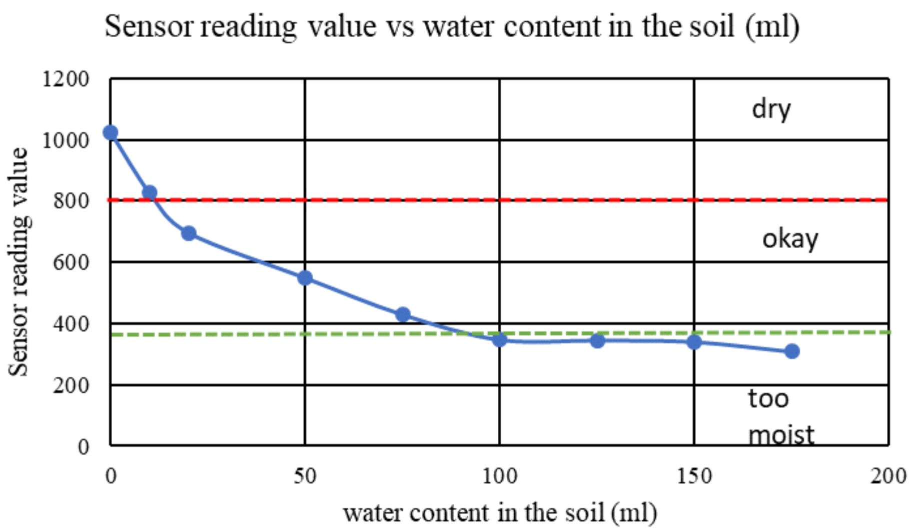

Fig. 10 - The solar powered automated irrigation and feritigation system

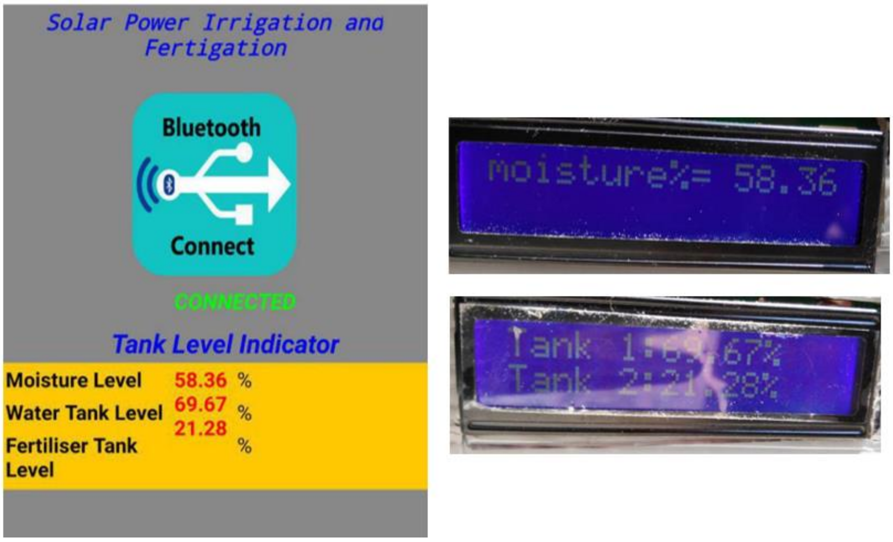

Fig. 11 - The solar powered automated irrigation and feritigation system

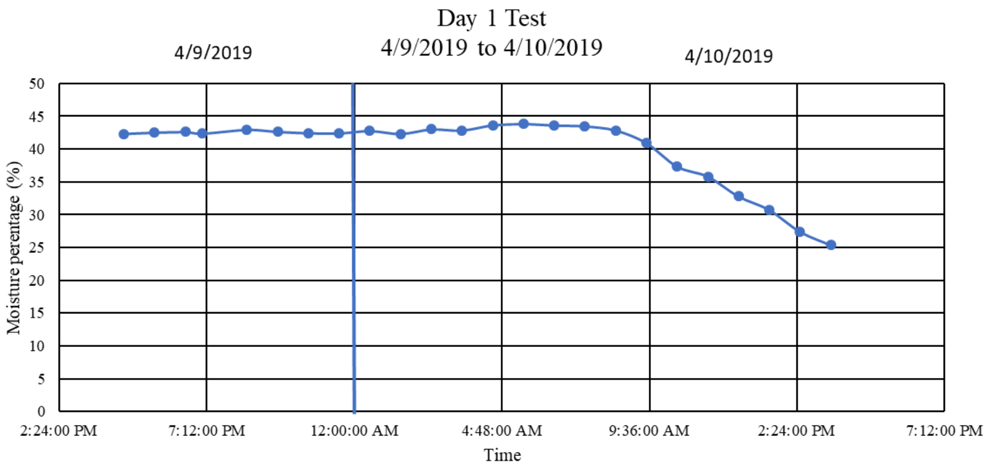

Fig. 12 - Soil moisture (%) with time for day 1

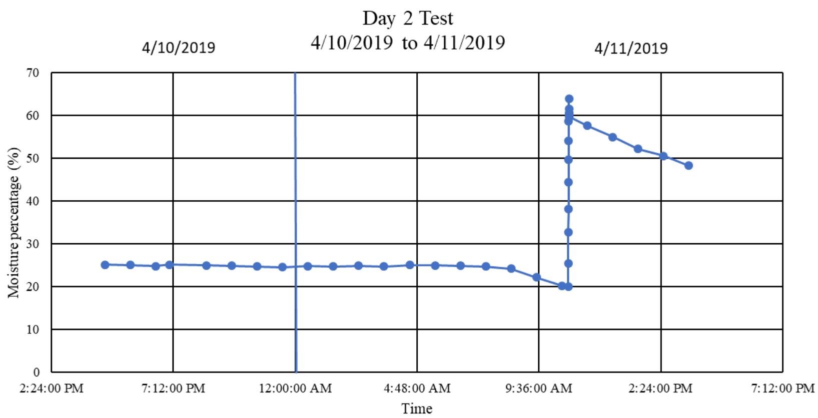

Fig. 13 - Soil moisture (%) with time for day 1

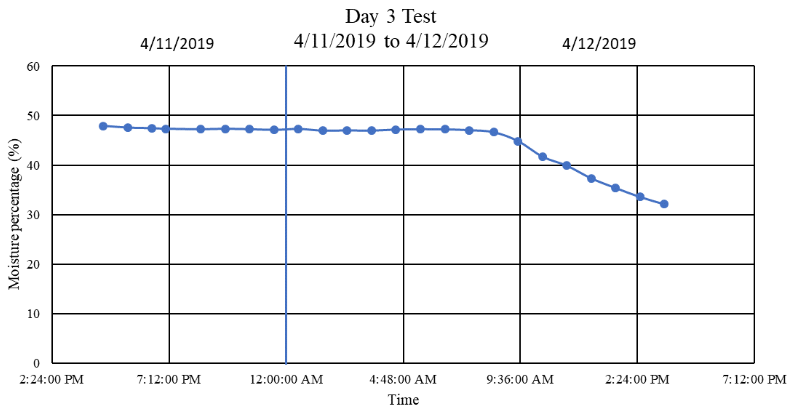

Fig. 14 - Soil moisture (%) with time for day 1

From the results obtained, when the experiment started, the moisture level percentage in the soil was approximately 42%. Between 4:30 PM and 8.30 AM in Day 1, it was seen that the moisture percentage in the soil remained approximately 42%. It remained almost constant because the temperature was lower at night. It can be seen from the figures after midnight, the moisture percentage in the soil increases by a small amount. The slight increase can be held accountable by the dew (water vapor) present in the air. After 8.30 AM there was a gradual decrease in the moisture percentage until 4:30 PM. This gradual decrease was because the temperature increases which caused the water in the soil to be evaporated to the air. From Figure 12, the decrease is almost linear. At 4.30 PM in 4/10/2019, the moisture percentage in the soil was recorded to be approximately 25%. This indicated that there was a 17% decrease in the moisture percentage.

In Day 2, between 4:30 PM and 8:30 AM, the moisture percentage approximately remained constant. After 8:30 AM, there was a gradual decrease in the moisture percentage. At approximately 8:45 AM, the moisture percentage decreased to 20%. This causes the controller to switch on the water pump responsible to pump water to the soil. The pump continued to operate until the moisture percentage reached 60%. After reaching the 60% mark, the controller switched the pump off. From Figure 13, the peak moisture percentage was greater than 60%. This because of the excess water dripping that was still present in the hose after the pump was switched off. The time it took for the pump to increase the moisture percentage from 20% to 60% was approximately 90 seconds. The peak reading was recorded at 10:46 AM. From Figure 13, it was observed that, the moisture percentage rapidly decreases from approximately 64% to 60% in a matter of 30 seconds. This was due to the excess water being drained out of the system through the holes of the base. The draining is required to prevent the system from flooding. From 10:46 AM to 4:30 PM in the same day, it was seen that there was a decrease of approximately 9.5% in the moisture percentage.

The trend observed in Day 1 occurred again in Day 3. After 4:30 PM, the soil moisture percentage approximately remained constant until 8:30 AM the next day. Between 8:30 AM and 3:30 PM, the decrease in moisture percentage was calculated to be approximately 14.5%. From the results obtained, it can be assumed that, it took about 3 days depending on the weather for the moisture content in the soil to decrease from 60% to 20%. The rate of the moisture losses depends on the temperature surrounding the system, types of plant planted in the system and the time of day i.e. the rate increases when there is peak sunshine. It can also be deduced that, with increased soil volume used in the system, more time is needed to decrease the moisture percentage from 60% to 20% and required more time to increase the same amount of percentage when the moisture percentage reaches 20%.

During the start of the experiment, the water level of tank 1 was recorded to be 100% (10 litres). After the water pump switched on and switched off in Day 2, the water level of tank 1 was recorded to be 70% (7 litres). From this, it was deduced that, for the volume of soil, it required approximately 3 litres of water to increase the moisture percentage from 20% to 60%. In an ideal situation, if the system requires 3 litres of water every 3 days, the tank can last for up to 9 days before it required refilling. From the result recorded, it can also be deduced that, increasing the volume of soil used for the system will also increase the water requirement thus increasing the time needed for tank 1 to be refilled.

6. Conclusions

In this paper we present the design and implementation of low cost solar powered automated irrigation and fertigation system. The objective of the system is to provide farmers with low cost solutions and ease of taking care of their farms. The automated irrigation and fertigation system is powered by solar panels and controlled by microcontroller. Ultrasonic and moisture sensors are used to detect the state of the soil and the water tanks. The system performance was tested for a number of days and it was acceptable. When the soil becomes dry the system will automatically water the soil with the sufficient amount of water. With further improvements, this system will be implemented for public use and help improve productivity and profits of the local agricultural sector in Brunei.

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