Journal FORTEI-JEERI, Vol. 1, No. 1, May 2020: 9 - 18
https://jeeri.fortei.org/index.php/fortei-jeeri

Automatic Watering System for Tomato Plants Based on Soil Moisture Detection

Supriyanto Praptodiyono[1*], Wawan Setiawan[2], Sumardi Sadi[3]
Electrical Engineering Department Universitas Sultan Ageng Tirtayasa Banten, Indonesia[1,,2]
Electrical Engineering Department Universitas Muhammadiyah Tangerang Banten, Indonesia[3]
*Corresponding Author Email: supriyanto@untirta.ac.id

Abstract -- Water is the main element of growth for tomato plants; a further suitable watering system of the plants should be taken into consideration. Tomato plants require water that is under ideal soil moisture conditions so the plants can continue to flourish. Problems occur during the dry season; farmers must pay extra for watering. To address the issue, an automatic tomato plant watering system is needed. The system should streamline the use of water as well as the energy and costs of farmers in tomato cultivation. This research aims to find out the watering system prototype to tomato plants that use the solar cell as the energy supplier. The system used a control system with Arduino UNO as soil moisture levels detection. A DC pump is connected to the control system to supply water when law level soil moisture detected. Experiments were done to test the prototype using 25 tomato plants. The results showed that the system could control soil moisture 65% - 90% and streamline water usage by 24.71 litres per month. The 50 Wp Solar Cell can charge 20 Ah battery with an average charging current of 0.78 A, and adequate charging time is 7 hours per day.

Keywords:
Watering System
Arduino UNO
Soil Moisture
Tomato Plant

Article History:
Received: April 15, 2020
Revised: May 16, 2020
Accepted: May 31, 2020
Published: June 3, 2020

DOI: 10.46962/forteijeeri.v1i1.02

I. INTRODUCTION

The development progress of a country is influenced by the availability of energy resources, water, and food production (agriculture). To stay a life, human needs food, that makes it very important needs their life. One of the most sought-after food commodities and consumed by Indonesian people is vegetables. Public awareness about the importance of healthy living resulted in increased demand for vegetables. One type of vegetable that is sought after and consumed by the public is tomato.

Plant growth requires sure soil moisture [1]. Like tomatoes, if soil moisture is too high, it will stimulate vegetative growth. It was resulting in flower loss and earlier fruit formation. Stress or lack of water that occurs at the time of transfer will inhibit the development of tomato plants, so that plant biomass is reduced [2]. Therefore, regulating water distribution for watering tomatoes is very important. This condition is closely related to tomato farmers who have to spend extra money and energy to water the plants during the dry season.

The current technology related to irrigation is still conventional and cannot manage water properly. Generally, tomato farmers visit their land to see the humidity or conditions on the ground periodically and irrigate agricultural land under the perspective of farmers.

There have been several previous studies related to soil moisture monitoring tools, including research conducted by Divani and Patil in India [3], making an automatic plant watering system. However, manufacturing is still using conventional electric power supplies. The problem that arises is when this automated plant watering system is applied in rural tomato plantations that have difficulty accessing electricity.

While the research of Yahwe, Isnawaty, and Aksara [4], discusses the design of prototype systems to monitor soil moisture by utilizing short message services based on the results of watering plants. In this study, the hardware used was soil moisture sensor FC-28 to determine soil moisture conditions. The FC-28 humidity sensor is easy to rust, and the readings are not accurate.

Therefore, researchers are interested in examining the implementation of solar cells in a soil moisture-based tomato sprinkler system such as [2], [5], [6]. They were facilitating the work of tomato farmers in optimizing their production. This research used solar cells that do not depend on conventional electricity as the power supply system. In contrast, this research uses capacitive soil moisture sensor v1.2 to monitor the humidity. This sensor is more accurate and rust-resistant. Further, it is expected to be able to overcome the problem of resistance sensors that are easily destroyed and can be more efficient at removing water for watering [7].

The rest of this paper provides methodology in Section 2, followed by result and discussion in Section 3. It contains the performance of the watering system prototype. The last section is a conclusion that consists of recommendations and future works.

II. METHODOLOGY

In the design of the watering system for tomato, plantation includes both the solar cell power supply and the controlling process by the humidity sensor Capacitive Soil Moisture Sensor. The monitoring system uses the Water Flow Sensor with the Arduino UNO microcontroller as the processing component. The overall building block of the system is shown in Fig. 1. From the Fig.1, it can be seen the watering system design is divided into three blocks, that each block is described as follows:

A. Power Supply Block

The first block is the Power Supply Block that consists of Solar Cells, SCC (Solar Charge Controller), and Batteries. The function of this block is to supply electrical power to the components in the monitoring block and controlling water use. The aim is to ensure that the power requirements of the entire device can be met. This block will calculate the number of requirements and the appropriate specifications of the solar cells, SCC, and batteries based on the power requirements that must be met in the monitoring block of water use and controlling soil moisture of plants.

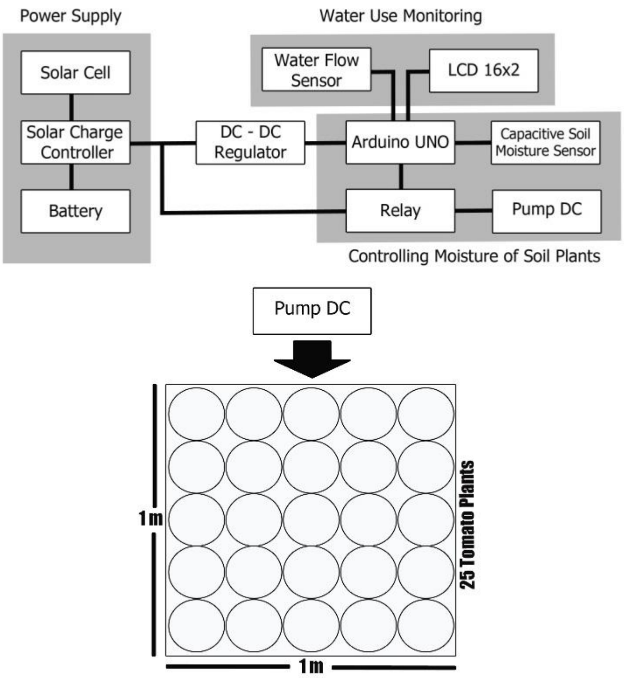

FIGURE 1.
Main block diagram of the prototype

B. Water Use Monitoring Block

In this block, there is the monitoring of water use, which aims to display daily water usage. There are 16 x 2 LCD components and Water Flow Sensor. This LCD serves to display the volume of water that is read or detected by the Water Flow Sensor in litres. So that this tool can read every litre of water spent on watering tomato plants every day, from the results of this block can calculate the efficiency of water usage in a soil moisture-based tomato watering system. The flow of the process of monitoring water use is as described in Fig. 2 below.

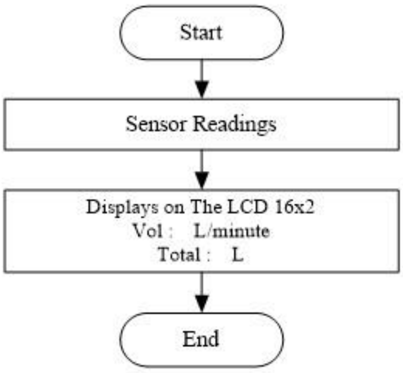

FIGURE 2.
Flowchart of water usage monitoring

From Fig.2, it can be shown, in the first step, the sensor starts reading the input obtained from the water flow sensor. The sensor is installed in the water flow pipe towards watering the tomato plants. The second step is forwarding the result to the Arduino UNO to process. The result is changing the data into a form of information. The last step is displaying the information in the 16 x 2 LCD. The LCD is then converted and displayed the information obtained from the Arduino in the form of volume display in units of L/min and total water usage if the pump turns on in Liters.

C. Soil Moisture Controlling Block

In this block, there is a controlling block of soil moisture that functions as an ideal water controller for tomato plants. This block was designed to control the water expenditure that resulted in a more efficient watering system that uses the water as needed. This block consists of 4 components include Arduino UNO, Capacitive Soil Moisture Sensor v1.2, Relay, and Pump DC.

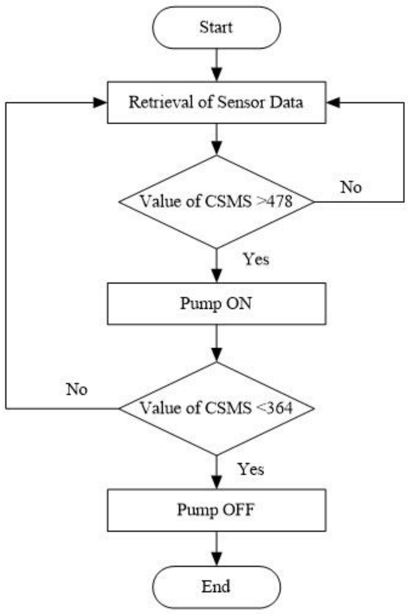

FIGURE 3.
Flowchart Soil Moisture Control Process

This block conducts its function that can be summarized as follows: Capacitive Soil Moisture Sensor detects the level of humidity of tomato plant soil media. The output of the sensor is then transmitted to Arduino UNO, which is then processed and justified whether the needs are watering or not. If so, the Relay responds and turns on the DC pump. When the ground no longer needs water, the relay cuts the power to the DC pump so that the DC pump turns OFF. Fig. 3 shows the flowchart of the soil moisture-controlling block.

The sensor first detects the level of soil moisture of the tomato plant media. If the soil moisture is detected in a dry state or the humidity level is below 65% with a sensor value of more than 478 RH (Relative Humidity), the Arduino UNO will process to activate the DC pump through a relay. Further, the DC pump is on following by spraying the plant, the sensor reads to a soil moisture level of less than 364 RH or 90%. In this state, the soil is moist and suitable for tomato plant conditions. Last step, the Arduino UNO conduct the process again that resulting in the DC pump is turned off.

III. Result and Discussion

A. Designing a solar power plant on a prototype

The watering system for a tomato plant with a solar power system was designed to meet the energy consumption of the device. The total electricity consumption that consists of DC pump operating for 1 hour and power requirements for Arduino, LCD 16x2 and two other sensors for 24 hours can be seen in the following Table 1.

TABLE 1.
Consumption of Electric Energy

Load	Power (W)	Usage (hour)	Energy (kWh)
Pump DC	65	1	0,065
Arduino UNO	0,2	24	0,0048
Capacitive Soil Moisture Sensor	0,025	24	0,0006
Water Flow Sensor + LCD	0,05	24	0,0012
Total Energy (kW/day)			0,0716

Based on Table 1, the consumption of electrical energy required to operate the prototype of a watering system based on soil moisture for a tomato plant is 0.0716 kW per day.

As for the electrical energy that must be supplied by solar power, the plant must be summed with the assumption of system losses. The electricity consumption provided by the solar power plant is summed to the assumption of losses in the system of 15%. The design of the solar power system used with the energy consumption supplied by the solar power system is as follows:

$$\begin{aligned} E_L &= (15\% \times Consumption\ of\ Electric\ Energy) + Consumption\ of\ Electric\ Energy \\ &= (15\% \times 0{,}0716\ kWh) + 0{,}0716\ kWh \\ &= 0{,}08234\ kWh \end{aligned}$$

The array area calculation is obtained using the following equation:

$$PV\ Area = \frac{0{,}08234\ kWh}{2{,}66\ kWh/m^2 \times 0{,}1359 \times 0{,}9906 \times 0{,}90} = 0{,}322\ m^2$$

From the calculation of the array area, the amount of power generated by the solar power plant (watt peak) is obtained using the following equation:

$$\begin{aligned} P_{Watt\ peak} &= 0{,}322\ m^2 \times 1000\ W/m^2 \times 0{,}1359 \\ &= 43{,}76\ Watt\ Peak \end{aligned}$$

Based on the amount of power generated, the number of solar panels is obtained using the following equation:

$$\begin{aligned} Number\ of\ Panels &= \frac{43{,}76}{50} \\ &= 0{,}88 \sim 1\ Solar\ Panel\ (50\ \text{Wp}) \end{aligned}$$

The need for solar panels to load DC Pump, Arduino, and two sensors is one solar panel. P watt peak solar power plant with a solar panel count of 1 is:

$$\begin{aligned} P_{Watt\ Peak} &= P_{MPP} \times Number\ of\ Panels \\ &= 50\ Watt \times 1 = 50\ Watt\ Peak \end{aligned}$$

B. Solar Panel Testing

The testing of solar panels here aims to determine the amount of output value of solar panels in the form of voltage, current, and maximum power when given a variety of conditions, namely sunny, cloudy, and cloudy conditions. The values of voltage and current output are tested using a multimeter and digital ammeter to see the magnitude of changes output voltage and current against a given condition.

The testing of solar panels in this study was conducted at 09.00 until 15.00 (March 4, 2019). The intensity of the sun will appear in the morning (starting at 09 am) and will disappear around 15:00 (03 pm). This range of time was considered as a suitable time on getting sunlight. Besides, the research site is flanked by a hill so that sunlight will be blocked at 15:00. In the testing scenario, the solar panel was placed on solar panel support with a height of 1.2 meters, and the solar panel data was taken once an hour. The results of the solar panel testing are shown in Table 2.

TABLE 2.
First Testing of 50 Wp Solar Panel using Sunlight

Time	Voltage (V)	Current (A)	Power (W)	Condition
09.00	18,22	0,84	15,30	Bright
10.00	19,05	0,91	17,34	Bright
11.00	19,55	0,46	8,99	Cloudy
12.00	19,64	1,19	23,37	Bright
13.00	19,70	1,48	29,16	Bright
14.00	18,28	0,68	12,43	Cloudy
15.00	18,44	0,35	6,45	Cloudy

The results indicate that the voltage and power usage on the system is relative to the condition of sunlight. The voltage is more stable than power. When the cloudy condition met, the power is down about half.

C. Battery Capacity

The amount of battery capacity required is depended on the need for electrical energy consumption (EL), the percentage of deep of discharge DOD) that is determined by 80%, and the system voltage on the battery (Vs). Another parameter that influences the battery capacity is the determination of Autonomy Days. The last factor is the state of the battery, whether it can supply the load when there is no energy coming from the solar panels or the conditions when the weather is cloudy and rainy. The determination of Autonomy Days in this study is two days.

With the amount of deep of discharge (DOD) on the battery 80%, the battery capacity (Cb) needed are:

$$Cb = \frac{0{,}08234 \times 2}{12 \times 0{,}8} = 17{,}2\ Ah$$

From the calculations that have been made, it means that the battery requirement that must be prepared to supply the research prototype system is 17.2 Ah or above.

D. Battery Charging Test

The testing of the battery current was done using SCC (solar charge controller). This test aims to find out how long the battery charging process duration and the level of voltage stability. The battery used in this study is a 12-volt Deep Cycle battery. The test was conducted using a voltage input for a 17-20 V DC solar panel voltage that is regulated by the SCC up to a 14 V DC voltage using a PWM ((Pulse with Modulation) SCC type. The battery charging test results using the PWM SCC type, as shown in Table 3.

TABLE 3.
Battery Charging Data

Time	**Voltage (V)**	**Current (A)**	**Power (W)**
09.00	14,5	0,47	6,82
10.00	14,5	0,87	12,62
11.00	14,5	0,92	13,34
12.00	14,5	0,94	13,63
13.00	14,6	1,14	16,64
14.00	14,5	0,76	11,02
15.00	14,4	0,34	4,90

The testing was done from 09.00 am until 3.00 pm. The results of battery testing in Table 3, obtained the average total current value of 0.78 Amperes per day. When calculated the length of time needed to charge a 20 Ah battery is as follows:

$$Charging\ Time = \frac{20\ Ah}{0{,}78\ A}$$
$$= 25{,}64\ h \sim 26\ h$$

So, the charging time of battery with a capacity of 20 Ah is 26 hours.

E. Water Flow Sensor Monitoring Test

Water flow sensor testing aims to find out how much water is needed by tomato plants during the growth period. The types of plants area that were watered consist of 25 plants placed in 25 polybags, with a plot size of 1 m^2. Fig. 4 shows the watering system, especially the tomato plant area.

FIGURE 4
Tomato Plant Position

The tomato watering system is intended to maintain soil moisture as a means of sustaining plant growth. The humidity level of tomato plants must always be maintained in the range of 65 - 90%. If the soil lacks water, it will dehydrate the plant so that the stems and leaves also dry out, and the leaves come falling. Likewise, on the contrary, too much water in the soil will cause the soil to saturate and make the plants lack of oxygen because the soil structure is too much water. Tomato plants will quickly rot both leaves, stems, and fruit.

Furthermore, to know the implementability of this watering system, the water flow sensor testing was carried out for one month as the planting period determined. The water flow function is to measure the need for water discharge that is splashed to the plant area. Further, the required water for tomato plants can be known. The test was conducted for 31 days after planting (March and April 2019). The data of water flow sensor testing can be seen in Table 4.

TABLE 4.
Water Flow Sensor Monitoring

Day	**Water** (Liter)	**Day**	**Water** (Liter)
1	13,19	**17**	13,20
2	13,12	**18**	13,65
3	13,25	**19**	13,22
4	12,91	**20**	13,18
5	13,22	**21**	12,88
6	13,37	**22**	13,67
7	13,48	**23**	13,89
8	12,82	**24**	13,06
9	13,64	**25**	13,46
10	13,52	**26**	14,12
11	13,25	**27**	12,55
12	13,76	**28**	12,79
13	12,98	**29**	13,23
14	13,50	**30**	13,42
15	13,41	**31**	13,30
16	14,01		
Total watering for 31 days			**413,05**

Data listed in Table 4 were collected only on days without rain. It aims to determine the tomato plant water requirements per day in real count according to what is read by the sensor. Thus, the total water in a month can be calculated without any other water source. The daily water need is not constant every day. However, the variety is not significant.

F. Capacitive Soil Moisture Sensor and DC Pump Testing

This test aims to determine whether the soil moisture level is under the humidity needed by tomato plants. In this test, the data produced by the capacitive soil moisture sensor. In this measurement, the soil moisture level was measured in the range of 1–10, ranging from dry to wet. Then this value is converted into the percent to 10% - 100%. The suitable humidity for tomato plants themselves is in the range of 65-90%. Fig.5 is the soil moisture measurement tool used in this test.

FIGURE 5.
Soil Moisture Measurement

In this measurement, the Arduino has been programmed before read the soil humidity. Arduino will find out the value of sensor output in the time soil moisture level detected in the ranges between 65-90% in the soil moisture meter. The results of the capacitive soil moisture sensor test and the conditions of the DC pump can be seen in Table 5.

TABLE 5.
Capacitive Soil Moisture Sensor

Test	**Soil Humidity**	**Sensor Reading (RH)**	**Pump DC Status**
1	65%	477-479	ON
2	70%	436-438	ON
3	80%	399-401	ON
4	90%	363-365	OFF

From Table 5, when the soil humidity is at 65%, the soil moisture sensor results are 477 until 479. In the range, Pump DC status is ON. The pump is still ON when the sensor reading results in 436-438 for soil humidity 70% and the range of 399-401 for soil humidity of 80%. The pump is then OFF the soil moisture meter is 90% with a capacitive soil moisture sensor value of 363 - 365 RH.

For the record, the smaller the number reads on a soil moisture meter, the soil conditions are drier, and the opposite is also the case. The larger the number that reads, the soil is more humid. This concludes that the Arduino COM was reading in the range of 477-479 RH when the gauge is at 65%. The test is carried out in a soil medium where the humidity level is arranged in such a way. Table 6 shows the frequency of pump runs for watering and the duration it takes for watering the tomato plant.

TABLE 6.
Duration of DC Pump in ON Condition (for one day)

Watering	**Time**	**Duration (Minute)**
1	09.07	7,4
2	10.28	7,6
3	11.25	7,5
4	12.30	7,8
5	13.35	7,7
6	14.50	7,4
7	15.48	7,2
8	17.29	7,1

As seen in Table 6, the DC Pump turns on eight times with variable glowing time. With the lowest time of 7.2 minutes at 3.48 pm and the highest time of 7.8 minutes at 12:30 pm. The total time of the eight times of watering is 59.7 minutes per day. In other words, the tomato plants need to be watered about 1 hour per day to stay grow up.

Soil moisture measurements were carried out in each polybag using a soil moisture meter to measure the soil condition of each polybag after watering. This measurement was done to ensure the watering method runs well and optimally on all planting media of tomato plants. The measurement results are in Table 7.

TABLE 7.
Soil Moisture Measurement after Watering

Polybag No.	Soil Moisture Value (%)	Polybag No.	Soil Moisture Value (%)
1	90	14	88
2	90	15	89
3	90	16	90
4	88	17	90
5	90	18	91
6	91	19	92
7	89	20	91
8	89	21	90
9	90	22	90
10	92	23	88
11	90	24	92
12	87	25	87
13	90	**Average**	**89,8**

From Table 7, it can be seen, the soil moisture data from each polybag after watering, the soil moisture value of each polybag tends to fluctuate. The lowest soil moisture value is 87%, while the highest is 92%, and the average of all of them is 89.8%. Wind conditions cause the difference in humidity values, so water that should water the polybags carried by the wind and change direction. However, this difference in value is not very significant, because the interval of the difference in value is only around 1% - 5%.

G. Testing of Usage Length

Calculation of usage time on 12 Volt 100 Ah batteries with DC Pump load and Control and Monitor Box is

$$I = \frac{71{,}6\ Watt}{12\ Volt}$$

$$= 5{,}97\ Ampere$$

$$t = \frac{20\ Ah}{5{,}97\ A} = 3{,}35\ hour$$

$$Duration\ of\ use = 3{,}35 - (20\%\ x\ 3{,}35)$$

$$= 3{,}35 - 0{,}67$$

$$= 2{,}68\ hour$$

From the calculation results obtained, the duration of the use of batteries with a capacity of 20 Ah with a total load of 71.6 Watt is 2.68 hours or 2 hours 41 minutes the battery can survive, leaving 20% of battery energy. The experiment with the load are battery, DC Pump, and the Monitor Box; there was obtained the value of the battery voltage. The percentage of the battery per hour is shown in Table 8.

When testing, the battery was filled with a voltage of 13.38 V with a 100% battery percentage and then given a load of 1 DC Pump and 1 Control and Monitor Box (Arduino, Sensor, and LCD) with a total power of 71.6 watts. Testing was done to find out how long the actual battery usage by taking data every hour. However, there are differences between the calculation and testing data, as shown in Table 8. Table of the results of long battery usage tests, the battery can last for 10 hours until it reaches the critical point of the battery (leaving 20% of battery energy). While from calculations, the battery can only last for 2 hours 41 minutes.

TABLE 8.
Observation Results of Total Load on the Battery

ON duration (minutes)	A load of Pump DC, Control and Monitor Box	
	Battery Voltage (V)	Battery Energy Percentage
0	13,38	100%
60	12,79	92%
60	12,72	85%
60	12,63	79%
60	12,54	72%
60	12,24	66%
60	11,95	57%
60	11,62	48%
60	11,51	40%
60	11,33	31%
60	11,12	21%

The table shows, in the ON duration (10 x 60 minutes), the battery energy reduces up to 21%. This means that the battery can reach for 10 hours to stay ON. Whereas the average of the DC Pump is ON is 1 hour per day. The accumulation of the battery life for the watering system is ten days. After that, the battery should be charged. However, this condition is influenced by the state of the battery that is still new and the right weather conditions.

IV. Conclusion

Watering system technology that can help automatically ON when needed to water tomato plants is required to assist the farmer in a dry season. The farmer need not stay at the tomato plant during the dry season. A prototype of the watering system for the tomato plant had been created in this research. The system used solar cells as the power supply. The Solar Cell can charge a 20 Ah Battery with an average charging current of 0.78 A per hour. The battery is fully charged for 26 hours with effective charging 7 hours/day. The 20 Ah battery can provide power supply to the prototype of the soil moisture-based tomato watering system with the number of tomato plants 25 pieces of land size of 1 m^2 for ten days each time charging. The design of the prototype watering system based on soil moisture using solar cell power supply managed to adjust the soil moisture level of tomato plants in the range of 65% - 90%. The DC pump turns on when the Capacitive Soil Moisture Sensor is higher than 478 RH or 65% on the humidity gauge. The DC pump will be stopped when the Capacitive Soil Moisture Sensor is less than 364 RH or 90% oof the humidity.

V. REFERENCES

[1] Matenge, G. R. "Soil Moisture Based Irrigation Test in a Remotely Monitored Automated System." *Irrigat Drainage Sys Eng* 6.192 (2017): 2.

[2] Zotarelli, L., Dukes, M. D., Scholberg, J. M. S., Munoz-Carpena, R., & Icerman, J. "Tomato nitrogen accumulation and fertilizer use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling." *Agricultural Water Management* 96.8 (2009): 1247-1258.

[3] Divani, Drashti, Pallavi Patil, and Sunil K. Punjabi. "Automated plant Watering system." *2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*. IEEE, 2016.

[4] Yahwe, C. P., Isnawaty, & Aksara, L. F., “Designing Prototype System Monitoring Soil Moisture Through SMS Based on Results of Watering Plants.” Jurnal Universitas Halu Oleo Seman TIK, Vol. 2, No. 1, ISSN : 2502-8928, 2016.

[5] Nugroho, A. P., Okayasu, T., Inoue, E., Hirai, Y., Mitsuoka, M., & Sutiarso, L. "Real-time Evapotranspiration Monitoring in Tomato Greenhouse."

[6] Nafeh, El-Shafy A. "Design and economic analysis of a stand-alone PV system to electrify a remote area household in Egypt." *The open renewable energy journal* 2.1 (2009).

[7] Singh, Pushkar, and Sanghamitra Saikia. "Arduino-based smart irrigation using water flow sensor, soil moisture sensor, temperature sensor and ESP8266 WiFi module." *2016 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*. IEEE, 2016.