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Development of IoT Based Smart Irrigation System with Programmable Logic Controller

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ABSTRACT

Smart irrigation system is an automatic irrigation and monitoring system on agricultural land with a sensor, automation, and control technology based on the Internet of Things (IoT). This system can reduce the agricultural activities that were previously performed manually into an automatic system with reduced human supervision. Smart Irrigation systems that are widely developed used Arduino as the controller. Arduino still lacks in response, low durability, and sensitivity to temperature change, hence requiring frequent maintenance to avoid weather disturbances, insects, and others. This paper presents a development of a smart irrigation system using a Programmable Logic Controller (PLC) as the controller and a soil moisture sensor as a humidity condition measurement tool. The advantage of using PLC as a controller is more stable and has sensor compatibility with higher accuracy. Hence the results are more consistent and accurate. The PLC system is expandable, allowing for the inclusion of more channels for sensors and other measurement instruments. The developed system can collect data on soil moisture conditions, trigger valves, and perform auto irrigation using sprinklers, reducing or even eliminating the need for human intervention. The IoT collects data from sensors and updates the data into a database system, allowing users to monitor the land conditions in real-time. The developed system was predicted to save manpower (20%) and water usage (42.47%) compared to the conventional method.

Keywords:
Smart Irrigation; IoT; PLC; Moisture Sensor; Sprinkler

1. Introduction

Agriculture is one of the most important sectors in the Indonesian economy. One of the problems faced by Indonesia's agricultural sector is the limited resources such as land and agriculture labor. Agriculture also needs a lot of water, yet, Indonesia's agriculture is still heavily dependent on rainfall. To overcome these challenges, we need a method that can effectively control the use of water, for example by using an irrigation system. Smart Irrigation System refers to the application of information technology and computers to control the irrigation system is an automatic system that can monitor the water conditions on agricultural land by utilizing sensor technology, automation, and control based on the Internet of Things (IoT).

Studies on smart irrigation systems have been conducted previously. For example, a solar-powered smart irrigation system used solar panels and converters to change the sensor readings on the actuators and subsequently activate the irrigation system (Darshna et al., 2015), (Mérida Garcia et al., 2018). In other work, sensors were used in a microcontroller system to activate the irrigation system. However, they could not be used for monitoring and controlling as they were not an internet-based system (Harishankar et al., 2014). A non-fully automated smart irrigation system had been introduced. However, the water pump must be turned on manually before the system can operate. Besides, the system was only created for monitoring, without controlling function (Rawal, 2017). A design of a smart irrigation system, using sensors and microcontrollers has been introduced, but it has not yet been implemented in the field (Saraf & Gawali, 2017). The smart irrigation system in Indonesia is still in its early stages of growth. In early 2019, an IoT-based field irrigation system was developed and implemented under the Habibie Garden brand in several farms as pilot projects (Habibi, 2019). This system collects data from sensors and transmits it through the internet, but field watering is still performed manually. In other work, a smart irrigation system with sensors and a drip irrigation system has been introduced, but still unstable and errors during the implementation (Harsono, 2019). Furthermore, these studies and another study still employ Arduino as a microcontroller which has low durability and sensitivity to the changes in temperature, hence, requiring frequent maintenance to avoid weather disturbances, insects, and others (Benyezza et al., 2018; Castañeda-Miranda & Castaño-Meneses, 2020; Namala et al., 2016; Nawandar & Satpute, 2019; Walter et al., 2017; Wang et al., 2020).

Based on these previous studies, a new method is needed to develop a smart irrigation system that can be employed for a larger scale of agricultural land. This paper is about a smart irrigation system with PLC (Programmable Logic Controller) based, integrated with internet control, and attached to sprinkler irrigation networks. The advantage of using a PLC as a controller is more stable than a microcontroller and has sensor compatibility with higher accuracy. Hence the results are more consistent and accurate (Kumar, 2016).

The system has an automatic and manual mode for monitoring and controls. The real-time sensed data allows farmers to control and monitor their agricultural land through a smartphone or computer device. This system uses a soil moisture sensor to obtain data about soil moisture conditions. The controller processes the data, and makes a decision whether watering will be carried out or not, and determine the length of time to water. The application of this system can ensure the availability of sufficient water for plants, efficient use of water, reduce human supervision, and allows modification of the irrigation system to carry out physiological treatments for plants so that plants can develop according to user expectations.

2. Materials and Methods

This research started with the identification and initial research of current conditions in the Indonesian Center for Agricultural Engineering Research and Department (ICAERD)'s land for soil moisture and humidity conditions. Soil samples were collected from the different depths, which represent plant root's depth level, like 5, 10, 15, and 20 cm. The soil samples were checked by "Balai Penelitian Tanah" (Soil Research Center, SRC) of the Agriculture Ministry for the information of pore space, water level, water content, and drainage pore. The soil samples as shown in Figure 1 and the result of soil analysis from SRC are given in Table 1.

Figure 1. Soil samples from different depths (5-20 cm)

Table 1. The result of soil data condition

Weight content (BV) (g/cc)	Pore Space Total (% Vol.)	Water content (% Vol.)				Drainage pore (% Vol.)		Water Level (% Vol.)
		pF 1	pF2	pF 2.54	pF 4.2	Fast	Slow	
1.15	56.4	50.7	45.1	41.6	36.7	11.3	3.5	4.9
0.94	64.4	62.4	41.3	35.7	29.2	23.1	5.6	6.5
1.02	61.2	59.4	49.3	45	34.4	11.9	4.3	10.6
Depth of soil taken (cm)	Pore Space Total (% DW*)	Water content (% DW*)				Drainage pore (% DW*)		Water Level (% DW*)
		pF 1	pF2	pF 2.54	pF 4.2	Fast	Slow	
5	49.0	44.1	39.2	36.2	31.9	9.8	3.0	4.3
15	68.5	66.4	43.9	38.0	31.1	24.6	6.0	6.9
20	60.0	58.2	48.3	44.1	33.7	11.7	4.2	10.4

*) DW (dry weight)

As shown in table 1, the water content of the soil was around 30 % to 60%. The data range used for this research was 40% (minimum) to 60% (maximum), in case 30% was too dry for a soil moisture condition, this soil data used as a basis of the system logic. Furthermore, the research continued with the PLC-based design of irrigation system software, which applied to tuberose flower fields. The automation part of the irrigation system can be realized using a control system architecture which can be divided into two types: open-loop and closed-loop systems (Brinkhoff et al., 2019). For this research, the control system concept design used the open-loop system method with a modification, namely the addition of a soil moisture sensor to provide information on the actual soil moisture value. The aim was to minimize the potential for water wastage by reading the value of soil moisture, compared with the reference limit, and refer to the activation time duration. For example, if the reference limit was set at 55±5%, and activation time was set at 08.00 – 10.00, if the soil moisture value is still within the wet reference limit (sensor reading at 58%), irrigation will not be activated even though it is within the active time duration (08.00-10.00). This cannot be achieved using the conventional open-loop method. The diagram block of the open-loop method with modification is shown in Figure 2.

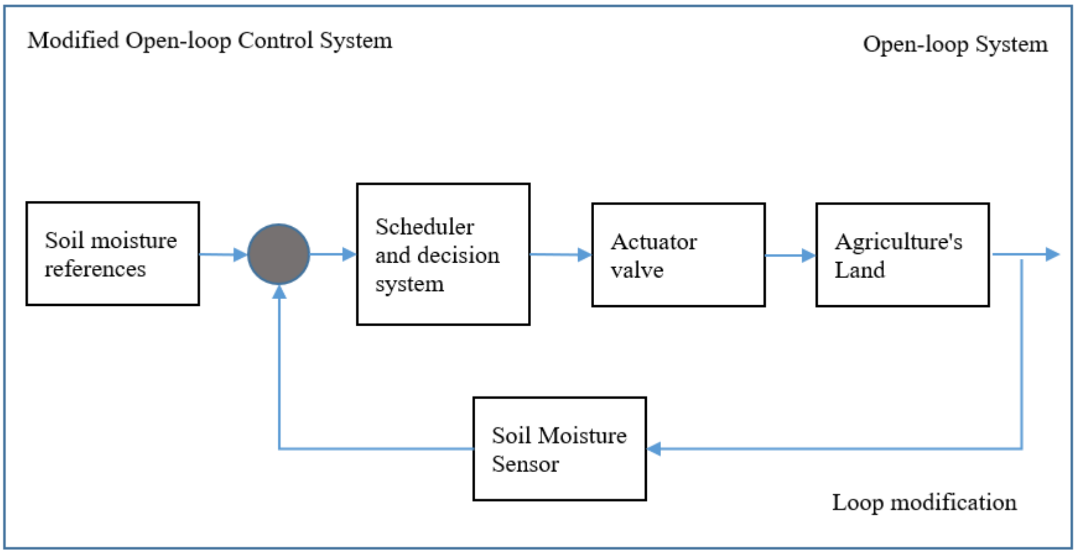

Figure 2. Modified open-loop control system block diagram

The process was followed by hardware installation, such as sensor and irrigation network, which take place in the agriculture's land. The sensor was installed in the depth of plant roots level, around 10-15 cm (Figure 3).

Figure 3. Sensor installation

Sprinkler irrigation with PVC pipes with diameters of 0.5, 2, and 3 inches was designed as part of the irrigation system (Figure 6). For water reach level, the sprinkler mounted had a capacity of 9.5 meters. Besides, the water reservoir was installed with a capacity of 20,000 liters, equipped with an electric pump which was able to provide water with a capacity of 101,400 liters/hour. The human-machine interface (HMI) was connected to hardware and software from Weintek. Through a local area network connection, the operator was able to access the irrigation system using a computer or laptop that had Weintek software installed. If remote access was desired, the operator was able to access the system using a computer/laptop on Weintek's "EasyAccess" webpage by entering login data and password. Besides that, users were also able to use the mobile version via the Android app.

To verify the system control able to work properly and the hardware working as instructed, we performed a functional and performance test. The functional test aims to check whether the system control and hardware installation can function individually. The HMI test, sprinkler uniformity test, and system control verification were all conducted as functional tests. HMI test aims to verify item in the monitor display can function well. Sprinkler irrigation network uniformity test was carried out to check whether the sprinklers were able to water all the plants in the land. After HMI test and sprinkler uniformity test completed, followed by system control verification. The system control verification aims to check whether the system controls able to connect, not only locally, but also by using an application. After the functional test completed, the performance test comes next. Performance test was carried out to verify irrigation activation systematically in sequence, starting with setting the soil moisture reference value in HMI, setting the irrigation time, and activating the system to check the connection of software and hardware. Lastly, data analysis was carried out to analyze the testing result, such as water and time consumed during the irrigation process. The data were compared with the data obtained by using the manual/ conventional method. Based on this data, and considering the rainfall will have an impact on soil moisture, prediction of human power and water consumption saving can be analyzed. The steps of the experimental method can be seen in Figure 4.

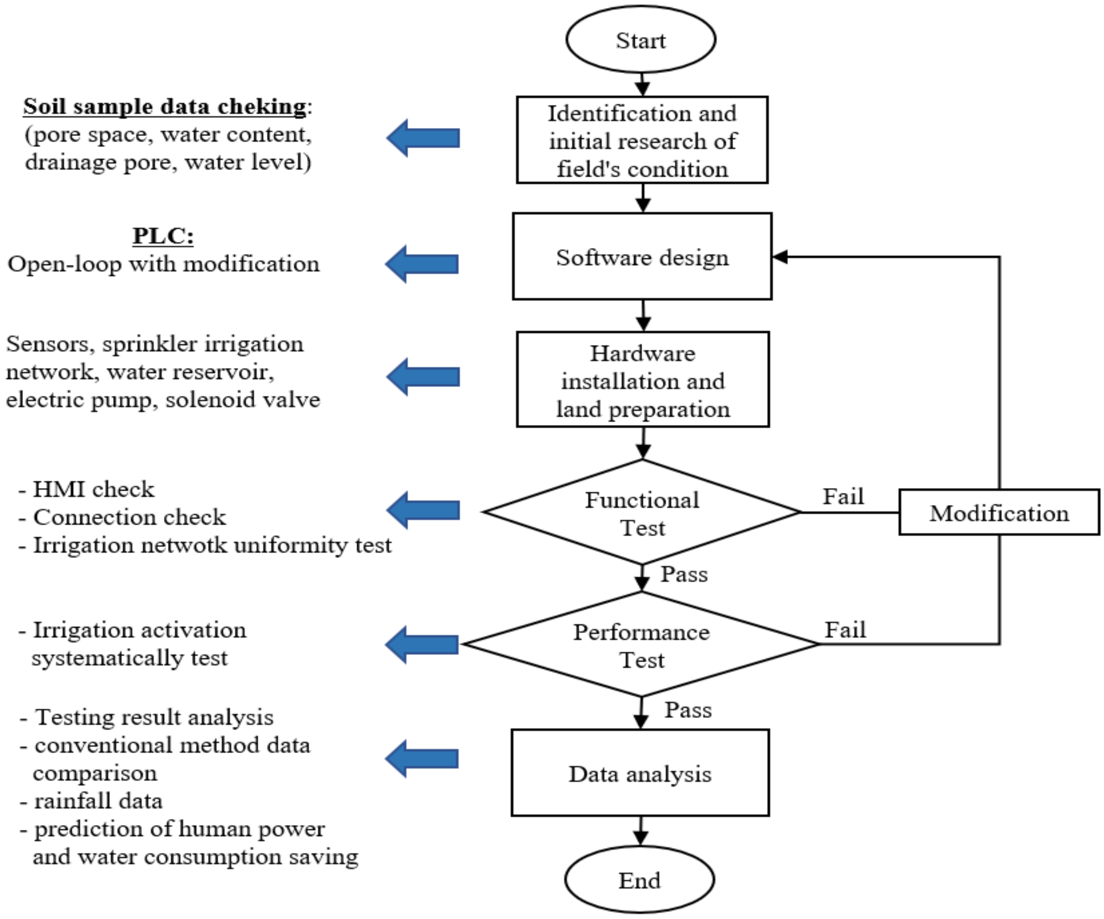

Figure 4. Flowchart of the experimental method

3. Results and Discussion

3.1 Prototyping Smart Irrigation System with PLC

3.1.1. Conceptual Design

The system of smart irrigation PLC-based applies the concept design of the open-loop method with a modification, namely the addition of a soil moisture sensor to provide information on the actual soil moisture value. The sensor feedback able to control the activation of irrigation refers to the reading value of soil moisture condition, which cannot be achieved using the conventional open-loop system method. Besides, there is an interface framework for organizational and remote access applications. The operator will use the interface device to set the time and length of active irrigation, interpret the soil moisture value, and set the wet reference value for soil moisture. Operators can track and carry out irrigation operations from a remote location using the remote access system, which provides access to the internet network.

However, because of factual data on soil moisture during the active irrigation cycle, the possibility of water waste can be minimized. When the active irrigation cycle ends, the control unit compares the current soil moisture data to the reference value set by the operator. If the value is out of range (dry conditions), the control unit will command the valve to open, allowing water to flow, and stop when the duration is over. Else, the control unit would not order the valve to activate if the actual soil moisture value is within the range (wet conditions). The conceptual design of the system is shown in Figure 5.

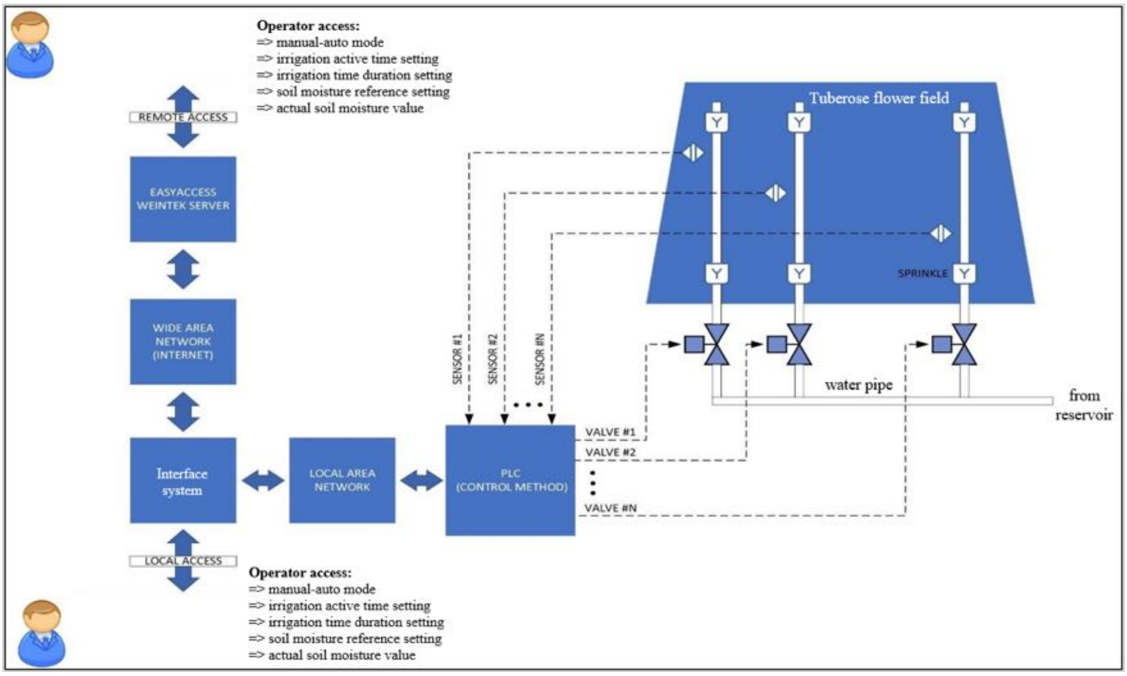

Figure 5. Conceptual design of Smart Irrigation System PLC-based

3.1.2. Sprinkler Irrigation Network

Sprinkler irrigation is a way of providing irrigation water by spraying water into the air and letting it fall across the plants like rain. Spraying is made by passing pressurized water through a small orifice or nozzle. The use of sprinkler irrigation allows all parts of the plant to be splashed by water, which then falls to the ground and seeps into the soil to meet the water needs of the roots. The sprinkler irrigation system can be used in various land surface conditions, both flat and wavy. This system is very suitable to be applied in dry land agriculture.

In this research, the conceptual design of the sprinkler irrigation network applied to the tuberose flower field is shown in Figure 6.

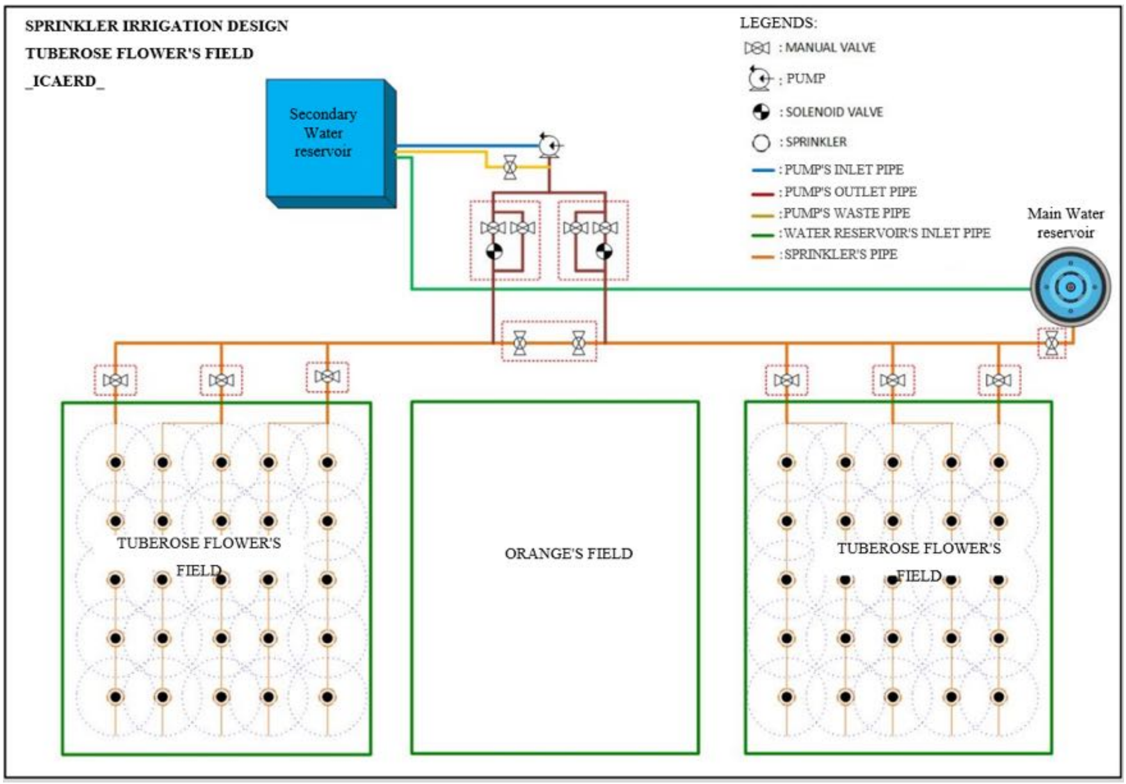

Figure 6. Design of sprinkler irrigation network

3.1.3. PLC Controller and Human-Machine Interface (HMI)

a. PLC Controller

For the input equipment, the sensor for example, and output devices such as the solenoid valve are directly attached to the PLC through cables. The PLC will operate as a control device, reading the soil moisture value from the sensor, controlling valve work, and connecting with the interface device through the local network. This platform also allows operators to view information both locally and remotely through the internet. By readings from each acquired sensor, operators can keep track of individual soil moisture levels. The irrigation system can be accessed via a computer or laptop using a local area network connection. If remote access is required, the user can log in to its commercially built-up software webpage using a device or laptop by entering login data and password. Aside from that, the program offers a smartphone edition with an Android app.

b. HMI Anatomy

The human-machine interface was built using hardware and software from Weintek, programmed to provide operator access both locally and remotely. There are two modes of operation, namely manual and auto. The operator may operate the solenoid valves independently in manual mode using two references: the scheduled time and the soil moisture value. Otherwise, auto mode refers to a predetermined reference value and fully delegated solenoid valve activation to the PLC controller. The controller and HMI are set up to cover two blocks of tuberose flower fields with 1 soil moisture sensor and 2 solenoid valves installed in each field. To expand the greater field's area, the PLC controller can load up to 16 soil moisture sensors and 7 solenoid valves. The anatomy of HMI is shown in Figure 7.

Figure 7. The anatomy of HMI

Legends:

1. Button to select the active field
2. Current time
3. Actual soil moisture values and the average (if installed more than 1 sensor)
4. Controller operation mode selection
5. Reference of schedule to determine the active period of irrigation; in AUTO mode, the irrigation will be involved when it is in the setting time (5), and the soil moisture value is below the soil moisture reference value (6)
6. Reference of soil moisture value; in AUTO mode, the irrigation will be active when it is in the setting time (5), and the average soil moisture value is below the set soil moisture reference value (6)
7. Button to see real-time trend graph of soil moisture value (Figure 8)
8. The button for controlling the solenoid valve independently in MANUAL mode, else it will be disabled in AUTO mode

Figure 8. Trend data display screen to observe soil moisture value

3.2. Testing Result of The System

3.2.1. Sensor calibration and verification testing

Sensor calibration testing aims to check and ensure the sensor reading represents soil moisture condition properly. The calibration began with collecting three soil samples, recording the sensor value reading, and proceeding with the gravimetry test to determine the soil's exact water content. The calibration is shown in Figure 9.

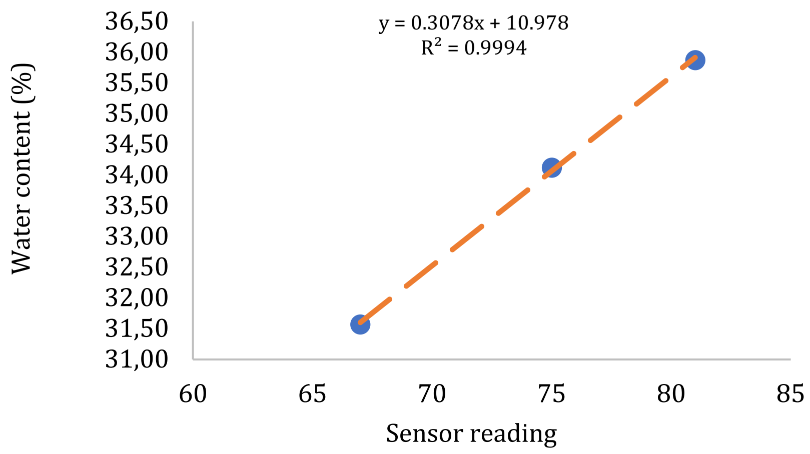

Figure 9. Relation of sensor and water content

Figure 9 shown a linear relation of sensor reading and actual water content of the soil. A higher soil reading value corresponds to a higher soil water content, which represents a proper representation of sensor and soil moisture data.

Sensor verification testing aims to check the PLC program will trigger the valve, followed by the irrigation system, and accurately reflect soil moisture conditions. The moisture target is 40% - 60%, indicates that the soil is dry enough to allow the sprinkler valve if the moisture content is less than 40%. However, if the sensor value is greater than 60%, the water level is sufficient for the plants, and irrigation is not needed. Calibration and verification of the sensor and PLC system are shown in Table 2.

Table 2. Verification result of sensor and valve activation

Sensor/ Valve	Rh (%)	Valve	Status	Sensor/ Valve	Rh (%)	Valve	Status
1	67	OFF	OK	2	65	OFF	OK
	22	ON	OK		22	ON	OK
	48	ON	OK		31	ON	OK
	52	ON	OK		40	ON	OK
	55	OFF	NOK		46	ON	OK
	58	OFF	NOK		47	ON	OK
	51	ON	OK		48	ON	OK
	47	ON	OK		51	ON	OK
	43	ON	OK		53	ON	OK
	57	OFF	NOK		58	OFF	NOK

Table 2 shows valve triggering data based on sensor reading data (Rh), which can already reflect the system control logic. Sprinkler irrigation is used to water the plants when the Rh value is between 40% to 60%. However, there is also a delay that causes the valve state to deviate from the logic system. For example, the Rh value is 55%, 57%, and 58%, the valve could still be in activation mode, but it is already shutting down. These situations may occur as a result of sensor data transmission delays from the real land to the database system control. However, it is also sufficient since the value is almost equal to the optimum Rh value of 60%, and the soil and water levels are adequate for tuberose flower.

Uniformity testing

Uniformity testing is required to ensure that all plants receive water from the sprinkler nozzle in a consistent manner. During the irrigation process, this test will check the watering capability. The uniformity coefficient, which can be calculated using the formula below, is used as a benchmark for good uniformity.

$$CU = 1{,}0 - \frac{\sum |X_i - x|}{\sum X_i} 100\%$$

CU = coefficient uniformity
Xi = the value of each observation (mm)
$\underline{X}$ = observation of mean value (mm)
n = total number of observations

Table 3. The uniformity coefficient of sprinkler

Line	The volume of water per bowl (ml)						CU
	1	2	3	4	5	6	
1	2.01	0.45	3.55	3.95	11.05	20.05	83.4%
2	16.95	12.95	6.95	12.95	2.45	25.05	
3	4.95	7.95	8.95	4.95	7.95	19.05	
4	17.95	24.95	1.45	3.95	2.55	13.55	
5	2.55	*)	1.55	2.95	6.05	14.55	
6	7.01	10.95	9.95	15.95	0.45	14.05	

*): the data was taken out due to water on the bowl cannot measure properly
The high efficiency of sprinkler irrigation (good uniformity) is considered when the CU value is greater than 85%. Based on the calculation and analysis of the data obtained from the uniformity test, the CU value for the tuberose sprinkler irrigation network was 83.4% which was close to the minimum limit. Furthermore, there is a need to check and ensure there is no issue with the nozzle, such as a jammed nozzle that prevents the nozzle from properly discharging irrigation water.

3.2.2. Performance testing

The performance test aims to ensure that the PLC system control, HMI, and hardware are all working properly. The testing began with the Rh reference value being set in HMI, after which the device would verify the current condition of soil moisture and compare it to the reference value. The PLC controller will trigger the valve, open the pump, and water will be flowing through the irrigation pipe and sprinkler nozzle, watering the plants until the actuals reach the range. The irrigation mechanism will continue until the soil moisture value reference provided by the PLC controller is met, at which point the valve will be closed and the pump will stop supplying water through the irrigation system.

Figure 10. Sprinkler activated by a smart irrigation system

4. Data Analysis (Prediction of the System Advantages)

The functional and performance confirm that the system can work properly. Unfortunately, since the data used are secondary, the system's benefits were predicted based on the presumption that rainfall influenced soil moisture, causing the soil moisture value to surpass the maximum data of soil moisture reference. It means that on rainy days, the irrigation system would not need to be turned on because the sensor sensed that the soil was moist enough at the root level, which the operator cannot see from the surface. The research was conducted in Banten province with rainfall data and the number of rainy days as shown in Table 4.

Table 4. Rainfall and rainy days data for Banten Province.

Year		**2015**	
Province	BMKG Station	Rainfall (mm)	Number of rainy days
Banten	Serang	1310.1	155

Source: Indonesian Central Bureau of Statistics 2015

Based on the above condition, a comparison between conventional and smart irrigation method predicted as below calculation:

1. Optimizing the use of irrigation water

Conventional method	Days	Irrigation Status
Workdays	269*)	ON

*) excludes Saturday and Sunday

Smart Irrigation System	Days	Irrigation Status
Rainy days	155**)	OFF
Non-rainy days	114	ON
Water-saving***)		42.47%

**) includes Saturday and Sunday
***)155 rainy days/ 365 days per year

2. Optimizing the use of manpower

The conventional irrigation method for tuberose flower fields (figure 5) took around 1,5–2 hours per day, while working time is 8 hours a day (saving time around 20%). The time saved by using a smart irrigation system may be used to complete other farm activities.

5. Conclusion

In Indonesia, smart irrigation is not widely used, especially where a PLC is used as a controller. The Indonesian Center for Agricultural Engineering Research and Development (ICAERD) has developed an Internet of Things (IoT) based Smart Irrigation System with PLC. The system ensures that water is delivered at the right time, in the right amount, and to the right location in the field. Additionally, the system minimized human interference and permitted irrigation to be carried out from a remote area. The advantage of using PLC as a controller is more stable and has sensor compatibility with higher accuracy. Hence the results are more consistent and accurate. The PLC system is expandable, allowing for the inclusion of more channels for sensors and other measurement instruments. The developed system is able to gather data on soil moisture conditions through sensor information, trigger valves, and perform auto irrigation using sprinklers, reducing or even eliminating the need for human intervention. This research using secondary data and rainfall data to predict the optimization of water consumption (42.47%) and manpower (20%). Furthermore, primary data must be collected for the length of the irrigation process to be triggered, including how long it would take to reach the range soil moisture comparison, starting from the lowest value and progressing to the highest (range: 40%-60%). This circumstance would indicate whether the irrigation during the range timing indeed more beneficial and productive compare to the conventional method. Different land environments, crop commodities, and landscapes need to be used for further development.

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