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NETWORK APPLICATION IN OIL PALM SEEDLING WATERING MONITORING SYSTEM USING ESP32

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ABSTRACT
This research aims to design and implement an Internet of Things (IoT) based monitoring and control system for watering and fertilizing oil palm seedlings using the ESP32 microcontroller. The system was developed to overcome the weaknesses of manual watering methods which still rely on estimated soil conditions so that they are less efficient and risk inhibiting seedling growth. The system utilizes a soil moisture sensor to detect soil moisture and a DHT22 sensor to monitor temperature and air humidity in real-time. The data from the sensor readings is sent through the internet network and displayed on the Telegram application as a medium for remote monitoring and control. The system was tested for 14 days under morning and evening watering conditions with Quality of Service (QoS) analysis using throughput, delay, packet loss, and jitter parameters. The results of the study show that the system successfully works automatically and is able to monitor the environmental conditions of the seedlings in real-time. The average value of the QoS index in morning watering was 2.46 with a quality percentage of 61.50%, while afternoon watering was 2.39 with a quality percentage of 59.75%, both of which are in the medium category. The packet loss parameter shows excellent performance with packet loss close to zero, while delay and jitter are in the good to good category. However, the throughput parameters are still relatively low, so it is necessary to improve network quality for system optimization. Overall, the system is designed to support the monitoring and control process of watering oil palm seedlings automatically with a fairly stable data communication quality.

INTRODUCTIONS

Oil palm is Indonesia's leading plantation commodity with high economic value, and Riau Province is one of its important production centers, so the sustainability of this industry must be maintained from the nursery stage as the foundation of future productivity (BPS & BPS Riau Province, 2025). Oil palm nurseries consisting of pre-nursery and main-nursery require proper watering because it has a direct effect on water availability, growth quality, and seedling survival (Banowati et al., 2024; Rifaat et al., 2024). However, seedling care in the field is still mostly done manually based on estimates, so it is difficult for managers to accurately monitor soil moisture and pH and risks causing inaccuracies in maintenance that can inhibit growth and even cause plant death (Wulandari & Afriyanto, 2022; Utomo et al., 2021). To answer this problem, Internet of Things (IoT) technology is a relevant solution because it is able to connect devices over the internet to exchange data and support precision agriculture, including monitoring soil moisture quickly and efficiently (Artono & Susanto, 2018; Sinaga et al., 2025). This study designed an ESP32-based system that is integrated with soil moisture, soil pH, temperature, and air humidity sensors, and then displays the data in real-time via Telegram (Nizam et al., 2022; Waluyo & Son, 2024). Since the system relies on internet connectivity, the quality of the network needs to be tested using the Quality of Service (QoS) approach with throughput, delay, packet loss, and jitter parameters, which are analyzed through Wireshark as a network packet capture and analyzer tool (Laili & Marpaung, 2025; Saputra et al., 2024). Based on this, this study focuses on designing a prototype of IoT-based oil palm seedling watering monitoring and automation to improve maintenance accuracy and assess the reliability of the network that supports the system.

Palm Oil

Oil palm (Elaeis guineensis Jacq.) is one of the main plantation commodities in the world and is known to be the most efficient producer of vegetable oil compared to other crops. At a productive age of more than six years, one oil palm tree is able to produce around 200 kg of fresh fruit bunches per year which can be processed into around 40 kg of crude palm oil (CPO) (Nugroho, 2019). Scientifically, oil palm belongs to the Kingdom Plantae, Magnoliophyta Division, Class Liliopsida, Order Arecales, Family Arecaceae, Genus Elaeis, and species Elaeis guineensis Jacq. In Riau Province, palm oil has an important role in the economy because palm oil is used as a raw material for various industrial sectors, such as cooking oil, industrial products, and biodiesel, and has advantages in the form of resistance to oxidation, the ability to dissolve certain chemicals, and good coating power (BPS Riau Province, 2025). This plant grows optimally in tropical regions with temperatures of 24–28°C and annual rainfall of 1,500–4,000 mm, making it very suitable for cultivation in tropical climates (Putra et al., 2024). To obtain optimal production results, the cultivation process must start from the good nursery stage through pre-nursery and main nursery as the basis for successful plant growth before being transferred to permanent land (Siahaan & Sitepu, 2018).

In the nursery stage, watering is an important factor because water functions as a solvent for nutrients, photosynthesis materials, and a medium for transporting nutrients to all parts of the plant (Sukmawan & Riniarti, 2020). Oil palm seedlings that still have fibrous roots are very susceptible to lack or excess water, so watering management must be carried out appropriately to prevent growth disturbances to the death of seedlings (Ardiyanto et al., 2021). The need for seedling water in the pre-nursery stage ranges from 0.1–0.3 liters per day and increases to 1–3 liters per day in the main nursery stage (Sari, 2018). In addition, setting the frequency of watering twice a day for 30 minutes has been proven to be able to maintain soil temperature and humidity optimally so as to support the growth of oil palm seedlings, with ideal soil moisture in the range of 65%–85% (Akbar et al., 2023; Fajar & Waluyo, 2024).

Internet of Things (IoT)

The Internet of Things (IoT) is a technological concept that allows various physical devices such as sensors, actuators, machines, and electronic devices to be connected through the internet network to collect, monitor, process, and control data automatically and in real-time (Efendi, 2018). This technology was developed to expand the use of the internet so that various devices, such as household appliances, CCTV, vehicles, monitoring sensors, and other digital devices, can integrate with each other and interact efficiently in one intelligent system (Wilianto & Kurniawan, 2018). In its implementation, IoT systems work through sensors that collect analog data from the environment, then the data is processed by the processor into digital data that can be sent through the internet network to the user's device to be monitored or controlled as needed (Komaludin, 2018). IoT architecture in general consists of three main elements, namely physical devices equipped with IoT modules as data collectors, connection devices such as modems and routers to transmit data over the internet, and cloud data centers that function to store, manage, and process data and applications. The three components are interconnected to form an integrated, automated, and capable IoT system that supports various data-based services in real-time (Setiawan et al., 2018).

ESP32

ESP32 is a System on Chip (SoC)-based microcontroller that has been equipped with WiFi 802.11 b/g/n connectivity, Bluetooth 4.2, and various supporting peripherals in one chip so that it is able to support the development of Internet of Things (IoT)-based systems efficiently (Nizam et al., 2022). This microcontroller was developed by Espressif System as a successor to ESP8266 with the advantage of integrating WiFi modules directly on the chip, making it easier to communicate data through the internet network without the need for additional devices (Muliadi et al., 2020). In addition, the ESP32 also has a Bluetooth feature that supports more flexible wireless communication for various IoT applications. This chip includes a processor, storage media, and General Purpose Input Output (GPIO) access, so it can be used as an alternative to Arduino with more complete capabilities. The ESP32 also has several advantages over other microcontrollers, such as a larger number of digital and analog pins, larger memory capacity, Bluetooth Low Energy (BLE) support, and stable WiFi connectivity capabilities for internet-based monitoring and control needs (Muliadi et al., 2020).

Soil Moisture Sensor

Soil moisture sensors are devices used to measure moisture content in soil media and are widely applied to automated irrigation systems to determine when watering needs to be done based on soil moisture levels (Agam et al., 2022). Soil moisture measurement is very important because lack of water can cause plants to be stressed, growth slows down, and leaves to turn yellow, while excess water can trigger root rot and inhibit the absorption of plant nutrients, including in oil palm seedlings (Barokah et al., 2024). In general, there are two types of soil moisture sensors that are often used, namely capacitive sensors and resistive sensors. Capacitive sensors work based on changes in capacitance values in dielectric materials to detect moisture content in the soil, where capacitance values increase when soil conditions are wetter (Rifaat et al., 2024). In contrast, resistive sensors measure moisture through changes in the electrical resistance of the soil, where resistance increases when the soil is dry and decreases when the soil is wet (Rifaat et al., 2024). In its application, capacitive sensors are superior because they have a better level of accuracy and durability than resistive sensors. This sensor can be directly planted in soil media and is able to reduce corrosion problems common with resistive sensors, making it more suitable for long-term Internet of Things (IoT)-based soil moisture monitoring systems (Maghuna et al., 2024).

DHT22

DHT22 is a digital sensor used to measure air temperature and humidity with a temperature measurement range between -40°C to 125°C and humidity between 0% to 100% RH. This sensor is widely used in Internet of Things (IoT) systems because it has a good level of accuracy, is stable, easy to use, and is compatible with various microcontrollers such as Arduino and ESP32 (Safitri & Gusmira, 2024). DHT22 works using a polymer capacitor as a sensor element and generates a digital signal through a single-bus communication system so that the measured data can be directly processed by the microcontroller without the need for additional conversion (Nainggolan et al., 2024). This sensor has four main pins, namely the Vs pin as the voltage source, the Data pin to transmit temperature and humidity data, the NC pin that is not used, and the Ground pin that is connected to the system ground (Utama, 2016). DHT22 works at a voltage of 3.3–6 Volts DC with a humidity measurement accuracy of ±2% RH and a temperature of less than ±0.5°C, and a measurement resolution of 0.1% RH and 0.1°C. In addition, this sensor has good long-term stability, an average reading time of about two seconds, and is capable of transmitting data up to a distance of 20 meters, making it flexible to use in a variety of environmental monitoring conditions (Nainggolan et al., 2024). Another advantage of DHT22 is that the calibration process has been carried out precisely at the factory and stored in the OTP's internal memory, so that the sensor can be used immediately without the need for recalibration and still provide accurate measurement results over a long period of time (Utama, 2016).

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Quality of Service (QoS)

Quality of Service (QoS) is a method used to assess how well a network is performing. The main purpose of QoS is to describe the characteristics and quality of services in a network. QoS refers to the ability of a network to provide optimal service performance for a specific type of traffic by utilizing various technologies. Thus, QoS plays an important role in network management so that telecommunication services can run as expected. QoS also serves to keep important parameters such as Throughput, Delay, Packet Loss, and Jitter within the user's tolerance limit (Laili & Marpaung, 2025). Equation 1 is used to calculate the QOS.

Equation 1 is used to calculate the QOS.

$$\text{Persamaan perhitungan } QoS = \frac{Jumlah\ QoS\ yang\ didapat}{Jumlah\ maksimum\ indeks\ QoS}\ x\ 100$$

The QOS Calculation Index can be seen in table 1.

Table 1 QOS Calculation Index (Matiin, et al., 2024)

Kategori QOS	Persentase (%)	Nilai
Bad	25 – 49,75	1 – 1,99
Medium	50 – 74,75	2 – 2,99
Good	75 – 94,75	3 – 3,79
Very Good	95 – 100	3,8 – 4

Throughput

Throughput is an indicator that shows how much data was successfully delivered in a given time span. This term can also be interpreted as the actual bandwidth recorded during the file delivery process. Throughput is calculated by dividing the total packets successfully received at the destination over a certain time interval by the length of that time (Nisa, et al., 2024). The Throughput value can be obtained by dividing the total data successfully delivered by the length of time it was delivered, as shown in equation 2.

$$Throughput = \frac{jumlah\ data\ terkirim\ (kb)}{waktu\ pengiriman\ data\ (s)}$$

The Throughput Index can be seen in table 2.

Table 2 Throughput Index (Nisa, et al., 2024)

Category Throughput	Throughput	Index
Bad	0 – 338 Kbps	0
Medium	338 - 700 Kbps	1
Good	700 - 1200 Kbps	2
Very Good	1,2 – 2,1 Mbps	3
Bad	>2,1 Mbps	4

Delay

Delay is a parameter that indicates the length of time it takes for a data packet to reach the receiving end. Some of the factors that can affect the occurrence of Delay include the distance traveled, the type of media or device used to send the package, and congestion on the network (Nugroho & Prasetyo, 2024). Equation 3 that can be used to calculate Delay.

$$Rata\ rata\ delay = \frac{total\ delay}{jumlah\ paket\ diterima - 1}$$

The Delay Index can be seen in table 3.

Table 3 Delay Index (Nisa, et al., 2024)

Category Latency	Delay (Ms)	Index
Bad	>450	1

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Medium	300 s/d 450	2
Good	150 s/d 300	3
Very Good	<150	4

Packet Loss

Packet Loss is the percentage of data packets that are not successfully sent during the transmission process. This loss can be caused by various factors, such as weakened signals on network media, damage to network hardware, and interference from radiation from the surrounding environment (Fahmi, 2018). The packet loss percentage can be calculated using the formula shown in equation 4.

$$Packet\ loss = \frac{(data\ terkirim - data\ diterima)\ x100\%}{data\ diterima}$$

The Packet Loss Index can be seen in table 4.

Table 4 Packet Loss Index (Nisa, et al., 2024)

Category Degradation	Packet Loss (%)	Index
Bad	>25	1
Medium	15 - 24	2
Good	3 - 14	3
Very Good	0 - 2	4

Jitter

Jitter is a parameter that shows a variation in the delay time. Jitter represents the difference between one Delay and another during the data transmission process (Nugroho & Prasetyo, 2024). Equation 5 is used to calculate Jitter.

$$Jitter = \frac{total\ variasi\ delay}{total\ paket\ diterima - 1}$$

The Jitter Index can be seen in Table 5.

Table 5 Jitter Index (Nisa, et al., 2024)

Category Degradation	Jitter (Ms)	Index
Bad	125 s/d 225	1
Medium	75 s/d 125	2
Good	0 s/d 75	3
Very Good	0	4

RESEARCH METHODS

Research Stages

This research is carried out systematically through several stages which include planning, field surveys, observations, interviews, literature studies, system design, and system testing. All stages of research are arranged in the form of flowcharts to facilitate understanding of the research workflow in a structured and sequential manner. This approach is used to make the research process run more effectively and produce a system that is in accordance with the needs of the field.

The research was conducted at CV. Utama Karya Sejati which is located in Taluk Kuantan. The research location has a land area of about 2 hectares with a nursery capacity of 20,000 oil palm seedlings. Field observations were carried out to identify the condition of the land, the layout of the nursery blocks, the planting distance, the water source, and the watering pattern applied. The data is used as a basis for designing an Internet of Things (IoT)-based watering automation system.

Field Surveys and Observations

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Surveys and observations were carried out to obtain factual data on the condition of the nursery and the technical needs of the system to be designed. Observations include watering methods, supporting infrastructure, environmental conditions, and oil palm seedling care activities. The observation results show that the watering process is still carried out manually, so there are often irregularities in the schedule and uneven distribution of water. In addition, manual processes also lead to a high dependence on labor.

Further observations were made on environmental temperature, soil moisture, water sources, and seedling conditions in various weather conditions. The observation data shows that changes in environmental conditions greatly affect the water needs of plants. Therefore, an automated monitoring system is needed so that watering can be carried out more accurately based on actual conditions in the field.

Interview and System Needs Analysis

Interviews are conducted with nursery owners to obtain information about the obstacles faced during the seedling care process. The results of the interviews show that the manual system often experiences problems in the form of worker negligence, watering delays, inefficient use of time, and the risk of damage to seedlings due to lack or excess water. These problems are the basis for analyzing the needs of IoT-based automated systems.

Based on the results of the needs analysis, the system is designed to be able to monitor and control watering in real-time. The system is also expected to be able to improve water use efficiency, reduce dependence on labor, and make it easier to monitor nursery conditions remotely through the internet network.

Literature Study and Systems Design

The literature study was conducted to strengthen the theoretical foundation of research which includes oil palm cultivation, Internet of Things technology, monitoring systems, data communication, and supporting hardware and software. This study uses the ESP32 microcontroller as the system control center. Some of the sensors used include soil moisture sensors, DHT22 sensors for air temperature and humidity, and pH sensors to monitor the condition of the planting medium.

The system also utilizes relays and water pumps as automatic watering actuators. The programming process is carried out using the Arduino IDE application, while the Telegram application is used as a remote monitoring and notification medium. In addition, Wireshark is used to analyze the quality of data communication networks used in IoT systems.

System Testing and QoS Analysis

The system testing phase is carried out over two weeks with multiple operating scenarios. The test includes automatic watering based on a specific time as well as based on the soil moisture value that the sensor reads. Testing is carried out to ensure that all system components can work according to the designed function and are able to provide an appropriate automatic response.

In addition to testing system functions, this study also conducts Quality of Service (QoS) analysis of data communication networks. The QoS parameters tested included throughput, delay, packet loss, and jitter. This test aims to evaluate the stability of the network in support of real-time sensor data delivery and actuator control. The test results are expected to show that the IoT system designed is able to improve the effectiveness, accuracy, and reliability of the monitoring process of watering oil palm seedlings in a modern and efficient manner.

RESULTS AND DISCUSSION

Views on Telegram App

Telegram is used as a medium for remote monitoring and control of IoT-based oil palm seedling watering and fertilization systems. In this study, Telegram was integrated with the ESP32 microcontroller through the Telegram Bot feature so that users can monitor system conditions and provide commands in real-time via smartphones. The initial appearance of the telegram apiasi can be seen in the following image.

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Figure 1 Telegram Bot Initial Appearance

When the user runs the bot by pressing the /start command, the system will display several main menus, namely Pump ON, Pump OFF, Fertilizer ON, Fertilizer OFF, and Status. The menu serves as a control interface to manage the watering and fertilization process automatically or manually. The display after pressing the menu available on the Telegram application can be seen in the following image.

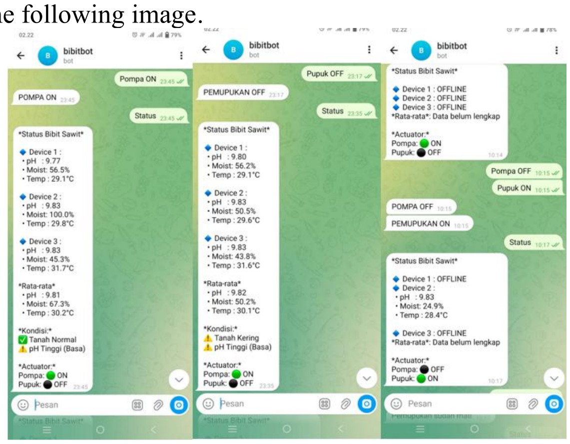

Figure 2 Monitoring and control system view on Telegram

The Pump ON menu is used to activate the watering pump, while the Pump OFF menu is used to stop the watering process. Next, the Fertilizer ON menu serves to activate the fertilization pump, and the Fertilizer OFF menu is used to turn off the fertilization pump. In addition to the control function, the system also provides a Status menu that is used to display information on the current condition of the system, such as soil moisture values, soil pH, temperature, air humidity, and whether or not the pump is active or not.

Sensor Data Transmission Process Testing

Based on the results of the tests that have been carried out, the IoT-based monitoring and watering control system of oil palm seedlings is able to work well in conducting sensor readings, data transmission, and automatic watering processes. Tests are carried out on morning and evening watering conditions to see the system's performance under various environmental conditions.

The parameters tested included the time of sending and receiving data, the value of soil moisture in each seedling, the average humidity, the temperature in each seedling, and the average environmental temperature. Tests are carried out before and after the watering process to determine changes in soil conditions after the system is run.

The test results showed that the soil moisture value increased after the watering process was carried out. In addition, the process of sending and receiving data takes place with a very small time difference so that monitoring data can be displayed in real-time on the system. Tests in the morning and evening also showed that the ambient temperature affected the soil moisture conditions in each oil palm seedling.

Full system test results data are presented in the following test tables.

Table 6 shows the results of morning watering tests based on the time of delivery and receipt of data, soil moisture values, and temperature of each oil palm seedling.

No	Shipping Data	Time Submit	Time to Receive	Humadity 1	Humadity 2	Humadity 3	Average Humidity	Temperature 1	Temperature 2	Temperature 3	Average temperature
1	Process	08:40:05	08:40:05	47.4%	39.1%	35.1%	40.5%	24.6°C	24.8°C	25.3°C	24.9°C
	After	08:45:05	08:45:05	100.0%	100.0%	90.5%	96.8%	25.0°C	25.2°C	25.5°C	25.2°C
2	Process	08:40:08	08:40:09	62.2%	49.3%	46.4%	52.6%	26.0°C	27.1°C	25.9°C	26.3°C
	After	08:45:07	08:45:08	100.0%	90.5%	88.7%	93.1%	26.5°C	27.7°C	26.5°C	26.9°C
3	Process	08:40:26	08:40:26	83.2%	61.7%	65.8%	70.2%	25.5°C	25.5°C	25.2°C	25.4°C
	After	08:45:07	08:45:07	100%	90.9%	90.5%	93.8%	25.5°C	25.6°C	25.2°C	25.4°C
4	Process	08:40:06	08:40:06	80.4%	88.7%	68.9%	79.3%	25.8°C	26.0°C	25.9°C	25.9°C
	After	08:45:06	08:45:06	100.0%	100.0%	92.8%	97.6%	25.9°C	26.2°C	25.9°C	26.0°C
5	Process	08:40:03	08:40:08	88.3%	88.3%	82.9%	86.5%	27.0°C	27.2°C	26.7°C	27.0°C
	After	08:45:10	08:45:11	100.0%	100.0%	94.6%	98.2%	27.1°C	27.4°C	26.9°C	27.1°C
6	Process	08:40:07	08:40:07	61.5%	57.7%	51.8%	57.0%	27.1°C	27.1°C	26.7°C	27.0°C
	After	08:45:08	08:45:08	95.5%	100.0%	91.4%	95.7%	27.4°C	27.6°C	26.8°C	27.3°C
7	Process	08:40:07	08:40:07	47.1%	65.3%	51.8%	54.7%	27.6°C	27.5°C	27.8°C	27.6°C
	After	08:45:08	08:45:08	93.8%	94.5%	94.1%	94.2%	27.8°C	27.7°C	27.8°C	27.8°C

Table 7 shows the results of afternoon watering tests based on the time of delivery and receipt of data, soil moisture values, and temperature of each oil palm seedling.

No	Shipping Data	Time Submit	Time to Receive	Humadity 1	Humadity 2	Humadity 3	Average Humidity	Temperature 1	Temperature 2	Temperature 3	Average temperature
1	Process	16:10:06	16:10:06	59.8%	38.7%	60.8%	53.1%	35.8°C	34.5°C	32.8°C	34.4°C
	After	16:15:06	16:15:06	80.1%	91.6%	83.3%	85.0%	35.6°C	35.2°C	33.1°C	34.6°C
2	Process	16:10:09	16:10:09	54.6%	68.6%	42.3%	55.2%	31.6°C	31.6°C	31.3°C	31.5°C
	After	16:15:07	16:15:08	91.8%	96.7%	80.6%	89.7%	31.9°C	32.1°C	31.4°C	31.8°C
3	Process	16:10:09	16:10:10	89.3%	80.3%	60.4%	76.7%	31.8°C	32.2°C	30.7°C	31.6°C
	After	16:15:23	16:15:23	100.0%	100.0%	87.8%	95.9%	31.6°C	32.3°C	30.3°C	31.4°C
4	Process	16:10:07	16:10:07	85.6%	79.2%	56.8%	73.9%	28.4°C	28.3°C	28.3°C	28.3°C
	After	16:15:07	16:15:07	98.6%	100.0%	86.9%	95.2%	28.5°C	28.7°C	28.5°C	28.6°C
5	Process	16:10:09	16:10:09	69.1%	77.0%	71.6%	72.6%	39.4°C	40.1°C	39.4°C	39.6°C
	After	16:15:10	16:15:11	100.0%	94.2%	92.8%	95.7%	37.6°C	38.3°C	37.7°C	37.9°C
6	Process	16:10:06	16:10:06	56.7%	64.6%	60.4%	60.6%	33.3°C	33.5°C	33.8°C	33.5°C
	After	16:15:06	16:15:06	85.9%	87.6%	82.0%	85.2%	33.3°C	33.5°C	33.8°C	33.5°C
7	Process	16:10:09	16:10:09	80.8%	86.5%	76.1%	81.1%	33.6°C	33.4°C	33.2°C	33.4°C
	After	16:15:09	16:15:09	98.0%	97.8%	94.6%	96.8%	33.9°C	33.6°C	33.2°C	33.6°C

Table 8 shows the results of the morning watering test based on the soil moisture and temperature sensor readings on each oil palm seedling.

Sosioedukasi
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No	Shipping Data	Time Submit	Time to Receive	Humadity 1	Humadity 2	Humadity 3	Average Humidity	Temperature 1	Temperature 2	Temperature 3	Average temperature
1	Process	08:40:06	08:40:06	94.5%	84.3%	73.9%	84.2%	28.6°C	28.5°C	28.8°C	28.6°C
	After	08:45:07	08:45:07	96.2%	86.5%	74.3%	85.7%	28.8°C	28.8°C	28.9°C	28.8°C
2	Process	08:40:18	08:40:18	48.1%	22.0%	26.6%	32.2%	27.2°C	27.1°C	27.1°C	27.1°C
	After	08:46:08	08:46:08	79.3%	57.5%	71.6%	69.5%	27.2°C	27.4°C	27.2°C	27.3°C
3	Process	08:42:09	08:42:09	46.9%	42.5%	47.1%	45.5%	27.4°C	27.7°C	27.7°C	27.6°C
	After	08:47:10	08:47:11	79.6%	74.2%	71.9%	75.2%	27.5°C	27.9°C	27.8°C	27.7°C
4	Process	08:40:07	08:40:07	45.0%	48.3%	52.3%	48.5%	26.9°C	26.6°C	26.5°C	26.7°C
	After	08:44:06	08:44:06	78.8%	74.2%	71.6%	74.9%	26.7°C	26.6°C	26.4°C	26.6°C
5	Process	08:40:09	08:40:09	61.3%	58.3%	45.0%	54.9%	26.8°C	26.5°C	26.7°C	26.7°C
	After	08:44:07	08:44:07	81.2%	73.9%	68.3%	74.5%	26.8°C	26.9°C	26.8°C	26.8°C
6	Process	08:40:17	08:40:17	55.8%	42.5%	31.1%	43.1%	27.6°C	27.6°C	27.5°C	27.6°C
	After	08:44:09	08:44:10	77.2%	69.8%	68.0%	71.7%	27.5°C	27.8°C	27.5°C	27.6°C
7	Process	08:40:07	08:40:07	51.9%	60.4%	57.4%	56.6%	26.5°C	26.8°C	26.2°C	26.5°C
	After	08:44:07	08:44:07	77.6%	76.2%	67.1%	73.6%	26.4°C	26.9°C	26.1°C	26.5°C

Table 9 shows the results of afternoon watering tests based on soil moisture and temperature sensor readings on each oil palm seedling.

No	Shipping Data	Time Submit	Time to Receive	Humadity 1	Humadity 2	Humadity 3	Average Humidity	Temperature 1	Temperature 2	Temperature 3	Average temperature
1	Process	16:10:12	16:10:12	49.3%	56.5%	33.8%	46.5%	29.8°C	30.0°C	30.1°C	30.0°C
	After	16:14:10	16:14:11	77.9%	49.9%	69.8%	65.9%	29.9°C	30.2°C	30.2°C	30.1°C
2	Process	16:10:09	16:10:09	52.2%	63.7%	54.1%	56.7%	30.8°C	31.2°C	31.2°C	31.1°C
	After	16:14:07	16:14:07	76.2%	82.4%	69.5%	76.0%	31.0°C	31.6°C	31.3°C	31.3°C
3	Process	16:10:08	16:10:08	46.6%	56.5%	55.0%	52.7%	31.1°C	31.5°C	31.6°C	31.4°C
	After	16:14:08	16:14:08	76.9%	79.0%	68.6%	74.8%	31.2°C	31.8°C	31.7°C	31.6°C
4	Process	16:10:06	16:10:07	50.0%	63.7%	47.4%	53.7%	33.4°C	33.5°C	32.6°C	33.2°C
	After	16:14:10	16:14:10	74.0%	76.2%	68.3%	72.8%	33.9°C	34.3°C	32.8°C	33.7°C
5	Process	16:10:10	16:10:10	46.2%	59.6%	35.3%	47.0%	30.9°C	31.0°C	31.0°C	31.0°C
	After	16:14:06	16:14:07	72.1%	68.5%	65.6%	68.7%	31.0°C	31.1°C	31.1°C	31.1°C
6	Process	16:16:08	16:16:08	48.1%	54.2%	57.1%	53.1%	31.0°C	30.8°C	30.4°C	30.7°C
	After	16:20:09	16:20:10	72.4%	73.9%	67.4%	71.2%	31.4°C	31.2°C	30.7°C	31.1°C
7	Process	16:10:08	16:10:09	57.5%	57.3%	52.3%	55.7%	34.5°C	34.2°C	36.1°C	34.9°C
	After	16:14:09	16:14:10	72.1%	71.1%	63.7%	69.0%	34.4°C	34.4°C	35.9°C	34.9°C

QoS Parameter Testing

Quality of Service (QoS) testing was carried out to determine the quality of data communication in the monitoring and control systems of watering and fertilizing IoT-based oil palm seedlings. The QoS parameters tested included throughput, delay, packet loss, and jitter. Tests are performed on the system both based on time and based on sensor readings. The test was carried out in the morning and evening to determine the performance of data communication under different time conditions.

Watering Testing

Troughput

Throughput testing is carried out to determine the speed of data transfer in the system during the data transmission process. The throughput value is derived from the amount of data that was successfully sent in a given unit of time. The greater the throughput value, the better the system's ability to transmit data.

Troughput Morning Watering Time

Table 10 shows the throughput test results on morning watering by time.

Day	Morning (kbps)			Average Troughput (%)	Index	Category
	Beginning	Middle	Final			
1	12,43	7,98	8,24	9,55	0	Bad
2	11,59	13,85	9,83	11,75	0	Bad
3	96,29	9,66	8,04	38,00	0	Bad
4	11,87	8,62	5,76	8,75	0	Bad
5	15,59	12,23	12,05	13,29	0	Bad
6	14,51	7,85	15,44	12,60	0	Bad
7	15,82	85,29	9,78	36,96	0	Bad
Average				18,70	0	Bad

Troughput Afternoon Watering Time

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Table 11 shows the throughput test results on afternoon watering by time.

Day	Afternoon (kbps)			Average Troughput (%)	Index	Category
	Baginning	Middle	Final			
1	15,32	9,28	7,57	10,72	0	Bad
2	9,61	6,61	8,07	8,10	0	Bad
3	29,37	10,74	9,14	16,42	0	Bad
4	9,88	8,20	7,14	8,41	0	Bad
5	8,45	13,56	10,25	10,75	0	Bad
6	27,63	10,80	9,46	15,96	0	Bad
7	8,95	7,24	7,62	7,94	0	Bad
Average				11,19	0	Bad

Troughput Morning Watering Sensor

Table 12 shows the results of throughput testing on morning watering based on sensor readings.

Day	Morning (kbps)			Average Troughput (%)	Index	Category
	Beginning	Middle	Final			
1	9,88	7,52	7,71	8,37	0	Bad
2	20,46	9,91	10,28	13,55	0	Bad
3	4,26	11,05	6,75	7,36	0	Bad
4	9,57	7,65	11,73	9,65	0	Bad
5	21,39	13,37	16,84	17,20	0	Bad
6	9,13	6,26	7,25	7,55	0	Bad
7	11,33	7,39	8,87	9,20	0	Bad
Average				10,41	0	Bad

Troughput Afternoon Watering Sensor

Table 13 shows the results of throughput testing on afternoon watering based on sensors.

Day	Afternoon (kbps)			Average Troughput (%)	Index	Category
	Beginning	Middle	Final			
1	26,27	9,86	11,45	15,86	0	Bad
2	8,11	7,78	8,18	8,03	0	Bad
3	13,41	7,59	8,96	9,99	0	Bad
4	21,78	8,71	8,88	13,12	0	Bad
5	15,35	11,35	12,97	13,23	0	Bad
6	9,09	7,47	7,94	8,17	0	Bad
7	8,33	6,70	8,84	7,95	0	Bad
Average				0,91		Bad

Delay

Delay testing is carried out to find out the time it takes for data from the sender to be received by the monitoring system. The delay value indicates the speed of response of data communication in the system. The smaller the delay value, the better the quality of data communication produced.

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JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Delay Morning Watering Time

Table 14 shows the results of the delay test on morning watering by time.

Day	Morning (ms)			Average Troughput (%)	Index	Category
	Beginggging	Middle	Final			
1	223,40	349,31	330,01	300,91	2	Enough
2	292,91	223,51	354,54	290,32	3	Good
3	79,23	242,88	318,63	213,58	3	Good
4	267,33	87,73	483,44	279,50	3	Good
5	262,63	251,50	254,58	256,24	3	Good
6	235,35	396,28	297,04	309,56	2	Enough
7	190,44	68,32	291,23	183,33	3	Good
Average				261,92	3	Good

Delay Afternoon Watering Time

Table 15 shows the results of the delay test on afternoon watering by time.

Day	Afternoon (ms)			Average Troughput (%)	Index	Category
	Beginning	Middle	Final			
1	195,00	343,68	390,25	309,64	2	Enough
2	334,87	438,12	370,05	381,01	2	Enough
3	107,06	260,29	290,87	219,41	3	Good
4	319,32	390,27	403,58	371,06	2	Enough
5	361,20	263,55	296,44	307,06	2	Enough
6	139,23	283,62	278,69	233,85	3	Good
7	351,56	409,77	399,34	386,69	2	Enough
Average				315,56	2	Enough

Delay Morning Watering Sensor

Table 16 shows the results of the delay test on the morning watering based on the sensor.

Day	Morning (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	314,39	377,87	401,11	364,46	2	Enough
2	178,65	344,92	294,66	272,74	3	Good
3	776,38	315,36	446,50	512,75	2	Enough
4	335,57	393,57	288,02	339,05	2	Enough
5	128,83	190,72	122,44	147,33	4	Very Good
6	350,45	482,75	411,29	414,83	2	Enough
7	284,48	394,84	354,66	344,66	2	Enough
Average				342,26	2	Enough

Sensor Afternoon Watering Delay

Table 17 shows the results of the delay test on afternoon watering based on the sensor.

Day	Afternoon (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	140,84	317,58	259,95	239,46	3	Good
2	384,60	396,54	389,39	390,18	2	Enough
3	223,53	393,60	367,40	328,18	2	Enough
4	197,59	341,10	340,91	290,20	3	Good
5	213,50	284,24	231,85	243,20	3	Good

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JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

6	348,51	405,04	391,71	381,75	2	Enough
7	379,31	461,27	378,47	406,35	2	Enough
Average				326,04	2	Enough

Packet Loss

Packet loss testing is carried out to determine the number of data packets lost during the data transmission process. A small packet loss value indicates that the data can be well received by the system without much data packet loss.

Packet Loss Watering Morning Time

Table 18 shows the results of packet loss testing on morning watering by time.

Day	Morning (%)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	0,00	0,00	0,00	0,00	4	Very Good
2	0,00	0,00	0,00	0,00	4	Very Good
3	16,42	8,42	9,33	11,39	3	Good
4	0,00	0,00	0,00	0,00	4	Very Good
5	0,00	0,00	0,00	0,00	4	Very Good
6	0,00	0,00	0,00	0,00	4	Very Good
7	0,00	0,00	0,00	0,00	4	Very Good
Average				1,63	4	Very Good

Packet Loss Afternoon Watering Time

Table 19 shows the results of packet loss testing on afternoon watering by time.

Hari	Afternoon (%)			Average troughput (%)	Indeks	Category
	Beginning	Middle	Final			
1	0,00	0,00	0,00	0,00	4	Very Good
2	0,00	0,00	0,00	0,00	4	Very Good
3	0,00	0,00	0,00	0,00	4	Very Good
4	0,00	0,00	0,00	0,00	4	Very Good
5	0,00	0,00	0,00	0,00	4	Very Good
6	0,00	0,00	0,00	0,00	4	Very Good
7	0,00	0,00	0,00	0,00	4	Very Good
Average				0,00	4	Very Good

Packet Loss Watering Morning Sensor

Table 20 shows the results of packet loss testing on the morning watering by sensor.

Day	Morning (%)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	0,00	0,00	0,00	0,00	4	Very Good
2	0,00	0,00	0,00	0,00	4	Very Good
3	0,00	0,00	0,00	0,00	4	Very Good
4	0,00	0,00	0,00	0,00	4	Very Good
5	0,00	0,00	0,00	0,00	4	Very Good
6	0,00	0,00	0,00	0,00	4	Very Good
7	0,00	0,00	0,00	0,00	4	Very Good
Average				0,00	4	Very Good

Packet Loss Afternoon Watering Sensor

Table 21 shows the results of packet loss testing on afternoon watering based on sensors.

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Day	Afternoon (%)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	0,00	0,00	0,00	0,00	4	Very Good
2	0,00	0,00	0,00	0,00	4	Very Good
3	0,00	0,00	0,00	0,00	4	Very Good
4	0,00	0,00	0,00	0,00	4	Very Good
5	0,00	0,00	0,00	0,00	4	Very Good
6	0,00	0,00	0,00	0,00	4	Very Good
7	0,00	0,00	0,00	0,00	4	Very Good
Average				0,00	4	Very Good

Jitter

Jitter testing was carried out to determine the variation in delay time in the data transmission process. Small jitter values indicate the stability of data communication in the pre-designed monitoring and control system.

Jitter Watering Morning Time

Table 22 shows the results of jitter testing on morning watering by time.

Day	Morning (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	1,30	1,46	4,83	2,53	3	Good
2	20,73	1,21	7,56	9,83	3	Good
3	0,07	0,48	1,52	0,69	4	Very Good
4	0,35	0,23	0,02	0,20	4	Very Good
5	0,32	1,20	0,07	0,53	4	Very Good
6	0,95	23,38	14,48	12,94	3	Good
7	12,70	0,50	17,43	10,21	3	Good
Average				5,28	3	Good

Jitter Afternoon Watering Time

Table 23 shows the results of jitter testing on afternoon watering by time.

Day	Afternoon (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	2,32	13,45	1,07	5,61	3	Good
2	1,00	31,38	0,46	10,95	3	Good
3	0,00	1,35	2,13	1,16	3	Good
4	0,11	1,27	3,22	1,53	3	Good
5	0,72	1,63	2,17	1,51	3	Good
6	0,05	0,44	8,65	3,05	3	Good
7	0,14	1,82	1,32	1,09	3	Good
Average				3,56	3	Good

Jitter Watering Morning Sensor

Table 24 shows the results of jitter testing on morning watering based on sensors.

Day	Morning (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	0,41	0,05	2,12	0,86	4	Very Good
2	0,10	0,16	4,49	1,58	3	Good
3	4,01	0,31	38,67	14,33	3	Good
4	0,65	0,62	4,60	1,96	3	Good

5	1,17	2,82	0,52	1,50	3	Good
6	1,12	3,70	1,31	2,04	3	Good
7	0,20	2,12	0,12	0,81	4	Very Good
Average				3,30	3	Good

Jitter Afternoon Watering Sensor

Table 25 shows the results of jitter testing on afternoon watering based on sensors.

Day	Morning (ms)			Average troughput (%)	Index	Category
	Beginning	Middle	Final			
1	0,51	1,20	10,82	4,18	3	Good
2	0,19	0,02	0,06	0,09	4	Very Good
3	0,02	1,61	0,33	0,65	4	Very Good
4	0,22	0,25	3,58	1,35	3	Good
5	0,47	0,86	0,96	0,76	4	Very Good
6	1,66	1,85	5,37	2,96	3	Good
7	0,15	1,16	2,09	1,13	3	Good
Average				1,59	3	Good

Overall Results of QOS Index Calculation

At this stage, the Quality of Service (QoS) index is calculated on the IoT-based monitoring and watering system of oil palm seedlings. The recapitulation was carried out to determine the parameters of throughput, delay, packet loss, and jitter. The test was carried out for 14 days in morning and evening conditions. Table 26 shows the overall results of the throughput index on the system.

Day	Troughput			
	Morning	Category	Afternoon	Category
1	0	Bad	0	Bad
2	0	Bad	0	Bad
3	0	Bad	0	Bad
4	0	Bad	0	Bad
5	0	Bad	0	Bad
6	0	Bad	0	Bad
7	0	Bad	0	Bad
8	0	Bad	0	Bad
9	0	Bad	0	Bad
10	0	Bad	0	Bad
11	0	Bad	0	Bad
12	0	Bad	0	Bad
13	0	Bad	0	Bad
14	0	Bad	0	Bad

Table 27 shows the overall results of the delay index on the system

Day	delay			
	Morning	Category	Afternoon	Category
1	2	Enough	2	Enough
2	3	Good	2	Enough
3	3	Good	3	Good
4	3	Good	2	Enough
5	3	Good	2	Enough

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

6	2	Enough	3	Good
7	3	Good	2	Enough
8	2	Enough	3	Good
9	3	Good	2	Enough
10	2	Enough	2	Enough
11	2	Enough	3	Good
12	4	Very Good	3	Good
13	2	Enough	2	Enough
14	2	Enough	2	Enough

Table 28 shows the overall results of the packet loss index on the system

Hari	Packet Loss			
	Morning	Category	Afternoon	Category
1	4	Very Good	4	Very Good
2	4	Very Good	4	Very Good
3	3	Good	4	Very Good
4	4	Very Good	4	Very Good
5	4	Very Good	4	Very Good
6	4	Very Good	4	Very Good
7	4	Very Good	4	Very Good
8	4	Very Good	4	Very Good
9	4	Very Good	4	Very Good
10	4	Very Good	4	Very Good
11	4	Very Good	4	Very Good
12	4	Very Good	4	Very Good
13	4	Very Good	4	Very Good
14	4	Very Good	4	Very Good

Table 29 shows the overall results of the jitter index on the system

Hari	Jitter			
	Pagi	Category	Sore	Category
1	3	Good	3	Good
2	3	Good	3	Good
3	4	Very Good	3	Good
4	4	Very Good	3	Good
5	4	Very Good	3	Good
6	3	Good	3	Good
7	3	Good	3	Good
8	4	Very Good	3	Good
9	3	Good	4	Very Good
10	3	Good	4	Very Good
11	3	Good	3	Good
12	3	Good	4	Very Good
13	3	Good	3	Good
14	4	Very Good	3	Good

Table 30 shows the average results of the overall QoS index on the system based on throughput, delay, packet loss, and jitter parameters in morning and evening watering tests during the 14 days of testing.

Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Day	Morning				Average index	Category	Afternoon				Average index	Category
	Troughput	Delay	Packet Loss	Jitter			Troughput	Delay	Packet Loss	Jitter		
1	0	2	4	3	2,25	Medium	0	2	4	3	2,25	Medium
2	0	3	4	3	2,50	Medium	0	2	4	3	2,25	Medium
3	0	3	3	4	2,50	Medium	0	3	4	3	2,50	Medium
4	0	3	4	4	2,75	Medium	0	2	4	3	2,25	Medium
5	0	3	4	4	2,75	Medium	0	2	4	3	2,25	Medium
6	0	2	4	3	2,25	Medium	0	3	4	3	2,50	Medium
7	0	3	4	3	2,50	Medium	0	2	4	3	2,25	Medium
8	0	2	4	4	2,50	Medium	0	3	4	3	2,50	Medium
9	0	3	4	3	2,50	Medium	0	2	4	4	2,50	Medium
10	0	2	4	3	2,25	Medium	0	2	4	4	2,50	Medium
11	0	2	4	3	2,25	Medium	0	3	4	3	2,50	Medium
12	0	4	4	3	2,75	Medium	0	3	4	4	2,75	Medium
13	0	2	4	3	2,25	Medium	0	2	4	3	2,25	Medium
14	0	2	4	4	2,50	Medium	0	2	4	3	2,25	Medium
Average					2,46	Medium	Average				2,39	Medium

Based on Table 30, the results of the Quality of Service (QoS) test on the automatic watering system carried out for 14 days showed that the average QoS index in the morning watering was 2.46 in the medium category, while in the afternoon watering the average index was 2.39 in the medium category. These values are obtained by combining the throughput, delay, packet loss, and jitter parameters in each test.

In the throughput parameters, all tests obtained an index of 0 which indicates that the throughput quality is still low. However, the delay, packet loss, and jitter parameters showed quite good results, where delay was in the index of 2 to 4, packet loss was dominated by index 4, and jitter was in the index 3 to 4. This shows that the stability of data transmission on the system is quite good with a very small packet loss rate even close to no packet loss.

Overall, the QoS test results show that the system is able to work fairly stably in both morning and evening watering. Although throughput is still low, other network parameters support good enough data communication so that the system can still carry out the monitoring and watering control process optimally.

Table 31 shows the results of the percentage of QoS quality in the system of morning and afternoon watering activities based on the average value of the QoS index obtained during the test.

Activities	Value	Percentage (%)	Category
Morning Watering	2,46	61,50	Medium
Afternoon Watering	2,39	59,75	Medium

Based on Table 31, the Quality of Service (QoS) quality percentage results were obtained on the automatic watering system during the test. In the morning watering activity, an average QoS index value of 2.46 was obtained with a quality percentage of 61.50% which is included in the medium category. Meanwhile, in the afternoon watering activity, the average QoS index value was obtained of 2.39 with a quality percentage of 59.75% which is also in the medium category.

These results show that the network performance in the morning and evening watering systems has a relatively stable quality and does not have too significant a difference. The QoS percentage value in the medium category indicates that the data communication system on IoT devices is able to work quite well in supporting the monitoring and control process of automatic plant watering.

In addition, the percentage difference between morning and evening watering was affected by the condition of QoS parameters such as delay, throughput, packet loss, and jitter at each test time. Overall, the system can still run the data transmission process reliably enough so that the functions of the automatic watering system can run as needed.

CONCLUSION

Sosioedukasi
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Based on the results of research and testing, the monitoring and control system for watering and fertilizing oil palm seedlings based on the Internet of Things (IoT) using ESP32 has been successfully designed and implemented by utilizing soil moisture sensors, DHT22 sensors, relays, and water pumps to monitor soil and environmental conditions in real-time as well as carry out automatic watering and fertilization according to predetermined parameters. The results of the Quality of Service (QoS) test showed that the average QoS index in morning watering was 2.46 with a quality percentage of 61.50%, while in afternoon watering it was 2.39 with a quality percentage of 59.75%, where both were included in the medium category. The packet loss parameter shows excellent performance because the data packet loss is very small and even close to zero during the test. In addition, the delay and jitter parameters are in the category of good enough so that data communication between IoT devices and monitoring systems can run stably. However, the throughput parameters still obtained low scores throughout the tests, so it was necessary to improve network quality to optimize system performance. Overall, the system designed has been able to support the automatic monitoring and control of plant watering with a fairly good quality of network service.

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JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
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