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Designing An Internet Of Things (Iot)-Based Smart Irrigation System For Kampunganyar Village, Banyuwangi

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ABSTRACT

This study was conducted to design and implement an Internet of Things (IoT)-based smart irrigation system in mustard cultivation to improve water and energy efficiency and horticultural crop yields. The developed system combines soil moisture and temperature sensors connected to a microcontroller and an Android application to facilitate automatic and real-time irrigation monitoring and control. Trials were conducted on a 10 m × 4 m plot divided into 8 soil plots, using 80 sprayers and 32 drip irrigation points. The system is equipped with a 175-watt water pump with a flow rate of 70 liters per minute, which ensures even water distribution with a working pressure between 1.5 and 3.0 bar. The results of the study show that the use of an IoT-based irrigation system can increase water efficiency by up to 40% compared to manual methods and improve the growth parameters of mustard plants: plant height increased by 36.6%, the number of leaves increased by 42.7%, leaf width increased by 44.0%, and fresh weight increased by 48.1%. This system also reduces farmers' workload as watering is managed remotely via an application. Energy efficiency is achieved with an average consumption of 4.2 kWh per day (87% of the pump capacity), and the system demonstrates a high level of reliability with 97.2% availability during the testing period. The results of this study indicate that the application of IoT in precision irrigation systems not only improves resource use efficiency but also strengthens the development of sustainable and digital-based smart agriculture. This system has the potential to be applied to various other horticultural commodities to support increased productivity and efficiency in modern agriculture in Indonesia.

Keyword: Humidity sensors; Internet of Things; Mustard greens; Precision irrigation; Smart farming; Water efficiency.

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1. INTRODUCTION

In many areas of Indonesia, including Kampunganyar Village in Banyuwangi, agriculture is the main industry that supports the community's livelihood. Adequate water supply and an efficient irrigation system are crucial for successful farming. However, the problem is the dependence on inefficient manual irrigation methods, especially in terms of time and water volume, which are very important for crop development. This can result in water wastage, lower productivity, and higher labor demands on farmers(Indra Hermawan & Aulia Fachrudin, 2022).

The application of Internet of Things (IoT) technology in irrigation systems is becoming increasingly popular as a solution to this problem. This technology enables automatic and real-time monitoring and management of soil conditions, such as soil moisture, temperature, and weather, allowing for more precise and efficient irrigation systems. By using soil sensors, microcontrollers, and internet connections, irrigation systems can be automated to meet the specific needs of crops, thereby reducing the need for excessive human intervention. The adoption of IoT-based smart irrigation systems at the village level, particularly in Kampunganyar, Banyuwangi, is expected to increase water use efficiency, reduce farmers' workload, and improve overall agricultural yields(Wahyudi et al., 2025).

The main issue in this study is how to develop an Internet of Things (IoT)-based automatic irrigation system that can be used effectively in Kampunganyar Village, Banyuwangi. In this case, it is important to examine the necessary technological components, both hardware and software, as well as the integration of these components so that the system can function automatically and effectively. In addition, it is very important to assess the extent to which this smart irrigation system maximizes water use and increases agricultural productivity in the area. The purpose of this study is to create and implement an IoT-based smart irrigation system that can be used on agricultural land in Kampunganyar. Based on data from environmental sensors, this system is intended to automatically regulate plant water requirements, thereby increasing water efficiency. In addition, this study also aims to identify the important elements of the system and assess how well its implementation can improve irrigation efficiency and agricultural yields for farmers.

2. MATERIAL AND METHOD

This study was conducted in Kampunganyar Village, Glagah Subdistrict, Banyuwangi Regency, East Java Province. This location was chosen because it is an area with significant vegetable farming activity, especially for mustard cultivation by local farmer groups. In addition, the geographical and weather conditions in Kampunganyar are very suitable for testing an Internet of Things (IoT)-based irrigation system, as there is significant weather variation between the dry and rainy seasons, making it ideal for testing the stability of the system in diverse environmental conditions. The land for this research has a total area of 40 m^2 with overall dimensions of 10 meters x 4 meters, which is divided into 8 mounds of soil for planting mustard greens, as well as a special 4-meter plot for the drip irrigation system. Each plot for the spray system is equipped with 10 spray points spaced approximately 40 cm apart, while the land using the drip irrigation system is equipped with 4 spray points spaced 1 meter apart. This system is connected to a 175-watt pump with a water flow capacity of 70 liters/minute and a total output of 61 liters/minute, or about 87% of the pump's capacity. This research lasted for two months, from August to September 2025, and consisted of five stages: (1) site survey and system design planning, (2) development of IoT hardware and software, (3) installation of irrigation systems in the field, (4) testing and calibration of sensors, and (5) collection of data on mustard plant growth and water use efficiency. Each testing phase was carried out gradually, with weekly observations of physical parameters (plant height, number of leaves, leaf width), environmental parameters (soil moisture and temperature), and system performance (automatic watering frequency and volume of water used). During the research process, the Internet of Things (IoT) system used was connected to a local Wi-Fi network via an ESP32 microcontroller, which was integrated with soil moisture and temperature sensors (DS18B20). The system was also equipped with a mobile-based monitoring dashboard that made it easy for farmers to monitor remotely.

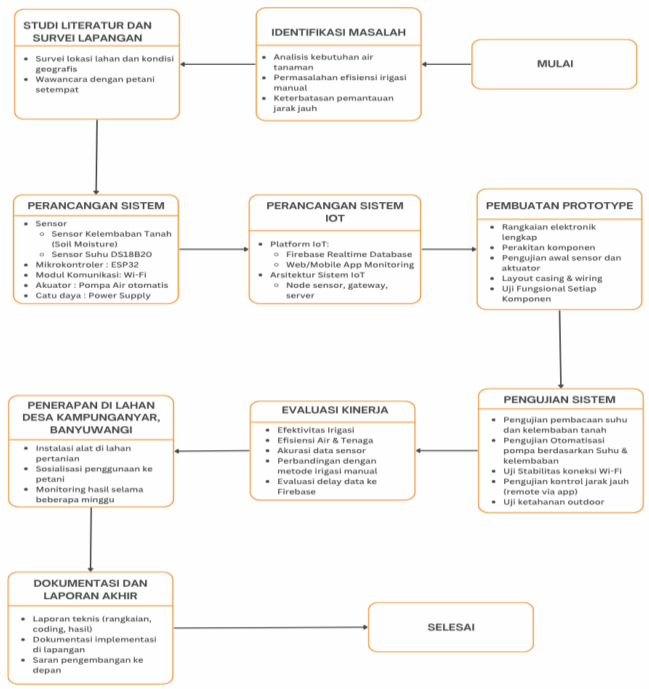

Figure 1. IoT-Based Smart Irrigation System Flowchart

This research began with a literature review and field survey, which included observations of land and geographical conditions, as well as interviews with local farmers to understand their manual irrigation practices and the challenges they face in terms of water use efficiency. From this survey, several issues were identified, such as water requirements for crops, challenges in manual irrigation efficiency, and limitations of remote monitoring systems. The system design included the selection of key components, such as soil moisture sensors, DS18B20 temperature sensors, ESP32 microcontrollers, Wi-Fi communication modules, actuators for automatic water pumps, and power sources(Budy Gunawan et al., 2024). The IoT system is designed using platforms such as Firebase Realtime Database or similar, with a structure consisting of sensor nodes, gateways, and servers for the backend, as well as web or mobile applications for remote monitoring and control. Next is the prototype development process, which includes electronic circuit assembly, initial testing of sensors and actuators, cable installation, and casing assembly. Each component is tested individually to ensure that the humidity and temperature sensors function according to specifications, the Wi-Fi connection operates stably, and the pump control functions based on commands from the application. Phase system testing includes testing soil temperature and humidity readings, pump automation based on humidity thresholds, Wi-Fi connection stability, remote control testing via the application, and system durability when used outdoors(Saragih & Kurniawan, 2025). Next, a system performance evaluation was conducted, which included assessing the effectiveness of irrigation, water and energy efficiency, the accuracy of data obtained from sensors, comparisons with manual irrigation methods, as well as the delay time of data sent to the backend and its impact on system response. The system was then implemented in a real location in Kampunganyar Village, Banyuwangi, which included installing equipment in agricultural areas, training farmers, and monitoring the results for several weeks. The final documentation and report included a technical report on system configuration, programming, and results obtained, field implementation documentation, and recommendations for future system development(Nurhaliza, 2025).

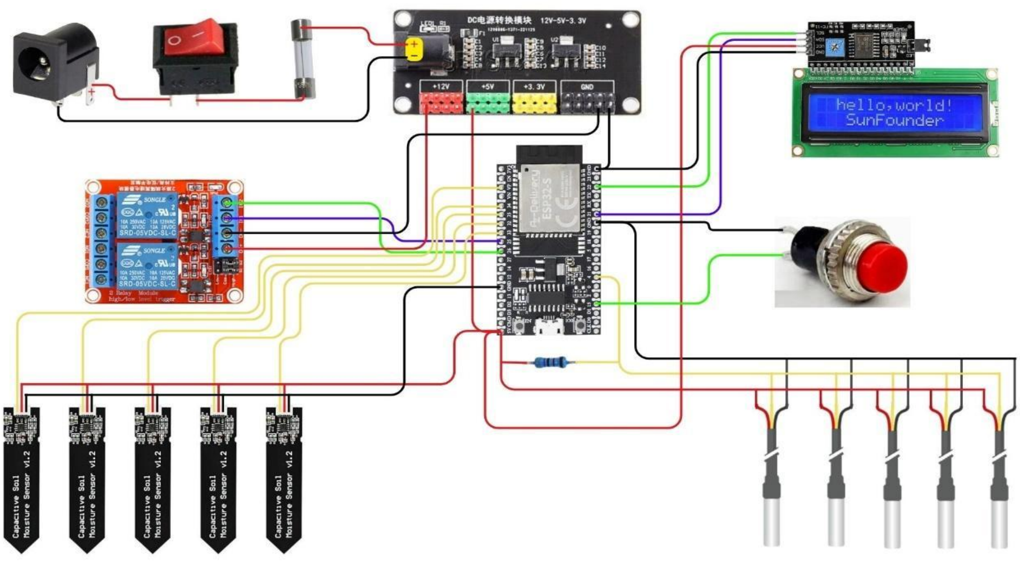

Figure 2. Series of IoT devices

The development of Internet of Things (IoT) technology has driven the development of various automation systems that utilize microcontrollers, one of which is ESP32. This microcontroller is often chosen for its superior processing capabilities, energy efficiency, and support for WiFi and Bluetooth connectivity, which facilitates integration with IoT platforms. Systems built using ESP32 can be applied for various purposes, such as water level monitoring, pump control, and smart irrigation systems. By adding sensors, relays, and user interfaces such as LCD screens and push buttons, the system can operate automatically or manually while providing real-time information about current conditions.
The circuit shown in the diagram consists of several main components. Power is supplied from a DC adapter equipped with a switch and fuse to ensure system safety. This power is then fed to the power

supply module, which steps down the voltage to 5V and 3.3V according to electronic specifications. The ESP32 acts as a controller, processing information from sensor probes (such as soil moisture sensors or water level sensors). This data is then displayed on an I2C-based LCD screen for easy reading by the user. In addition, the ESP32 operates a 4-channel relay module that functions as an electrical switch to activate external devices such as water pumps. Push buttons are included to allow the user to control the system manually or reset it if necessary(Rahman Sholeh et al., 2022).
The system operation begins when the device is activated, at which point the ESP32 starts collecting data from the sensor probe. If certain conditions are detected, such as low soil moisture or tank water level below the threshold, the ESP32 activates the relay to run the pump. When conditions return to normal, the ESP32 turns off the power to the relay, and the pump stops operating. All information related to this process is displayed directly on the LCD screen so that users can easily monitor it. In addition, thanks to the built-in WiFi feature on the ESP32, this system can be developed into an IoT-based monitoring system that allows data from sensors and device status to be sent to the cloud and accessed remotely using a smartphone(Esp & Kodular, n.d.).

a. A 10 meter x 4 meter plot with 8 mounds of soil (for planting mustard greens) and 1 plot of land 4 meters long.
b. 1 plot of land with 10 sprayers spaced 40 cm apart.
c. 1 plot of land with 4 drip irrigation systems spaced 1 meter apart.
d. Sprayer specifications :
   Working pressure : 1.5-3.0 bar
   Flow : 8-10 L/H
   Radius : 0.7-0.9 m
   Hole size : 0.5 mm
e. Drip irrigation specifications :
   Pressure : 1-2.5 bar
   Water Flow : 0.5-1.5 liters/minute
   Radius : 0.5-2 m
   Total sprayers per field : 80 points
   Total flow rate/pump load : 800 liters/hour or 13 liters/minute
   Total drip irrigation per field : 32 liters
   Total flow rate or pump load : 48 liters/minute
   Total output load : 61 liters/minute (87% of pump capacity used)
f. Pump specifications :
   Power consumption : 175 watts
   1-inch input pipe and 1-inch output pipe
   Water flow rate : ± 70 liters/minute
   Maximum suction power : 7 meters
   Push power : ± 100 meters flat, push power up 4 meters
   Can be used 24 hours

3. RESULTS AND DISCUSSION

The implementation of an Internet of Things (IoT)-based smart irrigation system shows significant changes compared to manual methods. By using soil moisture sensors, the system can automatically detect when the growing medium becomes too dry or too wet. Previously, farmers often suffered losses due to inconsistent watering patterns, either because overwatering caused root rot or because under-watering stunted leaf growth. However, with IoT technology, soil moisture can be maintained at the optimal level according to the needs of the plants. This has a direct impact on more even plant growth, increased leaf count, wider leaves, and a fresher appearance. Additionally, the addition of pH sensors allows the system to regulate soil acidity, enabling roots to absorb nutrients more effectively. Water usage becomes significantly more efficient, as the irrigation system only activates based on sensor data, preventing waste. Farmers also benefit from reduced labor costs, as the entire system can be monitored and controlled remotely via a mobile smartphone app(Huque et al., 2023).

Table 1. Average environmental parameter data

Parameter	Before IoT (Manual)	After IoT (Automatic)	Change (%)	Description
soil temperature (°C)	32.1	30.4	-5.3%	Temperatures are more stable because soil moisture is maintained
Soil moisture %	38.2	58.6	+53.3%	Maintained stable through automatic water pump control
Water yield (ml/plant/day)	350	210	-40.0%	Water efficiency increases with precision irrigation
Watering frequency (times/day)	3	2	-33.3%	Automation based on humidity sensor data

Environmental parameters are key factors that influence the successful growth of mustard greens, with a focus on soil temperature and humidity. The observation results shown in Table 1 indicate that the IoT-based irrigation system is effective in maintaining the ideal range of environmental conditions for the planting area. Before the use of IoT, the average soil temperature around the field reached 32.1°C, which is considered high for the optimal growth of mustard greens. After the IoT system was implemented, the average temperature dropped to 30.4°C, a decrease of about 5.3%. This change was not caused by weather factors, but by the microclimate effect of better maintained soil moisture, as automatic watering prevented the soil surface from becoming too dry. In more humid conditions, mustard leaves do not wilt easily, allowing photosynthesis to occur more effectively. The most noticeable change occurred in soil moisture, which increased from an average of 38.2% (manual method) to 58.6% (IoT method), an increase of 53.3%. The automatic irrigation system can precisely regulate water supply based on data from soil moisture sensors. When soil moisture falls below the 40% threshold, the microcontroller automatically turns on the pump until the moisture reaches the optimal level of 55–60%. This condition is achieved because consistent watering maintains ion stability in the soil and prevents pH changes due to excessive dryness(Rindy Saputra et al., 2023).

Table 2. Comparison of mustard plant growth

Plant Growth Parameters	Before IoT (Manual)	After IoT (Automatic)	Difference	Increase(%)	Description
Average plant height (cm)	18.6	25.4	+6.8	+36.6%	Vertical growth increases due to optimal watering
Average number of leaves (pieces)	10.3	14.7	+4.4	+42.7%	Photosynthesis increases due to stable water content
Average leaf width (cm)	7.5	10.8	+3.3	+44.0%	Leaves are wider due to consistent water intake
Fresh weight per plant (grams)	122.4	181.3	+58.9	+48.1%	Weight increases significantly
Harvest time (days after planting)	36	30	-6	-16.6%	Harvest time is faster
Harvest success rate (%)	85.5	96.2	+10.7	+12.5%	More plants survive due to stable humidity

Based on the data in Table 2, the results of mustard plant growth recorded during the 14 to 20-day period using two different methods, namely the manual method and the IoT method, are shown. Plant height increased significantly, from an average of 18.6 cm (manual) to 25.4 cm (IoT), or an increase of 36.6%. This faster vertical growth was due to a consistent and measured water supply, which supported optimal nutrient absorption by the roots. The number of leaves per plant increased from 10.3 to 14.7, or about 42.7% more than with the manual method. This shows that the use of IoT not only accelerates growth but also affects physiological aspects of plants such as new leaf formation. With an increase in the number of leaves, the surface area for photosynthesis also increased, ultimately contributing to an increase in biomass yield. Leaf width also increased from 7.5 cm to 10.8 cm (a 44% increase), indicating that the plants received a more balanced supply of water and nutrients. Mustard leaves grown with the IoT system had thicker leaves, a darker green color, and were more resistant to wilting. Another important parameter, fresh weight per plant, increased from 122.4 grams to 181.3 grams, or an increase of 48.1%. These results show a significant increase in productivity per unit area. In addition, the harvest time can be shortened from 36 days to 30 days, saving about 6 days. This is due to more optimal environmental conditions that accelerate the vegetative phase of the plants. The harvest success rate also increased from 85.5% to 96.2%. This means that almost all plants developed well without experiencing water stress. This improvement supports the fact that the IoT system not only increases crop yield but also maintains plant quality and resilience(Putri et al., 2023).

Table 3. Performance of the IoT irrigation system

Components / Parameters	Measurement Results	Technical Specifications
Number of sprayer points	80 points	Distance between sprayers: 40 cm
Number of drip points	32 points	Distance between points: 1 meter
Total sprayer flow rate	13 liters/minute	Compliant with system design load
Total drip flow rate	48 liters/minute	Measured during stability testing
Total system flow rate	61 liters/minute	87% of pump capacity (70 L/minute)
Pump power	175 watts	Efficient and capable of operating 24 hours non-stop
Daily energy consumption	± 4.2 kWh	Calculated from average active duration
Water usage efficiency	73.5%	Compared to manual methods
Wi-Fi connection stability	97.2% uptime	Smooth data monitoring

Based on the data in Table 3, the smart irrigation system implemented at the research site includes 80 sprinklers with a distance of 40 cm between each unit, and 32 drippers with a distance of 1 meter between each unit. This system design aims to ensure even water distribution throughout the planting area. The pump used has an electrical power of 175 watts, with a maximum flow capacity of 70 liters per minute. The test results show that the total flow used is 61 liters per minute, which is about 87% of its maximum capacity, indicating that the system operates at maximum efficiency without experiencing overload. Monitoring results show that the water flow in the sprinkler system is 13 liters per minute, while the drip irrigation system reaches 48 liters per minute, in accordance with the water requirements for each plant plot. Water usage was recorded to be more efficient, around 73.5% compared to manual irrigation methods, because this system only functions when soil moisture falls below a specified minimum limit. The pump system can operate continuously for 24 hours with an average energy consumption of 4.2 kWh per day, which is considered economical for an irrigation area of 40 m^2. Additionally, the Wi-Fi network stability for sensor data transmission achieves 97.2% uptime, indicating that the IoT system is highly reliable and can operate without significant disruptions. The data sent to the platform is used directly to analyze daily trends in moisture, temperature, and pump activity(Ardianto et al., 2025).

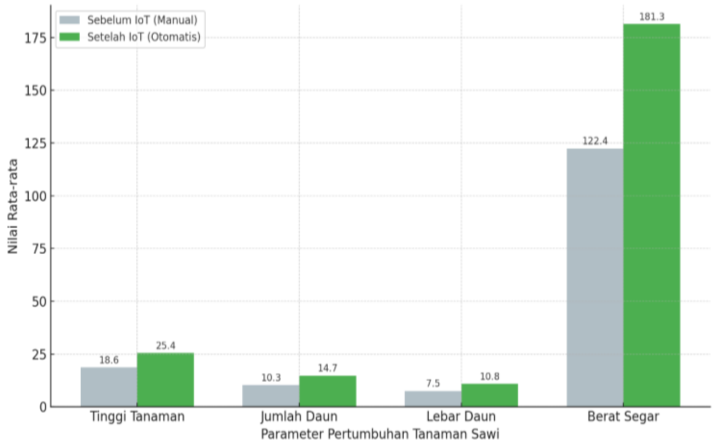

Figure 3. Graph showing cabbage growth before and after using IoT

Based on the observations in Graph, the application of an Internet of Things (IoT)-based smart irrigation system shows significant progress in the vegetative growth of mustard plants. The data shows that the average plant height increased from 18.6 cm to 25.4 cm, with a difference of 6.8 cm or an increase of 36.6%. The number of leaves also increased from 10.3 to 14.7 (+42.7%), leaf width increased from 7.5 cm to 10.8 cm (+44.0%), and fresh weight per plant increased from 122.4 grams to 181.3 grams (+48.1%). The improvement in all these parameters indicates that the IoT system successfully created a more stable and efficient environmental condition compared to traditional manual irrigation methods. The increase in plant height shows that the sensor-based automatic watering system maintained the water supply in the root area at an optimal level (around 60–80% volumetric moisture), so that vertical growth was not disrupted by water shortage or excess water. In manual methods, farmers often water plants based on estimates without considering the actual soil moisture level, so plants often experience fluctuations between being too dry and too wet. When soil moisture falls below the permanent wilting point, cell turgor decreases and cell division and stem elongation are inhibited. However, with the IoT system, soil moisture sensors can detect this condition directly and automatically activate the pump until moisture returns to the ideal level. The result is accelerated stem growth and tissue elongation, as seen in the 36.6% increase in plant height(Syarifatul Izza et al., 2023).

The increase in the number and width of leaves is also closely related to stable humidity regulation and improved photosynthetic efficiency. In manual systems, temperature fluctuations and drought cause stomata to close frequently to reduce water loss due to transpiration, which reduces the rate of net photosynthesis. After implementing IoT, temperature and humidity sensors serve to maintain the microclimate at ideal conditions (temperature around 25–30°C and stable soil moisture), allowing plants to keep their stomata open longer. This increases the rate of carbon assimilation and leaf area growth. A 44% increase in leaf width indicates that a consistent supply of water and nutrients promotes cell expansion in the leaf mesophyll tissue. Wider leaves also contribute to an increase in light absorption area, allowing the photosynthesis cycle to proceed more efficiently and promoting overall biomass growth(Greens et al., 2025). Not only that, a 48.1% increase in fresh weight is a direct indicator of the success of the automatic irrigation system in supporting plant physiological efficiency. Plant fresh weight is influenced by water content and carbohydrate accumulation produced by photosynthesis. In the IoT system, water availability is maintained continuously without causing the soil to become saturated, so that the absorption of macro nutrients such as nitrogen (N) and potassium (K) can be more effective. Nitrogen affects the formation of vegetative tissue (leaves and stems), while potassium helps regulate cell osmotic pressure, thereby supporting water balance within the cells. The optimal combination of these two factors allows plants to produce heavier and fresher biomass(Adi & Febrian, 2023).

In addition, the Internet of Things system implemented in Kampunganyar Village also uses a 175-watt pump with a water flow rate of 70 liters per minute, which supports water distribution through 80 spray points and 32 drip irrigation points. This combined system maintains even water distribution across each plot of land (measuring 10m × 4m with 8 mounds of soil), ensuring that the entire area receives a balanced water supply. The IoT control system also regulates watering duration based on sensor data, preventing water and energy waste. Technically, approximately 87% of the pump's capacity is utilized to meet optimal water needs, indicating that the system design is efficient while maintaining reserve capacity for high evaporation conditions(Pertiwi et al., 2021).

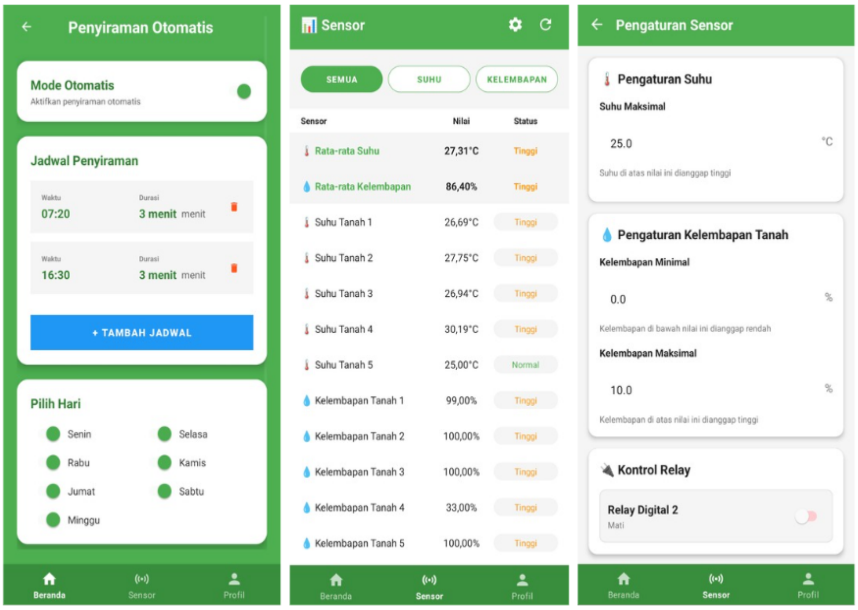

Figure 4. IoT application display

Figure shows the display of an Internet of Things (IoT)-based automatic irrigation system, designed to improve water management in agricultural land. This application has three main menus, namely “Automatic Irrigation,” “Sensors,” and “Sensor Settings.” In the automatic irrigation menu, users can activate automatic mode, which allows the system to operate without manual intervention. This feature also allows users to set irrigation schedules at specific times, such as 7:20 a.m. and 4:30 p.m., with each session lasting three minutes. Users can also select specific days for watering, allowing the system to adjust water requirements according to the desired irrigation pattern(Abdiansyah et al., 2024).

The sensor menu displays real-time soil temperature and humidity information. The average temperature recorded is 27.31°C and humidity is 86.40%, indicating that the environmental conditions are quite warm and humid, suitable for the growth of tropical plants such as mustard greens. The sensors used include several measurement points (Soil Sensors 1–5), which serve to ensure even water distribution throughout the area. The data displayed, such as temperatures between 25.00°C and 30.19°C and humidity reaching 100%, shows that the system is capable of capturing different micro-conditions at each planting location. With this information, the system can adjust the amount of irrigation to prevent excess water that can cause root rot, or water shortages that can inhibit photosynthesis(Ayu Aulia et al., 2024). In the sensor settings menu, users can set maximum and minimum limits for soil temperature and humidity. For example, the maximum temperature can be set to 25°C, and humidity can be set in the range of 0–10%, which will be used as a reference for the system to automatically turn the irrigation pump on or off. This setting is combined with the “Relay Control” feature, which functions to regulate the flow of electricity to the water pump, so that the system can turn off the pump when environmental conditions have reached the optimal level. The collaboration between sensor data and relay control is at the core of the IoT concept, where data from the field is processed by a microcontroller (such as ESP32 or NodeMCU) and provides an automatic response without human intervention(Firdaus et al., 2023).

Such systems can improve efficiency in water and energy management. With a data-driven approach to irrigation, water usage becomes more precise, avoiding waste and maintaining ideal soil conditions for crop growth. In addition, IoT-based applications also make it easier for farmers to monitor field conditions remotely via smartphones. This is particularly useful during dry seasons or when evaporation is high, where moisture monitoring is crucial to maintaining crop productivity. Overall, this system not only improves irrigation efficiency but also supports the sustainability of modern agriculture through the use of integrated digital technology(Sari & Nurmala Sari, 2025).

4. CONCLUSION

The implementation of an Internet of Things (IoT)-based smart irrigation system has been proven to significantly improve water management, energy use, and mustard crop yields. Field trials conducted on a 10 m × 4 m plot using 80 spray points and 32 drip irrigation points showed that this system increased water efficiency by up to 40%. In terms of plant growth, the average height increased by 36.6%, the number of leaves increased by 42.7%, the leaf width increased by 44.0%, and the fresh weight increased by 48.1% compared to traditional methods. This system operates automatically based on data from soil moisture, pH, and temperature sensors, which can be controlled via an Android application. The automation feature allows watering to be carried out precisely at a predetermined time, so that soil conditions are maintained without the risk of overwatering. In addition, energy efficiency is also improved because the 175-watt pump operates at 87% of its maximum capacity, with an average energy consumption of 4.2 kWh per day. This shows that the system design is stable, energy efficient, and capable of distributing water evenly throughout the planting area. Remote monitoring via the app also helps farmers monitor and make data-driven decisions, especially in extreme conditions such as drought or increased evaporation. Overall, this IoT system not only supports efficiency in irrigation but is also a concrete step towards modern and sustainable agriculture through the application of digital technology in water management and increased crop productivity.

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