



Integrated agricultural development real time analysis based on Internet of Things in Jenggawah Village

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ABSTRACT

Jenggawah Village, Jember Regency is a lowland area with great potential as an agricultural barn. However, the abundance of agricultural commodities has not been balanced with the application of modern technology, so that productivity is disrupted by conventional methods and unpredictable climate change. To overcome this, an integrated agricultural system based on the Internet of Things (IoT) was implemented through a real-time analysis method to predict climate and monitor land conditions. This program includes surveys, system design, installation of monitoring tools, and socialization of precision agricultural technology. This system uses five main sensors (soil moisture, light intensity, rainfall, wind speed, and air quality) connected to a mobile website, allowing farmers to monitor their land in real time. In testing, the monitoring tool recorded daily energy consumption of 136.32 Wh, supported by a 100 Wp solar panel and a 56.8 Ah battery. This program is accompanied by training and technology transfer to farmers to increase productivity, soft skills, and welfare. As a result, the community accepted the technology well, accelerated the digitalization of agriculture, and made Jenggawah Village a pilot model for the application of precision agricultural technology in other areas.

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1. INTRODUCTION

The Farmers Group in Jenggawah Village, Jenggawah District, Jember Regency, was selected as the partner in this community service program. Geographically, Jenggawah Village spans approximately 920 hectares and is situated in a lowland area at an elevation of 65 meters above sea level. The village is recognized as a center for plantation, livestock, and agricultural activities, with rice cultivation being the dominant commodity, covering a harvested area of 866.75 hectares (Badan Pusat Statistik Kabupaten Jember, 2020). These geographical characteristics, combined with the availability of fertile land, position the agricultural sector as the primary driver of the local economy, particularly for farmer groups that continue to rely on conventional farming practices.

The primary challenge faced by farmer groups in Jenggawah Village lies in the limited adoption of modern technology in agricultural practices. Farmers predominantly rely on conventional cultivation methods, such as continuously planting the same crop varieties without considering climatic variability. Such practices increase vulnerability to crop failures due to increasingly unpredictable weather patterns,

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higher pest infestations, and progressive degradation of agricultural land (Akhtar et al., 2021; Raj et al., 2021; Santoso et al., 2022). Preliminary surveys conducted by the community service team further revealed that farmers lack decision-support tools based on real-time data to monitor land conditions. Consequently, farmers experience difficulties in assessing production feasibility and are exposed to significant risks of economic losses, both for themselves and for consumers.

To address these challenges, the community service team introduced an Appropriate Technology solution based on the Internet of Things (IoT) in the form of a real-time agricultural land monitoring system. The system is equipped with five primary sensors connected to a solar panel as a renewable energy source, enabling continuous operation without the high maintenance costs typically associated with battery replacement. The collected data are integrated into a mobile-based website, allowing farmers to easily monitor land conditions in real time. The implementation of this technology is expected to support farmers in making more accurate, efficient, and productive decisions regarding agricultural practices.

The application of IoT-based technology is justified by previous studies. Sari (2021) highlighted that integrating solar panels with real-time monitoring systems provides an effective strategy for advancing clean energy use in agriculture. Similarly, Wang et al. (2019) noted that solar panel utilization helps lower maintenance expenses by reducing the dependence on battery replacement, while Data et al. (2020) reported that technology-driven integrated farming systems are effective in mitigating crop failure risks. Based on this evidence, the adopted solution can be regarded as highly relevant and capable of generating measurable improvements in agricultural productivity.

The primary aim of this community service program is to build the capacity of farmer groups in Jenggawah Village to implement IoT-based precision agriculture, thereby enhancing land productivity, reducing vulnerability to crop losses, and ultimately promoting the sustainable welfare of the farming community.

2. METHODS

Activity Design

This community service program was implemented in Jenggawah Village, Jenggawah District, Jember Regency, located approximately 25.06 km from the center of Jember City. The primary partner in this activity was the Jenggawah Village Farmers Group, which consists of around 40 active members. The program was supported by several facilities, including an Internet of Things (IoT)-based land monitoring device, a mobile website for real-time data visualization, and an electrical system powered by solar panels as a renewable energy source.

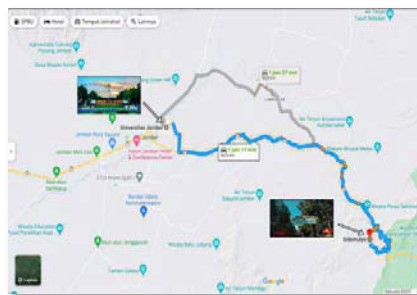


Figure 1. Site plan for the implementation of precision agriculture technology in Jenggawah Village, Jember Regency

The concept applied to the partner community is an IoT-based integrated farming system equipped with five primary sensors, namely a soil moisture sensor, a light intensity sensor, a rainfall sensor, a wind speed sensor, and an air quality sensor. The system's operational design allows these sensors, which are installed in the agricultural field, to transmit data in real time through a wireless sensor network (WSN) connected to a central server. The collected data are then visualized via a mobile website for ease of access by farmers. The system is powered by solar panels integrated with a battery, enabling autonomous operation without reliance on conventional electricity sources.

Program Implementation Method

The program implementation method consisted of several stages, namely: (1) IoT Technical Training for farmer groups in Jenggawah Village, conducted in the form of workshops and hands-on practice. The training materials included the introduction of agricultural IoT systems, techniques for interpreting sensor data, and solar panel energy management, with participants drawn from members of the local farmer group; (2) Field Implementation Assistance, which involved the installation and testing of the land monitoring system at the partner's agricultural sites. This stage was accompanied by direct mentoring from the service team to ensure that farmers were able to operate the system and interpret the monitoring results through the mobile website; and (3) Program Evaluation, which was carried out using quantitative indicators, including: (a) The success rate of sensor data transmission, with a target of at least 95 percent of data successfully recorded on the server; (b) The reliability of the solar panel energy system, with a minimum operational target of 12 hours without interruption; (c) Agricultural productivity improvement, with a target increase of at least 10 percent compared to pre-intervention conditions; and (d) The proportion of farmers capable of operating the system independently, with a target of at least 80 percent of farmer group members.

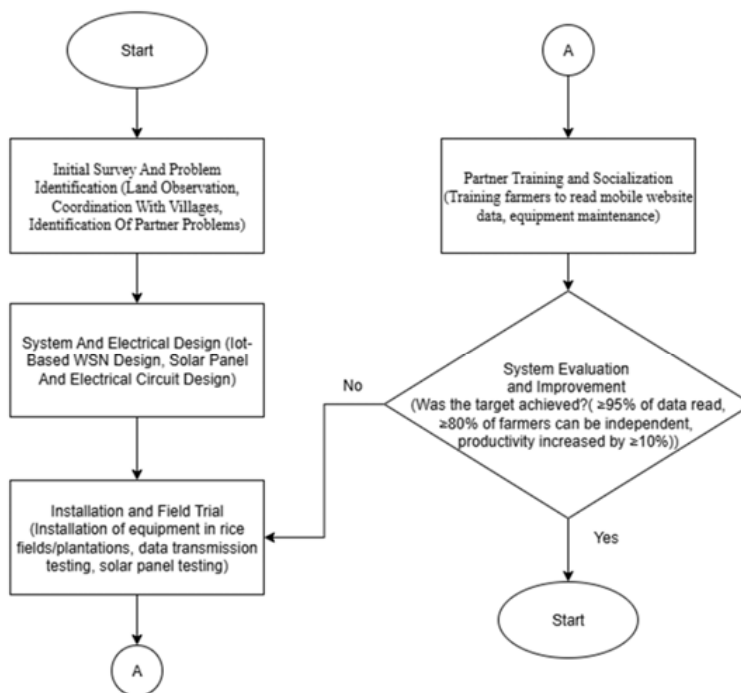


Figure 2. Community service activity flowchart

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Table 1. Stages of activity implementation

Activity 1	Initial Survey	Time
Activities	<ul style="list-style-type: none"> - Field survey and direct observation of agricultural land in Jenggawah Village. - Coordination with the village government regarding the program implementation plan. 	February 2023
Goals	Identification of farmers' problems, mapping of agricultural land potential, and determination of strategic sensor installation sites.	
Activity 2	System Design	Time
Activities	<ul style="list-style-type: none"> - Design of the wireless sensor network (WSN) using a tree topology. - Selection of components, including the Mappi32 microcontroller and LoRa communication module. - Database and mobile website development for real-time data visualization. 	Early May 2023
Goals	Development of an IoT-based precision farming system to monitor land conditions in real time.	
Activity 3	Electrical Design	Time
Activities	<ul style="list-style-type: none"> - Design of the electrical system, including solar panels, batteries, inverters, and controllers. - Component verification and readiness testing of devices. 	End of May 2023
Goals	Ensuring a sustainable and stable energy supply for continuous monitoring operations.	
Activity 4	Installation and Testing	Time
Activities	<ul style="list-style-type: none"> - Installation of monitoring devices at three locations: rice fields, plantations, and the Village Hall (as the gateway). - Testing of sensor data transmission to the gateway and mobile website. - Performance evaluation of solar panels and battery capacity. 	Early October 2023
Goals	Validation of system functionality, accuracy of real-time monitoring, and adequacy of energy supply.	
Activity 5	Launching and Socialization	Time
Activities	<ul style="list-style-type: none"> - Official launching of the IoT-based monitoring system. - Training sessions for farmers on sensor data interpretation, mobile website usage, and device maintenance. - Interactive discussion with the community. 	End of October 2023
Goals	Enhancing farmers' digital literacy, ensuring independent use, and supporting system sustainability.	

3. RESULTS AND DISCUSSION

Results

As a concrete step in realizing the community service program, the implementation was systematically and purposefully designed in accordance with the previously described methods. Each stage of the activity was carried out carefully and guided by the established plan to ensure the achievement of program objectives. This structured approach not only facilitated effective monitoring of the implementation process but also minimized the potential for errors at each stage. The results and discussion of this program are presented in detail through points that correspond to the implementation methods outlined earlier.

The first activity, a direct field survey in Jenggawah Village, Jember Regency, was conducted in February 2023. During this stage, the community service team observed agricultural conditions while simultaneously coordinating with village officials. The survey findings revealed that the village possesses considerable agricultural and plantation potential; however, most farmers continue to rely on conventional methods, which are insufficient in adapting to climate variability. The agricultural land was also found to be vulnerable to drought and pest infestations due to the absence of data-driven monitoring. Furthermore, farmers lacked decision-support tools to determine optimal planting schedules and irrigation practices, thereby increasing the risk of crop failure. Based on the survey, strategic locations for installing monitoring devices were identified, including rice fields and plantation areas as sensor node points, and the Village Hall as the primary gateway site. The survey activities and coordination with village officials are illustrated in Figure 3.



Figure 3. Jenggawah Village apparatus survey and coordination activities

The survey activity produced several quantitative findings. First, Jenggawah Village has approximately 866.75 ha of rice fields along with extensive plantation areas; however, agricultural activities remain largely conventional, resulting in suboptimal productivity. Second, field observations identified three strategic points for the placement of real-time monitoring devices: the rice field area to represent paddy cultivation, the plantation area as a model for non-food commodities, and the Jenggawah Village Hall as the location of the gateway node. The selection of these sites was based on criteria of accessibility, land topology diversity (lowland at 65 meters above sea level with humidity levels ranging from 70–95 percent), and the need for representative data covering both agricultural and plantation sectors. With these site selections, the IoT-based system is expected to provide a more accurate and comprehensive overview of agricultural environmental conditions.

The second stage involved the design of the Wireless Sensor Network (WSN), which was carried out in early May 2023. This design process included the selection of network topology, microcontroller, and data transmission method. The chosen configuration employed a tree topology, with the Mappi32 microcontroller as the processing unit and LoRa (Long Range) as the communication protocol for data transmission. The WSN design is presented in Figure 4.

The WSN design employed a tree topology, as recommended by [Sanjeevi et al. \(2020\)](#). This topology was selected because it aligns well with the systematic flow of data transmission required for the real-time land monitoring system in Jenggawah Village. The system utilized the Mappi32 microcontroller, which is equipped with an integrated LoRa RFM95 communication module. Within the network, sensor nodes function as transmitters that send data collected from five sensors to the gateway node. The gateway node, in turn, acts as the receiver of the sensor readings transmitted by the sensor nodes ([Li & Yang, 2021](#)). Once the data are received, the gateway forwards them to the Firebase Realtime Database. Subsequently, the processed data are visualized through a mobile website interface ([Nugroho et al., 2017](#)). The interface of the mobile website is shown in Figure 5.

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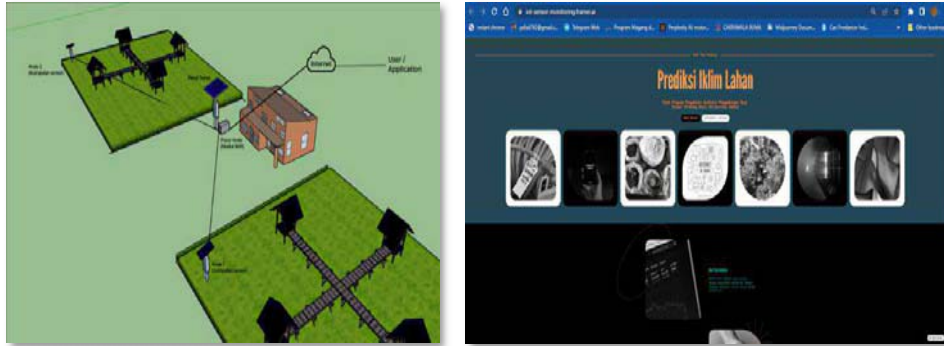


Figure 4. System design

Figure 5. Mobile Website View (<https://real-time-analysis-iklim.web.app>)

The mobile website consists of several pages, namely *Home*, *Shop*, and *Account*. The *Home* page serves as the main interface, displaying real-time information on temperature, rainfall, soil moisture, and wind speed. In addition, it provides various tools that can be accessed by farmers and the community of Jenggawah Village to support their agricultural activities.

The third activity involved the design of the electrical system for the real-time land monitoring device, which was carried out in late May 2023. Following the completion of the WSN design, the electrical configuration of each component and device was developed. Several key electrical components were integrated into the system: (1) A solar panel was used as the primary power source to supply electrical energy to the monitoring device; (2) A Miniature Circuit Breaker (MCB) was installed as a safety system to disconnect the current flow in the event of an electrical overload; (3) A solar charge controller was employed to regulate the output from the solar module to the battery and the microcontroller; (4) the Mappi32 microcontroller was used to receive data from five sensors, including rainfall, wind speed, light intensity, air quality, and soil moisture, and transmit them to the gateway node; (5) An inverter was included to convert Direct Current (DC) into Alternating Current (AC) for powering lighting systems in agricultural and plantation sectors in Jenggawah Village; (6) A battery was installed to store energy generated by the solar panel and provide backup power to the monitoring device when the solar panel does not receive sunlight. The overall design of the electrical system is illustrated in Figure 6.

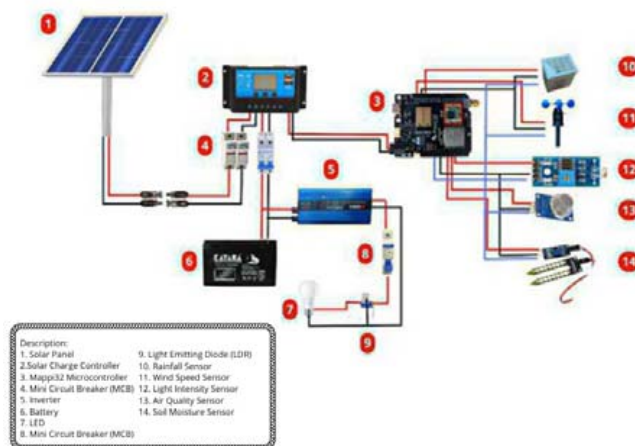


Figure 6. Electrical system for real time land monitoring tools

The design of the electrical system produced a schematic diagram of the circuit, which served as the basis for installation and deployment. In this system, the solar panel functions as the primary energy source to supply power to the land monitoring device. During the design stage, the community service team also conducted component testing, including the battery, inverter, and solar charge controller. This testing aimed to ensure that each component could be activated, operated properly, and was ready for use during the installation phase. The component testing process is presented in Figure 7.



Figure 7. Checking the components and devices used in land monitoring equipment

The inspection results confirmed that all devices were in good condition and ready for installation and testing. The verification process included cable connections to the Mini Circuit Breaker (MCB), battery, inverter, and solar charge controller, followed by testing each component by activating them within the real-time land monitoring system.

The fourth activity was the installation of the monitoring devices, conducted in early October 2023. Installation was carried out at three designated points, accompanied by testing of battery capacity, solar panel performance, and sensor readings displayed through the mobile website. The installation process was conducted collaboratively by the community service team, local residents, and the Jenggawah Village farmer group. The community and farmers showed strong enthusiasm for the deployment of this system, recognizing its role in supporting agricultural digitalization in the village. The installation activities are illustrated in Figure 8.



Figure 8. Installation of real-time land monitoring equipment in Jenggawah Village

The installation of land monitoring devices was carried out at three strategic locations in Jenggawah Village. The first location was a rice field representing the agricultural sector, the second

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was a plantation area representing the plantation sector, and the third was the gateway node placed at the Jenggawah Village Hall. Following installation, performance testing was conducted to analyze energy requirements, with the aim of determining appropriate solar panel and battery specifications to support the operational needs of the monitoring system. The energy performance analysis involved measurements and calculations on system components, including the Mappi32 microcontroller and lighting units, to ensure that daily energy demands could be met (Dhanaraju et al., 2022). The results of this analysis were then used to define the optimal specifications for the solar panel and battery according to system requirements. The process of energy performance analysis is presented in Figure 9 and Table 2.



Figure 9. Energy performance analysis testing on real time land monitoring tools

Table 2. Power characteristics testing on solar panel systems

Time	Irradiasi (W/m ²)			Solar Panels - SCC									SCC - Baterai						Weather									
				Voltage (V)			Current (A)			Power (W)			Voltage (V)			Current (A)			Power (W)									
	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3				
05.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	
06.00	13.4	10.9	12.7	12.71	11.74	12.02	0.05	0.02	0.04	0.635	0.2348	0.4808	12.43	10.88	11.78	0.05	0.01	0.05	0.6215	0.1088	0.589	0	0	0	1	1	1	
07.00	650	597	634	13.94	13.23	13.75	1.6	1.5	1.6	22.304	19.845	22	13.83	12.74	12.97	1.4	1.6	1.5	19.362	20.384	19.455	1	1	1	1	1	1	
08.00	723	784	843	14.46	14.56	15.16	2.1	1.8	1.9	30.366	26.208	28.804	14.39	13.69	13.14	1.8	1.7	1.7	25.902	23.273	22.338	1	1	1	1	1	1	
09.00	899	910	878	15.43	15.76	15.27	2.2	2.3	2.1	33.946	36.248	32.067	14.42	13.57	13.21	2.1	1.9	1.8	30.282	25.783	23.778	1	1	1	1	1	1	
10.00	923	920	913	16.78	16.77	16.53	2.6	2.4	2.4	43.628	40.248	39.672	14.45	13.63	13.47	2.3	2.1	2.1	33.235	28.623	28.287	1	1	1	1	1	1	
11.00	1026	970	974	16.88	16.85	16.76	3.4	3.2	3.2	57.392	53.92	53.632	14.49	13.78	13.72	2.5	2.7	2.5	36.225	37.206	34.3	1	1	1	1	1	1	
12.00	1043	1023	981	17.11	16.98	16.87	3.2	3.1	3.02	54.752	52.638	50.9474	14.42	14.26	13.86	2.7	2.8	2.6	38.934	39.928	36.036	1	1	1	1	1	2	
13.00	907	879	864	16.67	15.31	15.13	2.2	2.1	2.1	36.674	32.151	31.773	14.21	14.17	13.19	2.1	1.7	1.8	29.841	24.089	23.742	1	1	1	1	1	2	
14.00	861	810	743	15.25	14.89	14.12	2.1	1.6	1.5	32.025	23.824	21.18	14.17	13.25	13.02	1.8	1.4	1.5	25.506	18.55	19.53	1	2	2	1	2	2	
15.00	792	724	542	14.68	14.24	13.25	1.7	1.5	1.2	24.956	21.36	15.9	13.82	13.11	12.78	1.5	1.5	1.1	20.73	19.665	14.058	1	2	3	1	2	3	
16.00	571	375	127	13.62	12.46	12.46	1.3	0.8	0.1	17.706	9.968	1.246	12.84	11.76	11.69	1.3	1.2	0.1	16.692	14.112	1.169	1	2	3	1	2	3	
17.00	12.3	0	0	12.01	0	0	0.03	0	0	0.3603	0	0	11.45	0	0	0.02	0	0	0.229	0	0	0	1	2	3	1	2	3
Rata-Rata	647.746	615.608	577.823	13.81	12.52	12.40	1.73	1.56	1.47	27.29	24.36	22.9	12.69	11.14	10.99	1.51	1.43	1.29	21.3507	19.3632	17.1755							
Total				4	9	2	8	2	6	45	45	02	92	84	83	19.57	18.61	16.75	277.56	251.722	223.282							

Weather information: 1 = sunny, 2 = sunny with clouds, 3 = drizzling

Based on the data presented in Table 2, it can be analyzed that the power characteristics generated by the solar panel are strongly influenced by solar irradiance. Measurement results indicate that the

panel's output voltage remains relatively stable within the range of 12–17 V, while the output current is highly dependent on irradiance levels. During the early morning (05:00–07:00), when solar intensity is relatively low (13–650 W/m²), the panel produces only 0.6–19 W of power. As irradiance increases at midday (09:00–13:00) reaching 899–1043 W/m², panel power output rises significantly to approximately 39–41 W. After the peak irradiance period, output power declines in the afternoon (15:00–16:00) in line with the reduction of sunlight intensity. These findings confirm that panel output power is directly proportional to effective solar irradiance, with maximum production occurring between 11:00 and 13:00. However, not all energy generated by the solar panel can be fully stored in the battery. Consequently, charging efficiency becomes a critical factor in determining the effectiveness of the storage process. This efficiency can be calculated using the Equation 1.

$$\eta \text{ Battery Charging} = \frac{\text{Total Charging Energy (Wh)}}{\text{Battery Energy Capacity (Wh)}} \times 100\% \quad (\text{Equation 1})$$

Day-1:

$$\begin{aligned} \eta \text{ Battery Charging} &= \frac{277.56 \text{ Wh}}{300 \text{ Wh}} \times 100\% \\ &= 92.52\% \end{aligned}$$

Day -2:

$$\begin{aligned} \eta \text{ Battery Charging} &= \frac{251.72 \text{ Wh}}{300 \text{ Wh}} \times 100\% \\ &= 83.9\% \end{aligned}$$

Day -3:

$$\begin{aligned} \eta \text{ Battery Charging} &= \frac{223.282 \text{ Wh}}{300 \text{ Wh}} \times 100\% \\ &= 74.3\% \end{aligned}$$

The calculation results indicate a decline in battery charging efficiency over a three-day period, with the highest efficiency observed on the first day. Several factors contribute to this decrease, including weather and environmental conditions, component quality, cable losses, and the orientation and tilt angle of the solar panel relative to the sun. The relatively high efficiency on the first day is attributed to more evenly distributed solar irradiance throughout the day. The system load consists of an LED lamp with a rated power of 40 W. This lamp operates only at night for approximately four hours per day. Thus, the total daily energy requirement for the lamp can be determined using the Equation 2.

$$\begin{aligned} E &= P_b \times t && (\text{Equation 2}) \\ E &= 40 \text{ Watt} \times 4 \text{ jam} \\ E &= 160 \text{ WH} \end{aligned}$$

After obtaining the load demand value, the next step is to calculate the total required energy. To account for system losses, an additional 20 percent margin is included in the calculation. These losses represent the proportion of energy dissipated during the transfer process from the solar panel to the load. Energy losses may occur due to several factors, such as the efficiency of the solar panel, cabling, and other supporting components. Thus, the total required energy can be systematically expressed using the Equation 3.

$$\begin{aligned} E_{\text{total}} &= E_{\text{system}} + (E_{\text{system}} \times 20\%) && (\text{Equation 3}) \\ E_{\text{total}} &= 160 \text{ WH} + (160 \text{ WH} \times 20\%) \\ E_{\text{total}} &= 160 \text{ WH} + 32 \text{ WH} \\ E_{\text{total}} &= 192 \text{ WH} \end{aligned}$$

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Based on the calculations, the daily energy requirement for the load, which consists of a 40 Watt DC LED lamp, is 192 Wh. The power consumption pattern of the system shows a clear distinction between daytime and nighttime usage. During the day, the solar panel supplies energy directly to the load while simultaneously allocating part of the output for battery charging. At night, when the panel no longer produces energy, the entire electricity consumption relies on the stored energy in the battery. With a 40 W LED lamp as the load, the theoretical daily energy of approximately 250.8 WH is sufficient to power the lamp for about 6 hours and 27 minutes, as shown in the Equation 4.

$$t = \frac{250,8 \text{ Wh}}{40 \text{ W}} = 6.27 \text{ hours} \quad (\text{Equation 4})$$

This indicates that the energy supplied by the solar panel is sufficient to support nighttime lighting needs, although in practice the actual operating duration may be lower due to system losses.

Data transmission testing from the sensor nodes to the gateway node was conducted by comparing the readings displayed by the Mappi32 microcontroller as the sensor node with those presented on the mobile website (Higashiura & Yamamoto, 2021). This test aimed to verify that the mobile website can provide accurate and real-time data reflecting the actual conditions in the field. The comparison of readings between the Mappi32 microcontroller and the mobile website is presented in Figure 10 and Table 3.

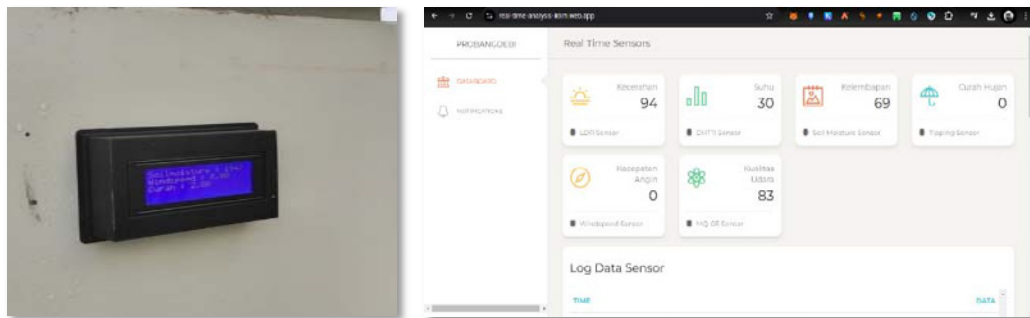


Figure 10. Reading results on sensor nodes and mobile website

Table 3. Sensor reading results on mobile website

Time	Brightness	Soil Moisture (%)	Air Quality (AQI)	Wind Speed (km/h)	Rainfall
2023-10-20 12.00	80	34	70	0	0
2023-10-20 12.05	83	36	74	1	0
2023-10-20 12.10	82	35	74	2	0
2023-10-20 12.15	80	35	72	4	0
2023-10-20 12.20	79	34	73	3	0
2023-10-20 12.25	83	36	72	3	0
2023-10-20 12.30	81	34	71	2	0
2023-10-20 12.35	82	35	72	1	0

Based on the testing results, the energy performance analysis of the real-time land monitoring system was carried out by measuring voltage and current across each load (Risnandar et al., 2021). The 100 WP solar panel produced variable power output depending on solar irradiance, with an average power conversion efficiency sufficient to meet daily load requirements. Measurements indicated that the available power from the solar panel was proportional to the power consumed, demonstrating that the system operated with high efficiency. The total daily energy demand was calculated at 136.32 WH, consisting of consumption by the Mappi32 microcontroller and five sensors of approximately 0.5–0.7 W, as well as an additional 6 W consumed by the LED lamp used at night. The consumption pattern showed a clear distinction between daytime and nighttime usage, where daytime loads were dominated by sensors and the microcontroller, while nighttime loads increased due to lighting requirements. Based on this energy demand, the appropriate system capacity was determined to be a 100 WP solar panel and a 56.8 Ah battery (Barik & Naz, 2021), enabling the device to operate sustainably without energy shortages.

The socialization and official launch of the land monitoring program in Jenggawah Village were met with strong enthusiasm from both the community and local government officials. The activity began with a presentation by the community service team outlining the program's objectives and benefits, emphasizing the role of IoT-based precision agriculture technologies in enhancing productivity and sustainability within the agricultural sector. Participants, consisting of farmers, village officials, and farmer group members, were introduced to the operation of the monitoring device, the function of each sensor, and the use of the mobile website for real-time data access. During the socialization session, participants were trained to interpret data outputs from the monitoring system, including soil moisture, rainfall, wind speed, light intensity, and air quality. The training also covered practical maintenance steps, such as cleaning sensors, checking device connectivity with the gateway node, and ensuring the solar panel operated in optimal condition. These efforts were intended to ensure that the community could independently operate and maintain the system after the program's completion.



Figure 11. Socialization and launch of real-time monitoring tools

The question-and-answer session served as an interactive moment where farmers expressed their needs and raised inquiries regarding the implementation of this technology. Many participants demonstrated strong interest in how the device could assist them in determining planting schedules, irrigation requirements, and more efficient land management practices. The community service team also provided guidance on utilizing the data generated by the monitoring system to minimize crop failure risks caused by unpredictable weather conditions. Following the socialization activities, the official inauguration of the monitoring devices was conducted at the designated installation sites. The

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community was invited to directly observe the system in operation, including demonstrations of real-time data collection from the sensors displayed on the mobile website. The event was also attended by village officials, who expressed their appreciation for the program, highlighting its potential to positively impact farmers' welfare while promoting more modern and efficient land management practices.

Discussion

The discussion of this community service program highlights its success in implementing a technology-based solution to address agricultural challenges in Jenggawah Village. The initial survey conducted by the service team served as a crucial foundation for designing approaches aligned with the community's needs. As indicated in the preliminary survey (Table 3), the primary obstacle faced by farmers was the continued reliance on conventional land management methods, which proved inadequate in anticipating the impacts of climate variability.

Table 4. Condition data before monitoring system implementation

Indicators	Initial Conditions (Before Implementation)
Soil moisture measured	Not systematically monitored
Rainfall	Recorded manually, inconsistently
Wind speed	Data unavailable
Access to agricultural information	15 percent of farmers use digital applications/data

After the implementation of appropriate technology in the form of an IoT-based monitoring system, field conditions showed significant improvement. The monitoring devices were installed at three strategic locations representing agricultural areas in Jenggawah Village, and environmental data could be accessed in real-time through the mobile website.

Table 5. Condition data after monitoring system implementation

Indicators	Condition After Implementation
Soil moisture measured	Installed sensors, real-time data
Rainfall	Automatically recorded and archived
Wind speed	Available with minute-by-minute updates
Access to agricultural information	68 percent of farmers actively access data via the mobile website

The integration of IoT sensors with LoRa communication has proven effective in covering extensive agricultural areas, even in remote locations. The use of solar panels and batteries further ensures the sustainability of the system's energy supply (Balamurali et al., 2024). From a social perspective, the training provided successfully improved the community's digital literacy. A post-training survey revealed that 82 percent of farmers were able to read and interpret soil moisture data to determine more accurate irrigation schedules. Overall, the comparison between pre- and post-implementation conditions demonstrated that this technology not only enhanced agricultural productivity but also expanded access to information for the people of Jenggawah Village. This achievement underscores that the application of IoT-based appropriate technology can serve as a model for developing precision agriculture in other regions (Sharma & Shivandu, 2024).

The identification of strategic locations for installing monitoring devices was also a crucial factor, ensuring that the technology could be accessed and optimally utilized by the community. During the design stage, the IoT-based monitoring system was developed to address the identified local needs. The system employed sensors capable of monitoring environmental conditions in real time, including soil moisture, rainfall, and wind speed, with the data displayed directly through an easily accessible mobile website. Using a tree topology and LoRa communication modules, the system guaranteed efficient data transmission over long distances, even in remote areas. This provided a significant advantage in delivering accurate and up-to-date information to farmers, enabling them to make data-driven decisions.

The implementation process of the system was carried out with active community involvement, which served as a key strategy to ensure the program's sustainability. The installation of devices in three strategic locations reflected the team's commitment to ensuring that the technology could cover diverse agricultural areas in Jenggawah Village. The testing phase not only verified the functionality of the devices but also evaluated the energy requirements necessary for optimal operation. The integration of solar panels and batteries into the system was a crucial step in guaranteeing both efficiency and sustainability, particularly given the limited energy access in certain areas (Balamurali et al., 2025). Furthermore, the training and socialization sessions conducted with the community played an important role in effectively introducing this new technology. These sessions not only covered the technical aspects of device operation but also emphasized the interpretation of data displayed on the mobile website. This enabled farmers to understand how the data could be applied to optimize their land management practices.

The enthusiasm demonstrated by the community during the training highlighted the acceptance of the technology and confirmed the program's relevance to local needs. Overall, the community service program delivered tangible benefits for the people of Jenggawah Village. Beyond improving agricultural productivity, the program also provided education on the importance of digitalization in the agricultural sector (Sharma & Shivandu, 2024). Another positive outcome was the increased awareness of environmental sustainability through the adoption of clean energy solutions, such as solar panels. With the success of this program, Jenggawah Village has the potential to serve as a model for precision agriculture implementation in other regions, demonstrating that technology can be an effective solution to address local challenges in the agricultural sector.

4. CONCLUSION AND RECOMMENDATIONS

The community service program based on precision agriculture technology in Jenggawah Village successfully provided concrete solutions for farmland management. Through an Internet of Things (IoT)-based monitoring system, farmers were able to monitor land conditions in real time using five main sensors, such as soil moisture, light intensity, rainfall, wind speed, and air quality, connected to a mobile website. This system enhanced management efficiency, reduced the risk of crop failure due to climate variability, and promoted the use of clean energy through solar panels. During testing, the system demonstrated optimal performance with an average daily energy consumption of 192 Wh, supported by a 100 Wp solar panel and a 25 Ah battery. The active participation of the community in installation and training reflected strong acceptance of the technology, which contributed to improving agricultural productivity while introducing digitalization in farming practices. However, attention must be given to the system's capacity during the rainy season, when solar irradiance decreases significantly. Assuming the primary load is a 40 W LED lamp operating for 4 hours per night (160 Wh), while the average daily energy available from the solar panel is only around 136 Wh, this results in an energy deficit of approximately 24 Wh per day. With a battery capacity of 300 Wh, the system can still support the load for 6–10 consecutive

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days despite reduced daily energy production. Nevertheless, prolonged cloudy conditions could cause the battery's state of charge (SoC) to drop below safe levels. Therefore, operational strategies such as reducing lamp usage duration, increasing solar panel capacity, or employing larger-capacity batteries are strongly recommended to ensure the system's sustainability during the rainy season.

To ensure the sustainability and maximize the impact of this program, several strategic steps need to be taken. First, the maintenance of the monitoring devices must be prioritized by establishing a local team responsible for ensuring that the tools remain functional and in optimal condition. Without proper maintenance, the long-term benefits of this technology could be disrupted. Second, the technological features should continue to be improved. The addition of new sensors, such as soil pH sensors or early warning systems, would provide farmers with more comprehensive data. This would support more accurate decision-making, particularly in addressing risks related to climate change and pests. Third, local government and universities should support the replication of this program in other villages. With wider adoption, precision agriculture technology could serve as a collective solution to increase agricultural productivity across Jember Regency and beyond.

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