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Internet of things-based rice field irrigation evaporation monitoring system

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ABSTRACT

The urgency for efficient irrigation in Indonesia's agriculture sector, particularly in paddy fields, is evident. However, existing methods for monitoring water levels are antiquated, often requiring manual measurements with a ruler. This research introduces a comprehensive "monitoring system for light intensity and water temperature as an analysis of evaporation for rice irrigation based on the internet of things". The system integrates various sensors an anemometer for wind speed, an ultrasonic sensor for water level, a DS18B20 waterproof sensor for water temperature, and a GY-8511 sensor for sunlight intensity. All data are collected by an Arduino Mega controller, connected to an ESP32 for transmitting the readings to the Blynk app and an I2C 20×4 liquid crystal display (LCD) screen. The control mechanism employs a closed-loop system with a direct current (DC) motor actuator to operate the water gate, which can also be manually controlled via a cellphone. The system effectively meets daily evapotranspiration requirements of 1.44 mm, with optimal conditions yielding water levels of 3 cm, water temperatures of 38.53 °C, sunlight intensity of 4.59 mW/cm², and wind speed of 0.21 m/s.

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1. INTRODUCTION

In the field of agriculture, a well-functioning water supply system, often referred to as irrigation, is essential, especially for rice crops [1], [2]. There are two primary classifications of rice fields: irrigated and non-irrigated. A field is considered irrigated if it has an irrigation system and is under the supervision of the local populace or agricultural services [3]–[5]. Conversely, non-irrigated fields are those dependent on natural conditions such as rainfall [6]–[9]. Based on data from the central bureau of statistics, the total land area, including both irrigated and non-irrigated, reaches 1,174,586 Ha [10], [11]. Therefore, irrigation emerges as a primary strategy for enhancing rice production by controlling the appropriate water supply [12]–[16].

While the alternate wetting and drying (AWD) method is still widely used [17]–[20], there is a need to develop more efficient irrigation techniques. Concerns arise regarding the efficiency of water use in conventional irrigation systems. Rice crops require constant monitoring of water availability, and the conventional approach necessitates farmers to check field conditions daily. The AWD technique, as elaborated in journal [21], combines both wet and dry methods. However, this method results in a 33% increase in water consumption compared to conventional irrigation. Climatic conditions, such as solar radiation and wind speed, affect the effectiveness of water supply [22]–[25]. This influences evaporation and the water needs of the rice plants [24]–[34].

There have been previous efforts in developing systems to monitor light intensity and water temperature to enhance irrigation [35]–[37]. Contribution of this article: in response to the need for a more efficient system, this research develops the “light intensity and water temperature monitoring system” as a solution to the identified problems. This system is expected to minimize water consumption and maximize rice production yields.

This system has the potential to minimize air consumption and maximize rice production for several reasons. First, it allows farmers to maintain environmental conditions, such as sunlight intensity, air temperature and wind speed in real-time. With this information, the system can intelligently regulate irrigation, reducing air use when environmental conditions support healthy plant growth, such as high sunlight and lower temperatures. This contributes to air conservation because air is only used when needed. Second, this system uses advanced ultrasonic sensors to precisely measure the air level in the rice fields, ensuring the rice plants receive the appropriate air level, thereby minimizing air consumption. In addition, this system maintains the air temperature, which significantly affects the evaporation rate.

By measuring air temperature and combining it with wind speed and sunlight intensity data, the system can predict potential evaporation levels and optimize irrigation to compensate for air loss due to evaporation, ensuring plants receive enough air without wasting it. Finally, with real-time data transmission, the system allows farmers to combine and control irrigation remotely via their smartphone. The subsequent sections will discuss the research methodology, the implementation of the proposed monitoring system, and an evaluation of the results and potential applications in the future.

2. METHOD

This research method aims to determine the research steps for designing a system for monitoring light intensity and water temperature as an analysis of evaporation for paddy field irrigation based on the Internet of things. The following is an image of the flow diagram of this research.

2.1. Flowchart

Figure 1 is program design for an evaporation monitoring. The work of this tool system is that when the system reads the water level measurement which decreases to 3 cm and the evapotranspiration decreases to approximately the same as 2.88 mm, the direct current (DC) motor will turn on and rotate clockwise to move the water gate to open the irrigation of the rice fields. The water gate fill water according to the needs of rice plants or evapotranspiration. If evapotranspiration has reached a water level of 5 cm, the DC motor will be off and the iron shaft will rotate counterclockwise to close the water gate. So the system can control the evaporation of rice irrigation.

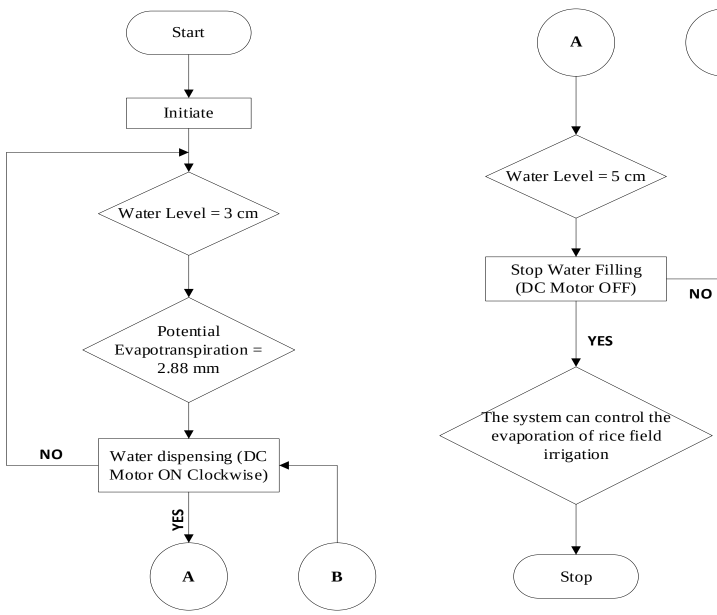

Figure 1. Control system flowchart for the evaporation monitoring system

2.1.1. Evaporation monitoring system hardware design

Figure 2 explains the entire sensor in the evaporation pan. The tube body is made with holes so that water can still enter the pipe and an ultrasonic sensor can read the elevation or difference in water level every hour, and above the evaporation sensor there is a dome shape or plastic cover whose function is to prevent the sunlight intensity sensor from being directly exposed to water. All of the ultrasonic sensor cables, sunlight intensity sensors, and DS18B20 sensor wiring will be placed on the sensor body at point number 3.

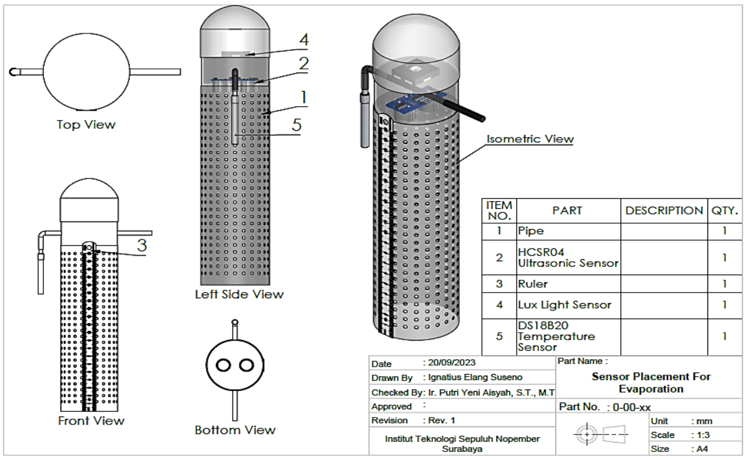

Figure 2. Overall mechanical design of the evaporation pan sensor

Figure 3 explains the design of a water gate consisting of two main parts: the water gate for the irrigation opening of the rice paddy and the panel box for the electrical components. There are five main components in this water gate, including the iron shaft of the motor, which serves as the mechanism for moving the water gate plate. This iron shaft will be connected to a DC motor to operate the water gate plate. A rope is used to raise or lower the water gate plate, allowing water to enter the rice paddy. Inside the panel box for the water gate, there are a relay and a DC motor. The DC motor drives the iron shaft at a variable speed using a dimmer, controlling the winding of the rope to lift the water gate plate. This system is controlled by a relay connected to an Arduino to switch the DC motor on or off. This relay system is also equipped with an optocoupler as an electrical safeguard, preventing reverse current or voltage from the DC motor that could damage the electrical components connected to the DC motor.

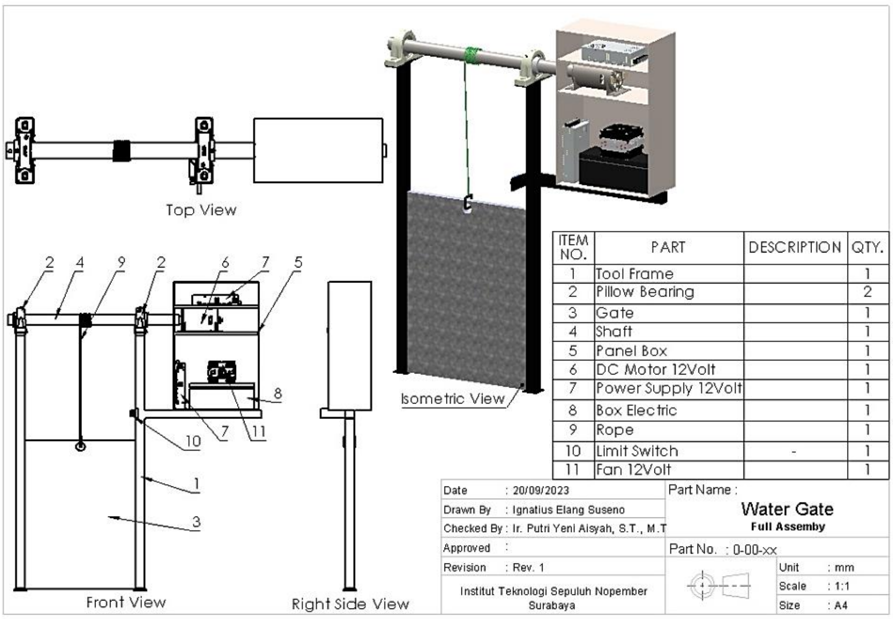

Figure 3. Overall water gate mechanical design

2.1.2. Program design for an evaporation monitoring system

Figure 4 is a display of the user interface on a cellphone which is displayed in the blynk application. Evaporation is measured with an evaporation open pan (Evaporimeter) [38], [39]. The Evaporimeter is placed in an open area, not obstructed by other plants, and exposed to direct sunlight. This evaporimeter uses an open pan filled with water and any changes in water level due to this evaporation will be calculated every day in liters [40], [41].

Figure 4. Blynk display design on cellphone

The calculation of this open pan evaporimeter is:

$$Ep = (\Delta\, water\ level \times\ pan\ area)\ \times\ 1000 \tag{1}$$

where Ep is pan evaporation (liters) and Δ water level is difference in water level in the pan for a day (m).

$$Pan\ area = \pi\ \times\ r^2 = 3{,}14\ \times\ pan\ radius\ (m^2) \tag{2}$$

to find the potential evaporation, use (3):

$$ET_0 = K_p \times E_p \tag{3}$$

where ET_0 is potential evaporation (liters/day); K_p is pan coefficient (between 0.4 – 0.85) [42]; and E_p is pan evaporation (liters).

$$ET_c =\ K_c \times ET_O \tag{4}$$

where ET_c is potential evapotranspiration (liters/day); K_c is rice plants coefficient; and ET_O is potential evapotranspiration (liters).

Rice plants coefficient can be determined based on waterlogging and rice plants varieties [43], [44]. Rice plants coefficient is defined as the ratio between the amount of potential evapotranspiration with the reference evaporation of plants under normal growing conditions [45]–[47]. After obtaining the potential evapotranspiration, the next step is the calculation of the potential evapotranspiration based on the area of rice fields. The formula for potential evapotranspiration based on rice field area is:

$$ET_{Cs} =\ ET_C \times \left(\frac{L_S}{L_p}\right) \tag{5}$$

where ET_{Cs} is potential evapotranspiration based on rice field area (liters/day); ET_C is potential evapotranspiration (liters/day); L_S is rice field area (m^2); and L_p is pan area (m^2).

3. RESULTS AND DISCUSSION

3.1. Results of hardware

The results of the hardware design of the monitoring system can be seen in Figure 5. The hardware consists of 4 parts, namely water gate, sensor, electrical panel box, and evaporimeter. The water gate box functions as a container for electrical components to move the iron shaft to rotate. Inside the evaporimeter there is a water temperature sensor, light intensity sensor, anemometer, and water level sensor.

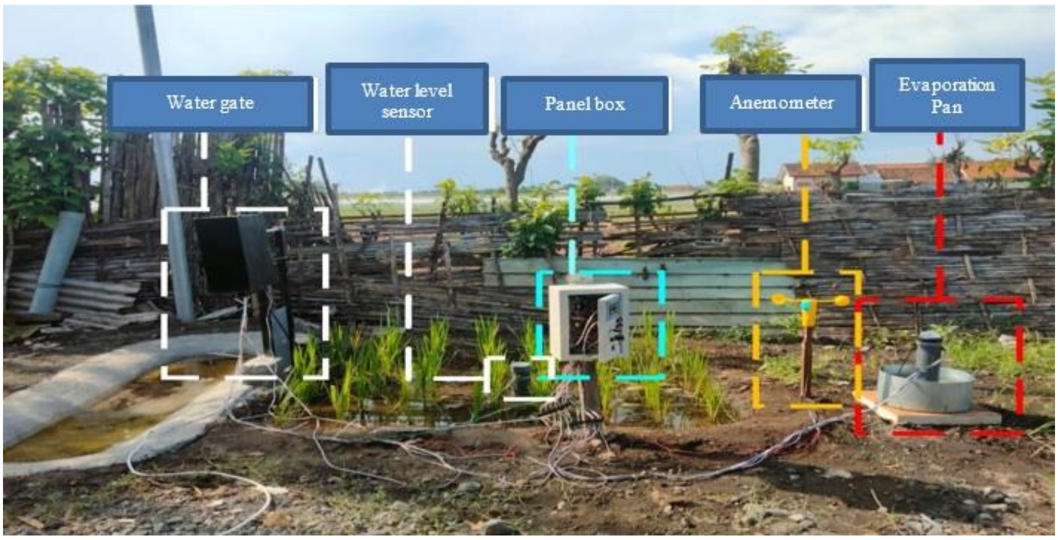

Figure 5. Result of hardware of the evaporation monitoring system

3.2. Validation test

Sensor validation aims to determine and compare the results of sensor readings to measurement readings from standard measuring instruments. The validation performance is analyzed from the error value and the accuracy of the sensor comparison results with standard measuring instruments. If the error is less than 5% and the accuracy is between 90-100% then the sensor performance is good [48].

In this study, ultrasonic sensor validation testing was carried out using 2 sensors. Ultrasonic sensor 1 to measure the water level based on the evaporation that occurs in the pan. Ultrasonic sensor 2 to measure the water level in the rice field miniplant. Water temperature sensor test with a digital thermometer as a validator. Light intensity testing is carried out every day from morning to evening with sunny weather conditions. From the experimental results in Table 1, error and accuracy are at a good value so that the sensor can be integrated into the designed system.

Table 1. Validation results

No.	Component	Sensor reading average	Standard instrument reading average	Error (cm)	Accuracy (%)
1	Ultrasonic sensor 1	10.53	10.1	0.43	95.76
2	Ultrasonic sensor 2	10.29	10	0.29	96.607
3	Water temperature sensor	40.1	40.03	0.07	99.834
4	UV light sensor	3.745	3.71	0.035	99.048

3.3. Actuator test result

Actuator testing is carried out to determine the performance of a DC motor by measuring the voltage, current and rotational speed of the DC motor. The test variations are actuators without load and actuators with load. Table 2 is the data when testing the performance of a DC motor with a load of iron shafts and iron plates.

The voltage value of the DC motor with the addition of the load decreases to 11.95 V. The decrease in voltage causes the current to increase to 5.86 A. The rotational speed of the motor decreases to 762 rpm with the electricity consumed being 70.30 watt. This power consumption does not exceed the maximum power specifications of a DC motor of 100 watts. So, it can be said that the actuator can perform its function according to the purpose of the system.

Table 2. DC motor performance test with load

No	Time (minutes)	Current (A)	Voltage (V)	Power (watt)	Rotating speed (rpm)
1	1	6	12.00	72	784
2	2	5.89	12.00	70.68	784
3	3	5.83	12.00	69.96	784
4	4	5.81	11.98	69.72	740
5	5	5.81	11.98	69.72	740
6	6	5.81	11.98	69.72	740
	Average	5.86	11.99	70.30	762

3.4. Comparison of sensor and evaporimeter measurement results for the water gate response test

Data collection is carried out to find out whether the response of the controlled water gate is according to the specified setpoint. To find out whether the designed system is suitable for the evaporation that occurs, a comparison is made with the evaporation value measured by the evaporimeter. Table 3 is a data comparison of the results of sensor and evaporimeter measurements with the following information:

- HWP: high water pan (water level in the evaporation pan).
- HWS: high water paddy fields (water level in the paddy fields).

Table 3. Evaporation data collection

No	Time	HWS (mm)	HWP (mm)	Water temp. (C)	UV light (mW/cm^2)	Wind speed (m/s)	Ep (mm)	Eto (mm)	Etc (mm)	Water gate
1	08.00	36	134	30.52	0.53	0.12	2	1.5	1.44	Off
2	09.00	35.9	134	32.81	1.47	0	2	1.5	1.44	Off
3	10.00	34.2	134	34.00	2.22	0	3	2.25	2.16	Off
4	11.00	32.3	133	35.47	2.76	0.11	3	2.25	2.16	Off
5	12.00	31.1	133	38.85	4.70	0.08	3	2.25	2.88	Off
6	13.00	30	133	37.91	3.74	0.11	4	3	2.16	On
7	14.00	50	132	35.11	2.55	0.02	0	0	0	Off

In Table 3 that higher temperatures and greater light intensity at 12.00 cause an increase in the evaporation rate. This is in accordance with the basic principles of the evaporation process. When the air temperature is higher, water molecules become more energetic, allowing them to move faster and eventually evaporate from the surface of the water. Greater light intensity can also increase the surface temperature of the water, speeding up the evaporation process.

In Table 3, a comparison is made between the sensor and evaporimeter measurement results with several relevant parameters, such as HWP, HWS, water temperature, UV light intensity, wind speed, and water gate position (on or off). It can be seen that the comparison between the HWP and HWS values shows that the difference between the water level in the rice field and the water level in the evaporation pan is not very significant, which indicates that the temperature and water level sensor measuring instruments have good accuracy in reflecting the evaporation conditions in the field. The sluice control system works by measuring the reduction in water level by up to 3 cm and evapotranspiration is reduced by around 2.88 mm. When this condition is reached, the DC motor will be activated and move the water gate to open irrigation for the paddy fields so that the rice plants get water according to their needs.

4. CONCLUSION

The sensor used has a good level of accuracy, namely the ultrasonic sensor as a water level sensor has an average accuracy of 98.106%. The DS18B20 type water temperature sensor has an average accuracy of 99.811%. The anemometer as a wind speed measurement tool has an accuracy of 98.105%. The ML8511 type light intensity sensor has an accuracy of 99.382%. So that all sensors can be integrated into the evaporation design system because they have an average error of less than 5%. The response of the water gate due to the parameters of temperature and light intensity measured by the monitoring system has results that are comparable to the evaporation value measured by the evaporimeter. From the results of research carried out for 8 days, the water gate provides irrigation in the lowland rice mini plant every 2 days with a difference between evaporation in the pan of 2 mm/day and evapotranspiration of the rice plants of 1.44 mm/day. The highest average evaporation value was at 13.00 WIB with sunlight intensity of 4.59 mW/cm^2, air temperature of 38.53 °C, and wind speed of 0.21 m/s.

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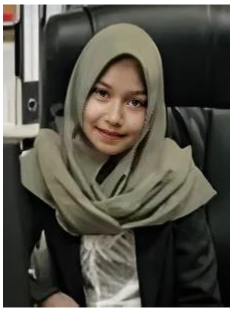

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