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Real-time paddy grain drying and monitoring system using long range-internet of things

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ABSTRACT

Grain drying environmental parameters are an important issue throughout the paddy grain production process. A real-time monitoring system requires rapid, online, and accurate measurement results. In the paddy grain drying process, the heated air velocity, temperature, relative humidity, and moisture content have to be carefully monitored and maintained to ensure product quality and safety. This study aimed to propose a real-time paddy grain drying and monitoring system using a long-range internet of things (LoRa-IoT). The real-time monitoring system consisted of sensors, LoRa, and IoT platforms. The LoRa end node and gateway were utilized as a wireless radio communication platform of IoT for long-distance signal transmission. From the experiment, the gateway received data from the end node at a distance of 2 km with a time on air (ToA) of 981 ms. As a result, the proposed monitoring system succeeded in measuring and recording the heated air velocity, temperature, and relative humidity data during the paddy grain drying process from 25% moisture content down to 14%. Regarding moisture content, the accuracy of real-time monitoring information was confirmed with a direct measurement method, resulting in a root mean square error (RMSE) of 6.17%.

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1. INTRODUCTION

Rice is a cereal grain from the grass species Oryza sativa, a staple food for most people in Asia, Latin America, and Africa. The quality of rice depends on the moisture content, extraction rate (percentage of broken rice), cleanliness, and whiteness/polished degree [1]. The rice processing affects its quality, ultimately determining consumer preferences and rice prices.

After threshing, the harvested paddy (rough rice kernel) is still enclosed by its husk. Several stages of the post-harvest paddy grain include drying, storage, and milling. The drying process is a crucial stage and aims to reduce the moisture content before it is stored and further processed into rice. As the hygroscopic material, paddy grain quality depends on the moisture content level [2], [3]. High moisture content leads to rapid fiber degradation, making the paddy grain too frail to mill. Additionally, storing the moist grain promotes mold growth [4] and causes grain discoloration.

In tropical regions, the moisture content of fresh post-harvest paddy grain generally ranges between 20% and 28%, depending on the dry or rainy season [5]. The paddy has to be dried properly to protect against grain deterioration. The paddy grain with a maximum moisture content of 14% is safe against fungal and micro-bacterial activity and can be stored for up to 3 months before milling.

Two methods are commonly used to conduct the paddy grain drying process: naturally and artificially [6]. The natural drying method is when the wet paddy grain is left to dry under natural sunlight and wind conditions. This process typically requires 3 to 5 days of drying in sunny weather conditions with an average air temperature of 25 °C to 30 °C. The natural drying method is weather-dependent, and consequently, it performs a slow drying process. The artificial drying method involves hot air drying [4], [7], oven drying [8], microwave drying [7], [8], vacuum drying [9], and electric heater drying [10]. The studies reported that the artificial drying method performs better than natural drying. Moreover, the natural drying method has no control over airflow, temperature, and relative humidity, whereas these conditions can be well controlled in the artificial drying method.

A monitoring system is necessary to ensure the drying process runs appropriately. Information regarding heated air velocity, temperature, and relative humidity becomes essential for grain drying. The heated air velocity, temperature, and relative humidity should be carefully monitored and maintained during drying to confirm product quality and safety [11]. Wang *et al.* [10] used an A/D module, a temperature measurement module, and a weighing module to record the air temperature, air humidity, grain temperature, and grain weight during the drying process. Viviane *et al.* [12] built a continuous monitoring for the corn grain drying. They used a smartphone and a liquid crystal display to monitor temperature, relative humidity, and light intensity during drying.

The moisture content of grain affects its quality and long-term storability. Real-time monitoring of moisture content during the drying process plays a vital role in achieving the desired grain drying rate. With the real-time monitoring system, overdrying and underdrying, which lead to the production of low-quality dry grain, can be avoided. Overdrying results in cracking and loss of viability, whereas underdrying may produce moist grain that is not ready to be stored for a certain period. However, measuring the moisture content of the grain is one of the main difficulties associated with the requirement for specific measuring instruments. There are two methods for measuring the moisture content of grain: direct and indirect measurements. Direct measurements are more accurate than indirect ones but are time-consuming and require special facilities. Indirect measurements are widely used because of their accessibility and fast response. Khairetdinova *et al*. [13] introduced a method based on the dependence of temperature and moisture content and its gradient to measure grain moisture content. This method had the ability to monitor moisture content in the range of 13%-20%. Liu *et al.* [14] designed an online grain resistance sensor to detect grain moisture during drying. The grain moisture content was then obtainable through frequency signals, temperature nonlinear correction, and moisture calibration in a mathematical model. Hay *et al*. [15] used another way to determine grain moisture level by using an equilibrium curve at a specific temperature. Another related study on indirect measurements was proposed by Hu and Jiang [16], who employed a parallel plate capacitor to perform real-time monitoring of grain moisture content in a dryer. In this way, a microcomputer was applied to convert frequency data collected from the capacitor into grain moisture content values. In another study, Lewis *et al*. [17] found that the indirect measurement using the correlation between temperature and relative humidity had low accuracy results in grain moisture content values. This was due to the accuracy of moisture content determination decreasing significantly at high temperatures and relative humidity.

Most of the aforementioned studies were limited to investigating various grain drying methods and developing instruments to measure grain moisture content. In this study, a real-time monitoring system was constructed to measure parameters associated with the paddy grain drying process, such as the heated air velocity, temperature, relative humidity, and moisture content. The drying process parameters were monitored continuously using long-range internet of things (LoRa-IoT) platforms. Experimental investigations were also carried out to monitor the information obtained from the drying process and send the data from LoRa communications to the internet of things (IoT) cloud. In this way, the stored measured data could be read at any time for traceability of dry grain production. In terms of moisture content, the accuracy of real-time monitoring results was confirmed with a direct measurement method.

2. METHOD

2.1. Real-time monitoring system

Figure 1 shows the real-time monitoring system for a grain dryer. The real-time monitoring system consists of sensors, LoRa, and IoT platforms. A capacitive grain moisture sensor [18], [19] is applied to measure the moisture content (MC) of grain, and different types of sensors are also used for the measurement of heated air velocity (v), temperature (T), and relative humidity (RH) inside the dryer. The sensors continuously detect v, T, RH, and MC, then send these signals to an ESP32 chip as the information processing unit. The ESP32 is a low-power microcontroller with integrated wireless fidelity (Wi-Fi) [20].

LoRa is utilized as a wireless platform of the IoT for long-distance signal transmission. It is designed to provide communications between the sensors, end node, gateway, and cloud server as shown in Figure 1. The main advantage of LoRa is that it communicates in radio bands so that it can operate in areas where internet networks are not available. Additionally, it has a long-distance signal coverage. The LoRa platform has a gateway and an end node. The LoRa end node and gateway are installed with ESP32 chips. ESP32 chips are capable of connecting to sensors and different devices. The end node is the edge device with low bit rates, and it collects data from sensors and sends them to the gateway. In the end node, the ESP32 chip is used to save the measuring data from sensors. The gateway has the responsibility of receiving data from the end node and transmitting the data to the network. The gateway receives data from the end node via LoRa wireless without requiring an internet connection. In the gateway, the ESP32 chip is used to transmit data to the cloud server over Wi-Fi, ethernet, or cellular. As seen in Figure 1, the real-time monitoring is done using a computer browser through Antares, the Telkom Indonesia IoT platform.

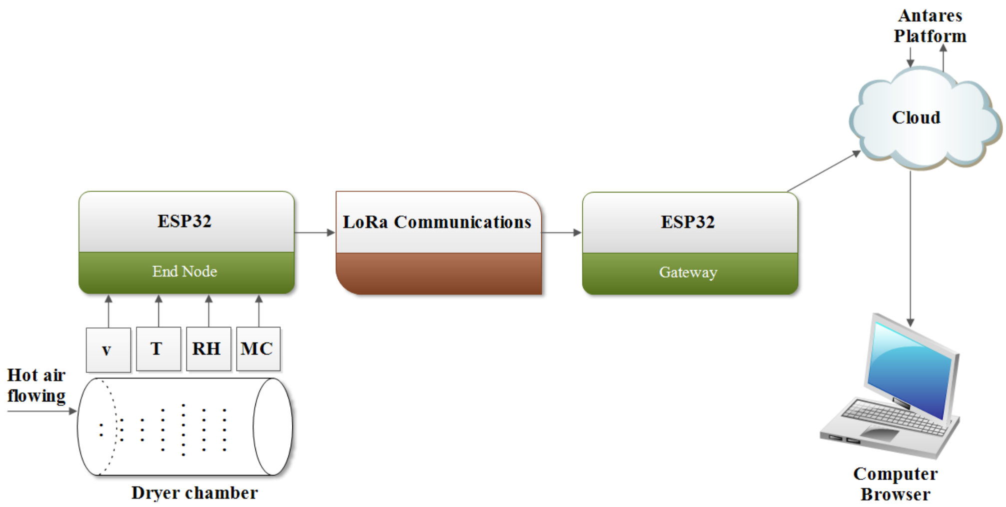

Figure 1. Real-time monitoring system

2.2. Experimental setup

Initially, the post-harvest paddy grain with a moisture content of 25% is introduced into the dryer by pouring it manually. In this study, the drying process is convective, with heat supplied by hot air. The heated air velocity is set at 12.5 m/s during the drying process to get optimum distribution air flows [21]. Hot air flows in the drying chamber, and the paddy grain receives the hot air evenly, which raises the temperature of the grain to a certain level. Meanwhile, the drying chamber temperature is set to a maximum of 55 °C to prevent overheating, which impacts the rice quality. Xu *et al.* [22] recommended optimal paddy drying temperatures between 45 °C and 60 °C. Finally, the paddy grain is unloaded when the moisture content reaches 14%. According to Flor *et al.* [23], hygroscopic grains with a moisture content above 14% are not safe to store because they can trigger the growth of fungi, insects, and germs.

Sensors are installed directly inside the drying chamber for data collection. The v, T, RH, and MC data are continuously monitored during the tests. The measuring data are collected and recorded every 15 seconds. The data are then transmitted via LoRa-IoT platforms. The performance of LoRa depends on the spreading factor (SF), bandwidth (BW), and coding rate (CR). The combination of these three values determines the success rate of data transmission. In this study, LoRa is configured to the best SF, BW, and CR values to cover data communications at a distance of 2 km. Furthermore, the successful communication between the end node and gateway is indicated by the received signal strength indicator (RSSI), signal-to-noise ratio (SNR), and time on air (ToA) values.

Separately, a direct determination of the moisture content of paddy grain is conducted on a wet basis using the association of official analytical chemists (AOAC) gravimetric procedure as described in [24] and then calculated as (1):

$$MC = \frac{WM-DM}{WM} \times 100\% \quad (1)$$

where *MC*, wet sample mass (*WM*), and dry sample mass (*DM*) are the moisture content "%", the wet sample mass "kg", and the dry sample mass "kg", respectively. In this procedure, the paddy grain sample is collected every 10 minutes. The wet basis moisture content of paddy grain is expressed as a percentage of moisture based on wet mass. The direct method is used as the benchmark for evaluating the accuracy of the real-time monitoring results of the moisture content of paddy grain for its high reliability. In this case, the real-time monitoring results are used as the indirect measured data. Meanwhile, the root mean square error (RMSE) method is applied to compare the difference between the indirect and the direct measured data. The RMSE value is expressed as (2):

$$RMSE = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left[MC(ind)_j - MC(dir)_j\right]^2} \times 100\% \quad (2)$$

where N is the number of measured data, while $MC(ind)$ and $MC(dir)$ are the moisture content with indirect and direct methods, respectively.

3. RESULTS AND DISCUSSION

LoRa has three parameters SF, BW, and CR to be appropriately set to ensure the successful communication between the end node and gateway. These parameters influence to the speed and distance range of data transmission. The SF values from 7 to 12. The high SF is necessary for long distance communication but requires more time on air to send data from the end node to the gateway. There are three BW values: 125, 250, and 500 kHz. The BW of 125 kHz is better for a large distance, while 500 kHz is for a fast transmission. In terms of CR, LoRa has four options: 4/5, 4/6, 4/7, and 4/8. The value 4/5 is the biggest CR and the smallest CR is 4/8. The larger CR offers the faster data transmission. In this study, the best parameters combination for LoRa data communications between transmitters and receivers at a distance of 2 km are presented in Table 1, LoRa is set to work at SF, BW, and CR of 12, 125 kHz, and 4/5 respectively.

Indicators of successful LoRa communication between the LoRa end node and LoRa gateway are the RSSI, SNR, and ToA. From the experiment, the RSSI, SNR, ToA values are -112 dBm, -8.7 dB, and 981 ms, respectively, as presented in Table 1. It should be note that the worst RSSI is -120 dBm and LoRa can demodulate signals in the range of -7.5 and -20 dB. The value -20 dB indicates the worst signal quality. Higher ToA means spending more time in data transmission from end the node to gateway [25] and hence, entails more battery energy consumption.

The decrease in paddy grain moisture content obtained from both indirect and direct measurements during the drying process is shown in Figure 2. The moisture content decreased from 25% to 14% within 6630 seconds or 110.5 minutes. From this graph it can also be seen that the indirect measurement has the same trend with the direct measurement. It is found that the RMSE value between the two methods is 6.17%, indicating that the indirect measured data is in agreement with the direct measured data.

Table 1. The best parameters and performance of LoRa

Parameters			Performance		
SF	BW (kHz)	CR	RSSI (dBm)	SNR (dB)	ToA (ms)
12	125	4/5	-112	-8.7	981

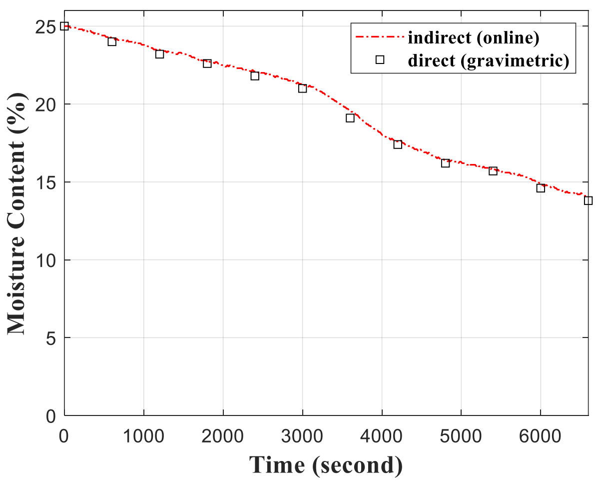

Figure 2. Moisture content of paddy grains

The temperature in drying chamber is shown in Figure 3. The temperature is limited to a maximum temperature of 55 °C to prevent overheating. When the rice is first put into the drying chamber, there is a decrease in the temperature because paddy grain with high moisture content affects the temperature of the drying chamber. According to Figure 2 and Figure 3, the moisture content in the grain decreases as the drying chamber temperature increases. During the drying process, the temperature difference between the chamber and the grain causes the higher temperature air to transfer heat energy to the grain, thus raising the temperature of the grain. The driving force, the difference in moisture concentration between the grain and the hot air, triggers an evaporation process which reduces the moisture content in the grain. Reducing the moisture content of grain takes time because of the slow process of water diffusion from the inside to the surface of the grain. Heat energy breaks the physical and chemical bonds between water and grain which causes the mass transfer of water from the grain to the air.

The relative humidity in drying chamber is shown in Figure 4. Relative humidity determines the amount of water contained in the air inside the drying chamber. Apart from that, the relative humidity also indicates the ability of the drying air to accommodate water that evaporates from the grain. At the beginning of the drying process, the relative humidity is still high because a lot of water has evaporated from the wet grain. The relative humidity in the drying chamber reduces over time in the grain drying process, because the air temperature increases due to hot airflow and the moisture content in the grain decreases. The high temperature of the drying air causes low air humidity so that more water can be absorbed by the drying air. Thus, low air humidity is required for a good drying process. In the end, the air humidity in the drying chamber equals the humidity of the hot airflow entering the drying chamber.

During the drying process, the monitoring system shows a constant heated air velocity of 12.5 m/s and the temperature of the drying chamber is controlled at a maximum value of 55 °C. Higher air temperatures and greater drying air velocities can indeed speed up the drying process, but result in decreased drying thermal efficiency. In other words, the amount of heat energy provided to the grain is large, however, most of this heat energy is not utilized but is wasted into the environment.

From the aforementioned results, the LoRa-IoT monitoring system offers the advantage in inspecting paddy drying conditions remotely. Hence, the status of the drying process can be recorded and analyzed properly. In this manner, decisions can be taken immediately to enhance the quality of dry grain based on information from the real-time monitoring system. The application of this technology obviously has a good impact on the post-harvest paddy processing. Although LoRa has difficulty in sending large packets of data over long distances, it is adequate to deal with sending small data collected from sensors such as heated air velocity, temperature, relative humidity, and moisture content.

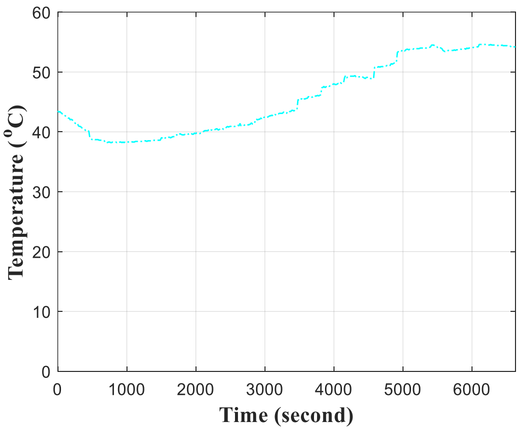

Figure 3. Temperature in drying chamber

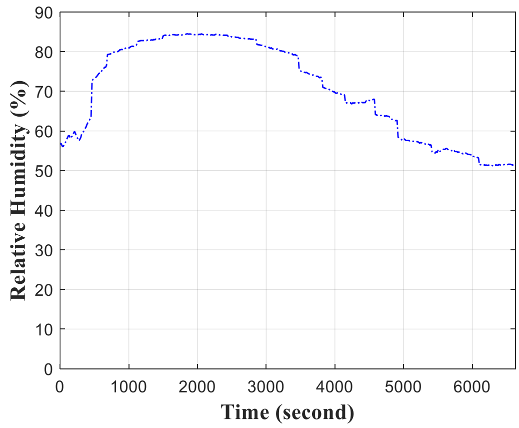

Figure 4. Relative humidity in drying chamber

4. CONCLUSION

A real-time paddy grain drying and monitoring system was developed using sensors, LoRa, and IoT platforms. By using ESP32 chips and LoRa-IoT platforms, it was possible to monitor grain drying parameters online, enabling trend analysis, and early intervention when necessary. The paddy grain drying monitoring system using IoT allowed users to obtain real-time information on the drying process. The real-time system processed the incoming data in real-time and gave immediate responses. LoRa had the advantage to transmit data from area without internet connection to gateway. With LoRa-IoT, it was possible to remotely access the drying system and control it from anywhere. This LoRa-IoT system also enabled continuous measurement of grain moisture content at an acceptable level of accuracy for normal drying operations. Moreover, the LoRa-IoT system offered a reliable framework for drying process in real-time. The study also demonstrated that the real-time monitoring system had the ability to provide fast and precise information regarding heated air velocity, temperature, relative humidity, and moisture content from a distance of 2 km with a time on air of 981 ms. According to the achievements of this study, the further study can be carried out to control all communication and drying parameters automatically.

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