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Field trial and performance evaluation of IoT poultry farm monitoring system

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***Abstract*—IoT technology revolutionizes poultry farming by enabling real-time data collection and analysis. Traditional manual methods for monitoring temperature, humidity, and AC voltage are being replaced with automated systems. The IoT setup includes three sensor nodes, CCTV, an IoT gateway, and a web server. Temperature ranges from 27 to 35°C in off-fattening periods and consistently above 30°C during fattening. Humidity fluctuates between 60% to 90% in both periods. The CPU temperature remains within safe limits. Uplink data rates exceed 2 Mbps, while AC voltage initially falls below standards but improves over time.**

***Keywords*—IoT; poultry; farming; monitoring; humidity; temperature; sensors**

I. Introduction

THE poultry industry plays an essential role in meeting the ever-growing global demand for animal protein [1]. However, modern poultry farming faces challenges related to efficiency, animal welfare, and environmental sustainability. In recent years, the development and integration of technology for monitoring and control into farming, and agriculture, specifically through the Internet of Things (IoT) [2] [3], has emerged as a promising solution to address these challenges.

The Internet of Things refers to the network of interconnected devices that can communicate and exchange data with each other through the Internet. In the context of poultry farming, IoT technologies offer opportunities to collect and analyze real-time data from various sources, enabling farmers to make informed decisions and optimize their operations [4] [5]. Poultry farming, in particular, can benefit significantly from IoT applications due to its potential to improve animal welfare, reduce resource wastage, and increase overall farm productivity [6].

Poultry farms are dynamic environments where factors such as temperature, humidity, air quality, and lighting play critical roles in the well-being of poultry farming [7]. Traditional methods of monitoring these parameters often rely on manual measurements and observations, which can be time-consuming and prone to human error. An IoT-based monitoring system allows for continuous, automated data collection, providing farmers with a comprehensive view of the conditions within the poultry house [8] [9]. This real-time data can facilitate prompt interventions to prevent disease outbreaks, optimize feed consumption, and create optimal living conditions for the chickens. Furthermore, by minimizing the environmental impact, IoT-enabled monitoring systems can also help ensure the sustainability of chicken production and the global push towards sustainable farming practices and responsible resource management [10] [11] [12].

In the farm, there are two periods: off-fattening period and on-period fattening. During the off-fattening period, the farmer usually cleans and does general maintenance on the farm. The off-fattening period lasts for 8 days. During the on-fattening period, the chickens are introduced to the facility at the age of one day. For a day-old chick (DOC) up to the age of 22 days, the suitable temperature typically ranges from 30 to 33 degrees Celsius. While humidity should generally be maintained at around 50% to 70% [13]. This level of humidity helps to prevent dehydration and maintain optimal chick health. It's important to provide a warm environment for young chicks to ensure their comfort and well-being. While the temperature can be gradually reduced as the chicks grow and feather out, maintaining the appropriate temperature during their early days is crucial for their health and development. The current method of monitoring temperature and humidity is direct measuring on the farm three times a day. To maintain the temperature, the farmer uses three exhaust fans and two flame heaters fueled by liquid petroleum gas (LPG). According to the farmer, despite the risk of fire, he preferred a flame heater over an electrical because it heats the farm more quickly. The exhaust fans also can help to regulate the humidity and extract other unwanted gases. This paper aims to explore the application of IoT-based monitoring systems in poultry farms, focusing on camera monitoring, temperature, and humidity sensors to enhance the management, health, and productivity of poultry.

The application of IoT in the livestock and agriculture industry has yielded significant benefits. Most of the implementations in this field use wireless sensor networks (WSN) to collect data from various sensors placed in various nodes. Various studies have been conducted to develop IoT that supports the agricultural and livestock sectors. Doan Perdana, et al. studied sending data from soil moisture sensors to Android applications through the LoRaWAN communication

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protocol and architectural system [14], as a result, sensor data can be sent via LoRaWAN with the appropriate Signal Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI) parameters. Yuli Afril Liani, et. all in their research sent the chicken coop temperature sensor data through the Arduino board to LoRa Dragino and then the data was sent again to the remote LoRa receiver. From this LoRa receiver, the data is sent to the LoRa server application which can be viewed on a smartphone. As a result, LoRa can facilitate communication in an ad-hoc, point-to-point manner [15]. Noridayu Manshor and Amir Rizaan in their research use Raspberry Pi to detect power supply, read the temperature, connect to a cloud database for real-time data reading, send data to a smartphone via a mobile application, and provide an alarm to the user when an abnormality occurs [16]. If the power goes out, the power bank will automatically turn on. The program's main window has such selection options, current, temperature, humidity, light status, and a toggle button. In their research, Ms. Sakshi Mishra et al. use sensors and microcontrollers to perform feeding, water supply, and temperature monitoring operations. These three things are the main cause of disease in poultry. The microcontroller node receives the temperature signal from the sensor and sends it to the adafruit server. Adafruit servers activate relays that control high-voltage electrical equipment such as lights and fans [17].

These reviews provide insights into the concept and demonstrate how IoT-based monitoring systems can be implemented in a poultry farm using various tools, devices, and hardware. An Arduino Nano board is selected to send data from the sensor. Transitioning from a Raspberry Pi to a NanoPi NEO Plus2, which has similar specifications to the Raspberry Pi 3, seems to be a viable option as a gateway. It acts as a data pooling and temporary storage device for sensor data before sending them to the web server. When it comes to cloud storage and real-time web interface, we decided to build an indigenous website using CodeIgniter as the suitable choice. Primarily, building it ourselves allows us to have full control over its design, layout, and functionality. The connection between the gateway in the poultry farm and the web server relies on the 4G mobile network. This paper reports the implementation of an IoT and 4G mobile network-based poultry farm monitoring system designed for continuous and diligent surveillance. This system gathers sensor data in predetermined time intervals and enables users to access them through a web interface. The instantaneous data offers prompt information to users, facilitating responses to any unforeseen events.

II. METHODS

The IoT monitoring system was installed in a 30x8 meter indoor chicken farm in Bogor Regency, Indonesia. The facility accommodates a population of 7,000 chickens, undergoing a 22-day fattening process. The IoT system for monitoring the poultry farm consists of three sensor nodes, CCTV, IoT gateway, and IoT web server as shown in Fig. 1. There are three sensor nodes used in this research. Sensor nodes 1 and 2 are used to monitor the environment of the farm (temperature and humidity), and sensor node 3 was used for monitoring AC voltage in the farm. Fig. 2 illustrates the placement of the IoT

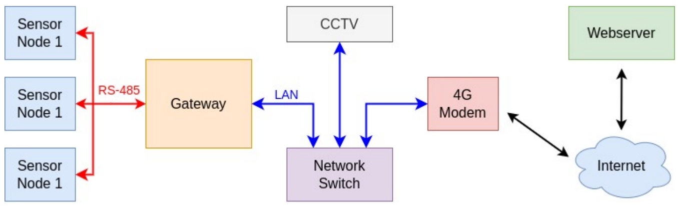


Fig. 1: Dataflow and connection diagram of the IoT system

monitoring system within the poultry farm in this study. The zigzag patterns represent the locations of windows on the farm. The red boxes represent the gas heaters used on the farm. A fan within the heater assists in distributing the heat. On hot days, the fan in the heater is utilized to draw outside air into the farm. The blue boxes indicate sensor node 1 (located near the heater) and sensor node 2. The IoT gateway is installed at the rear of the farm (depicted as the yellow box) in proximity to three large exhaust fans (depicted as green boxes) designed to extract hot air from the farm. These three exhaust fans remain operational during the on-fattening period when chickens are present on the farm, while they are turned off during the off-fattening period when no chickens are housed on the farm.

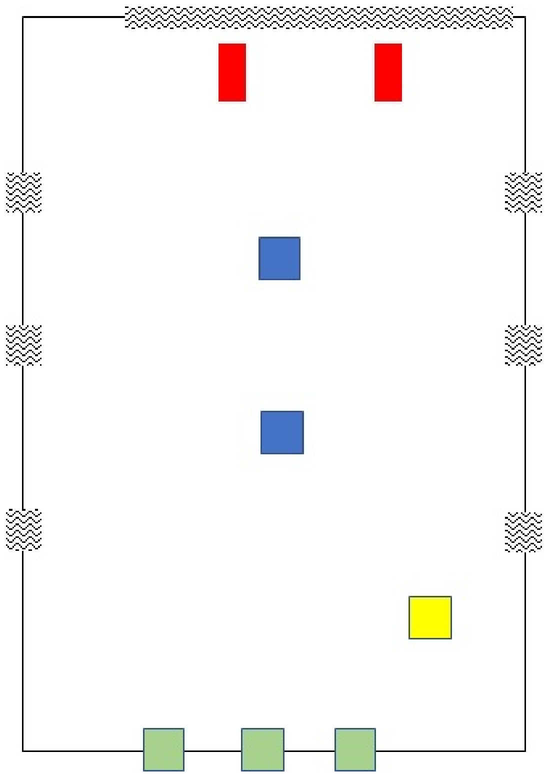


Fig. 2: IoT monitoring system installation location in the poultry farm

A. Sensor Nodes

The main part of each sensor node is Arduino Nano V3. Arduino nano V3 is an open-source firmware and development kit that provides an easy-to-use programming environment for the ATmega328 microcontroller. It has 10-bit ADC, DAC, serial communication, I2C, SPI, and low power consumption. Arduino Nano V3 uses Arduino IDE (Integrated Development Environment) to program the microcontroller. Arduino IDE itself is a software application that serves as the primary tool for programming microcontroller boards. It provides essential features like a code editor, board manager, library manager, examples, and a serial monitor, which streamline the development process and enable users to create a wide range of electronic projects and prototypes. The Arduino IDE uses a programming language that is based on a simplified version of C++. The language is often referred to as the ”Arduino programming language” or ”Arduino sketch language”. In environmental monitoring, Arduino Nano's main job is to collect data from stainless-steel cased temperature and humidity sensors from dfrobot. This sensor uses CHT8305C which is made by Sensylink microelectronics. CHT8305 has 3% RH accuracy for humidity and 0.5°C accuracy for temperature. The chip is already factory-calibrated so it doesn't need to be recalibrated. Arduino Nano and the sensor communicate using an I2C connection. The temperature and humidity data are taken every 5 minutes and sent to the IoT gateway through RS-485 communication. In between data collection, Arduino nano V3 is set to sleep to conserve energy.

For AC voltage monitoring, we use a ZMPT101B alternating current (AC) Voltage Sensor. The ZMPT101B AC Voltage Sensor is a module designed for measuring AC voltages up to 1000 Vac in electronic applications. Operating on the voltage divider principle, it samples a portion of the input AC voltage and produces an analog DC voltage output that is proportional to the AC voltage being measured. To enable voltage monitoring, the analog voltage output is connected to the analog input of the Arduino Nano V3. The Arduino Nano V3 then measures AC voltage at five-minute intervals. Fig. 3 shows a flowchart of the program run in Arduino Nano V3 that was used for environmental and AC voltage monitoring in this research.

B. CCTV

This research uses a CCTV camera from Trendnet TV-IP314PI. It provides 2688x1520-pixel video at 20 fps. The camera can be installed indoors and outdoors since it has IP66 weather-rated housing and operating temperature from -30 to 60°C. The CCTV camera is bundled with the manufacturer's cloud service to view and store video, to store the video on a user-determined website, we use RTSP (Real-Time Streaming Protocol). It is a client-server protocol that enables the efficient transfer of real-time media from a source (such as a CCTV camera) to a client (such as a gateway computer) over IP networks.

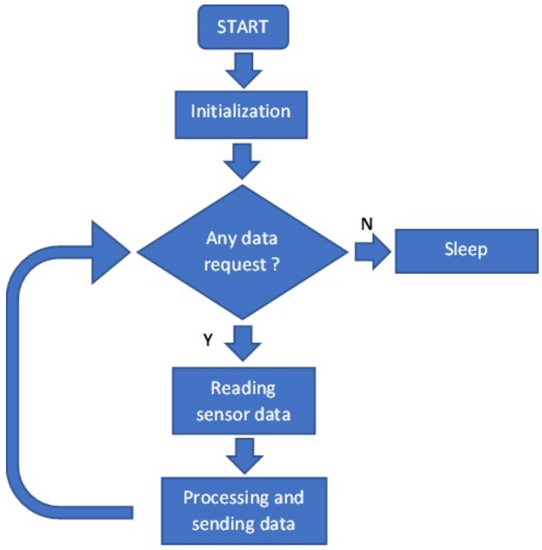
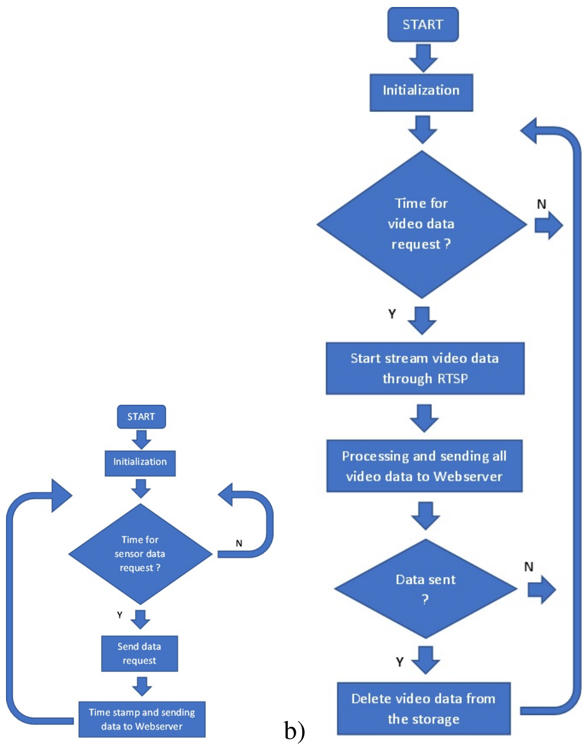


Fig. 3: Flowchart of sensor nodes measurement program

C. IoT Gateway

The IoT gateway in this research acts not only as a temporary storage of video and measurement data but also as a sender of the video data to the IoT web server through a mobile internet connection. The IoT gateway consists of a NanoPi NEO Plus2 single-board computer (SBC), a 4-port network switch, and a 4G/LTE modem. The NanoPi NEO Plus2 is an ARM-based board created by FriendlyElec, utilizing Allwinner's 64-bit quad-core A53 System-on-Chip (SoC) accompanied by a hexa-core Mali450 GPU. This board is equipped with 1GB of DDR3 RAM and 8GB of eMMC storage. Linux is used as an operating system for the IoT gateway. Within the gateway, two separate Python programs fulfill specific functions. One functions solely as an RTSP client, responsible for gathering video data from the CCTV camera. A 1-minute video data is gathered 4 times a day at 12 am, 6 am, 12 pm, and 6 pm. Meanwhile, the other program's exclusive role is to collect sensor data from all sensor nodes. Fig. 4a shows how the python program is gathering sensor data, when the time for gathering data comes (every 5 minutes in this research), it begins to send data requests to a sensor node. In the sensor node side, once it receives a data request from the gateway, it wakes up from its sleep state and starts collecting, processing, and sending the data to the gateway. Once sensor data is received, the sensor data will be time-stamped and sent to the web server. Fig. 4b indicates the flowchart of the python programs for the RTSP client. It starts a request to video data at a predetermined time from a CCTV camera through RTSP and temporarily stores the data in the SBC's internal memory. After the video is stored, the program will try to send the stored video to the IoT web server through a cellular network. If data transmission fails, the video data will be retained until it is successfully sent to the web server. After successful transmission, the program will delete the video to conserve storage space. The connection to the internet is provided by SXT LTE kit from Mikrotik.

The SXT LTE Kit is a complete outdoor wireless device that combines a high-gain antenna with an integrated LTE modem. The kit includes a rugged enclosure, LTE modem, high-gain directional antenna, power supply, and mounting hardware. An ethernet cable is used to physically connect between SBC and the SXT LTE kit. The mobile operator used in this research is By U.



a) b)

Fig. 4: Flowchart of python programs for (a) sensor data collector and (b) RTSP client.

D. IoT Web Server

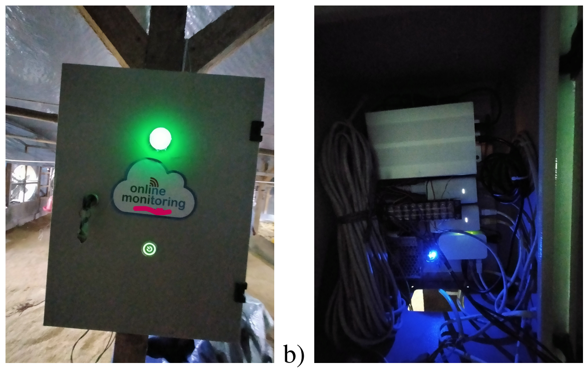
A web was constructed as a front to display all data that was taken by the sensor node. The web was written using Codeigniter, an open-source PHP web application framework that facilitates rapid development of web applications. It follows the Model-View-Controller (MVC) architectural pattern and provides a set of libraries, helpers, and tools to simplify the development process and improve code organization.

At first, the web server will display a login page to ensure people who access the web have valid credentials. The user is then directed to the dashboard page where the user can select all the features available. IoT station locations, recent data received, and station status are displayed as well on the dashboard page. Other features that can be selected on the dashboard page are real-time data, historical data, and configuration. The web server also adds a time stamp to every data received from the gateway. These time stamps are used to measure the uplink data rate between the gateway and web server. The uplink data rate measurement data is needed to measure internet connection quality on the farm. Equation (1) is used to calculate the uplink data rate. The received data used in equation (1) is the video data received by the web server.

$$\text{Data Rate (Mbps)} = \frac{\text{Received data (Mb)}}{\text{Server - Gateway time stamp (s)}} \quad (1)$$

III. RESULTS AND DISCUSSIONS

The IoT system was installed during off fattening period (5 January 2023), after installation, the system started to collect data. Fig. 5a shows the actual hardware installation of the IoT system in the poultry farm. The IoT gateway is stored in a panel box with a green light indicator to indicate the power status of the system. A push button is also installed on the box to power on or off the entire system. Fig. 5b presents an inner view of the box. The gateway, ethernet switch, power supply, and sensor node 3 can be seen in the picture. Sensor node 1, sensor node 2, and SXT LTE kit are installed outside the box.



a) b)

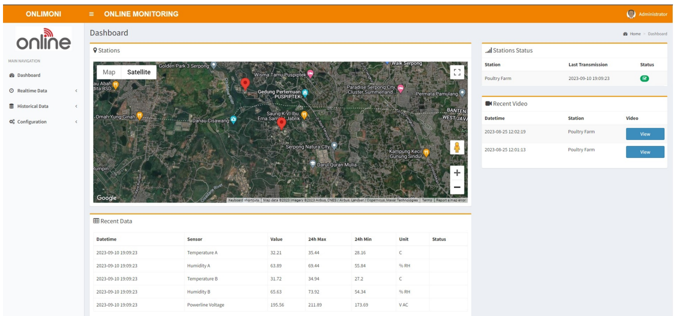
Fig. 5: Deployed IoT systems (a) outside view and (b) inside view of the system.

Table I shows the initial test result of the IoT system, the tests consist of sensor node to gateway connection test, gateway to web server connection test, and web interface functionality test. A test is considered successful when the device is working as intended. A screenshot of the deployed IoT web page is shown in Fig. 6. The dashboard page (Fig. 6a) contains essential information, such as the geographical location of IoT stations, recently received sensor and video data, and other selectable features. The real-time data page displays the latest received sensor data from all locations, presented in tabular and chart form (Fig. 6b). Moreover, the historical data page presents all data stored on the IoT web server, also displayed in tabular and chart form. Users have the flexibility to select the data period they want to display and can download it in CSV format for further analysis. The web interface also allows

TABLE I: IoT System Test

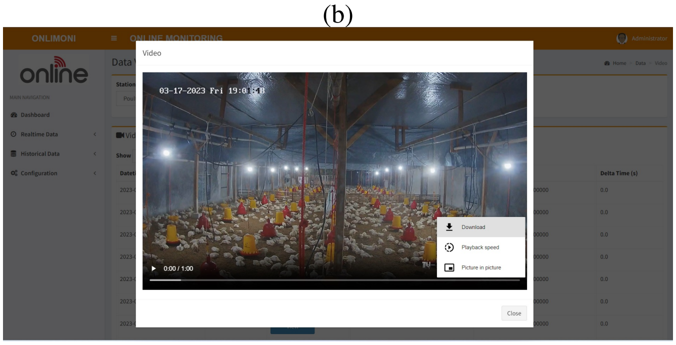
	Test type	Result
1	Sending sensor data to the gateway	Success
2	Request video stream from CCTV camera and record it in the gateway	Success
3	Sending sensor and video data to the web server	Success
4	Downloading sensor data (CSV) and Video data (mp4)	Success

users to stream and download video data (Fig. 6c). The video data collected by the IoT system serves for general activity monitoring within the poultry farm. To ensure data privacy, it's stored outside of the manufacturer's cloud system. On average, every 1-minute video recorded is about 35 Mb in size.



(a)

(b)



(c)

Fig. 6: Deployed IoT web interface (a) dashboard page (b) real-time data page (c) video stream and download page.

The temperature values reported by both sensor nodes 1 and 2 exhibit a degree of similarity in their patterns and trends (Fig. 7). Throughout the recorded timeframe (a week during the off-fattening period), the temperature values show a consistent pattern of fluctuation, suggesting a certain level of stability within the farm's environment. Notably, there are no abrupt spikes or drops in temperature, indicating that the conditions within the chicken farm remain relatively controlled and regulated. During the off-fattening period, the temperature inside the farm started to rise at 6 am and reached its peak at noon, remaining at peak temperature for 2 hours. Afterward, the temperature began to steadily decline until it reached its lowest point at 6 a.m. The temperature difference between the lowest and highest values is between 4.5 to 7°C. The poultry farm experiences varying highest and lowest temperatures daily, which can be attributed to external weather conditions and activities taking place within the farm, particularly during the off-fattening period. Notably, during the initial two days of monitoring, cloudy and rainy weather prevailed. This led to lower temperatures within the farm compared to the rest of the monitoring period, resulting in an average temperature decrease during these initial days. On the first day of monitoring, cleaning activities were carried out within the farm, contributing to higher relative humidity levels compared to the subsequent days. There are fluctuations in the relative

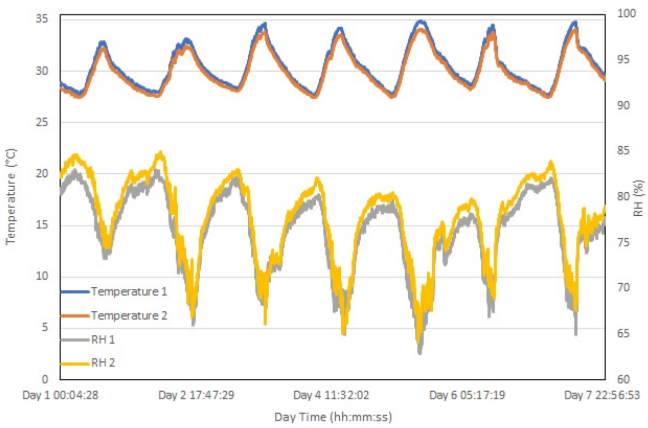


Fig. 7: Temperature and humidity data from sensor nodes 1 and 2 during the off-fattening period

humidity (RH) values between sensor nodes 1 and 2 as shown in Fig. 7. The differences in RH between sensor nodes 1 and 2 are not consistent over time. There are periods where the two locations' RH values move in tandem, showing similar patterns of increase or decrease. At certain time points, there are sudden shifts in the RH difference between sensor nodes 1 and 2. The differences in RH could be influenced by the wind from the outside of the farm bringing more humid air into the center of the farm where sensor node 2 is located. The

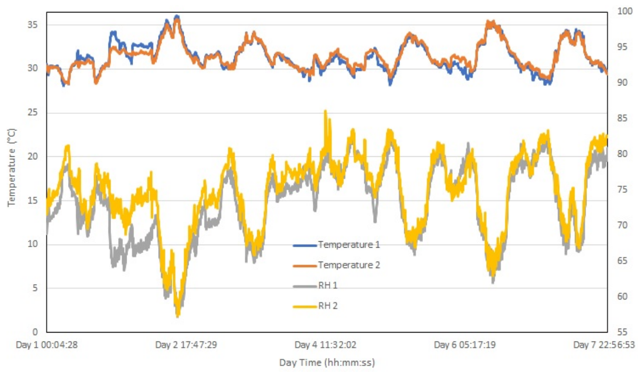


Fig. 8: Temperature and humidity data from sensor nodes 1 and 2 during the on-fattening period

data displayed in Fig. 8 presents temperature and humidity measurements during the on-fattening period in the poultry farm. In comparison to the off-fattening period, the temperature data during on-fattening shows a relatively lower level of fluctuation. This consistency in temperature can be attributed to the farmer's practice of using a heater during the night from 7 p.m. to 6 a.m. to maintain a temperature above 30°C. As evidenced by the chart, this strategy results in nighttime temperatures predominantly exceeding 30°C. However, an exception occurred on the first day of monitoring when rain persisted from morning until night, causing the temperature to fall below 30°C. Consequently, the farmer employed the heater again during the early afternoon (around 3 p.m.) until 7 a.m. the next day. Figure 8 also illustrates the impact of the heater during rainy conditions. Sensor node 1, situated near the heater, recorded higher temperatures compared to sensor node 2. Correspondingly, humidity levels during this period were lower in the area near the heater (sensor node 1) in contrast to the area farther from the heater (sensor node 2). Throughout the data, there has been an instance where the heater's gas supply was depleted, resulting in temperature drops during the night. When the gas tank was replaced with the new one and the heater restarted, temperatures rebounded. Notably, each time the heater was turned off, temperature reductions were observed in the area surrounding sensor node 1 before influencing the area in sensor node 2. This disparity can be attributed to the closer location of sensor node 1 to the fan and windows, facilitating quicker heat dissipation. At the onset of the day on the last day of monitoring, a gradual temperature decline occurred, once again linked to the heater's gas depletion. During the on-fattening period, there were many occasions when the temperature and humidity exceeded the suitable values for poultry up to two weeks old, which are 33°C and 70%, respectively. These conditions induced stress in the chickens and increased the risk of mortality [10].

Similar to the off-fattening period, a reverse relationship between humidity and temperature was observable, as temperatures rose, humidity levels decreased. This is because warmer air can hold more moisture, causing a decrease in relative humidity as the temperature rises, even when the actual amount of water vapor remains constant [18]. On multiple occasions, the humidity in the area of sensor node 1 was lower compared to the area of sensor node 2 due to the fan located nearby, which circulated humid air and heat toward the area of sensor node 2 and subsequently vented it out of the farm.

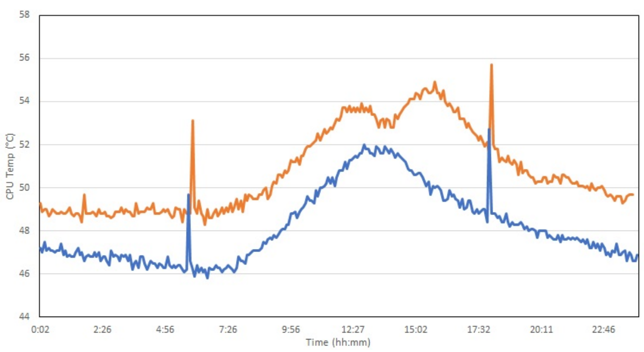


Fig. 9: CPU temperature during on and off-fattening periods

Fig. 9 displays the CPU gateway's temperature over 24 hours of operation during both the on-fattening and off-fattening periods. The temperature pattern repeats daily in both fattening periods. During the off-fattening period, the lowest CPU temperature recorded is 46°C, while the peak temperature reaches 52°C. Similar to the farm temperature shown in Fig. 7, the CPU temperature begins to rise at 7 a.m. and reaches its peak at noon, remaining at the peak temperature for 2 hours before gradually declining. This pattern indicates that the CPU temperature is influenced by the farm temperature. There are brief spikes in CPU temperature at 5 am and 6 pm, each lasting for 5 minutes and reaching up to 49°C at 5 am and 53°C at 6 pm. These spikes are influenced by two simultaneous processes: sending sensor data and video recording.

During the on-fattening period, in general, the CPU temperature is higher than during the off-fattening period. This phenomenon may be due to the hot air from the heater flowing towards the back of the farm where the gateway is located. The lowest CPU temperature recorded in the farm during this period is 49°C, while the highest is 55°C. The spikes due to the two concurrent processes also occur during the on-fattening period, with temperatures reaching 53°C at 5 a.m. and 55°C at 6 p.m.

Overall, the operating temperature of the CPU gateway remains within the safe operating range. The highest allowed temperature during operation is 80°C, and if the CPU temperature reaches or exceeds this threshold, the system will automatically shut down to prevent CPU damage. These CPU temperature data suggest that the workload during monitoring does not excessively burden the CPU. Even during the spikes observed in both periods, the CPU temperature remains well below the maximum allowed temperature. This indicates that additional features or sensor nodes can be added for future development.

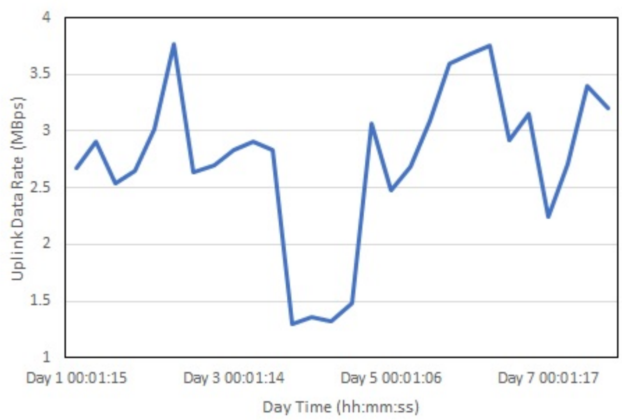


Fig. 10: Uplink data rate

Uplink data rate results of the IoT system, calculated using equation 1, can be seen in Fig. 10. The uplink data rate reaches peak performance at more than 3.5 Mbps on three occasions: day 2, day 5, and day 6. The lowest data rate observed was 1.4 Mbps. In general, the data rate during the 7 days of monitoring exceeded 2 Mbps, which is better than the national average uplink throughput in 2018, which was about 1 Mbps [19]. There is an 18-hour period where the data rate was at its lowest (from day 3 at 6 p.m. until day 4 at 12 p.m.), which may have occurred due to the network being used by many users during those days. Table II displays the average uplink data rate in other areas compared to this research. When compared to other areas in Indonesia, the uplink data rate in the location where this research is performed is better. Faster data transmission from the farm to the webserver is advantageous, especially for large data sets such as video data. The results of these uplink data rates are influenced by several factors, including the mobile operator, area density, and the distance between the farm location and the nearest (Base Transceiver Station) BTS [20]. Figure 11 shows the electrical voltage curve within the Poultry Farm area in January and April 2023 for four days. In January 2023, the electrical voltage curve exhibited a very low voltage drop. This was due to increased electricity usage by customers and high electricity consumption during peak load hours, which occurred from 18:00 to 22:00 Indonesian time, leading to load fluctuations. The lowest voltage recorded based on the curve was 143 volts, and the highest voltage was 180 volts. This situation poses a significant risk to the installations and equipment inside the poultry farm as it can damage equipment such as heaters, exhaust fans, and electric motors that this equipment used to maintain the temperature and humidity in the poultry area due to having a significant effect to the growth of chicken [24]. The voltage drop needs to be addressed promptly by the relevant electrical company to improve the voltage service to customers and bring it in line with standards. According to the General Requirements for Electrical Installations SPLN1: 1995 standards, the standard electrical nominal voltage of 220 volts. Power line voltage drop can occur due to various reasons, and it can significantly impact the performance of electrical systems, such as an Unbalanced load in the electrical grid, The resistance in the electrical conductors (wires and cables) can cause voltage drop. When current flows through a conductor, it encounters resistance, which leads to a drop in voltage, High Load Demand, Weak Electrical Grid, Distance from the Power Source Substation too far, Low Quality or Aging Components in Transformer and electrical cables, losses can be higher, so supply voltage to poultry will be drop [25].

TABLE II: The average uplink data rate at other locations in Indonesia

	City/Regency	Uplink data rate (Mbps)	Measurement Year	Reference
1	Soreang	1.1	2019	[21]
2	Samarinda	1.7	2018	[22]
3	Medan	0.65	2019	[23]
4	Bengkalis	2.6	2022	[20]
5	Bogor	2.7	2023	Current Research

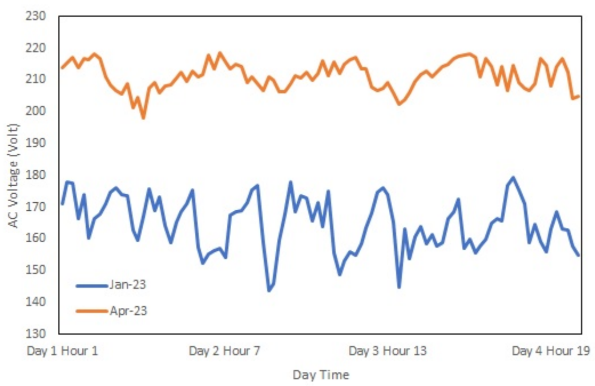


Fig. 11: Power line voltage in January and April 2023

In contrast to the electrical voltage conditions in April 2023, during the four days, it showed an improvement in electrical voltage within the Poultry farm area, still in the nominal standard voltage. The highest voltage recorded was 218 volts, while the lowest voltage was 198 volts. As for the electrical voltage conditions during peak load hours, it displayed a similar phenomenon, which was a voltage drop, but it was not as significant as in January 2023.

Resolving voltage drop issues in a power line typically requires a combination of preventive measures, the use of an electric stabilizer, and corrective actions such as properly sizing electrical conductors, reducing electrical load, regular maintenance for transformers and cables, correcting faults and short circuits, and electrical load balancing.

IV. Conclusions

The IoT poultry farm monitoring system was tested at an actual poultry farm for monitoring farm temperature, humidity, CPU temperature, uplink data rate, AC voltage, and the general condition of the farm through CCTV. Some issues in the farm were identified, including relatively high temperature, humidity, and AC voltage values. During testing, the data collected by the system was found to be real-time and reliable. This system is highly beneficial for the poultry industry as it offers convenient monitoring of critical farm parameters. Users can directly access and analyze parameter data from anywhere with an internet connection, enabling prompt responses if farm conditions deviate from standards. The video data provided by the system allows for general farm condition monitoring and supervision of farm workers' activities, such as feeding and cleaning schedules. The CPU gateway operates within a safe temperature even during high-load situations. In conjunction with the video data, additional features, such as artificial intelligence and other sensors, can be integrated in the future to obtain more comprehensive farm data. Since the system eliminates the need for constant on-site monitoring by humans, it optimizes the manpower required for monitoring tasks, leading to cost savings and improved product quality.

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