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Study of a Remote Wind Resource Assessment System Integrated with Internet of Things

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ABSTRACT

Wind energy is an emerging and popular source of clean energy due to its non-polluting nature and low cost. The efficient use of wind energy requires accurate and precise wind parameter measurements, which is where wind resource assessment (WRA) comes into play. The IoT and cloud-based systems have been applied to remote monitoring systems and provide crucial solutions for data acquisition, storage, and analytics in wind energy technology. This study aims to build a remote WRA system integrated with the Internet of Things. This study utilizes an Arduino Uno microcontroller, RK100-01 wind speed sensor, BMP280 temperature and pressure sensor, and SIM800L GPRS module to collect and transfer real-time data to the ThingSpeak cloud. The experiment was conducted at Atma Jaya Catholic University of Indonesia - Campus 3 BSD with the remote WRA system installed inside Stevenson screens to protect it from environmental conditions. Wind speed data is measured at a height of 10 meters, while air pressure and temperature data are measured at a height of 1.5 meters. Data retrieval utilizes two methods, viz. direct measurement every 15 minutes, and cloud-based retrieval every 30-second intervals. The study demonstrates that a remote WRA system integrated with IoT can measure, display, and upload three crucial parameters for assessing wind energy potential, namely wind speed, air pressure, and air temperature. This remote WRA system also provides flexibility in real-time data collection since it is accessible anytime and anywhere, thereby reducing the need for site visits during deployment.

Keywords: *Cloud storage, internet of things, real-time, remote system, wind resource assessment*

I. Introduction

The concern to decrease greenhouse gas emissions is gaining huge attention globally. It has become one of the greatest challenges that the world is facing today, with fossil-based energy being a leading cause of global warming and climate change. The world energy assessment report by the United Nations Development Programme (UNDP) was the first to recognize the negative impact of energy development on the environment and society, leading to the acknowledgment of energy as a driver of sustainable development and a potential challenge to sustainability [1]. The Millennium Development Goals (MDG) failed to consider energy as a major sustainability concern, but this changed with the UN MDG follow-up resolution, which recognized energy as necessary for achieving the MDGs and sustainable development. The UN Sustainable Energy for All initiative was launched in 2011, followed by the adoption of the 2030 agenda for sustainable development (the Sustainable Development Goals-SDGs) in 2015 and the Paris Agreement to limit global warming to 1.5 degrees by 2050. These commitments have led to new interests in developing

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and utilizing energy, with a focus on emission reduction approaches and justice dimensions in energy access and transitions [2]. At present, numerous countries have initiated several policies to minimize greenhouse emissions, such as encouraging the development of renewable energy and technical innovation in the renewable energy sector. Renewable energy like wind energy, solar, and biogas may provide an alternative opportunity to reduce greenhouse gas emissions and global warming issues by restricting the utilization of conventional energy resources [3], [4].

Wind energy is a renewable, nonconventional, inexhaustible, and non-polluting source of energy [5]. It has no adverse effect on the environment and avoids fuel provision and transport; therefore, it is going forth as a fast-emerging, developing, and popular alternative source of clean energy [6]. The maturity of the wind energy industry with low-cost, low-carbon electricity generation means that the growth of wind energy penetration into global electricity generation systems has long been recognized as a potential mechanism to reduce climate forcing [7]. Over the past two decades, wind energy deployed on land has become the cheapest source of electricity generation [8]. Modern wind turbines are becoming bigger and higher, reaching into the unknown turbulence and wind regimes of the atmosphere. It is essential to assess the availability of wind resources before starting a wind project [9] in terms of atmospheric characteristics that may generate turbulence, power production, and a successful return on project investment. The efficient use of wind energy requires exact, accurate, and precise wind measurements. The WRA system plays a significant role in the successful development of wind power [6].

Other side, the smart grid (SG) is the technological paradigm being proposed to satisfy the needs. SGs aim to distribute the intelligence of the energy distribution and control system to many peripheral nodes, which allows for better monitoring of energy losses and more precise control. The intelligent nodes in SGs have similar objectives to those of the Internet of Things (IoT) [10]. IoT involves expanding the web concept to link, monitor, and manage everyday objects. It will provide similar features as those found in internet applications for both human-to-machine (H2M) and machine-to-machine (M2M) interactions. Incorporating SGs into the IoT offers several advantages. It allows the system to use established security and privacy frameworks, wide connectivity, and effortless interoperability. Additionally, it opens the possibility of developing cloud computing systems for service virtualization and distribution. The availability of a broad set of established standards is also a crucial factor for this integration. The IoT can be defined as individual embedded devices with internet connectivity, that are capable of interacting with each other, with other services, and with people on a global scale. This level of connectivity can increase reliability, sustainability, and efficiency by improving access to information [11]. Furthermore, today’s IoT data can be analyzed at near real-time speeds, and one could argue that the effective use of IoT will be a key differentiator for the winners in this next phase of growth in the renewable energy sector. In addition to analyzing data for learning, near real-time analytics allows companies to react quickly to avoid problems, address them before they become serious, offer help, or simply better prepare in advance for an emerging issue to reduce its impact [12].

With the fact that wind energy technology is rapidly growing [13], the trend requires this technology to continuously find more innovative, efficient, and technological solutions. A previous study gathered wind energy data using a datalogger that stored the data on an SD card [14]. The rapidly evolving cloud-based IoT solutions with Industry 4.0 transformation will provide important solutions in wind energy technology, such as increasing the life span of devices and reducing operating and maintenance costs in wind turbine technology. This technology will provide real-time data storage and retrieval of wired or wireless information from the sensors [15]. Real-time monitoring of wind farms, especially in harsh operating conditions, provides pre-detection of faults and a better understanding of operating behavior to produce more economical solutions [16]. Implementation of IoT and cloud-based systems are used in many ways, such as wired or wireless sensor networks, intelligent control units, mobile platforms, different communication protocols, and security solutions [17], [18]. It plays an important role in remote monitoring systems and provides crucial solutions for data transmission, acquisition, storage, and data analytics [15].

This study aims to build a remote WRA system integrated with IoT. The remote WRA system measures wind speed, air pressure, and temperature, which are the crucial parameters for evaluating the wind energy potential. The collected data are sent and processed using the IoT platform. Thus, it can be accessed in real-time anytime, anywhere. The equipment used in this study is accessible and user-friendly and has not been used in previous research. For example, Arduino Uno, a user-friendly microcontroller, plays an important role in this study. Furthermore, a wireless connection is deployed to upload the data. Therefore, the problems that may occur due to a wire connection, such as a broken cable that can cause such noise in the data, can be eliminated. Moreover, a cloud platform to store and display the data is also included in this remote WRA system. Thus, the data are accessible anytime from anywhere.

II. Material and Methods

1. *Remote Wind Resource Assessment (WRA) System*

The remote WRA system in this study is located at the Atma Jaya Catholic University of Indonesia – Campus 3 BSD. The system is placed inside Stevenson screens (Figure 1) to protect it from environmental conditions, such as direct sunlight exposure that can affect sensor readings.

Fig. 1. A remote WRA system

The sensors installed in the remote WRA systems in this study are the BMP280 and the RK100-01 Wind Speed Sensor. BMP280 is a sensor that can measure both the air temperature and pressure data simultaneously [19]. It has an operating temperature range of

-40°C to +85°C [20], and an operating pressure range of 300 hPa to 1100 hPa [21], with an accuracy of ±1°C and ±0.1 kPa [22], respectively. It is powered by 3V [23].

The BMP280 sensor provides digital signal data at 30-second intervals, which is processed by the Arduino Uno microcontroller. The processed data is then sent to the ThingSpeak cloud for real-time visualization that can be accessed anytime, anywhere. Whereas the RK100-01 wind speed sensor is designed specifically for accurate and reliable measurement of wind velocity, particularly in harsh environmental conditions. It features a robust aluminum alloy shell and wind cups made from 304 stainless steel. The PCB board is coated with anti-corrosive material to enhance resistance to water and corrosion. Sealing rings are strategically placed inside and around the rotating parts, effectively shielding against water, salt fog, and dust infiltration [24].

2. *IoT Integration*

Architecture of IoT Integration

The schematic diagram of the IoT integration with a remote WRA system used for collecting and monitoring real-time data can be seen in Figure 2.

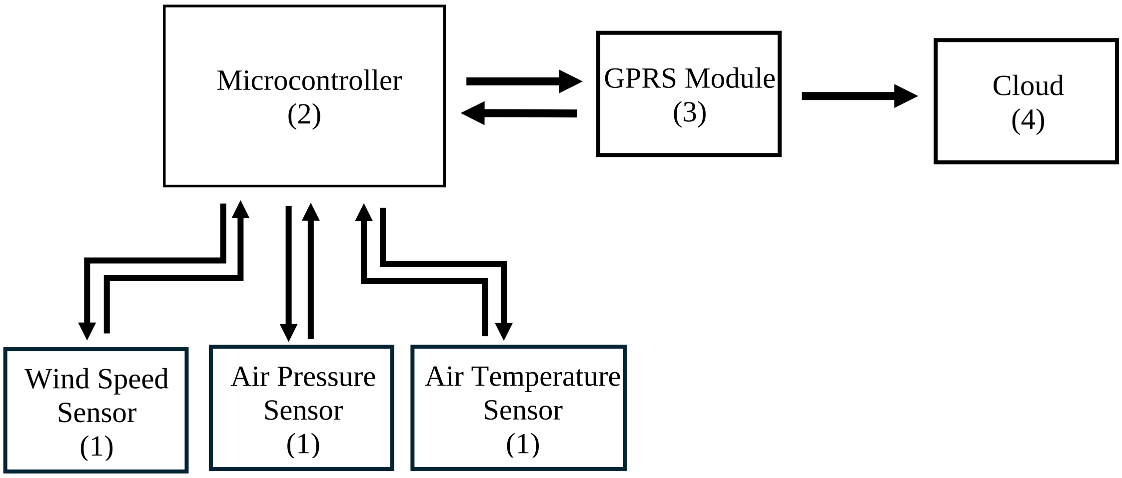


Fig. 2. Schematic diagram of the IoT integration with remote WRA system

The system comprises four parts. The first part is the remote WRA system, which includes the wind speed sensor, air pressure sensor, and air temperature sensor controlled by the microcontroller. The second part is the microcontroller, which acts as a datalogger and sends commands to upload the measurement data to the cloud. The third part is the data transfer, which uses the GPRS module to connect the microcontroller to the internet and upload data to the cloud using TCP/IP protocol via GPRS network The final part is a cloud platform used for cloud-based storage and real-time data visualization.

Microcontroller

The IoT platform in this study is powered by a microcontroller called Arduino Uno. This open-source microcontroller is easily programmable and can be reprogrammed at any time. It can act as a minicomputer that takes input and controls the output of various other electronic devices. When connected to an internet module, it can also send and receive information over the internet [25]. The Arduino Uno does not have a separate piece of hardware to load new code onto the board, it can be programmed easily using the C++ language in the Arduino IDE [26]. The Arduino Uno can be powered through a USB plug, which provides a regulated power of 5V. Alternatively, an external power supply with a regulated voltage of 9 to 12V can be used if the USB plug is unable to supply enough power [27].

Data Transfer

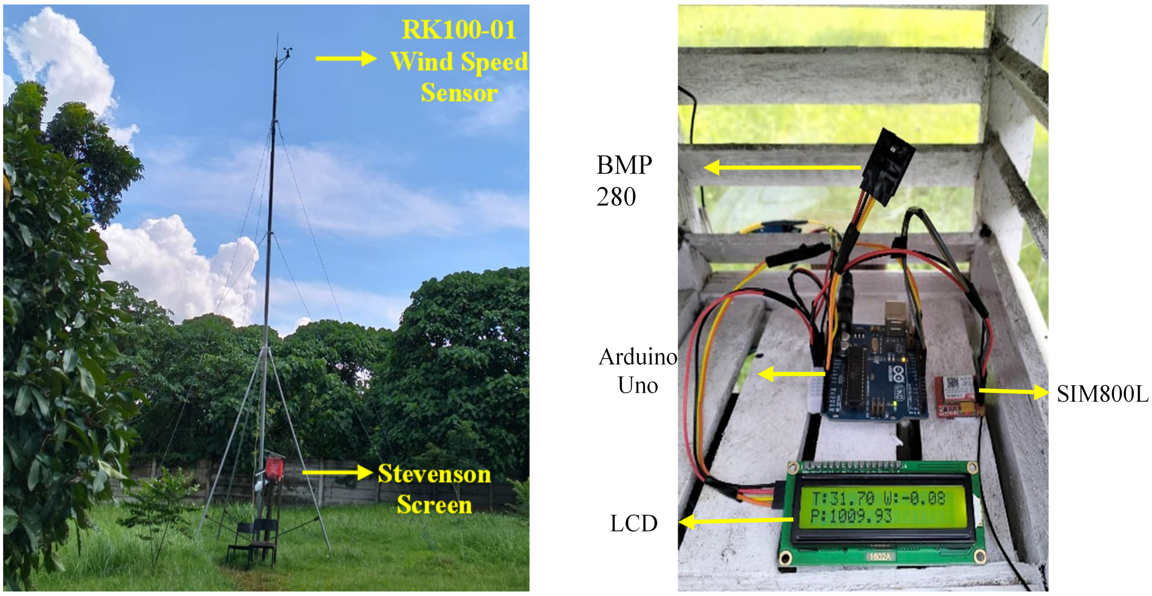
To enable the remote WRA system to connect with the internet, the SIM800L GPRS module is deployed. This is a mini cellular module that can be integrated into IoT projects and perform cellular transmissions like sending and receiving text messages, receiving phone calls, and connecting the device to the internet via GPRS signal. The module is based on the GSM cellular chip SIM800L and has an input voltage range of 3.4 V to 4.4 V [28].

Cloud Platform

The cloud platform used in this study is ThingSpeak. ThingSpeak is an open-source IoT platform that allows users to collect, visualize, and analyze data in real-time. It simplifies the process of building IoT systems without the need to set up additional servers. The main component of ThingSpeak is a channel that is used to store data sent from various devices. Each channel can store up to eight custom fields (parameters) of sensing that can be adjusted according to the user's needs [29]. ThingSpeak uses an internet connection as a mediator to upload data from sensors connected to a microcontroller to the ThingSpeak cloud, which therefore data can be retrieved, stored, observed, and analyzed by users [30]. To connect a sensor device to the internet, an Application Programming Interface (API) address of the ThingSpeak channel created should be integrated into the device's program. The API is a concept of an application programming interface function that facilitates access and utilization of an application by others without modifying the main code structure or system database and simplifies communication between different platforms [31]. ThingSpeak provides two types of APIs: Write API and Read API. The Write API is utilized to send the data to ThingSpeak channel that has been created, while the Read API is used to retrieve the data that has already been written to ThingSpeak channel [32].

3. Experiment of Remote WRA System Integrated with IoT

The experimental setup of a remote WRA system integrated with IoT is shown in Figure 3. The specification details of all the devices used in this study are listed in Table 1. The experiment is conducted at Atma Jaya Catholic University of Indonesia – Campus 3 BSD. Wind speed is measured using the RK100-01 Wind Speed Sensor at a height of 10 meters (Figure 3a). The air temperature and air pressure measurements are conducted at a height of 1.5 meters using a BMP280 sensor. The system is placed inside Stevenson screens (Figure 3b) to protect it from environmental conditions, such as direct sunlight exposure that can affect sensor readings.



(a) (b)

Fig. 3. Experimental setup of remote WRA system integrated with IoT: (a) Wind speed sensor installment; (b) Inside Stevenson screen

Table 1. Specification details

No.	Devices	Specifications
1	Microcontroller (Arduino Uno)	Source: Italy Chip atmega328 Power supply 9-12V Operational 5V Digital pin 14 Analog pin 6
2	Wind speed sensor (RK100-01)	Source: Hunan, China Supply voltage, 5V–24V Starting threshold <0.3m/s Range 0-60m/s Signal output, Pulses 4-20mA, 0-5V, RS485 Operating temperature, -30 - +70°C Accuracy, (0.3+0.03V) m/s (V current wind speed) Limit wind speed 70m/s
3	Air temperature and pressure sensor (BMP280)	Source: Germany Operating temperature -40 - +85°C Operating pressure, 300 – 1100 hPa Supply Voltage, 1.71 – 3.6V Resolution, temperature, 0.01°C Resolution, pressure, 0.0016 hPa
4	GPRS module (SIM800L)	Source: Shenzen, China GPRS module, SIM Card Supply voltage, 3.4 – 4.4 V Operating temperature, -40 - +85°

The data is collected at 30-second intervals. Furthermore, direct recording of air temperature and pressure data is also obtained during the experiment for data validation. It is carried out every 15 minutes.

III. Results and Discussions

1. *Wind Speed, Air Pressure, and Air Temperature Data*

This study showcases the integration of IoT with a remote WRA system. The collected data can be visualized in real-time on ThingSpeak (Figure 4) with each measurement taken at 30-second intervals.

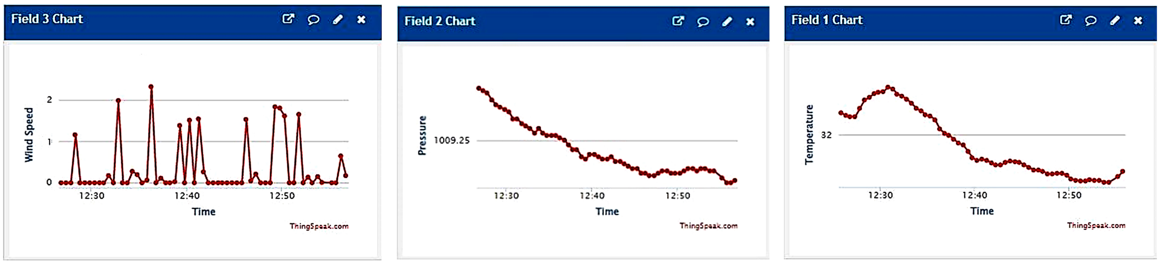


Fig. 4. Visualization of real-time data from ThingSpeak (wind speed in m/s, pressure in hPa, temperature in ^{o}C)

All collected wind speed data stored in the ThingSpeak cloud are then used to calculate daily average wind speeds, as shown in Figure 5. The highest average wind speed measured reaching 2.12 m/s. Conversely, the lowest average wind speed is found at 0.2 m/s.

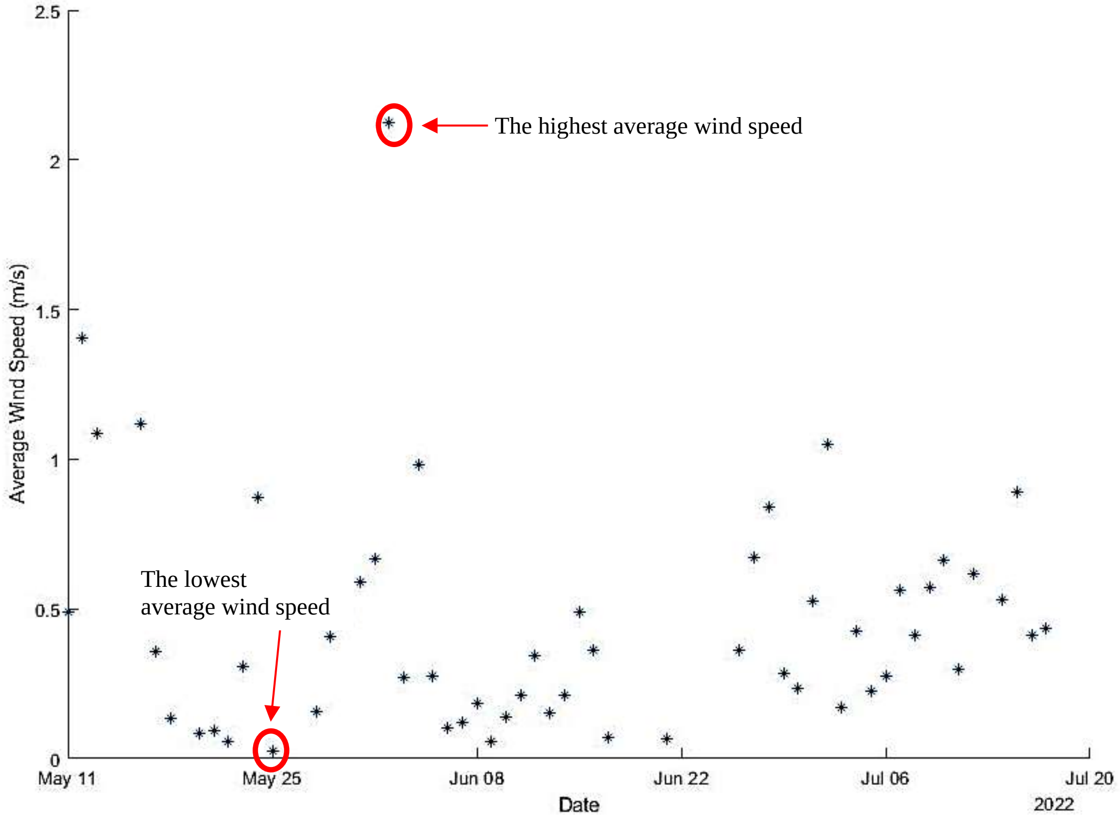


Fig. 5. Daily average wind speed data (m/s)

The data of air temperature and pressure that has been visualized and stored in the ThingSpeak cloud can be seen in Figure 6. This data represents the results of a remote WRA system integrated with IoT (remote WRA-IoT integration).

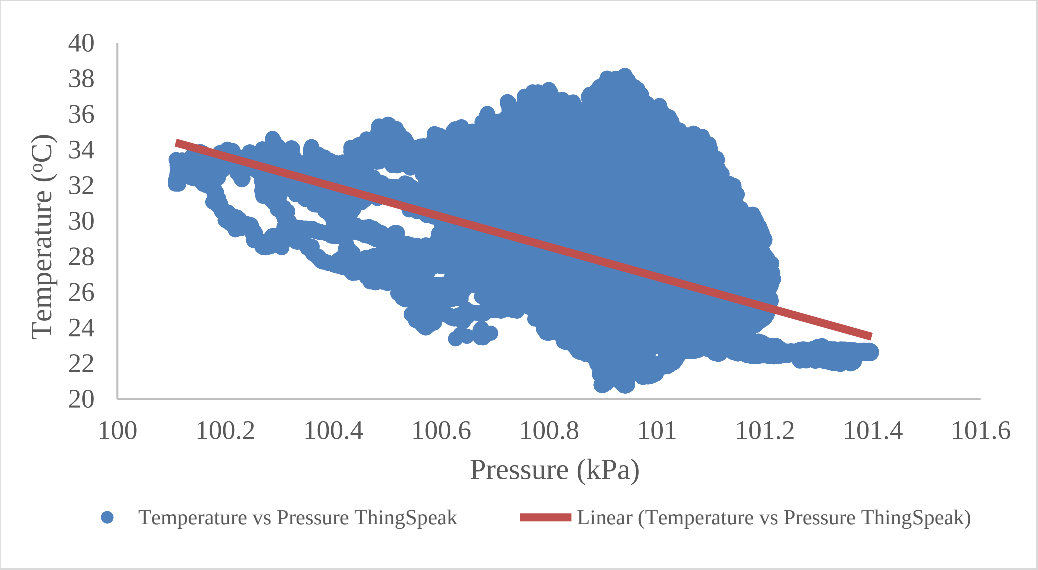


Fig. 6. Remote WRA-IoT integration data

To validate all the data that has been measured, uploaded, visualized, and stored in ThingSpeak cloud, direct recording is also conducted every 15 minutes. All these recording data are shown in Figure 7.

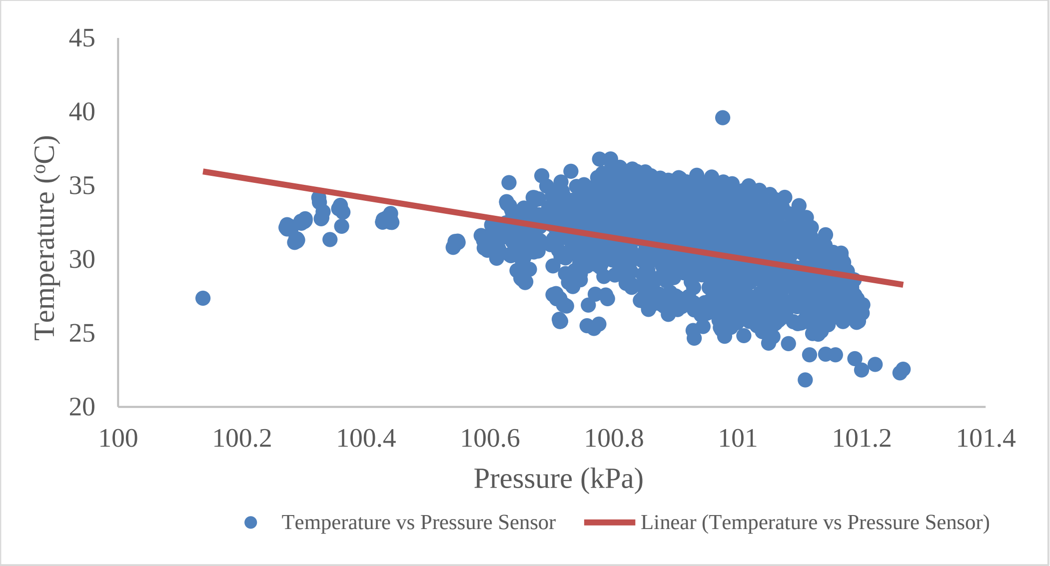


Fig. 7. Direct recording data

Both remote WRA-IoT integration data (Figure 6) and direct recording data (Figure 7) exhibit consistent agreement, showing a similar downward trend line. This trend indicates an inverse proportionality between air pressure and temperature, meaning that higher pressure values correspond to lower air temperatures which also can be seen from previous study (Figure 8) [33].

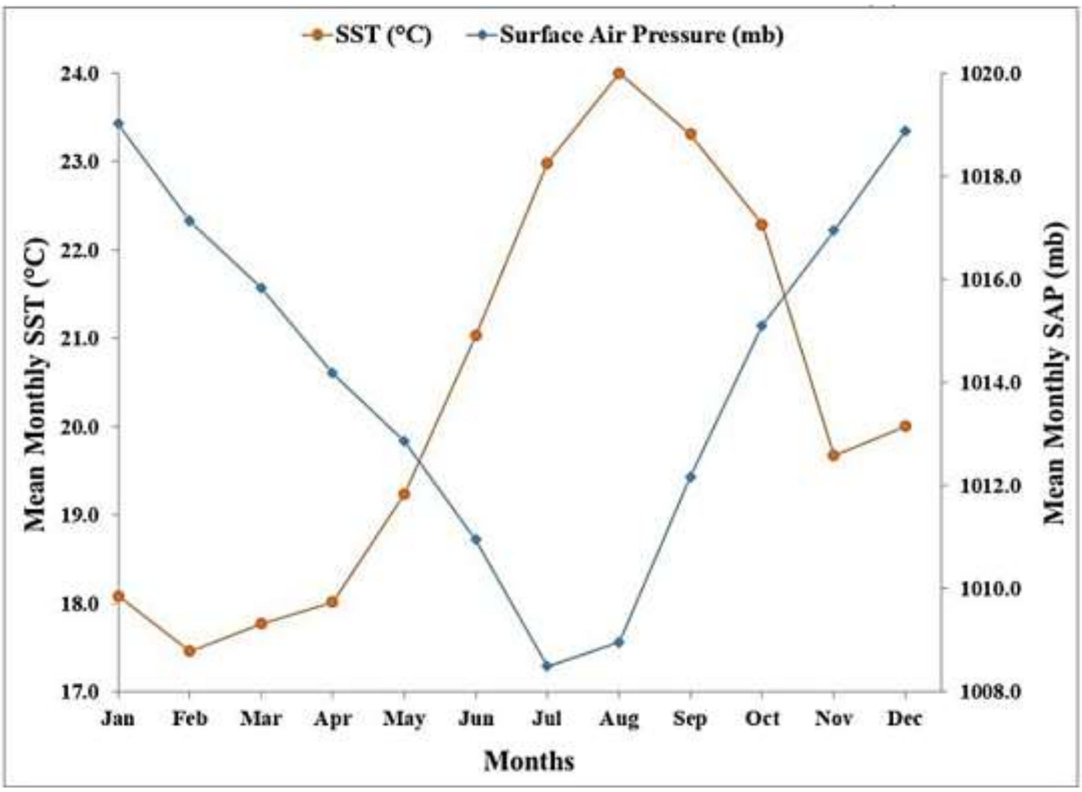


Fig. 8. Inverse relationship between air pressure and temperature [33]

2. Air Density

Parameters of air pressure and temperature can be related to air density since air density generally depends on air pressure and temperature. According to the ideal gas law, the density of most gases is proportional to air pressure, and inversely proportional to air temperature [34]. This relationship can be determined by equation (1).

$$\rho = \frac{mp}{RT} = \frac{3{,}484p}{T} \qquad \text{.........} \quad (1)$$

m is the mass of one kilomole, p is the pressure in kPa, and T is the temperature in Kelvin.

The results of air density based on air temperature and pressure from remote WRA-IoT integration data and based on direct recording data can be seen in Figure 9 and Figure 10, respectively.

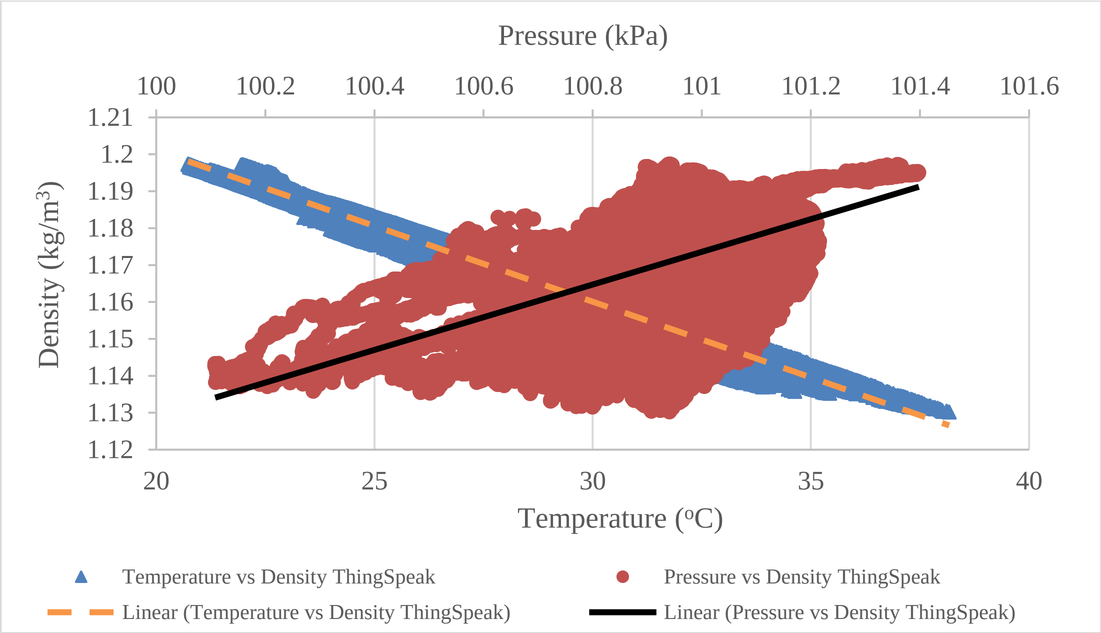


Fig. 9. Air density results based on remote WRA-IoT integration data

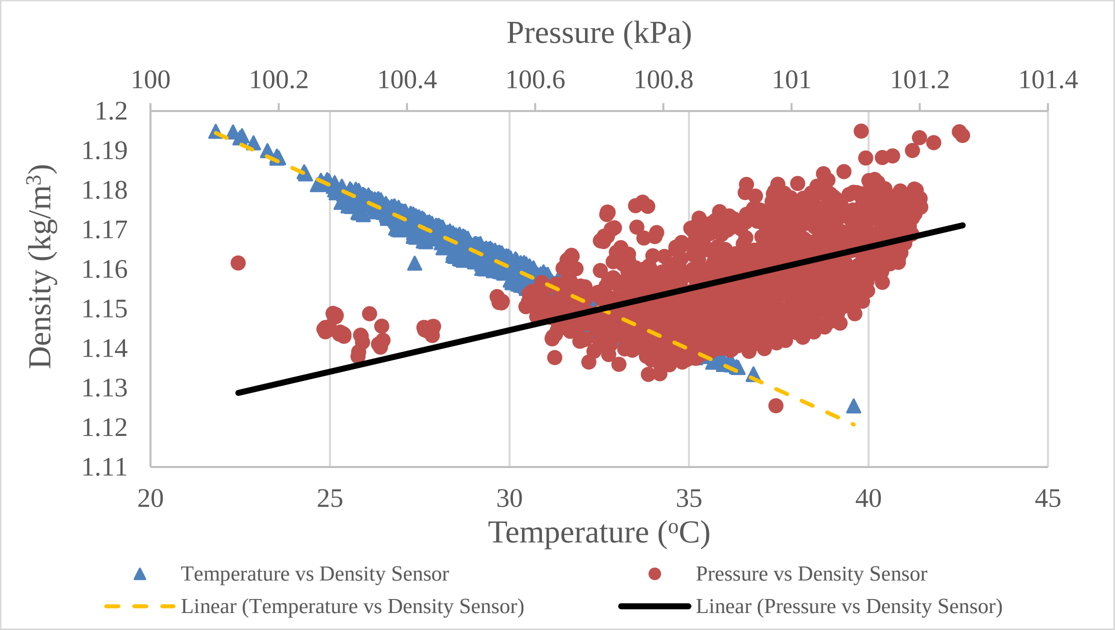


Fig. 10. Air density results based on direct recording data

Both air density results also agree with each other. These findings show a direct correlation with air pressure and an inverse correlation with air temperature. Specifically, higher air temperatures lead to lower air density, as illustrated in Figure 11 [35]. This inverse relationship between pressure and temperature on density arises because higher temperatures increase the kinetic energy of air molecules, causing them to move faster and thus expand, resulting in less dense air molecules. Conversely, lower temperatures slow down air molecules, limiting expansion and leading to denser air molecules, thereby increasing air density.

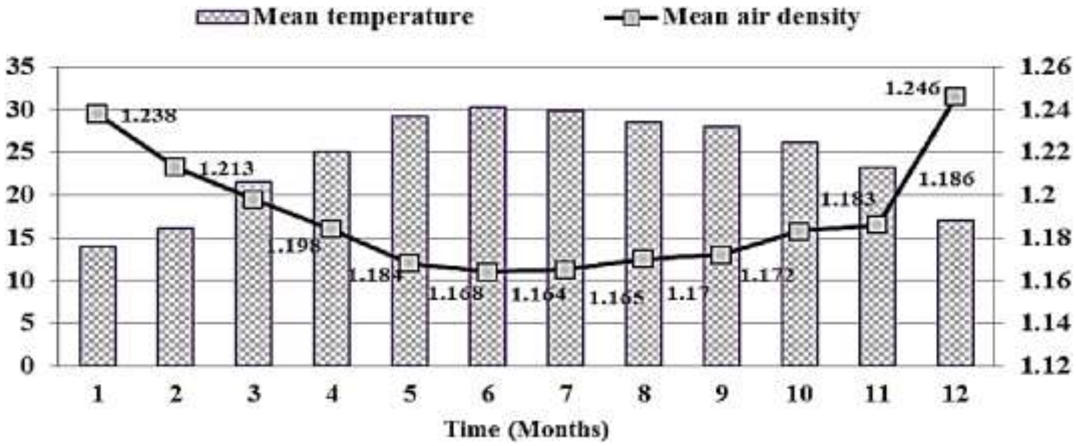


Fig. 11. Mean number of temperature (°C) and air density (kg/m³) for a period of a year [35]

This study has implemented a remote WRA system to measure wind potential energy parameters remotely. The system comprises an Arduino Uno microcontroller, RK100-01 Wind Speed Sensor, BMP280 air pressure and temperature sensor, and SIM800L GPRS module capable of measuring, displaying, and uploading data to the ThingSpeak Cloud. This setup enables wind energy potential measurements to be conducted anytime and anywhere. Future studies can further analyze these measurement results to calculate the amount of potential wind energy generated.

IV. Conclusions

This study focuses on a remote WRA system integrated with IoT at Atma Jaya Catholic University of Indonesia Campus 3 BSD. Data was collected at 30-second intervals and visualized in real-time using ThingSpeak. The study found that both the remote WRA-IoT integration data and direct recording data generate identical graph plots. It involves measuring three crucial parameters for assessing wind energy potential viz. wind speed, air pressure, and air temperature. This underscores that the integrated IoT-enabled remote WRA system not only captures and monitors data but also facilitates remote analysis. This capability allows for flexible real-time data collection accessible from any location, thereby reducing the necessity for frequent site visits. Furthermore, it presents a cost-effective solution for monitoring various renewable energy applications. Moreover, based on the three crucial parameters data obtained, further studies can now be pursued to calculate the magnitude of wind energy potential and provide those data remotely.

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