JOIV : Int. J. Inform. Visualization, 8(2) - May 2024 669-677

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

Environmental Monitoring System Using Wireless Multi-node Sensors-based Communication System on Volcano Observations Drones

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Abstract— **Indonesia is on the Ring of Fire and has the world's most active volcanoes. Volcanic activity has a significant effect on the landscape and on the people who live there. The difficulty of evacuating and helping victims requires hard work and sometimes even the safety of the rescue team itself. For this reason, high-tech tools are needed. Unmanned aerial vehicles (UAVs), also called drones, have become a hopeful tool for remote environmental monitoring in recent years. The system design has a monitoring platform, gateway, and sensor nodes attached to the UAV, which monitors the content of toxic gas contamination in the air. Using IoT technology, sensor data is sent wirelessly to a central monitoring station for a thorough and accurate volcanic activity study. This system is a flexible and complete way to monitor volcanic activity, learn more about it, and make it easier to respond to disasters. Tests are also done to measure system speed, including latency, and determine network service quality. The results show that data is successfully sent in real-time from the sensor nodes to the monitoring system. The average Round-Trip time for the payload transmission is 446.046226 ms. This shows how well the system works to send data from the sensors connected to the UAV to the monitoring station. The UAV has sensor nodes and a monitoring system platform. These can be used to build and optimize disaster mitigation systems.**

Keywords— **UAV; volcano; sensor nodes; IoT; disaster.**

Manuscript received 7 Jul. 2023; revised 4 Oct. 2023; accepted 15 Nov. 2023. Date of publication 31 May. 2024.

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I. INTRODUCTION

Indonesia is located in the Ring of Fire region, which has the most significant number of active volcanoes in the world. Indonesia has 129 mountains, with 30 of them located on Java Island, where approximately 60% of the Indonesian population is situated [1]. According to the National Disaster Management Agency (BNPB), there were 121 volcanic eruptions from 2015 to 2021, with the most eruptions occurring in 2018 with 63 eruptions [2]. According to the Volcanic Explosivity Index (VEI), volcanoes with a VEI of less than 5 have the potential to alter the natural landscape and the environment around them as a result of gas emissions, volcanic ash, lava flows, and landslides, as well as other factors that have the potential to directly affect the community that is in the immediate area, such as the destruction of agricultural land, flooding, famine, and disease. When the VEI is greater than 5, an earthquake can destroy cities and entire areas, cause disruptions to weather patterns, and interfere with air transport [3], [4].

Volcanic activity can significantly impact the environment and affect the lives of those nearby due to the emission of harmful gases, ash rain, and lahar flows. The eruption of Mount Raung in 2016 in East Java, which released volcanic ash to several surrounding areas such as Malang, Blitar, Probolinggo, Bondowoso, and Kediri [5]. Volcanic eruptions can release several chemicals into the atmosphere, including carbon monoxide (CO), carbon dioxide (CO2), hydrogen sulfide (H2S), sulfur dioxide (SO2), and nitrogen (NO2), all of which have the potential to contaminate the environment and cause the death of people. [6], [7]. Explosive eruptions will push gases into the atmosphere, and effusive eruptions will push lava out of the earth [8], [9].

When a disaster occurs, people tend to coordinate themselves to establish an effective disaster management command center and a real-time disaster observation platform to direct disaster relief teams to carry out their work based on the disaster situation. Communication between the disaster management command center and rescue teams is vital to the disaster response; however, commercial communication networks are frequently disrupted by the disaster [10], [11]. Therefore, technology is needed to aid the National Disaster Management Agency (BNPB) and affiliated institutions in monitoring volcanic areas, beginning with the visual state of the peak and moving on to the conditions of the gas and material surrounding the volcano top. This technology is required because it can help monitor volcanic locations.

The Internet of Things (IoT) has developed into a technological revolution that has altered the way in which people interact with various electronic devices as well as the surrounding environment. The evolution of the Internet of Things has resulted in the creation of a framework that enables a great number of devices to connect to and communicate with each other without any hitches [12]. The Wireless Sensor Network (WSN), which serves as the foundation of the Internet of Things's (IoT's) hierarchical structure, is one of the most important components of the Internet of Things's (IoT's) underlying infrastructure [13]. A wireless sensor network (WSN) is a collection of small nodes that are capable of interconnecting with one another, functioning independently, and being outfitted with sensing capabilities that allow them to collect data in real time [14], [15]. It is possible to install sensor nodes in a broad variety of different devices and locations, which enables monitoring and data gathering to be carried out in an effective and widespread manner [16]. The mitigation of natural disasters and the observation of affected areas can both benefit from the use of unmanned robotic systems[17]. Unmanned Ground Vehicles (UGV) and Unmanned Aerial Vehicles (UAV) are the types of robots that are currently frequently created in missions on handling and monitoring natural disasters [18]. Exploration and observation are two of the most common uses for unmanned ground vehicles (UGV), which are purpose-built to have good ground roaming capabilities [19]. After then, UAVs are utilized for air exploration missions in a more general sense for the goals of mapping and exploration by air [20].

Unmanned Aerial Vehicles (UAV), sometimes known as drones, have emerged as a viable alternative for remote environmental monitoring in recent years [21]. Even in dangerous conditions such as active volcanic regions, the use of drones outfitted with sensors offers a flexible and effective method for collecting real-time data. [22]. The utilization of multi-node sensor systems on UAVs enhances spatial resolution and data accuracy, enabling comprehensive and detailed analysis of volcanic conditions in the area [23]. Utilizing multi-node sensor systems on UAVs improves spatial resolution and data accuracy, allowing for a comprehensive and in-depth analysis of volcanic conditions in the region [24]. As a result, it is imperative to develop technological solutions capable of effectively monitoring and issuing timely warnings on volcanic activity, in order to mitigate the potential consequences of such disasters. In the present scenario, the utilization of the Internet of Things (IoT) and Unmanned Aerial Vehicles (UAV) or drones presents a viable alternative approach for the surveillance of volcanic activities. The data collected by the sensors is wirelessly transmitted to the central monitoring station, allowing for detailed and accurate analysis of volcanic activity. This technology has the potential to completely change the way that researchers and rescue teams monitor volcanic activity. As a result, it will be able to provide essential data for early warning systems and reduce the likelihood of catastrophic volcanic events occurring. The mobility problem and the handover latency of several generations of wireless communication are the primary foci of this study, which was conducted in both homogenous and heterogeneous situations.

II. Materials and Method

This research is a component of the master plan developed by the Robotics and Automation research group. The group's primary focus is on the development of exploration, observation, and rescue robots for use in natural disaster zones, particularly for the purpose of mitigating the effects of volcanic events and managing their aftermath. This research results in the production of two distinct types of robots that are supplied with a variety of mechanisms. One example is the unmanned ground vehicle (UGV), which is outfitted with a variety of mechanisms for walking to identify things, arm mechanisms, and sensory capabilities that are utilized for the purposes of observation and exploration [20], [25], [26].

This research focuses on the development of aerial exploration and observation with the assistance of UAVs so that the performance can be improved. The proposed technique has the potential to be helpful for acquiring data on volcanic sites, including terrain, temperature, gas, and other factors, for the sake of both exploration and mitigation. The system uses the concept of Wireless Sensor Network (WSN). WSN is a wireless network consisting of a large number of sensors spread over a large area. The proposed system consists of several devices in the form of sensor nodes mounted on a UAV. The devices are equipped with sensors to monitor temperature, humidity, carbon dioxide (CO_2), sulfur dioxide (SO_2), and carbon monoxide (O_2) levels [27]. The number of nodes used can be adjusted as needed. Each sensor node works in a coordinated manner to collect, transmit, and analyze data collected in the network [28]. The communication system between sensors utilizes the WiFi network found on the ESP32. Implementation of node deployment with UAVs as shown in Fig. 1.

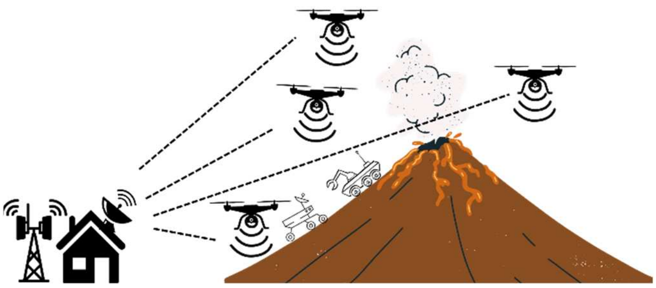

Fig. 1 Illustration of sensor node deployment

The system is designed to allow for flexibility in the exploration of the territory to be explored by making use of a large number of auxiliary UAVs. This makes it feasible to enhance the exploration coverage of the volcano area. The utilization of a large number of UAVs within the system makes this degree of adaptability possible. As a result of its utilization of unmanned aerial vehicle (UAV) technology and multi-functional sensors, the system is in a position to gather accurate data on a variety of various parameters associated to volcanic activity in real time. As a result, the technology has the potential to enhance both our knowledge about volcanoes and our monitoring abilities in a way that is reliable as well as secure.

A. System Analysis and Comparison

Previous studies in the field of environmental monitoring have encompassed a range of methodologies involving the utilization of unmanned aerial vehicles (UAVs) and wireless communication technology. One example pertains to the creation of a monitoring system that utilizes drones equipped with multi-node sensors to assess radiation hazard levels in the vicinity of nuclear power plants. This system can be operated remotely through the utilization of GPS technology [29]. The following study suggests the utilization of Software Defined Network (SDN) technology for the establishment of a Multi-Unmanned Aerial Vehicle (UAV) emergency communication system, with the aim of conserving energy in scenarios of disaster [30]. There is existing research that centers on the characterization of communications between Internet of Things (IoT)-assisted Unmanned Aerial Vehicles (UAVs) through stochastic analysis [31]. This study places particular attention on the development of adaptable schemes for deploying UAVs, with the aim of enhancing the Quality of Service (QoS) on the downlink side [32]. Research has been conducted to enhance power optimization in unmanned aerial vehicle (UAV) trajectories, which serve as relays for data transfer in multi-hop communications, with the aim of mitigating packet loss [22]. Subsequent investigations have employed unmanned aerial vehicles (UAVs) and wireless sensors to expand the communication range and gather geologic environment data. The study focused on the application of multi-robotics communication in disaster scenarios, specifically examining the effectiveness of two communication protocols: MQTT and CoAP [11]. The following study employs unmanned aerial vehicles (UAVs) to do post-volcano eruption mapping through the utilization of cameras [23]. Advantages of the proposed system include the comprehensive integration of multi-node sensors, the ability to expand the monitoring area by adding sensor nodes to the drone, the efficient MQTT communication protocol, and the availability of an intuitive web-based monitoring platform that simplifies the monitoring data acquisition process and has the potential to improve the understanding of and response to environmental conditions associated with volcanoes.

B. System Architecture

The architecture of the system is comprised of three primary components: the monitoring platform, the gateway, and the sensor node. Sensor nodes are multi-sensor components that are mounted to drones in order to collect data in the form of air quality data. This data is then delivered to the gateway after being collected by the sensor nodes. Every drone comes fitted with a sensor that can transmit data on gas levels, temperature, and humidity, in addition to GPS coordinates. The gateway functions as a computer and is responsible for collecting data from the sensors. The data that was captured by the drone is transferred to the gateway using Wi-Fi network. The gateway's responsibilities include both the receipt of data and the storage of sensor data in the database. The monitoring platform is built with a web-based system that is used to visualize sensor data. This gives users the ability to analyze data regarding air quality in real-time, access data history, carry out analysis and monitoring, and know the coordinates of each drone that is now in use. With this architecture, it is feasible to establish a distributed system that can assist in the collection of data regarding air quality through the use of drones that are administered through a web-based platform that has the potential to become a centralized monitoring system for the purposes of air quality analysis. The architecture of the system is to be built as shown in Fig. 2.

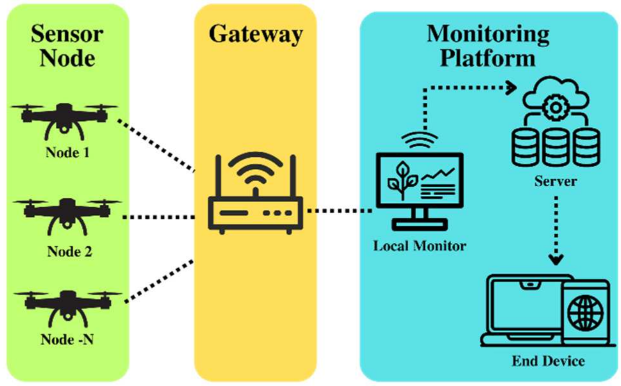

Fig. 2 The architecture of multi-sensor systems.

Sensor nodes are mounted on the UAV so that it can observe the area around the volcanic crater. To expand the coverage of the observation area, the number of sensor nodes can be increased by flying additional UAVs. The monitoring system can be used as a remote fixed station or a mobile station that can be accessed through a mobile device. The integration of sensor nodes on the UAV is shown in Fig. 3.

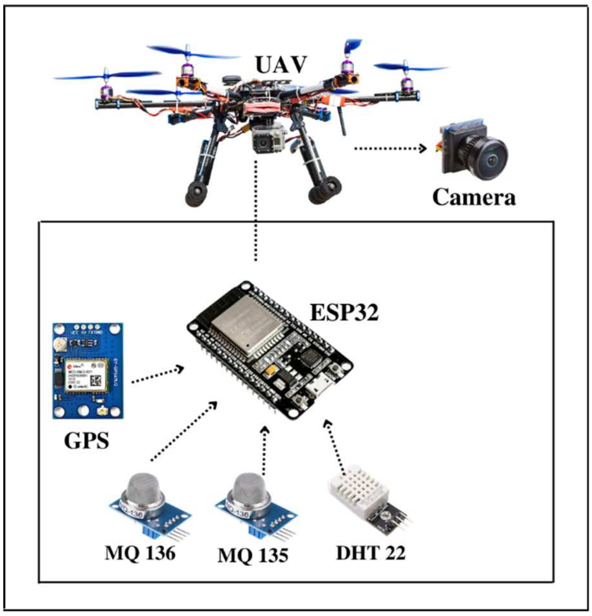

Fig. 3 Sensor Node

The air sensing device is mounted on an unmanned aerial vehicle (UAV), which is equipped with MQ136, MQ135, DHT22, and GPS sensors as part of a system built for the mitigation of the effects of volcanic disasters. The unmanned aerial vehicle (UAV) in this scenario is fitted with air monitoring equipment that can collect data from the environment around it in real time. Message Queuing Telemetry Transport, or MQTT for short, is the protocol that will be used to send data from sensor nodes to the ground station. This process is illustrated in Fig 3. The ground station serves as the primary location for UAV monitoring and commanding functions. With MQTT serving as the communication protocol for the Internet of Things network, data may be transmitted wirelessly to the ground station without going through the cloud. Even when a link to the internet is unavailable, data can still be transmitted from the related sensor nodes of the UAV using a local area network. When a link to the internet is established, the data collected by the sensors will be sent from a web page platform to a cloud server located in the cloud by way of a Wi-Fi network. Because of this, everyone who possesses a mobile device and access to the internet is able to take part in the process of monitoring the air quality using sensor nodes mounted on UAVs.

C. Monitoring Platform

In this section, we will introduce the monitoring platform as a monitoring system that can be used to do analysis on data collected from sensor nodes that have been connected to the internet of things (IoT) and have transmitted their data using the MQTT protocol. The monitoring platform system serves as a subscriber, while the sensor node functions in the role of a publisher. Using a framework written in Python, this application was converted into a web-based one. The display of the monitoring system interface is shown in Fig. 4.

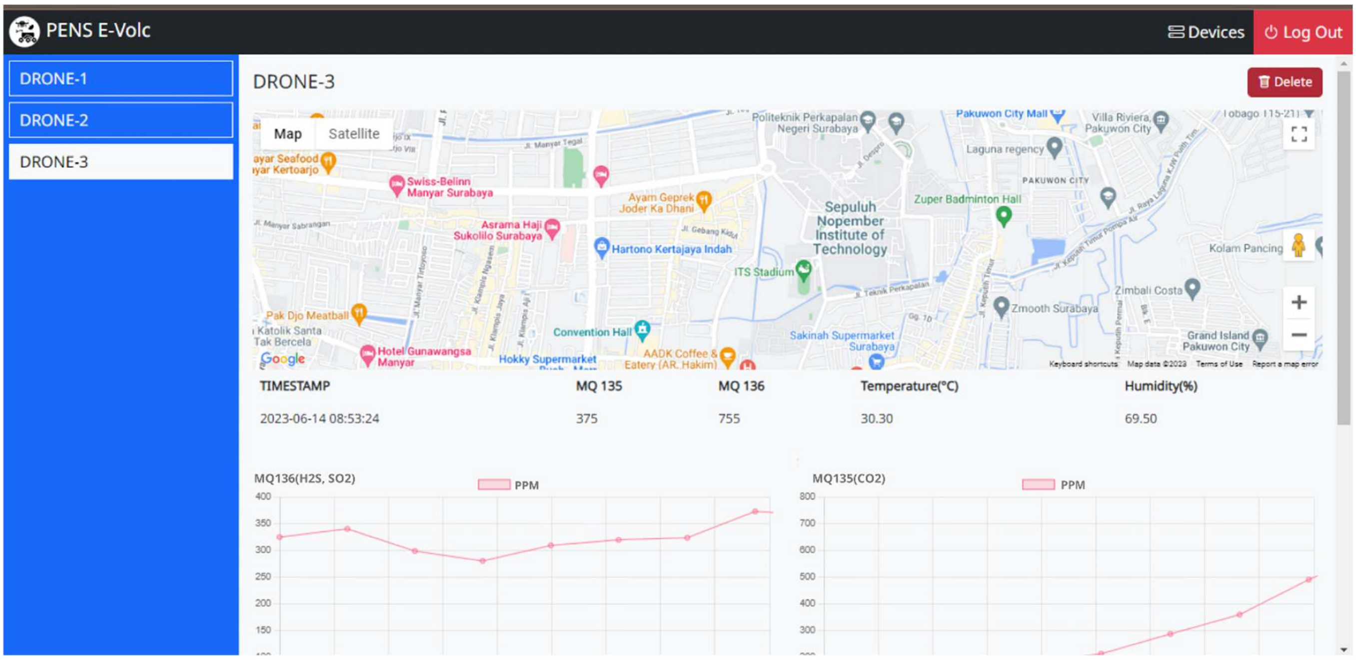

Fig. 4 Web-based monitoring system

On the web page, there is also a visualization in the form of a graph that displays sensor data generated every minute in real time. This is done so that it can make it simpler for officers to monitor circumstances based on sensor data. The data that was acquired by the UAV can be visualized using this web page platform, which plays a vital function. In addition to that, the web page will also receive the geographic location data that was collected from the GPS device. Graphs or other types of interactive displays will be used to provide the data that pertains to the many aspects of air quality, such as temperature, humidity, and pollutant concentration. On the map that is incorporated into the platform, the location of the UAV as well as its flight path will be displayed using the GPS data.

D. Testing Stage

The testing carried out in this research on system performance includes sensor reading response and network performance with several test scenarios made based on parameters such as latency on the network, QoS (Quality of Service) with parameters to be measured including bandwidth, delay, jitter and packet loss collected periodically from the publish subscribe scheme between sensor nodes [33]. When evaluating the quality of a network's data transfer, there are a number of characteristics that are typically considered. The amount of time it takes for data to transmit from one network node to another is referred to as the data latency. When performing experiments on a wireless sensor network (WSN), this parameter is crucial. The shorter the time between when data is sent and when it is received, the smaller the latency. Testing WSNs with a focus on latency can aid in network evaluation by keeping tabs on Quality of Service (QoS), which can then be used to guide decisions about which algorithms and protocols to implement and which network system issues to troubleshoot. Testing latency involves sending packets through a series of relays and then waiting to see how long it takes for them to arrive at their final destination. Latency data can provide insight into network performance and aid in enhancing WSN network efficiency and constraints.

III. Result and Discussion

Testing a multi-sensor system on a UAV is an important stage in the development of a system that involves several sensors installed on an unmanned aircraft. In this chapter, we provide an analysis of the test results in terms of response time, consistency, and various factors that can affect system performance. In the context of this development for natural disaster conditions, the results of testing a multi-sensor system on a UAV can also provide valuable information with regard to the effectiveness and efficiency of using the system for real-time detection and monitoring of natural disaster conditions, as well as the system's response to rapid and complex environmental changes. This discussion can serve as an essential basis for future enhancements to the system's efficiency and optimization of its use in natural disaster mitigation.

A. System Implementation

The purpose of this experiment is to evaluate the performance of the system when transmitting data from sensor node devices mounted on a number of UAVs to an IoT platform web service. This test employs five sensor nodes that can be modified as necessary. The air sensor device includes an ESP32 microcontroller with a MQ135 sensor as an air quality gas sensor with a detection range of 10-1000ppm that can detect ammonia gas (NH3), benzene (C6H6), nitrogen dioxide (NO2), and carbon monoxide (CO). With a detection range of 1-200ppm, the MQ 136 sensor is a hydrogen sulfide (H2S) gas sensor [34]. The DHT22 sensor is used to measure the temperature and humidity in the immediate area of the volcano. Then GPS is used to provide longitude and latitude location data. This sensor provides vital information about the air conditions surrounding the area, which can be used to estimate air and weather conditions and help in the monitoring and mitigation of hazards in the volcano area. In Fig. 5, we see the UAV with sensor nodes installed.

Fig. 5 Sensor node installation on the UAV

The UAV used in this experiment is an F450 Quadcopter with four propellers that has an APM 2.8 ArduPilot flight controller. Each sensor node contains measurement sensors pertinent to this study. Using the MQTT protocol, sensor data is transmitted from sensor nodes to the web page platform in real-time. The UAV is programmed to transport and transmit each sensor node to the ground station. In the created system, each sensor node equipped with an ESP32 functions as a publisher, packaging sensor node data into MQTT messages for transmission to the broker. The MQTT broker functions as an intermediary for communication between sensor nodes as publishers and web page platforms as subscribers. The utilization of the MQTT protocol enables the sensor node and the web page platform to exchange sensor data asynchronously and in real-time. Utilizing an assurance mechanism, the protocol guarantees the dispatch of messages to their intended destination. In testing WSN communication, three sensor nodes consisting of sensors equipped with ESP32 are used, as shown in Fig.6.

Fig. 6 Three UAV sensor nodes

The tests conducted at this stage are performed in a designated field area that serves as a representative sample of air and weather conditions for the purpose of collecting sensor data in accordance with its intended function. Fig. 7 presents a comprehensive depiction of the current circumstances encountered by sensor nodes in conjunction with unmanned aerial vehicles (UAVs).

Fig. 7 Conditions when the UAV and sensor nodes are in flight

The configurations were constructed with varied communication distances between UAVs so that the effect of changing distance and altitude conditions on the influence and performance of data transmission at sensor nodes could be observed. This was done in order to study the effect of changing distance and altitude conditions. Using the MQTT protocol, the web page platform is utilized to both receive and visually represent sensor data in real time. The communication of sensor data from the sensor nodes to the web page platform may be made swift, efficient, and reliable by utilizing the MQTT protocol. During testing, observations were performed to determine the influence of Wi-Fi network connection stability, the effect of Wi-Fi network connection reliability, and the reaction time from the sensor nodes attached to the UAV to the web page platform.

B. Communication Testing

There is a correlation between the employment of the MQTT protocol in the system and increased latency. Because the system makes use of the MQTT protocol, it can make the most efficient use of available bandwidth, reduce the amount of unnecessary communication overhead, and so shorten the amount of time required to transfer data. Testing the latency is accomplished by constructing a plan that involves delivering data packets from the sensor node to the ground station system in the form of a web page platform. This plan is then evaluated for its effectiveness. Latency is defined as the amount of time that elapses between when a packet is sent and when it is received at its final destination. For the purpose of this test, we recorded and logged communication with three sensor nodes that were attached to the UAV. We then connected to the local network in order to transfer data to the web platform for a period of five seconds.

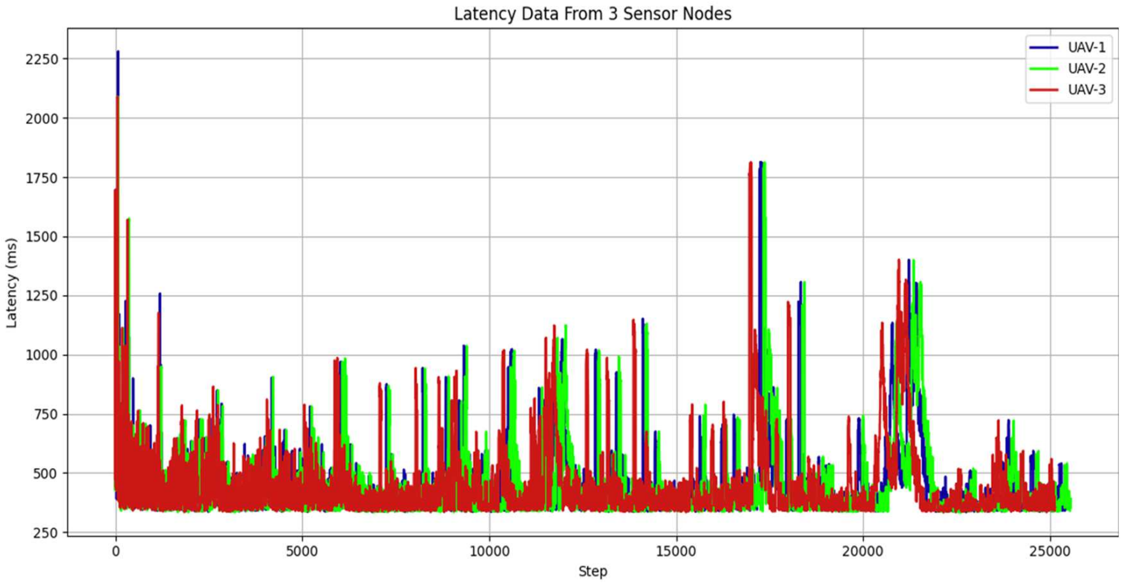

Fig. 8 Visualization of the latency graph of each sensor node

In Fig. 8, a graph shows how delay data measured in microseconds (ms) is recorded. This was the recording. The study above found that network conditions, distance, and packet count affect data transmission time. Each sensor node sends packets simultaneously for this test. Network scenario and packet size have significant results. In the lab, each sensor node sends almost the same data. The information given above can also be taken to mean that all packages have been sent where they were supposed to go. The amount of time it takes for a data packet to go from a sender to a receiver and then back to the source is measured by a matrix equation called RTT (Round-Trip Time). This equation is used to measure the quality of a network based on latency. The delay time was measured by sending a packet and then timing how long it took to come back at regular intervals. Based on those facts, this grid was made. The RTT can be used as a way to measure the quality of a network's service, with the assumption that a better network will have a lower RTT. The following is an example of a mathematical equation that can be used to calculate RTT:

$$RTT = T2 - T1 \quad (1)$$

The variable equation T1 represents the time at which the sender transmitted the payload. While T2 is the time the sender received the payload. Table I displays the outcomes of each sensor node's equation-based calculation.

TABLE I
AVERAGE LATENCY

Node UAV	RTT (ms)
UAV-1	447.389154
UAV-2	443.529704
UAV-3	447.219820
Overall average	**446.046226**

It can be noticed from the data that there is no major variation in the latency between UAV-1 and UAV-3, as both of them have almost the same latency value. Both of these drones practically have the same latency value. UAV-2, on the other hand, has a latency that is marginally lower than that of the other two UAVs.

When performing a study of the performance of a system, it is preferable to have a lower latency because this implies that the system can send data more quickly. On the other hand, the difference in latency that can be detected in this data table is not particularly substantial. Therefore, more tests or measurements that are more specific are required to obtain a more accurate assessment of the performance of the system. In addition, the overall figure for the average amount of latency is 446.046226 ms. This value can be used as a reference to compare the performance of the system with that of other systems that are analogous to it or with tests that were carried out at different times. The average latency number should be as low as possible for optimal performance in the system's ability to transfer data in real time.

C. Testing Website Performance

In addition, tests were performed to evaluate the quality of the web monitoring platform built with Lighthouse version 8.0. Testing is performed by applying various network condition schemes. This test simulation employs 3G Slow (0.4 Mbps), 3G Fast (1.6 Mbps), 4G (9 Mbps), and LTE (12 Mbps) networks. The test outcomes are shown in table II.

TABLE II
WEB PAGE PERFORMANCE RESULT

Connection	FCP	LCP	TBT	Speed Index
3G (0,4 Mbps)	9.8 s	13.2 s	230 ms	10.2 s
3G Fast (1,6Mbps)	8.7 s	8.7 s	70 ms	8.7 s
4G (9Mbps)	1.1 s	8.4 s	0 ms	2.9 s
LTE (12 Mbps)	0.5 s	1.4 s	320 ms	0.8 s

Some of the factors that can be used to figure out how good a web page is are First Contentful Paint (FCP) Time, Largest Contentful Paint (LCP), Total Blocking Time (TBT), and Speed Index. A method that uses a number of different network events is used to get these parameters. The following is how the parameters that were utilized function: The fill-control-point (FCP) is a parameter that is used to compute the maximum amount of time that a browser is able to show the content of the Document Object Model (DOM) when that material is presented in the form of images, text, and other items that are not white canvas. LCP determines the page's most substantial content's loading time. TBT is the total page time spent on factors that slow rendering to the point that it cannot take user input. The Speed Index scores the page's content's display speed, hence its name.

Because the purpose of the web page developed is to visualize data obtained from sensor readings in the form of sensor values in the form of text, graphics, and visualization maps, testing according to these characteristics is carried out throughout the process of analyzing the performance of a web page. Readings from sensors that measure gas, temperature, and humidity can be displayed using graph visualization. Fig. 9 provides an illustration of how the graph is visualized on the web page platform.

Fig. 9 Sensor Graph Visualization

Through the examination of the graph, individuals will have the capacity to observe the alterations in the pattern of gas concentration as time progresses. This methodology will assist observers in identifying potential origins of air pollution resulting from gas leaks in the volcano. Graphs that show temperature and humidity allow users to keep track of and figure out the likelihood of certain temperature and humidity levels at certain times. In these images, you can also find out about the weather. Graph visualization helps with analysis based on trends and patterns, and it can show sensor data clearly and easy to understand to help research teams, SAR teams, and other groups make the right decisions.

The website that was made has a feature that can instantly show which drones are connected to the network. This is done by setting the device name of a sensor node that has already been set up. Longitude and latitude data are sent through GPS in order to make maps that can be seen. Using GPS data, the map on the app will show where the UAV is and how it is flight. Fig. 10 presents a visualization of maps generated using GPS.

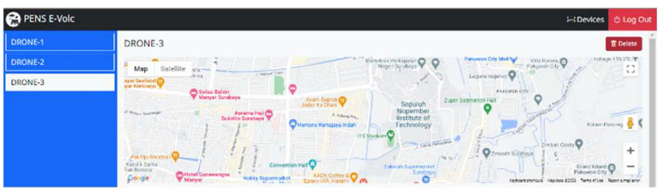

Fig. 10 Visualization of maps on web pages

IV. CONCLUSION

This research led to the creation and installation of an observation and monitoring system on a UAV for the goal of monitoring air contamination and mitigating volcano disasters. This system was installed for the purposes of volcano disaster mitigation. The generated system generates a web page platform that can be connected to the sensor node device that is coupled to the UAV. The sensor node device is attached to the UAV. The developed web page platform can be used to monitor and visualize multiple sensor nodes affixed on the UAV in one web page. The method proposed in this study incorporates wireless sensor networks on unmanned aerial vehicles (UAVs) for volcano monitoring with the potential to provide accurate data and early warning, which is anticipated to reduce the impact of disasters on the environment and society. The results obtained from many experiments conducted to examine the latency of data transmission in multi-sensor nodes deployed on three unmanned aircraft operated concurrently indicate that the quantity of nodes does not influence the efficacy of data delivery. The proximity between the sensor nodes and the gateway is a crucial determinant of delivery quality. Furthermore, experiments were also carried out on the website tool to assess the efficacy of data visualization following its collection from various sensors. In subsequent periods, there is a desire to enhance the data transmission infrastructure through the integration of LoRa networks and the augmentation of data processing capabilities for application servers.

ACKNOWLEDGMENT

This research was awarded financial support from the Ministry of Education, Culture, Research and Technology (Kemendibudristek) for the 2023 fiscal year by means of the Research and Community Service program's PTM (Master's Thesis Research) funding scheme. The title of this funding scheme is "Multi-Node Sensor Wireless Communication System on Volcano Observation Drones". The contract research numbers are 168/SPK/D.D4/PPK.01.APTV/VI/2023 and 4856.15/PL14/PG/2023. We would like to thank the Ministry of Education, Culture, Research and Technology (Kemendibudristek) and Politeknik Elektronika Negeri Surabaya (PENS) for all their support for this research.

REFERENCES

[1] N. A. Pambudi, "Geothermal power generation in Indonesia, a country within the ring of fire: Current status, future development and policy," Renewable and Sustainable Energy Reviews, vol. 81, pp. 2893–2901, Jan. 2018, doi: 10.1016/j.rser.2017.06.096.

[2] A. Adi *et al.*, *IRBI Indeks Risiko Bencana Indonesia Tahun 2021*. Pusat Data, Informasi dan Komunikasi Kebencanaan Badan Nasional Penanggulangan Bencana.

[3] M. N. Malawani, F. Lavigne, C. Gomez, B. W. Mutaqin, and D. S. Hadmoko, "Review of Local and Global Impacts of Volcanic Eruptions and Disaster Management Practices: The Indonesian Example," Geosciences, vol. 11, no. 3, p. 109, Mar. 2021, doi:10.3390/geosciences11030109.

[4] J. P. Terry, J. Goff, N. Winspear, V. P. Bongolan, and S. Fisher, "Tonga volcanic eruption and tsunami, January 2022: globally the most significant opportunity to observe an explosive and tsunamigenic submarine eruption since AD 1883 Krakatau," Geoscience Letters, vol. 9, no. 1, Jun. 2022, doi: 10.1186/s40562-022-00232-z.

[5] A. Wardoyo, J. Noor, G. Elbers, S. Schmitz, S. Flaig, and A. Budianto, "Characterizing Volcanic Ash Elements from the 2015 Eruptions of Bromo and Raung Volcanoes, Indonesia," Polish Journal of Environmental Studies, vol. 29, no. 2, pp. 1899–1907, Feb. 2020, doi:10.15244/pjoes/99101.

[6] G. Gudmundsson, "Respiratory health effects of volcanic ash with special reference to Iceland. A review," The Clinical Respiratory Journal, vol. 5, no. 1, pp. 2–9, Nov. 2010, doi: 10.1111/j.1752-699x.2010.00231.x.

[7] J.-F. Smekens, A. B. Clarke, M. R. Burton, A. Harijoko, and H. E. Wibowo, "SO 2 emissions at Semeru volcano, Indonesia: Characterization and quantification of persistent and periodic explosive activity," Journal of Volcanology and Geothermal Research, vol. 300, pp. 121–128, Jul. 2015, doi:10.1016/j.jvolgeores.2015.01.006.

[8] A. J. Prata and C. Bernardo, "Retrieval of volcanic SO2 column abundance from Atmospheric Infrared Sounder data," Journal of Geophysical Research: Atmospheres, vol. 112, no. D20, Oct. 2007, doi: 10.1029/2006jd007955.

[9] C. Heaviside, C. Witham, and S. Vardoulakis, "Potential health impacts from sulphur dioxide and sulphate exposure in the UK resulting from an Icelandic effusive volcanic eruption," Science of The Total Environment, vol. 774, p. 145549, Jun. 2021, doi:10.1016/j.scitotenv.2021.145549.

[10] N. A. Hidayatullah et al., "Volcano multiparameter monitoring system based on Internet of Things (IoT)," Australian Journal of Electrical and Electronics Engineering, vol. 17, no. 3, pp. 228–238, Jul. 2020, doi:10.1080/1448837x.2020.1817250.

[11] M. I. Yamin, S. Kuswadi, and S. Sukaridhoto, "Real Performance Evaluation On MQTT and COAP Protocol in Ubiquitous Network Robot Platform (UNRPF) for Disaster Multi-robot Communication," EMITTER International Journal of Engineering Technology, vol. 6, no. 2, pp. 369–385, Dec. 2018, doi: 10.24003/emitter.v6i2.305.

[12] Z. Wei et al., "UAV-Assisted Data Collection for Internet of Things: A Survey," IEEE Internet of Things Journal, vol. 9, no. 17, pp. 15460–15483, Sep. 2022, doi: 10.1109/jiot.2022.3176903.

[13] R. I. da Silva, J. D. C. V. Rezende, and M. J. F. Souza, "Collecting large volume data from wireless sensor network by drone," Ad Hoc Networks, vol. 138, p. 103017, Jan. 2023, doi:10.1016/j.adhoc.2022.103017.

[14] A. Miptahudin, T. Suryani, and W. Wirawan, "Wireless Sensor Network Based Monitoring System: Implementation, Constraints, and Solution," JOIV : International Journal on Informatics Visualization, vol. 6, no. 4, p. 778, Dec. 2022, doi: 10.30630/joiv.6.4.1530.

[15] A. Onasanya, S. Lakkis, and M. Elshakankiri, "Implementing IoT/WSN based smart Saskatchewan Healthcare System," Wireless Networks, vol. 25, no. 7, pp. 3999–4020, Jan. 2019, doi:10.1007/s11276-018-01931-2.

[16] K. Gulati, R. S. Kumar Boddu, D. Kapila, S. L. Bangare, N. Chandnani, and G. Saravanan, "A review paper on wireless sensor network techniques in Internet of Things (IoT)," Materials Today: Proceedings, vol. 51, pp. 161–165, 2022, doi:10.1016/j.matpr.2021.05.067.

[17] N. Nikhil, S. M. Shreyas, G. Vyshnavi, and S. Yadav, "Unmanned Aerial Vehicles (UAV) in Disaster Management Applications," 2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT), Aug. 2020, doi:10.1109/icssit48917.2020.9214241.

[18] K. Asadi et al., "An integrated UGV-UAV system for construction site data collection," Automation in Construction, vol. 112, p. 103068, Apr. 2020, doi: 10.1016/j.autcon.2019.103068.

[19] Y. Ding, B. Xin, and J. Chen, "A Review of Recent Advances in Coordination Between Unmanned Aerial and Ground Vehicles," Unmanned Systems, vol. 09, no. 02, pp. 97–117, Feb. 2021, doi:10.1142/s2301385021500084.

[20] M. A. Sanusi, B. S. B. Dewantara, Setiawardhana, and R. Sigit, "Online Terrain Classification Using Neural Network for Disaster Robot Application," Indonesian Journal of Computer Science, vol. 12, no. 1, Feb. 2023, doi: 10.33022/ijcs.v12i1.3132.

[21] B. P. A. Rohman, M. B. Andra, H. F. Putra, D. H. Fandiantoro, and M. Nishimoto, "Multisensory Surveillance Drone for Survivor Detection and Geolocalization in Complex Post-Disaster Environment," IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, Jul. 2019, doi: 10.1109/igarss.2019.8899804.

[22] D. Chen, Z. Liu, L. Wang, M. Dou, J. Chen, and H. Li, "Natural Disaster Monitoring with Wireless Sensor Networks: A Case Study of Data-intensive Applications upon Low-Cost Scalable Systems," Mobile Networks and Applications, vol. 18, no. 5, pp. 651–663, Aug. 2013, doi: 10.1007/s11036-013-0456-9.

[23] C. A. Rokhmana and R. Andaru, "Utilizing UAV-based mapping in post disaster volcano eruption," 2016 6th International Annual Engineering Seminar (InAES), Aug. 2016, doi:10.1109/inaes.2016.7821934.

[24] A. Y. Ponco Wardoyo, "An in Situ Volcanic Gaseous Emissions Concentration Measurement System: A Case Study for Welirang

Volcano, Malang, Indonesia," International Journal of Geomate, vol. 22, no. 93, May 2022, doi: 10.21660/2022.93.2506.
[25] R. Febriyanto, S. Setiawardhana, M. N. Tamara, B. Sena Bayu Dewantara, R. Sigit, and M. A. Sanusi, "Design and Realization of UGV Robot with Combined of Geared Wheel and Walked Mechanism for Uncertain Terrain in Volcanic Observation," 2022 International Electronics Symposium (IES), Aug. 2022, doi:10.1109/ies55876.2022.9888626.
[26] S. Salsabilah, M. N. Tamara, S. Setiawardhana, B. S. Bayu Dewantara, R. Sigit, and M. A. Sanusi, "Development and Control of an Unmanned Ground Vehicle (UGV) Robotic Arm for Volcanic Material Sampling Based on Kinematics Modelling," 2022 International Electronics Symposium (IES), Aug. 2022, doi:10.1109/ies55876.2022.9888452.
[27] J. Burgués and S. Marco, "Environmental chemical sensing using small drones: A review," Science of The Total Environment, vol. 748, p. 141172, Dec. 2020, doi: 10.1016/j.scitotenv.2020.141172.
[28] H. A. Hedworth, T. Sayahi, K. E. Kelly, and T. Saad, "The effectiveness of drones in measuring particulate matter," Journal of Aerosol Science, vol. 152, p. 105702, Feb. 2021, doi:10.1016/j.jaerosci.2020.105702.
[29] M. Sajid, Y. J. Yang, G. B. Kim, and K. H. Choi, "Remote monitoring of environment using multi-sensor wireless node installed on quad-copter drone," 2016 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), Dec. 2016, doi: 10.1109/iris.2016.8066093.
[30] J. Zhou, J. Yang, and L. Lu, "Research on Multi-UAV Networks in Disaster Emergency Communication," IOP Conference Series: Materials Science and Engineering, vol. 719, no. 1, p. 012054, Jan. 2020, doi: 10.1088/1757-899x/719/1/012054.
[31] S. Zhang, J. Liu, and W. Sun, "Stochastic Geometric Analysis of Multiple Unmanned Aerial Vehicle-Assisted Communications Over Internet of Things," IEEE Internet of Things Journal, vol. 6, no. 3, pp. 5446–5460, Jun. 2019, doi: 10.1109/jiot.2019.2902162.
[32] G. Zhang, H. Yan, Y. Zeng, M. Cui, and Y. Liu, "Trajectory Optimization and Power Allocation for Multi-Hop UAV Relaying Communications," IEEE Access, vol. 6, pp. 48566–48576, 2018, doi:10.1109/access.2018.2868117.
[33] D. Mahjabeen, M. A. Rashid, and S. B. Mohamed, "Network Quality Assesment of Wireless Communication Based on Mobility Issue," JOIV : International Journal on Informatics Visualization, vol. 2, no. 4–2, pp. 354–359, Sep. 2018, doi: 10.30630/joiv.2.4-2.178.
[34] J. Chu et al., "Identification of gas mixtures via sensor array combining with neural networks," Sensors and Actuators B: Chemical, vol. 329, p. 129090, Feb. 2021, doi: 10.1016/j.snb.2020.129090.