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SMART SENSOR SYSTEM TO CLASSIFY HOTSPOT TYPES POTENTIALLY FOR LAND AND FOREST FIRES

Evizal Abdul Kadir[1], Sri Listia Rosa[1], Mahmod Othman[2] and Hanita Daud[2]
[1]Department of Informatics Engineering, Universitas Islam Riau, Marpoyan, Pekanbaru, Riau, Indonesia
[2]Department of Fundamental and Applied Science, Universiti Teknologi Petronas, Seri Iskandar, Perak, Malaysia
E-Mail: evizal@eng.uir.ac.id

ABSTRACT

A fire hotspot exhibits the potential to create forest and wildfire, and the size of a hotspot determines the potential level to become a fire and its spread rate. Wild and forest fire is a major issue in some counties with a large forest area, especially in a tropical country, such as Indonesia. This research aims to identify and classify the fire hotspot types and their potential to become a large fire that spreads to forest and wild in a tropical region. A sensor detection system is developed to detect the type of fire hotspots. Several sensors are used to identify and classify the model and type of hotspots and their potential level to become a fire that threatens the wild and forest. The fire sensor is used as the main sensor to detect a fire, and other sensors are utilized to obtain supporting data, such as temperature, humidity, and carbon. A computer algorithm is used to classify the types of hotspot potential to spread to the forest on the basis of the data received from all the sensors, especially the fire sensor. The data received from the carbon sensor are used as parameters to determine whether a hotspot can cause a fire or not. Results show that the proposed sensor system can differentiate and classify whether the hotspot has potential to become a fire or only a small and controllable hotspot. The system can also classify the hotspot data in actual condition, including noises, such as flashlight, touch light, and hotspot from cigarette matches. The decision from the sensor system is extremely effective in assisting for forest fire preventive action rather than conventionally shutting down the fire in every hotspot detected.

Keywords: smart sensor, forest fire, hotspot, riau province.

INTRODUCTION

Indonesia is a country with a high risk of forest and wildfire. Disaster and fires occur mostly every year, especially during summer with a dry environment. In accordance with forest fire data, the total loss due to forest and wildfire in Indonesia in 1997 is 2.45 billion dollars [1]. The total loss in 1995 due to forest fire is 19.1 billion dollars, which is worst compared with that of 1997. This condition affected the economy and society, especially in Riau Province, Indonesia. Many places in Indonesia are impacted by forest fire, and Riau Province is an area with the largest risk and suffering due to this disaster because its land is typically flammable soil. In 2016, a forest fire disaster occurred in Riau Province, resulting in a total loss of 1.65 million dollars and huge economic and social damages. The economic losses impacted most of the activities, such as all the school and universities were closed and government offices and services to the community were stopped due to unhealthy environment with foggy air. The forest and wildfire impacted Indonesia and the surrounding ASEAN countries, especially Singapore, Malaysia, and Thailand. Currently, most of the methods used to obtain forest fire data are based on satellite images. The information obtained is used to analyze and find the location of fires. In some cases, the images are unclear, and identifying the location and determining the impact of forest fire to the community are difficult. In some cases of fire, identification and taking actions are difficult due to unclear information collected from satellite images**.**

Forest and wildfire emitted to the skies contribute to global warming, and the accumulation of gases and haze in the atmosphere (Co2) can damage the ozone layer. Forest fire occurs because the nature has hot environment and dryland. In some cases, forest fire occurs most likely because humans initiate the fire by opening the land for farming or other purposes. Although fires are a feature of forests worldwide for many years, their global impact is minimal due to their decreasing frequency of occurrence. Forest fire disasters occur, especially in the summer season, because several areas of dry land easily get dry and are prone to fire. Most major cases of fire are due to the effect of El Niño phenomenon caused by climate combined with improper forest management by authorities, thereby resulting in the destruction of millions of hectares of tropical forest. Forest fire disasters impact humans and result in economic losses because many activities are limited due to spread of haze and fog in the air. The respiratory health of students is highly at risk. Another disadvantage is ecological losses. These losses include reduction in the size of forest areas, reduction in clear air produced by plants and forests, and inability of forest to disrupt and regulate water for preventing land erosion.

Indonesia suffers from huge amounts of haze due to the occurrence of land and forest fires because it is located near the equator, thereby causing it to have long dry season spans from April to October. This condition largely impacts the local economy, environment, flora, fauna, and human health. Elderly people and children are severely affected due to haze. Millions of people have suffered from respiratory problems, and several have died or have serious health conditions. Providing an early indication of fires is vital and crucial to prevent many casualties. This research focuses on developing a ground-level smart monitoring system to detect and monitor the environmental behavior in terms of temperature, humidity, and gasses for determining whether a fire can become a forest or wildfire. The integration of smart sensors with the latest technology can save the environment and people's lives and provide knowledge and education, where people can access the information through the developed real-time database anywhere and anytime. Smart ground sensors are used to detect potential fire. These sensors can be deployed and implemented in other regions when the testing and application are completed, including standardization. A cheap and quick solution is to detect and determine the data for acquiring the potential of a fire to become a forest and wildfire. The solution is expected to be beneficial for the community, economic development, and social welfare, especially in Indonesia. This research proposes a developed system that can identify and classify the type of fire hotspots and their potential to become a forest or wildfire. Fire hotspot samples are collected and analyzed, and their impact to the forest is evaluated. Some fire hotspot samples are minor issue and cannot cause forest fire. The proposed system requires monitoring of fire hotspot in real-time provide fast information sharing to the public and local authorities.

RELATED WORKS

Many studies have been conducted on forest and wildfire. [2] presented a new technique to detect forest and wildfire through data aggregation combined with wireless sensor network (WSN) technologies. The proposed technique can provide quick and efficient detection of fire by validating the data received from the sensor, and simulation is conducted in a large number of experiments. The use of WSN system delivers high accuracy in managing disasters and rescue operations. In the alarm system, the sensor is used to detect water flooding, earthquake, forest and wildfire, landslides and water level, as elaborated in [3], [4]. The WSN technology is simulated to address the key design and issues in forest fire monitoring, including the initial location, number of sensors required for a particular case, and the coverage area that the system can cover.

An algorithm is implemented in the WSN system to identify malicious injected data and provide measurement data affecting the various attached sensors. The algorithm is applied and evaluated in three different scenarios, and three sets of WSN distribution data are obtained, as elaborated in [5], [6]. Another research applied the WSN technology to predict natural disasters, such as fire, rainfall, and flooding. The WSN stochastic method was used, and energy saving was implemented to reduce the delay in communication and data transfer for extending the network, as discussed in [7], [8]. The WSN system is applied in many applications, such as environmental monitoring, industrial automation and control system, remote sensing, and the healthcare industry. Similar application systems can perform environmental monitoring for forest and wildfire detection in real-time. In common scenarios, a WSN technology consists of several sensor nodes connected each other to make a network system. A sensor network is usually located in a remote geographical area and unreachable by normal people. In the actual implementation, a WSN node can detect the changes in environmental parameters to obtain information to be sent to a master node as a gateway; The main node transfers data to a backend system as a server [9].

The development and emergence of WSN technology have rapidly enhanced and changed to control the environment compared with the common methods using satellite imagery detections. This system can provide new environmental data and alerts for a fatal fire to occur in the land or forest and for flooding detection. [10] Performed ground-level detection to divide the parameters into three categories. [11],[12] used the Internet of things and Long Range (LoRa) technologies in WSN connectivity to make the network system fast, with strong signal level and high reliability. This method creates an intelligent system for the detection and analysis of land and forest fire data. A low-power wireless communication system is presented to provide a new technology in surveillance and detection systems. The integration of LoRa wireless area network technology helps the local community and provides access to the database in real-time at any time. This solution is cheaper and faster compared with other alternatives, such as the use of satellite data imagery to obtain data. Real-time data perception requires support from authorities to accept how the system is working, and an appropriate model must be developed to take action [13], [14].

Detection and monitoring systems are widely used for sensing objects or obtaining sensing data continuously. Nowadays, many types of detection and monitoring systems, such as environmental monitoring and air pollution monitoring systems, are used to retrieve parameters in various application for verifying the current environmental situation, especially in dry season [15]. Forest fire hotspot detection commonly uses satellite imageries to achieve and store image data in a database for analysis. However, satellite technology has several limitations, including low accuracy in fire hotspot detection, thick clouds in the sky, and unclear images for analysis. This system uses a new technique to obtain data, including temperature, particle changes, smoke detection, humidity, and other common parameters, as elaborated in [16],[17]. On the basis of literature review in several publications, gaps are found in previous research. These gaps include determining the potential of a fire hotspot to become a forest or wildfire, potential fire source location, and the size of fire. This research proposes a method to find and analyze a fire in any form of hotspot. The size of fire and its potential to spread and become a forest or wildfire are evaluated. The sensor data received from several parameters installed in the system are analyzed through complex calculation. Several sensors are set to detect different types of fire and their potential to become forest or wildfire [18].

SMART SENSOR SYSTEM

Most of the technologies in current detection and monitoring for forest and wildfires are using satellite communication system. The satellite technology cannot provide the real scenario at such particular locations, especially in bad weather conditions where the fire has already started. The delay in conveying information to local authorities makes the fire worst and uncontrollable. Therefore, a solution for this weakness is by using ground-level detection to have a quick and fast recovery and preventive actions. Another solution is by using LoRa wireless area network technology integrated with sensors. These sensors can detect environmental parameters, such as humidity, gasses, and temperature. The sensors are placed on the base station due to forestry environment, where most of the areas of peatland consist of vegetation. A radio propagation study needs to be conducted to ensure that radio signals can penetrate through the vegetation to the base stations or between base stations. A propagation measurement is needed to examine the differences in the information propagation pattern during emergencies. This process is essential to analyze and cluster the results into three classes with low risk, medium risk, and high risk. The results on peat soil characteristics are recorded. LoRa wireless network integrated with sensors is a good system to be developed. The information collected by the sensors are sent to the base station as a gateway to transfer the data to the monitoring system (data center). A large number of LoRa sensors must be deployed and installed at selected locations with LoRa technology to achieve accurate data because the data can be transmitted up to 30 miles.

Sensing System

The design of the sensing system needs to accommodate all the parameters related to fire, such as temperature, humidity, fire status, carbon, and wind speed. Figure-1 shows a block diagram of the sensor system with several sensors installed and the analysis and filtering of data from the sensor. The input data from the sensors have various signals, and noise filtering and signal conditioning are required to pass only the valid data to the microcontroller for further analysis with an algorithm. A microcontroller Unit (MCU) as main control processes all the data received to determine the output or conclusion in the status of fire whether it can spread and become a forest or wildfire. A radio frequency (RF) antenna is a used as communication system to the data center or backend system for further visual and monitoring. All the circuits and modules require power supply. The power is obtained from the battery, which is charged from the solar panel installed during daytime. The proposed standalone design is needed because in some remote areas have no available power supply or power utilities.

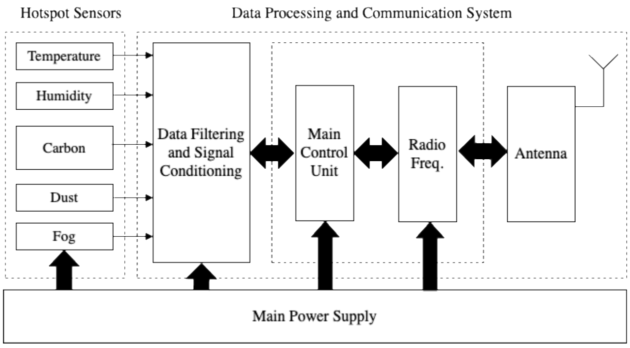


Figure-1. Block diagram of the sensor system to identify fire hotspot.

Fire Detection

The fire size and its potential to spread must be mathematically analyzed to determine whether a fire can become a large fire and spread to the forest or wild. Frandsen theory is used in mathematical analysis to determine how fast a fire hotspot can spread. This theory applies the conservation of energy principle to a unit of volume ahead of advanced fire in a homogeneous fire, which can be expressed as:

$$R = \frac{I_{xig} \int_{-\infty}^{0} (\frac{\partial I_z}{\partial z})_{zc}}{\rho_{be}\, Q_{iq}}\, dx, \quad (1)$$

where:

R = quasi-steady rate of spread (ft/min)

I_{xig} = horizontal heat flux absorbed by a unit volume of fire at the time of ignition (btu/ft^2 min)

ρ_{be} = effective bulk density (the amount of fire per unit volume of the fuel bed raised to ignition ahead of the advancing fire) lb/ft^3

Q_{iq} = heat of preignition (the heat required to bring a unit weight of fuel to ignition) btu/lb

$(\frac{\partial I_z}{\partial z})_{zc}$ = gradient of the vertical intensity evaluated at a plane at a constant depth *zc* of the fire bed btu/ft^3-min

The environmental temperature or heat surrounding the area affects the spread rate of a fire. The heat transfer from a fire hotspot to the spreading area can be written as a formula of energy transfer from a source to another area. This condition is because the heat required for fire is dependent, such as fire temperature, moisture content of fire, and the amount of fire involved in the firing process. The expression can be written as:

$$Q_{ig} = f(M_f . T_{ig}). B. t. \frac{u}{lb}, \quad (2)$$

where:

Q_{ig} = the energy per unit mass required for ignition is the heat of preignition

M_f = ratio of fire moisture to dry weight

T_{xig} = ignition temperature

ARPN Journal of Engineering and Applied Sciences

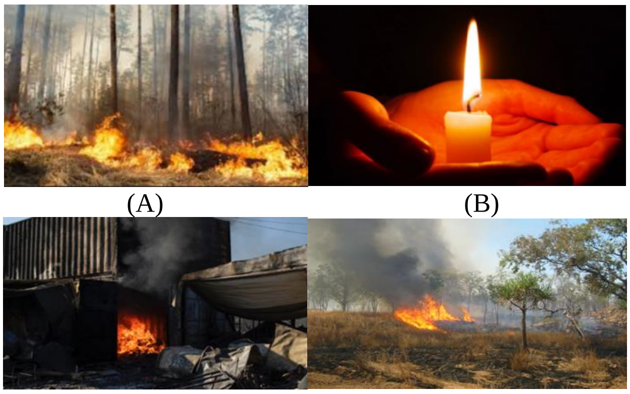
The amount of fire involved in the ignition is the effective bulk density ρ_{be} to aid interpretation and analysis. An effective heating number is defined by the ratio of the effective bulk density to the actual bulk density.

$$€ = \left(\frac{\rho_{be}}{\rho_b}\right). \quad (3)$$

The effective heating number is related to the number that is near to unity for fine fire and decreases toward zero with the increase in fire size. The expression can be written as

$$\rho_{be} = f\,(\text{bulk density, fire size}). \quad (4)$$

This research used four sensors installed in the stations to perform detection and monitoring and differentiate the amount of fire that is identified to have a high threat. The information collected by sensor base stations are kept in an internal database and sent to the monitoring system (data center) by using point-to-point radio communication or existing cellular communication systems. The sensor base stations are equipped with solar cells because they are left in the forest for months. The data are then processed, analyzed, and clustered. A real-time database is developed to disseminate and make the information available to the public and local authorities. All the information received from all the sensors is analyzed, and whether the fire detected has potential to spread and become a forest or wildfire is determined. Figure-2 shows several types of fire detected, and their potential is determined.



(A) (B) (C) (D)

Figure-2. Several types of fire and their sizes for detection and identification (a) forest (b) candle (c) building (d) wildfire.

Measurement Setup

The experiment and measurement setup of the fire sensing detection are conducted through fire simulation, as mentioned in the above types of fire. A fire module developed with several sensors is used as the fire parameter. This module is built with mini size and low power consumption for convenience in deploying and installing on site or any station. The experiment started one by one from the smallest fire that lights up a lighter and then checking the response for all the parameters of the sensor installed. The distance of simulation fire from the lighter is adjusted from nearest with 1 cm to 50 cm. The responses detected from all the sensors are recorded to analyze the data. Other types of fires, including forest fire, candle fire, wildfire, and building fire, are simulated. Figure-3 shows a complete setup system with a computer to display the results and several sensors installed and connected to the microcontroller. The sensing data are obtained to analyze the fire size and its potential to spread. In the actual measurement, the sensing system is placed near or around the sources of the fire area to obtain better detection that is representative of the actual fire. In this case, the fire measurement is conducted on four samples to obtain representative values under several fire scenarios. The data detected from all the sensors are analyzed, and their relationship is compared by using an algorithm to achieve high accuracy results. The final results are recorded in the computer memory, and a graph is developed for better display and to observe the fluctuation easily.

Figure-3. Sensors setup with Arduino microcontroller and connected to the computer for displaying the results.

The initial testing with the lighter is conducted in the laboratory. This process aims to ensure that all the sensors are calibrated and working well with the fire scenarios. The actual testing is conducted in an open area with the simulation of fire scenarios. Some challenges are encountered, and a careful detection by sensors is needed. This condition is because the fire sensor may determine some of the noises as fire incident when a red background is detected. These noises are similar to other environmental noises generated for fire data and parameters. The smart analysis in the controller unit with an algorithm can cover and handle these issues by minimizing or overcoming the noises. During the testing, the sensor can detect and differentiate which is the actual fire and artificial fire with a combination of several sensors. The data are combined to determine a conclusion. The right decision comes from a specific analysis of the data from all the sensors with valid data.

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RESULTS AND DISCUSSIONS

The measurement and testing of the sensor system for detection of fire incidents are conducted in several scenarios. The sensors and parameters represent fire parameters, such as temperature, gas, carbon, haze, and dust. The first scenario is to measure and detect the existing forest fire with the simulation of fire concentration. The results show that the fire exists and has potential to spread. The next testing and measurement are conducted on the fire from the candle, where the fire is placed on an area 10 m from the sensor. The data recorded for every sensor are checked and analyzed. The results show that some sensors detect fire spread, whereas other sensors do not detect any fire spread on the basis of sensor parameters. The carbon sensor does not detect any dust or haze from the candle fire. The results show that fire exists but does not have potential to spread. The third measurement and testing are performed on the fire inside the building or in house. The sensor detects the existence of fire on the basis of all parameters. The results from the system and data analysis from various sensors show that the fire exists and has potential to spread. The last scenario is for the simulation of wildfire. All the sensors and system are set to detect the incident of wildfire. The sensor detects the existence of fire, and the number of carbon and haze emitted from the fire are recorded. The analysis results show the existence of fire and its potential to spread in a large area. Figure-4 shows a measurement result for all the sensors installed in the system and the value of environmental parameters detected by sensors. A graph is plotted on the basis of the values for all the sensors for simple analysis and visualization. The main parameters in the graph are air temperature and humidity.

DATA	17:28:31	17:28:35	17:28:39	17:28:44	17:28:48	17:28:53	17:28:57	17:29:02	17:29:06	17:29:11
TEMPERATURE (C)	25	25	25	25	25	25	25	25	25	25
LPG (PPM) x 1000	0.001	0.003	29.327	1.46	1.939	5.198	8.929	-30.663	3.731	-27.134
CO (PPM) x 1000	-0.258	8.928	27.908	19.59	-21.877	-26.446	19.612	-29.346	4.006	8.994
HAZED (PPM) x 1000	4.202	7.335	24.826	4.298	-23.673	23.341	7.176	-28.661	4.599	-15.264
DUST (KG/m3)	-0.09	-0.09	-0.09	-0.1	-0.1	-0.08	-0.1	-0.1	-0.1	-0.1
FIRE STAUS	EXIST	EXIST	EXIST	EXIST	EXIST	EXIST	EXIST	EXIST	EXIST	EXIST

Figure-4. Results of carbon concentration measurement for four scenarios.

In accordance with the measurement results and decision from the system for each of the scenarios, the existence of fire and alert for its potential to spread can be referred to the carbon and dust parameters. On the basis of testing scenarios in four different types of environment, only one scenario of fire has no alert and potential to spread although the fire exists. The three scenarios are given the decision with fire detected, has potential to spread in a large area, and preventive action or precaution is needed. Basic environmental parameters are used to obtain an accurate decision for the status of fire and its potential to spread. However, a significant result on the existence of fire is not guaranteed. The consideration of carbon and dust sensor values is relevant and are the main factor to determine whether a fire exists. The analysis and prediction on the potential of fire to spread are related to the environmental parameters. Five sensors are installed in the system, and the two parameters are significant parameters to contribute and validate the detection of fire existence and its potential to spread in a large area. Whether the fire exists or not and whether a normal fire or has potential to spread and become a threat to the environment are determined and displayed in the monitoring system.

CONCLUSIONS

Forest and wildfire detection and spreading potential are measured and tested. Sensors are installed in the system to detect and monitor fire parameters. Basic environmental parameters, such as temperature and humidity, are used with additional parameters to support the decision of fire existence and potential to spread. The other sensors are gas, haze, and dust sensors to detect and monitor the particles emitted from the fire. Measurement and testing are conducted on several fire scenarios, such as forest fire, candle, in house, and wildfire. The testing is performed on the scenarios in accordance with the type of fires. These fire types are monitored through a remote system to obtain actual scenarios. The result shows that all the sensors can detect and monitor the existence of fire and differentiate whether the size or quantity of fire has potential to spread in the environment or only a normal fire. The monitoring results show the parameter values for each detection from the sensors. These values are displayed in graph for easy analysis. An algorithm is used in the data processing to obtain an accurate decision for differentiating the size and source of fire that can spread to the environment.

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REFERENCES

[1] L. Tacconi, 2013. Fires in Indonesia: Causes, Costs and Policy Implications. Bogor, Indonesia.

[2] Q. Liu, Y. Shan, L. Shu, P. Sun and S. Du, 2018. Spatial and temporal distribution of forest fire frequency and forest area burnt in Jilin Province, Northeast China. J. For. Res., 29(5): 1233-1239, doi: 10.1007/s11676-018-0605-x.

[3] E. A. Kadir, S. L. Rosa and A. Yulianti. 2019. Application of WSNs for Detection Land and Forest Fire in Riau Province Indonesia. in Proceedings of 2018 International Conference on Electrical Engineering and Computer Science, ICECOS 2018, doi: 10.1109/ICECOS.2018.8605197.

[4] D. Zhang, Y. Cao, G. Zhang and X. Lu. 2019. An Attention Convolutional Neural Network for Forest Fire Smoke Recognition. in 2019 6th International Conference on Systems and Informatics (ICSAI), pp. 1207-1211, doi: 10.1109/ICSAI48974.2019.9010577.

[5] E. A. Kadir, S. K. A. Rahim and S. L. Rosa, 2019. “Multi-sensor system for land and forest fire detection application in Peatland Area. Indones. J. Electr. Eng. Informatics, doi: 10.11591/ijeei.v7i4.1604.

[6] F. Alimenti *et al*. 2008. A Low-Cost Microwave Radiometer for the Detection of Fire in Forest Environments,” IEEE Trans. Geosci. Remote Sens., 46(9): 2632-2643, doi: 10.1109/TGRS.2008.921395.

[7] E. A. Kadir, H. Irie, S. L. Rosa and M. Othman. 2019. Modelling of wireless sensor networks for detection land and forest fire hotspot. Telkomnika (Telecommunication Comput. Electron. Control., doi: 10.12928/TELKOMNIKA.v17i6.12971.

[8] Z. Li, A. Khananian, R. H. Fraser and J. Cihlar. 2001. Automatic detection of fire smoke using artificial neural networks and threshold approaches applied to AVHRR imagery. IEEE Trans. Geosci. Remote Sens., 39(9): 1859-1870, doi: 10.1109/36.951076.

[9] E. A. Kadir, H. Irie and S. L. Rosa. 2019. Modeling of wireless sensor networks for detection land and forest fire hotspot. in ICEIC 2019 - International Conference on Electronics, Information, and Communication, doi: 10.23919/ELINFOCOM.2019.8706364.

[10] S. Gupta, A. Roy, D. Bhavsar, R. Kala, S. Singh and A. S. Kumar. 2018. Forest Fire Burnt Area Assessment in the Biodiversity Rich Regions Using Geospatial Technology: Uttarakhand Forest Fire Event 2016. J. Indian Soc. Remote Sens., 46(6): 945-955, doi: 10.1007/s12524-018-0757-3.

[11] E. A. Kadir, A. Efendi and S. L. Rosa. 2018. Application of LoRa WAN sensor and IoT for environmental monitoring in Riau Province Indonesia. in International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), doi: 10.1109/EECSI.2018.8752830.

[12] A. Divya, T. Kavithanjali and P. Dharshini. 2019. IoT Enabled Forest Fire Detection and Early Warning System. in 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), pp. 1-5, doi: 10.1109/ICSCAN.2019.8878808.

[13] E. A. Kadir, H. Irie and S. L. Rosa. 2019. River water pollution monitoring using multiple sensor system of WSNs (Case: Siak river, Indonesia). in International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), doi: 10.23919/EECSI48112.2019.8976991.

[14] P. Cottle. 2007. Insuring Southeast Asian commercial forests: Fire risk analysis and the potential for use of data in risk pricing and reduction of forest fire risk. Mitig. Adapt. Strateg. Glob. Chang. 12(1): 181-201, doi: 10.1007/s11027-006-9042-9.

[15] Aaron Don M. Africa and Phil Fredric D. Hermosa. 2020. Fuzzy temperature controller based on

Bluetooth low energy for indoor pet dogs. ARPN Journal of Engineering and Applied Sciences, 15(22), http://www.arpnjournals.org/jeas/research_papers/rp_2020/jeas_1120_8409.pdf.

[16] B. G. Sherstyukov and A. B. Sherstyukov. 2014. Assessment of increase in forest fire risk in Russia till the late 21st century based on scenario experiments with fifth-generation climate models. Russ. Meteorol. Hydrol. 39(5): 292-301, doi: 10.3103/S1068373914050021.

[17] E. A. Kadir, A. Siswanto, S. L. Rosa, A. Syukur, H. Irie and M. Othman. 2019. Smart sensor node of WSNs for river water pollution monitoring system. in Proceedings - 2019 International Conference on Advanced Communication Technologies and Networking, CommNet 2019, doi: 10.1109/COMMNET.2019.8742371.

[18] Adam R. H. Alhawari, A. H. M. Almawgani, Nasser Aboud Alsaleh, Saeed Ali Alyami, and Abdullah Mahdi Aslloum 2021. An efficient monitoring system for early fire automatic detection. ARPN Journal of Engineering and Applied Sciences, 16(1). http://www.arpnjournals.org/jeas/research_papers/rp_2021/jeas_0121_8466.pdf.