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Forest fire spreading and carbon concentration identification in tropical region Indonesia

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Abstract Global warming impacted the rise of temperature globally, some of the places a high risk of fire such as land and forest fire. Many efforts to prevent the occurrence of land and forest fire, but some methods are not achieved in optimum results. One of the issues is carbon emitted to the sky is in general concentration. The current sensor only detected carbon status and without the detail of the carbon concentration either from the forest fire or any other source that contribute carbon. This research identifies and detects the fog of haze emitted from a forest fire by identifying the carbon concentration. The carbon sensor detects particles flying in the skies and calculates based on number and size to identify if the fog comes from a forest fire or other fire sources. There are many other sources of haze in the skies. It can be from the pollution emitted from vehicles, fire from the garbage or rubbish, or fog emitted from the factory. The size and number of particles detected by the sensor were analyzed to identify the quantity and the size to match the type of particles emitted from the forest fire. Results show that particles from the forest fire are higher and bigger compare to other sources of fires. The fog's intensity less than from other fire sources because of forest fire the material mostly from the trees and leaves getting burn then gives less in quantity.

1. Introduction

The forest fire happened in many countries and contributed to global warming emitted from the fire to the skies. Accumulation of the gases and haze into the atmosphere can damage the ozone layer. Initially, forest fire occurs because of thought the nature of hot environmental and dryland, but in some cases, most likely because humans have a role to play in starting the fire to open the land for farming or other purposes. Although the fires are a feature of the forest worldwide for many years, suppose occurred lesser in terms of frequency, then the global impact should be in minimum. One of the disasters is a forest fire in Indonesia, especially in the summer season, which dries land. This is because of some area type of land, which is easy to get dry and fire. In most of the significant

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fire cases, which is the El Nino effect in climate change phenomenon and combination of improper way to manage the forest by the authority, the results destroyed millions of hectares of tropical forest. In the tropical region with typically forestry land the potential to get fire is very high due to high temperature weather and dry environmental, fire can destroy the forest in short of time then comes with air pollution. Material emits from forest fire to the air makes high concentration of carbon dioxide and haze which dangerous to the human health and environmental.

According to Development Planning Agency (DPA) of Indonesia with joint with the Asian Development Bank (ADB) predicted 9.75 million hectares of forest getting fired in Indonesia and keep continue every year. The actual forest fire including wild in the field relatively less because of some areas are not well documented and in remote area or villages. Directorate General of Forest Protection and Nature Conservation mention that wild and forest fire happen most in every year and in the year 2000 to 2002 was recorded up to 2.6 million hectares. Several impact of the forest fire to the environmental such as the accordance of fog, haze, and carbon to the air. The pollution caused by wild and forest fire disturbing of community activities and create the disease to the residences. Hospitals in many areas especially clinic in suburban has flooded with the patients with Acute Respiratory Tract Infection (ARTI). While older people and children with physical endurance is fragile having difficult to breathe the air due to smoke and haze.

The forest fire disaster impacted the human and economic losses because many activities are limited to the haze and fog spreading to the air. Students in the school highly risk to their health and respiratory. Other disadvantages are ecological losses that include a reduction in the forest area's size, reduction of clear air produced by vegetable and forest, and the loss of forest as the function of water disruption and regulator and to prevent erosion for the land. There are several dangerous impacts of wild and forest fire to the environmental and community. First, many people get acute respiratory infections especially school students and elderly people. Second, impact to the economic and social because of many school, shop, office and others sector closed due to unhealthy air the limited activity in outdoor. Third, losses either material and immaterial to the community, interrupted of economic and transportation give major impact to the community even pollution and haze going to the transboundary (crossboundary) to the neighboring region of countries for example Malaysia, Singapore, Brunei Darussalam and Thailand. All those impacts are only some examples of the major issue due to wild and forest fire to the communities, the detail impact in actual field in community is more than that with disturbing activities.

Table 1 shows wild and forest fire data in Indonesia from the year 2014 to 2019 based on area and size of the fire incident in hectare. The data among 34 of provinces in Indonesia, while Riau Province which is the location research have been conducted is one of the high numbers are getting fire in every year since year 2014 to 2019 data. The main reason of Riau Province very often getting wild and forest fire is due to the environmental and typical of the soil which is peat land that very high risk get fire when dry season.

The motivation for this research is to identify the exact carbon concentration on the sky with a complex particle. Carbon

concertation in the air most commonly caused by fire or other types of pollution such as transportation, factory, and forest fire. High number of carbon particles in the air makes high concentration of carbon that normally measured in parts per million (ppm). The current sensing system only detects the carbon status without detail particular concentration, then the authority or representative department has difficulties finding the correct solution and preventive action. By identifying the exact cause and source of the haze, the correct countermeasure can be done correctly. There are many sources of the smoke and haze polluting the air, such as pollution by the vehicle in the heavy traffic in land transportation, the carbon emitted from the industry, smoke from the burning of rubbish or waste in the community villages, and fog or haze spreading by land or forest fire that one of the main issues currently in the global. In the tropical region which commonly only have two seasons which are raining and dry season (summer), while in the dry season with hot environment that become one of most caused forest fire and air pollution by high carbon emits from the fire. The results are expected to identify and differentiate types of smoke and haze caused by which sources mention early, then proper action in the correct way to overcome the fire issues.

2. Related works

Some studies have been conducted in the previous for forest fire detection. However, most of them identify the size and detection of how the smoke potentially becomes the fire and spreading estimation. Mathematical modeling is used for the investigation of the size of smoke emitted from fire and prediction of the smoke spreading vertically and horizontally with the remote observation [1–3]. The antenna sends the signal using a microwave noise-adding radiometer to detect fire in the forest and environmental pollution. Then, with a low-noise block received, the signal reflected from the presence of fire, the bigger size of the smoke or fire. Then, a more significant signal will be received [4–6]. The study of forest burnt and assessment using geospatial technology to detect forest fire, especially during the summer season as reported in [7–9] the mapping and monitoring used satellite imaginary to get the data and analyze where the place got the hotspot and get the fire. Geographic Information System (GIS) identifies the area with a high probability of getting fire based on images analysis and models the area using a mapping plan to monitor any changes to prevent forest fire.

Detection of forest fire using Artificial Neural Network (ANN) based on imaginary satellite technique from remote sensing to identify the smoke spreading as discussed in [10] imaginaries captured by NOAA satellite with the Advanced Very High-Resolution Radiometer (AVHRR) analysis with a multi-threshold algorithm to get accurate results of the smoke spreading. A Convolutional Neural Network (CNN) is reported in [11,12] to achieve excellent and accurate results for the forest fire smoke spreading based on the CNN model. The model required an additional backbone network to identify fire smoke and extracted it precisely. Artificial Neural Network (ANN) is applied for smoke spreading detection in wildfire [13]. Computer vision technology detects smoke, heat, flame, and smoke spread. Then, the data analysis determines the potential of fire getting worst. Study on the changing of the soil conditions and direct altering used Arbuscular Mycor-

Table 1 Wild and Forest Fire Data in Indonesia from Year 2014 to 2019.

No	Province	2014	2015	2016	2017	2018	2019	Total (ha)
1	Aceh	155.66	913.27	9,158.45	3,865.16	1,284.70	141.78	15519.02
2	Bali	30	373.46	–	370.8	206.54	–	980.8
3	Bangka Belitung	–	19,770.81	–	–	2,055.67	–	21826.48
4	Banten	2	250.02	–	–	–	–	252.02
5	Bengkulu	5.25	931.76	1,000.39	131.04	8.82	1.47	2078.73
6	DKI Jakarta	–	–	–	–	–	–	0
7	Gorontalo	–	5,225.89	737.91	–	158.65	27.7	6150.15
8	Jambi	3,470.61	115,634.34	8,281.25	109.17	1,390.90	4.18	128890.45
9	Jawa Barat	552.69	2,886.03	–	648.11	4,104.51	–	8191.34
10	Jawa Tengah	159.76	2,471.70	–	6,028.48	331.67	–	8991.61
11	Jawa Timur	4,975.32	7.966,79	–	5.116,43	7.279,76	–	4975.32
12	Kalimantan Barat	3.556,10	93,515.80	9,174.19	7,467.33	68,311.06	2,273.97	180742.35
13	Kalimantan Selatan	341	196,516.77	2,331.96	8,290.34	98,637.99	52.53	306170.59
14	Kalimantan Tengah	4.022,85	583.833,44	6.148,42	1.743,82	41.521,31	27,00	0
15	Kalimantan Timur	325.19	69,352.96	43,136.78	676.38	26,605.57	5,153.07	145249.95
16	Kalimantan Utara	–	14,506.20	2,107.21	82.22	625.82	792.11	18113.56
17	Kepulauan Riau	–	–	67.36	19.61	320.96	4,969.85	5377.78
18	Lampung	22.8	71,926.49	3,201.24	6,177.79	14,963.87	–	95692.19
19	Maluku	179,83	43,281.45	7,834.54	3,918.12	14,131.33	180.03	69345.47
20	Maluku Utara	6.5	13,261.10	103.1	31.1	69.54	56.79	13528.13
21	Nusa Tenggara Barat	3.977,55	2.565,71	706,07	33.120,81	14.352,26	29,10	0
22	Nusa Tenggara Timur	980.87	85,430.86	8,968.09	38,326.09	55,207.64	99.13	189012.68
23	Papua	300	350,005.30	186,571.60	28,767.38	87,676.88	–	653321.16
24	Papua Barat	–	7,964.41	542.09	1,156.03	120.63	58.36	9841.52
25	**Riau**	**6,301.10**	**183,808.59**	**85,219.51**	**6,866.09**	**37,220.74**	**27,683.47**	**347099.5**
26	Sulawesi Barat	–	4,989.38	4,133.98	188.13	978.38	56.77	10346.64
27	Sulawesi Selatan	483.1	10,074.32	438.4	1,035.51	1,741.27	441.07	14213.67
28	Sulawesi Tengah	70.73	31,679.88	11,744.40	1,310.19	3,890.95	215.92	48912.07
29	Sulawesi Tenggara	2,410.86	31,763.54	72.42	3,313.68	8,121.35	16.42	45698.27
30	Sulawesi Utara	236,06	4.861,31	2.240,47	103,04	125,07	9,98	0
31	Sumatera Barat	120.5	3,940.14	2,629.82	2,227.43	2,421.90	60.68	11400.47
32	Sumatera Selatan	8,504.86	646,298.80	8,874.91	3,625.66	13,019.68	236.49	680470.4
33	Sumatera Utara	3,219.90	6,010.92	33,028.62	767.98	3,678.79	152.55	46858.76
34	Yogyakarta	0.27	–	–	–	–	–	0.27
Total (ha)		**32,438.97**	**2,012,184.19**	**429,268.22**	**125,399.82**	**447,285.81**	**42,674.34**	**3,089,251.35**

rhizal (AM) is a method to determine the potential of fire in a land. The viability of the function AM in the burnt area of soil then compare to the previous normal condition to determine the root of the most frequent burnt area [14,15]. A new method to approach and detect a smoke event in forest fire used a Variational Autoencoder and Neural Decision, as discussed in [16–18]. This method gives good advantages to detect smoke by combining a Variational Autoencoder with a random forest to classify the collected data into smoking and nonsmoking after data preprocessing.

The forest fire modeling used a sensor network for mapping the smoke spreading based on ground sensor installed [19], the mapping and modeling applications in one location or area with high potential to become forest fire and smoke or haze spreading to the city and community villages. Analysis of potential fire risk used of sink data reported in [20–21] is how to do a prediction of fire will happen. El Nino season effect related to the unpredicted season and risk of forest fire in the tropical area is a solution to forecast the forest fire [22], based on NASA satellite imaginaries, then analyze the season's changing Indonesia territory for the potential of the forest fire. The investigation of statistical relation between dynamics in fire events then compare to the landscape, climate change variable, and socioeconomic in Portugal to predict the potential of fire in the summer season as reported in [23–24]. The use of machine learning to predict wildfire is one of the methods used [25]. The approach is from a video recorded in the event of a forest fire. Then analysis uses Deep Belief Network and Boltzman machine technique to determine and extract and classify the smoke simultaneously.

Spatial distribution analysis to determine forest fire, as discussed in [26], gives a good response in the analysis of a significant amount of data. The data analyzed is in the long for the year 1969 to 2013 with the four-season area. Relationship between Moderate Resolution Imaging Spectroradiometer (MODIS) data and effect of climate change and global warming, as discussed in [27], the data analyzed during the year 2001 to 2017, where the increasing number of fire hotspot based on increasing of temperature because of global warming. The effect of vegetation on the surface temperature and global warming, as reported in [28–30], as the vegetable's growth cycle can lower the temperature and clean the air pollution because vegetables absorbed the carbon. Study and simulation on the time and quantity vegetable to be absorption the air pollution and haze reported. The influence of forest fire particles on the air and how many quantities per square meter, as

studied by the [31–33], development model and theoretical analysis of the particle characteristic spread to the air based on the types of the fires was studied. The use of the Internet of Things (IoT) for the detection of forest fire then analyzed the data according to the sensor detected the hotspot, as discussed in [34,35]. Modeling of the Wireless Sensor Network (WSN) for detection of number fire hotspot on the area of forest calculates to get forecasting data the impact of the hot sun in the summer [36], the use of technology including Long Range Sensor (LoRa) to get large coverage area detection. Simulating and forecasting the discharge of number particles discharge from the satellite data, especially for the remote area to get the data [37], the study of the correlation data to the measurement and number of discharges using a combination of data classification and outlier detection procedures. All those methods discussed above mostly mention and elaborate on how to detect and analyze the carbon and data to determine how much the impact. Thus, this research aims to elaborate in detail that assists in determining the carbon concentration source from the forest fire.

An attractive and reliable technique of analysis is implementing for construct a numerical solution for the fractional Lienard's model as enclosed with suitable nonhomogeneous initial conditions, often design to demonstrate the behavior of weakly nonlinear waves arising in the oscillating circuit. The fractional derivative considered in the Atangana-Baleanu-Caputo senses. The technique is namely, reproducing kernel Hilbert space method, optimization of numerical solutions bending on Fourier approximation theorem to generate a required fractional solution with a rapidly convergent form [38]. While, an Atangana-Baleanu fractional method for fathoming the Van der Pol damping model by using the reproducing kernel algorithm. The mathematical structure model of this new approach and some others numerical properties of solution. Furthermore, all need requirement for characterizing solution by apply the reproducing kernel algorithm as debated. In the orientation, modern trend and new computational algorithm in term of analytic and approximate of Atangana-Baleanu fractional solution applied in this model of identification forest fire carbon concentration [39].

3. Fire carbon spreading model

The spreading of a fire in a forest or wild can be calculate based on model and mathematical analysis, for example the energy of radiant from source of fire at the height of h from level surface of earth and at the started initial moment as shows in the Fig. 1. While R_0 is the distance from central fire source that create the radiation to cover of vegetation, h is the height of massif fire level at the source surface, 0 is epicenter of the center source of fire to decant coordinate at the surface area. The upper boundary of vertical $z = h$ of the massif fire of forest is act when an intensive of flux radiant $q_R(r, t)$, that can be determine at the flight stage according to the literature in in [40,41].

$$q_R(r,t) = \frac{t_p I Sin L}{4\pi R_0^2}, \quad I = 0.5 C_H \rho V^2 S_m \qquad (1)$$

while V, I and S_m are the velocity, brightness and midship sectional of square the Tunguska fireball, L is the angle between radiative of heat to the flux and cover of vegetation, C_H is the
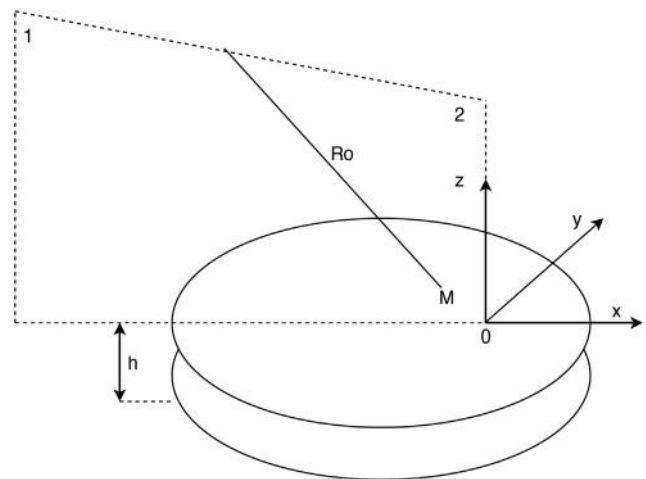

Fig. 1 Model of fire spreading and distance of impact area.

energy of kinetic fraction transform into radiation surface; ρ is the density of atmosphere at a height of H. Once the explosion of body of celestial (at the moment t = t_1) the flux of light is defined refer to the data as in [40].

$$q_R(r,t) = \frac{t_p P_m Sin L}{4\pi R_0^2} \begin{cases} \frac{t-t_1}{t_m}, t < t_m \\ \exp\left(-k_0\left(\frac{t-t_1}{t_m}\right)-1\right), t \geq t_m \end{cases} \qquad (2)$$

$$t_m = t_1 + 0.032 W_0^{0.5}, \quad P_m = 1.33 W_0^{0.5} \qquad (3)$$

R_0 is the radius distance from the center of source forest fire radiation; t_p is the coefficient of atmospheric transmissivity in the air; kT/sec, P_m is the number of maximum value of radiative impulse of heat at the moment $t = t_m$; W_0 is the weapon yield, kT/sec; k_0 is the coefficient of empirical. Fig. 2 shows the surface fuel of the forest fire versus percentage of moisture in various type of forest such as grassland to the forest with the highly of forest or trees. Typical of forest is determine the speed of fire spreading as well as according to the type of trees and grass on the surface of land. Forest with consist of trees is the high of fuel consumption and suddenly going down
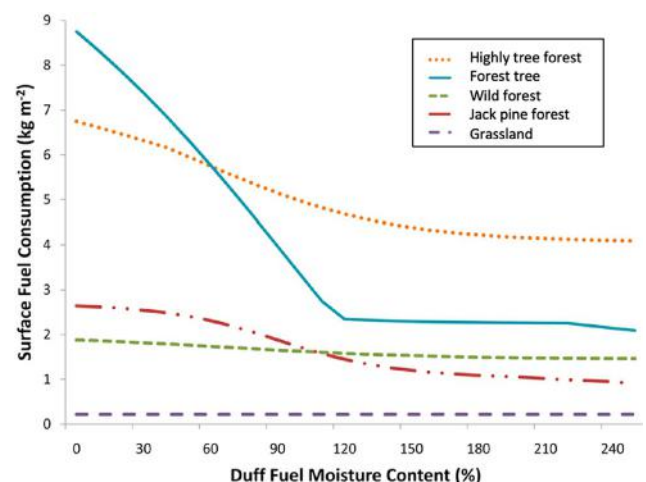

Fig. 2 Fire moisture in various types of the forest to estimate the spreading.

to the half of the way to become flat. While grassland is the lower fuel consumption with the stable and flat since started to the end of the graph.

4. Carbon dioxide sensing system

Carbon dioxide (CO_2) is one of the standard materials or gas on the earth's atmosphere. A significant concentration in the air then contributes to pollution and change in the climate. CO_2 can make the climate become warming and change the ecological system. The source of the CO_2 comes from various sources such as transportation, fire (forest fire), human population, etc. CO_2 is one of the essential factors to determine air quality, with the high concentration of the carbon in the air then gives a harmful effect to the human because difficult to breathe. Information on the CO_2 in the air is essential to know how clean the air in the area. There are several techniques to measure CO_2 concentration or air quality, and one of them is installing a sensor to detect the number of CO_2 particles in time. A nondispersive infrared (NDIR) sensor is one of the most commonly used sensors for detecting CO_2 particles. Using an infrared system, a small particle can detect and determine the concentration. To calculate the concentration of CO_2 in an area (room) can be calculated by the formula (4) as below [42].

$$C(t) = \frac{G}{aV}(1 - e^{-at}) + C_t \qquad (4)$$

where:

C(t) : concentration (ppm) at time t (h)
GCO_2 : generation rate (mL/h) introduced at t = 0
a : air exchange rate (h^{-1})
V : area (room) volume (m^3)
C_t : concentration in the replacement air (ppm(v))

The analysis based on the time interval during measurement by the sensor to determine the CO_2 concentration, typically from the starting to the steady of measurement according to the tick of the carbon in the air. The relative performance of the carbon NDIR sensor can be calculated as formula (5), Relative Standard Error (RSE) in % computed from all the sensors.

$$RSE = \frac{SE}{Mean} x100 \qquad (5)$$

where:

$$SE = \frac{SD}{\sqrt{N}}$$

In the real environmental, air pollution caused by CO_2 comes many possibilities of sources thus differentiate of source CO_2 is important to classify come from which sources either transportation or fire as well the fire need to specify from the forest or other fires. This research discusses the analytical of source CO_2 by using NDIR sensors to measure carbon concentrate as well as to identify other parameters related to the CO_2.

4.1. Sensing system

Measurement and sensing of the air's carbon concentration can be applied by installing sensors to detect the particles' quantity. In this research, several sensors are used to achieve better results. The sensors are temperature, humidity, carbon, and haze, or fog. Signal received from the sensors forwarded to the processing controller to do signal condition and cut off the noise. The microcontroller unit received signal analyzed using the algorithm to achieve the final results of the carbon concentration and other support parameters related to the CO_2. A wireless system is used to transfer and send data to the computer as the back-end system to display the final data. Fig. 3 shows a block diagram of a carbon detection system using an NDIR sensor to detect carbon concentration in the air. The system's design added with additional sensors, temperature, and humidity, to get related parameters affected the carbon concentration based on the fire sources. The microcontroller unit in this system used Arduino as the controller to analyze the data received from all the sensors, with the mini processor inside the Arduino be able to run an algorithm programmed in the chip. A radio unit in the Radio Frequency part uses to transfer the data wirelessly. This technique expected no restriction in the distance to place the sensor at the strategic location to detect carbon concentration. A display system is set up in the back-end system to visualize the sensors' results or data. With this data, it is possible to compare all the fire source to the carbon or CO_2 concentration. The system designed can be standalone and working in a remote area, provided self-power supply from the solar system, then the sensor system not depending on the fixed power utility. Furthermore, the system designed compact that suitable for a mobile application, and data transfer can be used with cellular data communication such as 4G network or point-to-point radio communication for rural or remote areas.

4.2. NDIR sensor

Nondispersive Infrared (NDIR) is a sensor system that is mostly used to do a measurement of the carbon concentration. The detection concept is based on the InfraRed (IR) signal sent to a medium, a tube. Then the light goes through inside the tube, filled with an optical sensor as a detector of carbon particles. The IR sensor can detect the small size of carbon particles in micron based on infrared light wavelength. Fig. 4 shows a model of how a sensor detects carbon particles. The tube completes with an inlet and outlet of the gas to let carbon particles pass through the medium. Then, the sensor detects the number of particles inside the medium, as shown in Fig. 4 (a). The optical detector at the end of the tube with a gap of optical filter can absorb light wavelength size in 4.26 μm, as
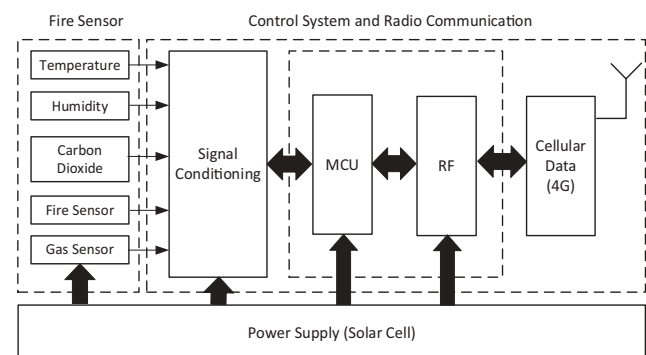

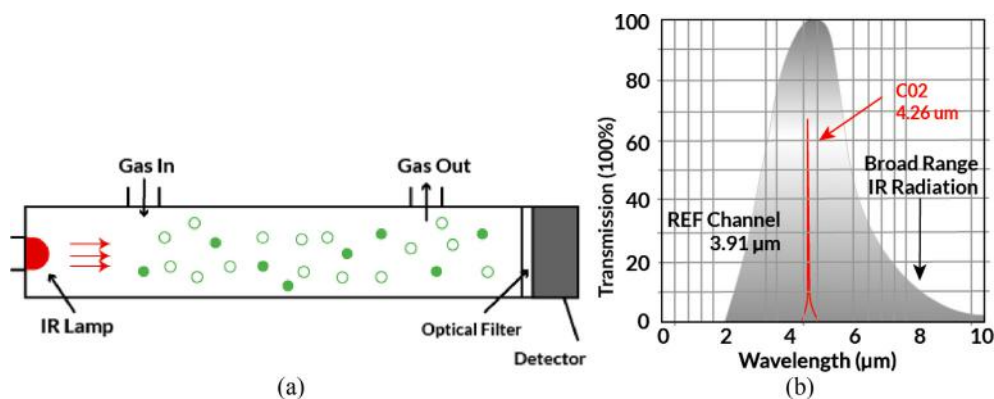**Fig. 3** Block diagram of carbon detection using NDIR sensor.

Fig. 4 NDIR sensor for CO_2 detection (a) sensor tube with detector (b) graph of the detection at 4.26 μm [43]

shown in the graph in Fig. 4(b). The detection up to 70% of the light transmission to detect the carbon particles, while the infrared wavelength range was effectively covered from 2 to 8 μm, as shown in the graph in Fig. 4(b).

The NDIR sensor's principle to measure the carbon particle is by calculating the difference of the source light from IR to the light received by the detector. The difference results of the light absorbed by the detector compared to the source proportional to the sample tube's carbon concentration. The sensor then detected the number of carbon particles inside the tube flowing from the inlet to the outlet through light flowing in the tube. The output signal from a sensor, an analog voltage range from 4 to 20 mA, is connected to the Arduino microcontroller equipped with Analogue to Digital Converter (ADC) to convert the data into digital. The digital data received by the processor analyzing to achieve the actual quantity of the carbon detected by the sensor.

4.3. Various sources of carbon

The carbon in the air, as mention in early, is the most common material of particles, especially in the polluted air. The carbon comes from various sources such as vehicle exhaust, factory emission, fire from the rubbish, or fire from the land or forest. One of the most common lands in the tropical region is with forest. In the summer or dry season, it is easy to get fire. Forest fire in Indonesia, especially in Riau Province, is one of the main issues that happens almost every year in the summer season. There is preventive action to reduce or overcome the disaster, but sometimes fire gets by itself because of the typical land and soil. Fig. 5(a) shows how the forest fire emitting the carbon into the air and get polluted. Air pollution from vehicle emission is another issue in Indonesia because some vehicles emitted with dirty carbon and get polluted, and traffic jams contribute more carbon. Every year the increasing number of vehicles very significant, then traffic in the city gets jams, and more pollution is caused by transportation. Fig. 5(b) shows vehicles emitting the carbon from the exhaust. Then, the air gets polluted. Some of the countries and region dispose of the housing garbage by firing. This method impacts air pollution and contributes carbon to the air. Fig. 5(c) shows that garbage gets firing to do clearance and contribute carbon to the air. The factory is one of the sources that make air pollution from the processing. Conventional processing emits dirty

smoke containing carbon. Fig. 5(d) shows a factory emitting black smoke with a high carbon concentration then polluting the fresh air.
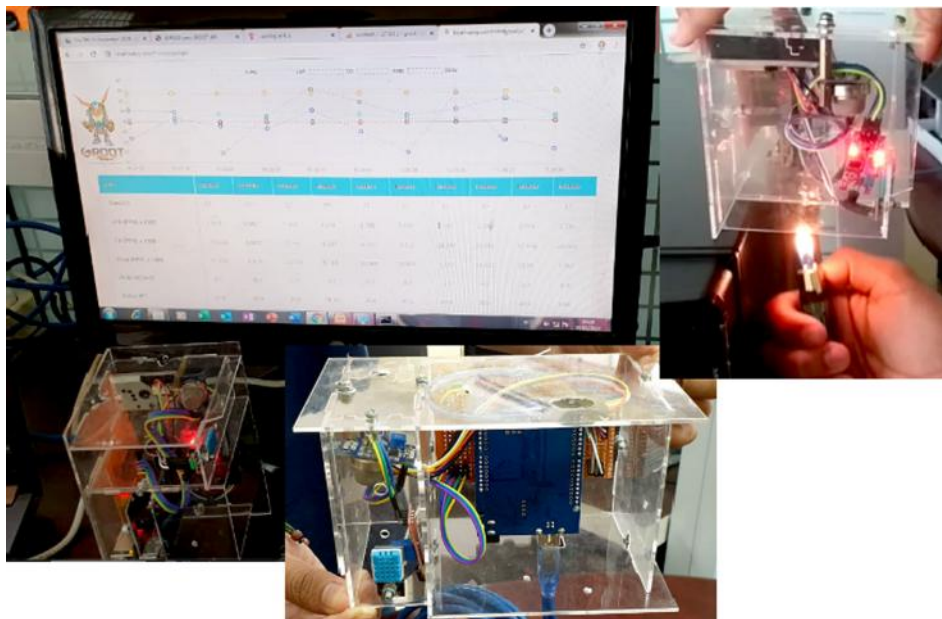
4.4. Measurement setup

The experiment and measurement of the air's carbon concentration based on the various sources have been set up to get the results. Carbon sensor used as the primary sensor to detect carbon concentration, while additional sensors related to the fire installed to achieve high accuracy of detected data. The additional sensors used, such as temperature and humidity of the air that high related to the fire, besides that gas sensor representative of smoke and haze in the air, and fire sensor to detect and indicate the fire's occurrence. Fig. 6 shows a complete setup system with a computer to display the results; several sensors installed and connected to the microcontroller and get the sensing data to analyze how much carbon concentration in the air refers to the fire scenarios, as mention in the previous section. In the actual measurement, the sensing system is placed near or around the fire area sources to detect a representative, actual polluted environment better. In this case, the carbon concentration measurement has been done for as long as 60 min to get representative values in several fire scenarios. Data detected from all the sensors analyzed and compared the relationship used an algorithm, then high accuracy results achieved. Final results logged into computer memory for the record, then a graph is drawn for better display and easy to see the fluctuate.

Fig. 7 shows a detail of schematic diagram sensor system for detection fire carbon parameters, 4 types of sensors used in this system which are fire, carbon dioxide, gas, temperature, and humidity sensor. All the sensors connected to the Main Control Unit (MCU), in this case Arduino Uni R3 used as controller to collect all the information detected by sensors. Filtering and pre-analysis of data have been done in the microcontroller such as to delete noise data and arrange used data before sending to database at the backend system. A Global System for Mobile Communication (GSM) modem were used as communication module from MCU to database at the remote location to transfer collected usable data for final analysis and presentation.

Fig. 5 Carbon polluting air sources (a) forest fire contribute carbon (b) air pollution from vehicle (c) smoke and carbon from fire of the rubbish (d) dark smoke with carbon emit from factory.


Fig. 6 Experiment setup during measurement and identification of carbon dioxide concentration.

5. Result and discussion

Measurement of carbon concentration has been done for various scenarios, as mention in early. The results were achieved based on testing according to the case scenario. Fig. 8 shows how the graph for every scenario drawn that the first scenarios, in which forest fire contributes the highest carbon concentration for a case of fire. While the other scenarios in which vehicle pollution, a garbage fire, and factory emission contribute similar carbon concentration, for the garbage fire, the graph
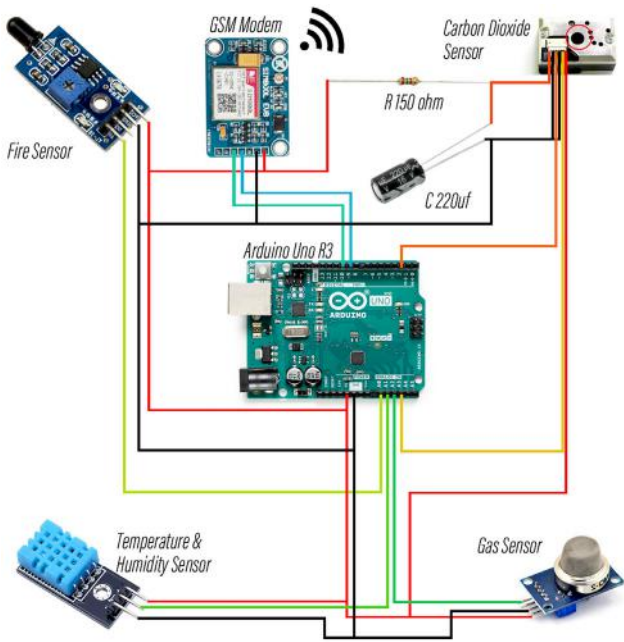
Fig. 7 Schematic diagram of sensor system for fire and carbon pollution detection.

keeping increase since start measurement. The fire scenarios are measured for the case on a small scale for the testing with fire coverage about 100 square meters, and the distance to the sensor is about 20 m. A sensor installed and set up around the fire simulated then measure the carbon concentration in the air by record the reading. NDIR sensor senses the number of particles going into the infrared tube and calculated estimation number of particles going through the hole then record the results. Besides that, carbon particles from the forest fire bigger in size than the others fire, followed by the second large is garbage particle when getting firing. While factory carbon and vehicle emit from the exhausts small is the size of the particles. The testing and measurement were done quickly, which is only

60 min to compare and find the typical carbon concentration from a fire, especially for the forest fire, which almost happens in a tropical region. The data give a good idea to identify and carbon concentration and the typical size of the carbon (particles flying in the air) for analysis and determine the fire's cause.

The second setup and measurement are to compare the fire effect to the temperature and analysis of how much impact of temperature to a fire. Every case of fire will contribute heat to the environment or air. On average normal heat increasing in these testing scenarios is 2–3 degrees. Fig. 9 shows a graph plotted by measurement results for the temperature in every case of fires. In the first case, forest fire contributes to high temperature and heat to the environment, which is up to 41 degrees Celsius. Other scenarios are average, and the temperature is mostly in maintaining value, which is 30 to 35 degrees Celsius. Similar to the carbon contribution, the garbage fire temperature graph keeps increase from the stated measurement to the end of the graph. The time is the same as carbon measurement, which is 60 min to compare carbon and temperature. The actual environmental temperature during the testing actual at 30 to 32 degrees Celsius, and fire contributes to increasing the environmental temperature. The temperature measurement used a particular sensor installed together with the carbon sensor in the system then recorded simultaneously for both parameters. Data in the graph as Figs. 8 and 9 obtained from the sensor system, the results of detection of data logged into a file which is text stored in the system memory then once connection establish, all the data transferring to database at the backend system. Initial plan to present all the results is to use plotting software to draw the graphic but the presentation is not informative then change to normal common software to plot the graphs and the source of data from the sensor system.

The results were achieved for both parameters, carbon concentration and environmental temperature, based on measurement with a similar procedure for all the scenarios of fires. A sensing system setup for detecting the environmental effect emits from the fire, the sensors such as carbon dioxide (particle), air temperature, humidity, and gas (smoke or haze). All
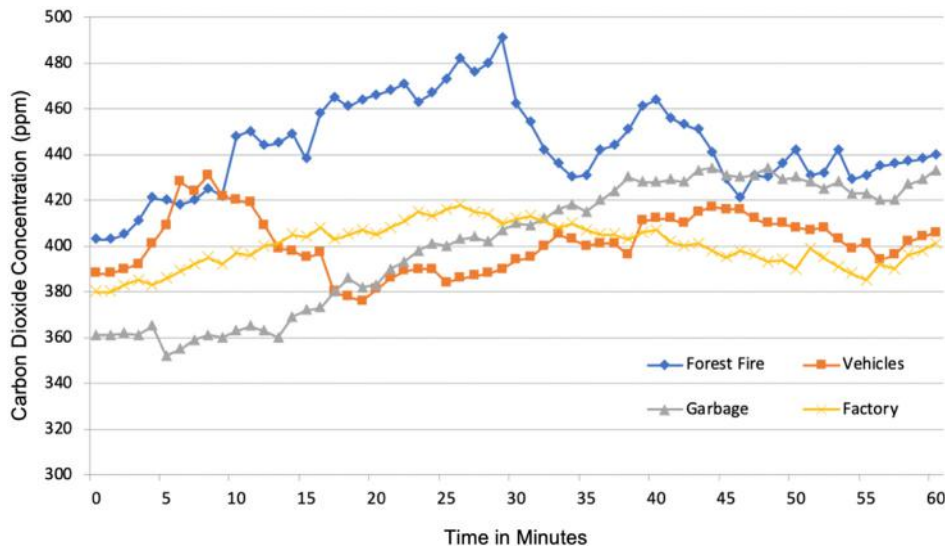
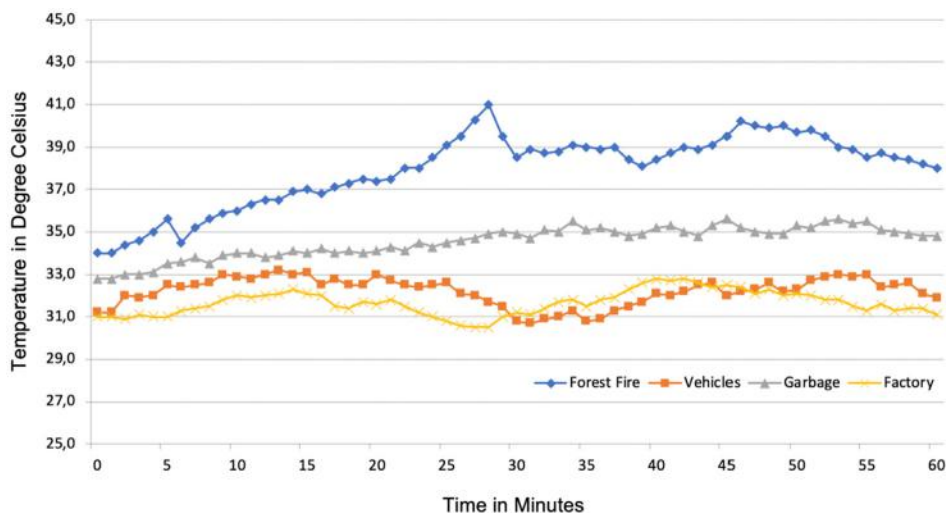**Fig. 8** Results of carbon concentration measurement for 4 scenarios.

Fig. 9   Results of temperature measurement for testing in 4 scenarios.

the parameter data from the sensors logged to the system with timing every 5 s, but the display shows that the data timing is minute (60 s). The final value shows are based on average data within the current minute logged. According to the four environmental parameters detected, the two most significant parameters impact the change while fire happens. The other two parameters are not significantly changing. In contrast, fire or sensors detect the fire in all scenarios. Anyhow the value is changing but not impactful. Thus, in the report, only two parameters are shown and discussed, carbon dioxide concentration and environmental temperature. Carbon particles emitted from forest fires are more in number and big because the forest's material with fast fire contributes more carbon, and the environment temperature changes while fire happens. This is because fire emits the heat according to the size and how big the firing area or material getting firing. Both of graphics representing how the pollution spread in the air that consist of polluted material such as carbon, haze, dust, and others dangerous particle for human life and environmental. Forest fire is top high values in both of graphs which temperature has direct impact to the forest fire and carbon concentration which main sources of air pollution. Effect of environmental in tropical region is one of factor contribute to the cause of forest fire and air pollution with thick concentration of carbon. Among four types of pollution sources, factory is one of the lower impacts to the air and environmental because a good factory has good waste management.

6. Conclusion

Detection and identification of the carbon emitted from a fire depend on the fire's material or region (forest fire) in the tropical region with a specific type of forest (trees). The soil gives more carbon and particles emits into the air. The sensing system is designed to detect how much carbon and particles emitted from fire and differentiate based on the type of fire and source of carbon emitted to air. Measurement results show that carbon concentration from forest fire gives more in quantity and particles bigger than other scenarios. Besides, the quantity of the carbon emitted from the forest fire fluctuates

according to the area's size getting fire and quantities of the trees. The fluctuation of the carbon detected depends on how fast the wind blowing into the direction. It is usual with the normal condition of wind blowing to the forest fire, then carbon detected in the average number. While if wind blowing in fast, then the detection of carbon suddenly with a significant number followed by the significant reducing number of carbons detected. The other scenarios, which are carbon from vehicles (transportation), garbage, and factory are detected the carbon but in average number. Garbage fire emits more carbon when starting the firing than when the material reduces and getting the finish, and the carbon emission reduces until the fire is stopped. All the scenarios tested and measured in the different areas according to the best location to do a measurement, but the procedure is the same to meet accurate data.

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