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Prototype of Forest and Land Fire Monitoring and Detection System Using IoT-Based WSN Technology

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Abstract: Forest and land fires are a recurrent issue in several Indonesian regions, necessitating advanced technological solutions for early detection and monitoring due to their significant impact. This research project focuses on developing a prototype system utilizing IoT-based Wireless Sensor Network (WSN) technology to detect forest and land fires. The prototype offers real-time remote monitoring of temperature, humidity, smoke levels, and wind speed in the forest through an Android app or web interface. To validate its performance, the prototype was compared to existing BMKG tools, with results showing minor temperature errors (2.41%) and a humidity error of 17.68%. The anemometer sensor exhibited a slight 4-second data transmission delay. Importantly, the prototype excelled in fire detection, effectively identifying temperature and humidity changes within a 2-meter radius or more indicative of fire outbreaks. This pioneering prototype promises to significantly enhance early warning and response mechanisms for forest and land fires in Indonesia, contributing to more effective environmental conservation and disaster management.

Keywords: anemometer sensor; DHT22 sensor; forest fire detection; IoT; MQ-2 sensor; NodeMCU

Introduction

Indonesia is one of the largest archipelagic countries in the world, consisting of thousands of large and small islands. Indonesia is also known as a country that has vast forests, so the world community knows Indonesia as the lungs of the world (Badan Informasi Geospasial, 2019). Forest and land fires are no longer a foreign phenomenon in some parts of Indonesia, especially Sumatra and Kalimantan (Rachman et al., 2020). Eight provinces in Sumatra and Kalimantan that are designated as areas prone to forest and land fires are Riau, Jambi, South Sumatra, Lampung, West Kalimantan, Central Kalimantan, East Kalimantan, and South Kalimantan. These eight provinces are at the center of forest and land fire hazard mitigation (PSDAL, 2009).

Forest fires are mostly caused by human negligence, such as activities to clear land for farming, gardening, preparing land for cattle, and so on by setting fire to forests (Danny, 2001). Climatic factors such as temperature, humidity, wind, and rainfall also determine the vulnerability of fires (Rasyid, 2014). Air temperature is one of the factors that can cause forest fires (Chandler et al., 1983). Constant air temperature affects the ease of a forest catchfire (Young & Giese, 1991). Fires will easily start during the day with a relative humidity of 70-80% and low moisture content (<30%), which will make the burning process go fast (Saharjo, 1997). Wind is one of the important factors that affect forest fires. The wind helps the drying process so that the water content in the air evaporates easily. Wind also promotes and enhances combustion by continuously supplying air and increasing propagation through the slope of the flame, which continues to spread to the unburned portion of the fuel (Chandler et al., 1983). Rainfall is a climate element that highly correlates with forest and land fires. During the dry season, rainfall tends to be low, causing the air condition

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around the area to dry so that the forest is more easily burned (Pandapotan et al., 2022).

Forest fires in Indonesia are seen as a global, regional disaster caused by the impact of forest fires felt by neighboring countries. The impact caused by forest and land fires is so significant that a technological system is needed to monitor and detect forest fires as early as possible. There are several techniques to detect forest fires. Radio acoustic sounding has been proposed to infer the meteorological flow or temperature profiles in forest areas (Sahin & Ince, 2009). Nevertheless, it lacks resolution, it is expensive (radars and acoustics sources required), and it is susceptible to interferences, such as wind direction changes.

There are systems based on satellite imagery (Nakau et al., 2006), but they are not used in real-time applications due to their long scanning time cycles, poor resolution, and cost. Other systems based on short-range images have been proposed, using optical, infrared, or thermal images. However, these approaches are very outlier sensitive: direct and intense sunlight, insufficient light, or smoke. They are also very false alarm-prone (Molina-Pico et al., 2016). The use of WSN technology in detecting forest fires is the best technique so far because besides being able to detect forest fires in real time, it can also monitor environmental conditions such as temperature conditions, humidity, smoke concentration, and others (Alkhatib, 2014).

A Wireless Sensor Network is an autonomous device explicitly distributed using internal sensors to monitor physical or environmental conditions, such as temperature, humidity, sound, vibration, pressure, movement at a different location, etc (Martinović & Simon, 2014). Monitoring environmental conditions using WSN is an application with excellent potential for people's lives, especially Indonesian people. Indonesia is a disaster-prone region that has a high level of disaster vulnerability. Therefore, it is necessary to provide early warnings related to information on environmental conditions so that it can respond appropriately to potential disasters that occur (Handayani & Pujiana, 2017).

WSN can use Internet of Things (IoT) technology, which aims to expand the benefits of continuously connected internet connectivity. According to Arafat (2016), the Internet of Things (IoT) is a concept that aims to expand the benefits of continuously connected internet connectivity, which allows machines, equipment, and other physical objects to be connected to network sensors to obtain data and manage their performance. IoT devices consist of sensors as a data collection medium, an internet connection as a communication medium, and a server as a collector of information the sensors receive for analysis.

Several studies have been carried out using sensor systems to detect forest fires remotely from a distance, as has been done by several investigators (Sasmoko & Mahendra, 2017; Kurniawan et al., 2018; Rahmad et al., 2021). Their research only focused on detecting the presence or absence of fires occurring in the forest but did not try to use a sensor system created to monitor the climatic conditions of the forest environment, which included temperature, humidity, smoke concentration, and wind. Wind is one of the influences of climate factors on forest fires. So, it is necessary to add a sensor that can detect wind speed.

Based on the problems described previously, A forest and land fire monitoring and detection prototype system has been created using WSN technology utilizing the Internet of Things (IoT) platform for sending data signals and displaying them via the Internet. The prototype that has been developed can perform the function of monitoring the weather conditions of the forest and land environment, such as temperature, humidity, smoke concentration, and wind speed, in real-time, which can be monitored via an Android cellphone or a web page.

Method

Prototype System Design

The sensor system prototype is designed using several sensors, namely, the DHT22 sensor, which can monitor and measure temperature and humidity values; an anemometer sensor, which can measure wind speed; and the MQ-2 smoke sensor, which can detect and measure smoke concentration. This prototype uses a 9v battery as a power supply. Arduino and NodeMCU ESP8266 are used as microcontrollers for processing data from sensors and as a medium directly communicating with the internet. The results of all data from sensors that have been processed are sent to the internet. The schematic diagram of the prototype system can be seen in Figure 1.

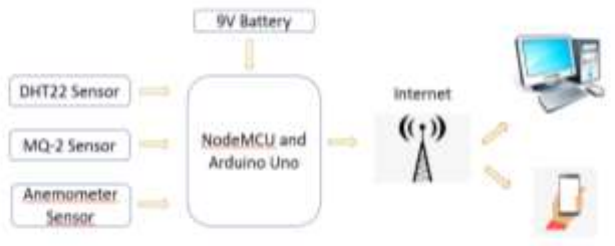

Figure 1. Schematic diagram of the prototype system

The sensor output display is set so that it can appear via the internet online on a PC and also on a smartphone by utilizing the IoT platform. The IoT platform used in this research is the Blynk application. The Blynk application is an application platform that can be downloaded for free for iOS and Android, which functions to control Arduino, Raspberry Pi, and the like via the internet. Blynk is designed for IoT to control hardware remotely, display sensor data, store data, visuals, and many other things. The Blynk application can be visited via the website directly by typing https://blynk.io (Supegina & Setiawan, 2017).

The prototype monitoring display can be viewed via a PC or Android cellphone using the Blynk application, as shown in Figure 2. The information displayed includes temperature values in degrees Celsius, humidity values in percent, smoke concentration in ppm, and wind speed values in m/s. When the sensor detects an indication of a fire, the prototype will provide a warning status to the user. The warning notification status will be sent via the internet to the Android cellphone and email. The prototype can provide a fire warning with the following conditions: cautious status will appear if smoke with a value of more than 50 ppm is detected, the alert status will appear if the temperature is detected ≥ 36 °C to < 41 °C and danger status appears if the temperature is detected ≥ 41 °C.

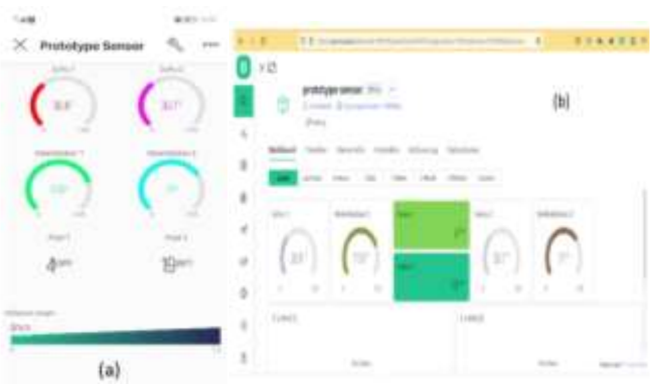

Figure 2. Monitoring display (a) Android cellphone (b) internet website

Prototype Hardware Design

The sensor system prototype was created by combining the DHT22 sensor, MQ-2 sensor, and anemometer sensor on the NodeMCU. The collection of sensors coupled with a microcontroller (NodeMCU) and the power supply itself is called a node sensor. The sensor node is one of the points that will form a wireless sensor network (Hudaya & Putro, 2018). How to install the DHT22 sensor, MQ-2 sensor, and anemometer sensor on the NodeMCU is relatively easy to do, and there are many examples of installation that can be seen online on the internet. Likewise, many Arduino programs to run these sensors can also be seen online. These sensors are assembled and placed in a box, as shown in Figure 3, to protect them from exposure to sunlight and rain.

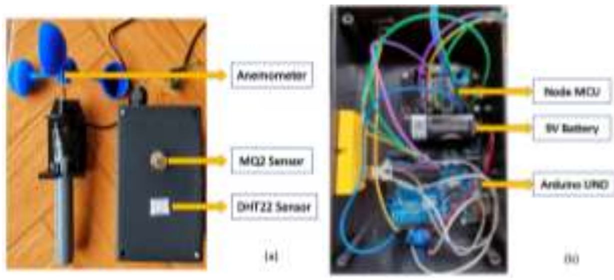

Figure 3. The physical form of the prototype (a) inside view (b) outside view

Sensors and Prototype Testing

Every sensor used in the prototype needs to be characterized and tested before being installed into the prototype. Sensor characterization and testing are carried out to check the sensor reading response capability and also ensure that the sensor output value is following the actual value. Characterization is done by comparing the sensor with a comparison instrument under the same conditions and time. The comparison results are seen from the error value between the sensors and the instrument. The smaller the error value, the more accurate the instrument's measuring value. Accuracy is a measure that shows how close the instrument reading is to the actual value (Santoso, 2017). The system's accuracy can be determined from the percentage error between the actual and visible values (Heidaryan, 2019). The error percentage can be determined by Equation 1 (Guang et al., 1995).

$$Percentage\ Error = \left|\frac{Y_n - X_n}{Y_n}\right| x\ 100\% \quad (1)$$

Y_n is the actual value on the comparison instrument, and X_n is the value read on the prototype sensor. The results of comparing the sensor with a comparison instrument become a reference for whether the sensor is suitable for use in the prototype or not.

Next, the finished prototype needs to be tested to see whether the sensor can work properly. There were two tests carried out on the prototype. The first step is testing the sensor system for its ability to detect forest meteorological conditions, which include temperature, humidity, and wind speed conditions. The test was carried out in conjunction with BMKG's temperature, humidity, and wind speed measuring equipment as a comparison. The prototype was brought and placed at the same point as the BMKG tool, as seen in Figure 4. The data obtained within a particular time is processed, and the results are compared with data originating from the BMKG tool. The data was analyzed to see how the prototype's ability to detect temperature, humidity, and wind speed compares with the tools owned by BMKG.

Figure 4. Installation of prototype sensors at BMKG

Second, testing the sensor system for its ability to detect fires in forests or land. In this test, the prototype is made into two nodes to see whether the two nodes can detect the same thing under the same conditions. Testing of the forest fire detection sensor system prototype was carried out by placing the node close to the fire source, which came from burning wooden twigs and dry leaves. Fires are usually characterized by changes in temperature, humidity, and smoke levels around the environment where the fire occurs. When a fire occurs, the temperature increases rapidly, humidity decreases, and smoke levels also increase rapidly. That is why sensors are needed to be able to detect all these changes (Fraden, 2007).

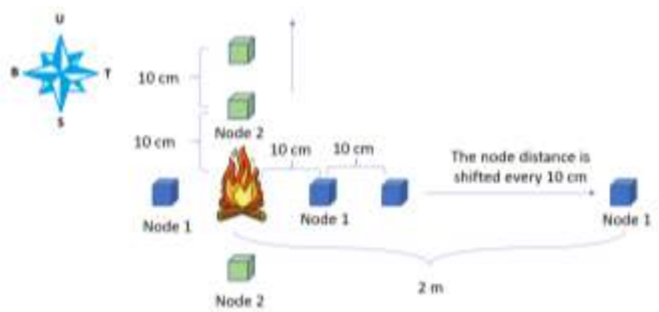

Figure 5. Variation in the distance of node 1 and node 2 to the fire source

The node positions are placed at various distances of 10cm, 20 cm, 30 cm, and so on, up to 240 cm. For each distance variation, data on temperature, humidity, and smoke concentration were recorded. The node position is adjusted in the direction of the cardinal direction. The position of node 1 from the east and node 2 from the north is carried out first. After that, node 1 is used from the west and node 2 from the south. The node's position is set so that it can see the distribution of heat and humidity values around the fire source from various radius distances. Variations in the position of node 1 and node 2 relative to the fire source can be seen in Figure 5.

Result and Discussion

Sensors Characterization and Testing Results

There are three sensors used in the prototype: a DHT22 sensor, an MQ-2 sensor, and an anemometer sensor. The three sensors were characterized and tested by comparing the output values of the sensors with a comparison instrument. DHT-22 sensor compared with digitals thermo-hygrometer. The DHT22 sensor and digital thermo-hygrometer are placed close to each other at a distance of 2 cm. These two instruments are placed close to the gas stove to see changes in temperature and humidity around the gas stove. The sensor output value is seen on the computer via the serial monitor in the Arduino IDE application.

A comparison of temperature values on the DHT22 sensor shows values that are not too different from the thermo-hygrometer. The difference in values obtained averages approximately 1°C for each data. The average error obtained is 2.2%. The comparison of the humidity value of the DHT22 sensor with a thermo-hygrometer also shows that the difference is not too significant. The average error value obtained was 6.1%. Based on the relatively small difference and error values, it can be concluded that the DHT22 temperature and humidity values have accurate values that are not much different from the actual values.

Characterization of the MQ-2 sensor is carried out by looking at how the sensor responds to smoke detection, as well as comparing the output value of the MQ-2 sensor to the output value of a comparative smoke detection sensor, namely, the ST8900 smart sensor. The two sensors are placed directly next to each other without any distance. The smoke detected by the two sensors comes from mosquito coils and cigarette smoke. The sensor output value is observed via the computer on the serial monitor in the Arduino IDE application.

The results of comparing the smoke values detected by the two sensors are different. This happens because the direction of smoke towards the two sensors is never fixed and constantly changes. Even though the smoke value detected by the MQ-2 sensor constantly changes, this value indicates the presence of smoke detected by the MQ-2 sensor. This also applies to the ST8900 comparison sensor so that based on the characterization and testing results, the MQ-2 sensor can function well.

The anemometer sensor test was carried out by comparing the anemometer sensor value with the comparison sensor value of the GM8902 air flow anemometer manufacturer. The test is carried out by calculating the speed of the wind coming out of the fan where the fan has three levels of wind speed. Each sensor is used to measure the wind speed produced by the fan. The measurement results of the two sensors show similar values for each fan speed level. The most significant error value was obtained at level 1 fan at 3.74%. Meanwhile, the most negligible error % was obtained at the level 2 fan, 0.75%. Based on the relatively small error value, the anemometer sensor can work well in measuring wind speed values.

Prototype Testing Results in Climate Monitoring

Prototype testing in monitoring climate was carried out by placing the prototype in the exact location and time as the equipment owned by the BMKG office at the Teluk Bayur Maritime Meteorological station branch. The BMKG station is in the coordinate latitude -0.99639 and longitude 100.37222. BMKG's temperature and humidity measuring equipment is located on the ground at a height of 1 meter, protected by a cage. The DHT22 sensor is placed in the cage with the same conditions as the BMKG tool. BMKG's wind speed measuring instrument is located at the top of the building, which has two floors, so the position of the anemometer sensor is also placed next to BMKG's measuring instrument to obtain the same conditions.

Data was taken within 4 hours for temperature and humidity measurements from 8.40 a.m. until 12.40 p.m. Meanwhile, wind speed data collection was carried out within 3 hours and 20 minutes, starting from 9.20 to 12.40. Weather conditions at the time of data collection were cloudy. The data analyzed is data per 10 minutes. This is because BMKG can only issue data every 10 minutes on average. The results of the 10-minute average comparison data obtained can be seen in Figure 6, Figure 7, and Figure 8.

The graphical results of the comparison of BMKG temperature and humidity values with the DHT22 sensor can be seen in Figure 6. The BMKG (T-AVG) temperature value with the DHT22 (T-Pro) sensor does not experience a very significant difference. In the graph, you can see that the difference in average values per 10 minutes is only 1°C at most. The graphic trend between the two sensors also shows the same trend; namely, when the climate temperature decreases, both sensors experience a decrease with values that are not much different. Meanwhile, when the temperature increases, the two sensors also increase with values that are not much different. When compared by error, the most significant error value is 2.41%. This shows that the DHT22 sensor's reading ability to detect temperature climate can function correctly.

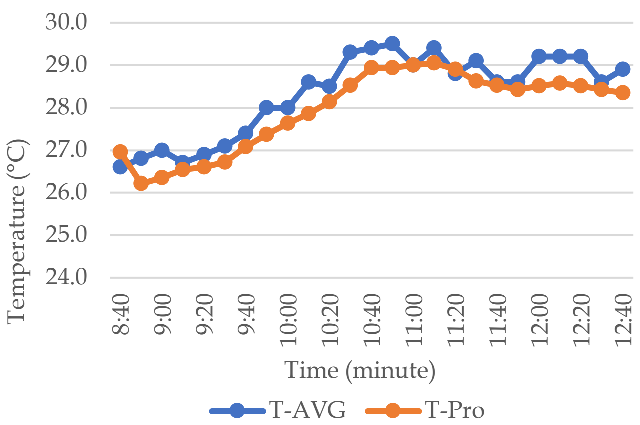

Figure 6. Comparison graph of BMKG (AVG) temperature values with the DHT22 (Pro) sensor

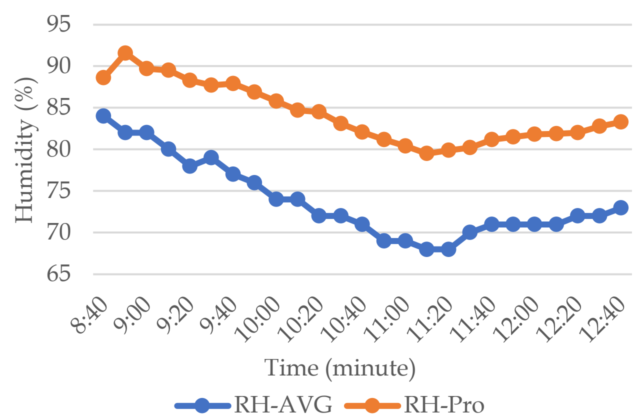

Figure 7. Comparison graph of BMKG (AVG) humidity values with the DHT22 (Pro) sensor

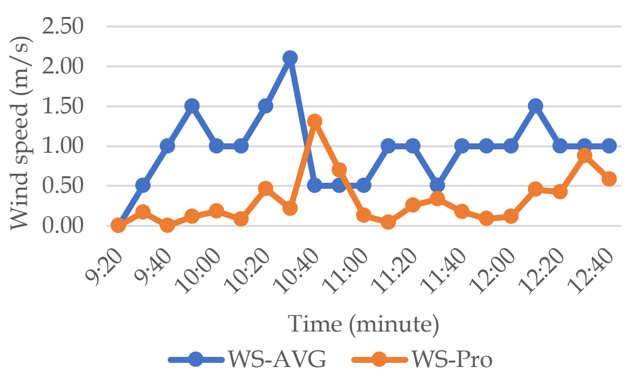

Figure 8. Comparison graph of BMKG wind speed values (WS-AVG) with anemometer (WS-Pro)

The results of comparing BMKG humidity values with the DHT22 sensor in Figure 7 show a slight difference in value, namely an average difference of 10%. The difference in values can also be seen in the error between the two sensors, which ranges from 10% to 15%. However, the graphic trend between the two sensors shows the same trend. When the climate humidity value decreases, both sensors experience a decrease with values that are not much different. Likewise, when the climate humidity value increases, the two sensors also increase with values that are not much different. Based on the error value, which is still small, and the graphic trend is not much different from the BMKG tool, the DHT22 sensor's ability to detect climate humidity can function quite well.

The graphical comparison results of BMKG wind speed values (WS-AVG) with the anemometer sensor (WS-Pro) can be seen in Figure 8. The results of the comparison graph show quite different values between the two sensors. Meanwhile, the trend graph shows a slightly different trend. The different value differences occur due to the delay in reading the sensor values into the blynk web. The reading delay is long, namely 4 seconds, so the sensor value reading is only partially real-time. The 4-second delay also means that not all data per second is stored in the Blynk application. A solution is needed so that the reading of the anemometer sensor value in the Blynk application does not delay so that the sensor can function appropriately as a wind speed meter.

Prototype Testing Results in Detecting Forest Fires

The second stage in testing the prototype is testing the sensor system for its ability to detect fires in forests or land. In this test, the prototype is divided into two nodes to see whether the two nodes can detect the same thing under the same conditions. Before the fire source is ignited, the conditions of temperature, humidity, and smoke concentration are recorded as environmental conditions before the fire occurs. Environmental conditions before the fire source is ignited are a temperature of 28°C, humidity of 81%, and a smoke concentration of 0 ppm.

Table 1. Test results for fire temperature, humidity, and smoke detection from the east (node 1) and north (node 2)

Dist. (cm)	East (Node 1)			Status	North (Node 2)			Status
	T (°C)	H (%)	Smoke (ppm)		T (°C)	H (%)	Smoke (ppm)	
10	54	41	67	danger, cautious	56	38	806	danger, cautious
20	51	41	74	danger, cautious	54	39	639	danger, cautious
30	48	45	143	danger, cautious	50	42	915	danger, cautious
40	46	46	36	danger	47	43	233	danger, cautious
50	42	50	18	danger	45	46	199	danger, cautious
60	40	52	6	alert	42	49	365	danger, cautious
70	37	57	19	alert	40	53	257	alert, cautious
80	36	62	0	alert	38	58	149	alert, cautious
90	36	63	4	alert	37	60	86	alert, cautious
100	35	64	3	-	37	61	65	alert, cautious
110	35	66	22	-	36	63	54	alert, cautious
120	35	67	23	-	36	63	13	alert
130	34	69	25	-	35	65	14	-
140	34	70	12	-	35	66	19	-
150	34	73	7	-	34	69	26	-
160	32	74	13	-	33	69	7	-
170	32	74	16	-	33	71	5	-
180	31	74	8	-	32	72	11	-
190	31	75	3	-	32	72	0	-
200	31	75	2	-	31	73	2	-
210	30	77	0	-	31	74	4	-
220	28	77	6	-	29	74	8	-
230	28	77	8	-	28	74	19	-
240	28	77	16	-	28	75	5	-

Table 2. Test results for temperature, humidity, and smoke detection from the west (node 1) and south (node 2)

Dist. (cm)	West (Node 1)			Status	South (Node 2)			Status
	T (°C)	H (%)	Smoke (ppm)		T (°C)	H (%)	Smoke (ppm)	
10	54	42	166	danger, cautious	53	40	54	danger, cautious
20	52	43	243	danger, cautious	51	41	63	danger, cautious
30	51	44	77	danger, cautious	51	43	177	danger, cautious
40	49	46	94	danger, cautious	49	45	28	danger
50	46	49	38	danger	47	48	23	danger
60	44	53	12	danger	45	52	5	danger
70	41	58	14	danger	42	56	4	danger
80	38	61	13	alert	38	60	18	alert
90	36	64	19	alert	37	63	10	alert
100	36	64	6	alert	36	64	12	alert
110	35	65	7	-	34	64	13	-
120	35	66	6	-	34	67	14	-
130	34	66	0	-	33	68	14	-
140	34	69	9	-	33	68	0	-
150	33	70	8	-	32	70	0	-
160	32	72	5	-	32	71	26	-
170	32	73	24	-	31	71	29	-
180	31	73	26	-	31	72	19	-
190	30	74	18	-	31	73	2	-
200	30	74	31	-	30	73	5	-
210	29	75	6	-	28	74	4	-
220	28	75	0	-	28	74	15	-
230	28	75	0	-	28	76	17	-
240	28	76	0	-	28	77	11	-

Prototype testing was carried out by placing the initial position of the node 10 cm from a fire source made from burnt wooden twigs and dry leaves. Data on temperature, humidity, and smoke concentration values were measured at a distance of 10 cm. This is then carried out at a distance of 20 cm, 30 cm, and so on until the data value returns to close to the condition before the fire. The node position is adjusted in the direction of the cardinal direction. The position of node 1 from the east and node 2 from the north is carried out first. After that, node 1 is used from the west and node 2 from the south. The node's position is set so that it can see the distribution of heat and humidity values around the fire source from various radius distances.

The detection results for node 1 (west) and node 2 (south) in Table 2 also show similar data compared to Table 1. Each data shows a fairly large decrease in temperature values from a temperature value of 54°C to 36°C (node 1) and 53°C to 37°C (node 2) from positions 0 cm to 90 cm. The temperature value decreases slowly until the node position is 240 cm. The humidity value increased quickly from 42% to 64% (node 1) and 40% to 64% (node 2) from 0 to 100 cm. The humidity value also increases slowly after passing the 100 cm position until the node position becomes 240 cm.

Based on the data displayed in Tables 1 and 2, it can be seen that the distribution of heat from the fire source in radius shows temperature values that are similar to the east, south, west, and north directions. The highest difference in temperature values occurs from the north, which is ± 2°C higher than other directions. This is related to the wind direction, which is more often towards the north, so the smoke is often towards the north (node 2). In Table 1, it can be seen that more smoke was detected by node 2 in the north direction. The direction of the smoke depends on the direction of the wind, so during testing, it can be concluded that the wind is more often directed towards the north. The wind speed value during the test cannot be displayed because the slow-moving wind speed at that time cannot move the anemometer sensor cup. Data obtained during testing using a fire source at a fire level the size of a campfire shows that the prototype can detect changes in temperature and humidity values within a radius of approximately 2 meters.

During testing of the prototype as a fire detector, the prototype was also tested for its ability to provide a warning status to the user when changes in temperature and smoke values occurred. During testing, node 1 and node 2 can warn users via Android cellphone notifications and email. The form of notification display via Android cellphone and email can be seen in Figures 9 and 10.

Figure 9. Warning display via Android cellphone notifications

Figure 10. Warning display via email

Conclusion

The developed sensor system prototype effectively fulfills the critical role of real-time weather monitoring in forest and land environments, providing vital data on temperature, humidity, and wind speed that can be conveniently accessed via Android mobile devices or web browsers. Nevertheless, it's important to note that the anemometer sensor does exhibit a slight reading delay of 4 seconds, resulting in minor deviations from BMKG measurements. In addition to its weather monitoring capabilities, the prototype excels in fire detection, reliably identifying temperature and humidity variations within a radius exceeding 2 meters. For optimal performance when deployed in a Wireless Sensor Network (WSN) with multiple nodes, it is advisable to position nodes at 5-meter intervals, allowing for the detection of even small fires, such as campfires. This comprehensive functionality makes the sensor system prototype a valuable asset for environmental monitoring and fire detection in diverse settings.

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Author Contributions
Authors listed in this article contributed to the research and development of the article. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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