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High accuracy sensor nodes for a peat swamp forest fire detection using ESP32 camera

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ABSTRACT

The use of smoke sensors in high-precision and low-cost forest fire detection kits needs to be developed immediately to assist the authorities in monitoring forest fires, especially in remote areas more efficiently and systematically. The implementation of automatic reclosing operation allows the fire detector kit to distinguish between real smoke and non-real smoke successfully. This has profitably reduced kit errors when detecting fires and in turn prevent the users from receiving incorrect messages. However, using a smoke sensor with automatic reclosing operation has not been able to optimize the accuracy of identifying the actual smoke due to the working sensor node situation being difficult to predict and sometimes unexpected such as the source of smoke received. Thus, to further improve the accuracy when detecting the presence of smoke, the system is equipped with two digital cameras that can capture and send pictures of fire smoke to the users. The system gives the users choice of three interesting options if they want the camera to capture and send pictures to them, namely request, smoke trigger and movement for security purposes. In all cases, users can request the system to send pictures at any time. The system equipped with this camera shows the accuracy of smoke detection by confirming the actual smoke that has been detected through images sent in the user's Telegram channel and on the graphical user interface (GUI) display. As a comparison of the system before and after using this camera, it was found that the system that uses the camera gives an advantage to the users in monitoring fire smoke more effectively and accurately.

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1. INTRODUCTION

High-precision early detection of peat forest fires is essential to make sure correct information sent to the users, rangers or authorities. The performance of the sensor nodes to detect and confirm the presence of smoke is very difficult when no camera is used in the built system. Various methods are used to improve the performance of sensor nodes such as the installation of cameras that serve to confirm the occurrence of forest fires through smoke images. Such a specified system can certainly help the authorities monitor forest fires more effectively and smoothly. Various parameters are used in the design of forest fire detection systems including smoke sensors, fire sensors, temperature and humidity sensors, water level sensors and wind sensors. The optimal system combines these sensors so that the accuracy of the system can be improved. Smoke and fire sensors are commonly used methods to detect forest fires.

The selection is based on its effectiveness, low profile, reasonable price, easy to use and can be employed with internet of things (IoT). Temperature and humidity sensors are used as secondary parameters to help the authorities take precautions as forest fires may occur due to drought and hot weather factors. Water level information in the ground can also help the authorities as preliminary information before a fire occurs. If the water level is low, then the authorities can patrol more frequently because the probability of fire is high. Wind sensors also play a big role due to strong winds may cause fire to spread quickly. Precautions should be taken if the wind speed is high during hot weather. Satellites and drones are high-tech and sophisticated system with high precision but their usage is very costly, complicated and difficult to operate at night, hard to detect small fires and delays in the received signal. Today, various efforts are made to produce high-precision and low-cost systems such as using smoke sensors and several additional sensors such as temperature, humidity and water sensors in one system as reported in [1], [2]. Preliminary results of fire detection kits using smoke sensors are reported [1]. The test involved a period of 6 months and the system operated well and smoothly. Researcher [1], [2] reported that the system is able to distinguish the real and non-real smoke as well as the location of the fire study in Hutan Simpan Ayer Hitam Muar, Johor, Malaysia.

Among the challenges in developing fire detection kits using smoke detection methods is the difficulty of designing a system capable of identifying the presence of smoke accurately and quickly. This situation has definitely given difficulties to the authorities in dealing with forest fire issues such as errors in detecting and late receipt of fire information with subsequent delays in assistance from firefighters. Such a situation should not have happened in the fourth industrial revolution (IR 4.0) era because today’s technology can be used to help humans perform tasks more systematically and effectively. Thus, in order to improve the accuracy of sensor nodes identifying the presence of smoke and avoiding the occurrence of fire extinguishing delays, efforts to improve the design of existing systems are necessary. The use of digital cameras is an effective method of confirming the presence of smoke through received smoke images. Another advantage is that the authorities can monitor the sensor node environment at any time to clearly see the real picture of the sensor node environment. Figure 1 shows the sensor node equipped with two camera units that can be used by the user to confirm the presence of detected smoke.

Although the camera is suitable for indoors, using a suitable waterproof casing allows the camera to be used in outdoor environments. In addition, the use of the ESP32 camera provides many advantages such as easy to be employed with IoT, practicality and small size. However, the camera will be activated when the smoke present and the image will be sent to the user each time smoke is detected. This will result in high data usage. This situation will definitely increase the operating costs of the system even though the performance of the system has been improved. The situation is exacerbated if the number of users is high. Therefore, the kit developed in this article is based on user request. In this case, the user can ask the system to send images of the smoke to confirm the smoke has been detected. Users can also monitor the state of the sensor node environment at any time or anywhere as long as the area has telco network coverage.

In addition, the system inside [1] is capable of detecting smoke and is able to distinguish real smoke and non-real smoke. By using the camera, users can confirm the presence of smoke. In other words, the accuracy of the smoke detection system can be improved with the smoke image verification. To improve the operation of the system, the developed prototype is equipped with two cameras that can take pictures if asked by the user to do so after the user receives a smoke detected message. Although the use of cameras is used in satellite and drone systems, the use of cameras in sensor nodes is also relevant and helps the authorities. Many past studies used cameras in their developed prototypes to detect forest fires as reported in [3]–[8]. A forest fire detection system is developed using image processing methods. This technique can help users detect areas of fire occurring based on the color images obtained [3]. The developed algorithm has been tested and the system operates well using dummy images.

Aa camera is used to measure the decrease in peat soil level and water level above the soil [4]. This water level information can be used in fire detection systems to monitor peat soil dryness. Although the correct method is to measure the water level in the peat soil, the water level at the surface also gives an idea of the dryness of the soil. Two types of high-resolution cameras are used to take images of vehicle smoke [5]. The developed system can detect vehicles that produce a lot of smoke. It shows that the use of a camera to detect smoke based on smoke images is practical even without using a smoke sensor. A camera is used to take smoke and flame images to determine the cause of the fire and the smoke concentration area [6]. However, no effort to optimize the performance of this system resulted in less accuracy of the system. Cameras are used to capture infrared images to detect forest fires [7]. Although the stability of the system is high, the use of infrared cameras requires a large cost. Fire detection systems use optical and thermal cameras that produce high-precision systems in which huge costs are required to develop the system [8]. However, the use of video cameras to record the presence of fire smoke is also a method that can be used and is not just limited to regular cameras. Using short-term video recording camera is sufficient to confirm the presence of smoke clearly and in turn can further increase the accuracy of the system. The node sensor system using cameras for various functions to detect forest fires are summarized in Table 1. Others related work on the forest fire monitoring system are presented in [9]–[25].

Table 1. Selected fire detection system with camera

Ref.	University, country, year	Method	Type/function of camera	Research focus
[3]	Northeast Forestry University, China, 2018	Forest fire detection using rule-based image processing technique	NA	The study is based on a forest fire detection method using image processing techniques including movement containing region detection based on background subtraction and color segmentation
[4]	University of Palangka Raya, Indonesia, 2021	Camera system for measuring peat subsidence and water level depth	- Time-lapse camera (Wingscapes TimelapseCam Pro WCB-00121) - Measure peatland subsidence and water level depth	The study is based on measuring of peat surface motion and water level depth using commercially available time-lapse cameras and image processing methods
[5]	VTT-Technical Research Centre of Finland Ltd, Finland, 2016	Multi-camera-based smoke detection	- Thermal camera FLIR ThermoVision A20M (left) and visible wavelength camera AXIS Q1755 (right) - Capture the smoke image	The study is based on a smoke from the vehicle
[6]	Yu Da University, China, 2019	Remote-monitoring smoke detection system using omnidirectional camera	- Capture the smoke and flame image	The study is based on a remote-monitoring smoke detection system classifies smoke and flame image data to determine and label the locations at which fire sources are located and smoke is concentrated
[7]	Universitat Politecnica de Valencia, Spain, 2013	Multisensor network system for wildfire detection using infrared image processing	- Capture the fire image	The study is based on infrared image obtained and advanced image sensors for automatic wildfire detection
[8]	Cyprus University of Technology, Cyprus, 2017	Integrated forest monitoring system for early fire detection and assessment using optical and thermal camera	- Monitoring the forest fire	The study is based on automatic early detection of wild forest-fire using stationary optical and thermal cameras
This work	Universiti Tun Hussein Onn Malaysia, Malaysia, 2022	IoT-based kit smoke detector integrated with two camera	- ESP32 camera - Capture the image based on user request	Developed a low-cost prototype kit to detect the smoke based on the image from the camera

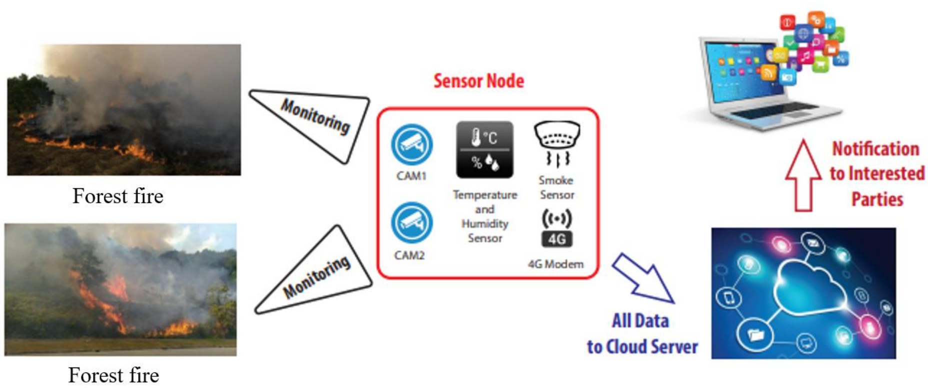


Figure 1. System overview

In this work, two cameras have been employed in the system to help the user confirm the presence of smoke when the smoke trigger system is detected. The camera users are aiming to improve the accuracy of sensor nodes in identifying detected fire smoke based on the received smoke images. In addition to improving the performance and ability of the system to operate, the use of the camera gives many advantages to the users such as helping users and the authorities monitor the environment of the sensor node when necessary.

2. PROPOSED PROTOTYPE

This section describes the fire detector kit developed including the physical structure, block diagram, wiring diagram, flow chart of the overall operation of the system and the flow-based programming tool using Node-RED software. Three (3) sensor node units are developed but for this proof-of-concept work only one sensor node is integrated with the camera.

Figure 2 shows a drawing of the sensor node developed in this research work. The design takes into account several factors such as sustainability, robustness, user friendly, green technology, low maintenance cost and practicality. The kit consists of sensors, solar PV, battery, two cameras, microcontroller circuit, wireless local area network (WiFi) module and antenna mounted on a solid pole. The initial design information of the system includes power consumption and data as reported in [1]. However, the system in this article is equipped with a camera and uses a fourth generation (4G) WiFi module. The increase in the number of microcontrollers as well as the replacement of these RF communication modules have changed the overall structure of the developed system. The prototype produced in this work has some interesting features such as high reliability, high accuracy, low power and low data consumptions, low cost, green technology, IR 4.0 technology, unlimited coverage, follow industry regulation, and low maintenance cost. The advantage of this prototype is that users can request the system to take pictures of the detected smoke.

Figure 3(a) illustrates a block diagram of a forest fire early detection system developed in this work. The system consists of a sensor unit, a camera, a microcontroller and a WiFi modem. There are three sub-systems, namely smoke, temperature, humidity and voltage sensor systems that use microcontroller 1 while two WiFi digital camera units use microcontroller 2 and microcontroller 3 respectively. Subsystem 1 is an automation system that has been developed in [1] while subsystems 2 and 3 are user request-based systems developed in this article. In this project, all subsystems use 4G WiFi modem to send data to the cloud server. This fire detector kit uses a smoke sensor method to detect fire smoke assisted by temperature and humidity parameters while two camera units are used to confirm the smoke that has been detected. The advantages of this camera are built-in WiFi and camera module on the board that contribute to a very compact system. The ESP32 camera uses 900 mW of power without turning on the flash. The resolution of this camera is almost 2 megapixels while the size and output format of the camera is 22 kB and jpeg respectively. Temperature, humidity and voltage sensors are used to detect the ambient heat, humidity and the battery level of the sensor node. The differences between the system in this article and the system developed in [1] are the use of cameras, the increase in the number of microcontrollers and WiFi modems. The prototype kit in [1] is developed using a global system for mobile communication (GSM) modem. The system is reconfigured using the 4G WiFi modem to be standardized with the ESP32 camera WiFi specifications. This prototype kit also has a notification system using a Telegram channel. Cameras are used to improve performance of the system. Both camera ESP32 microcontrollers are programmed to allow it to be connected to the existing WiFi gateway subsystem 1 for internet network access and to an IoT server to subscribe message queuing telemetry transport (MQTT) channels for the camera module. Once subscribed, the camera module will be ready to receive a request from the Telegram to trigger the camera module to capture a picture and reply this image to the user. The image file is stored in an image folder located on a web server referred to as cam1.jpg and cam2.jpg. Meanwhile, Figure 3(b) depicts the wiring diagram of the camera and WiFi system module.

Figure 4 shows the flow chart of the overall operation of the developed system. This developed prototype is an advanced version of the prototype reported in article [1]. The system developed in this article has an additional function using digital cameras. The objective is to double confirm the smoke has been detected through the smoke images obtained. Image transmission is triggered by human. With the camera, users have two options to activate the camera, namely (1) request, and (2) when the system triggers the smoke. This version of prototype allows the users to request the system to take pictures at any time or after the smoke trigger the system. The capture and send feature is the user's choice and it operates on a user request based as shown in the flowchart. Users who register for Telegram bot will have a unique user identification (user ID) or a different username/Telegram ID/chat ID. When a user requests the system to capture a picture, the server will capture the chat ID and will send the picture to the user. In this system, the user can choose either camera 1 or camera 2 to capture the picture. The advantage of this system is that the camera can work well in addition to the user receiving a clear image. The complete operation of the developed system is shown in the figure.

Figure 5 illustrates the flow-based programming tool using Node-RED software Nodered flow for camera 1 and camera 2. The operation is as follows; firstly, /p1cam1 is a command used by the user through the Telegram channel to request the system to send the image captured by the camera 1; secondly, the function will capture the chat ID of the user in question. Each user has a different chat ID; thirdly, /smoke/su/p1cam1 will send a triggering message to the MQTT channel which is /smoke/su/p1cam1. It is noteworthy that this channel has been subscribed by the camera module. The camera will be activated by capturing the image and uploading the image to the cloud server via this http protocol. Then, a 15 seconds delay has been set for the duration of uploading image. Next, after 15 s, the http request will give a command to take the image in the cloud server and bring it into the function using the relevant chat ID to be sent to the Telegram bot. Here, the type of data sent is image; lastly, Telegram bot sends the image to the user concerned. The use of camera 2 also involves a similar process. Figure 6 shows a flow-based programming tool using Node-RED software that provides readings of temperature, humidity, voltage level, smoke image, receive user request, notification message and smoke status on the GUI display.

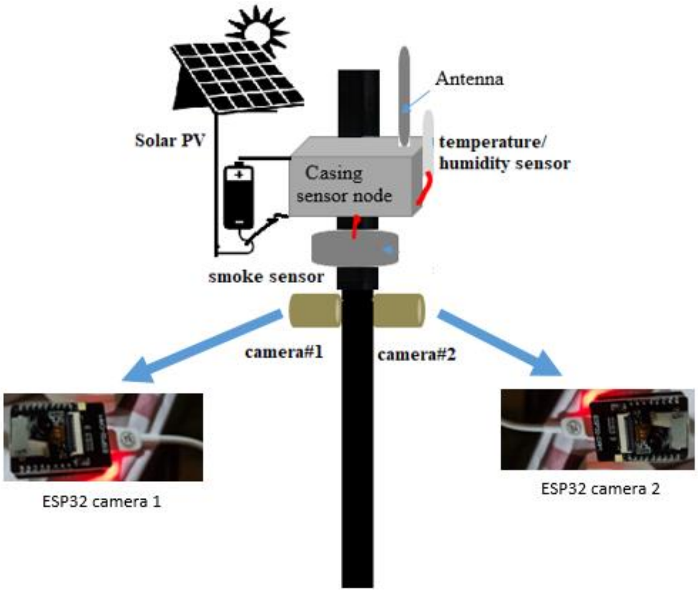
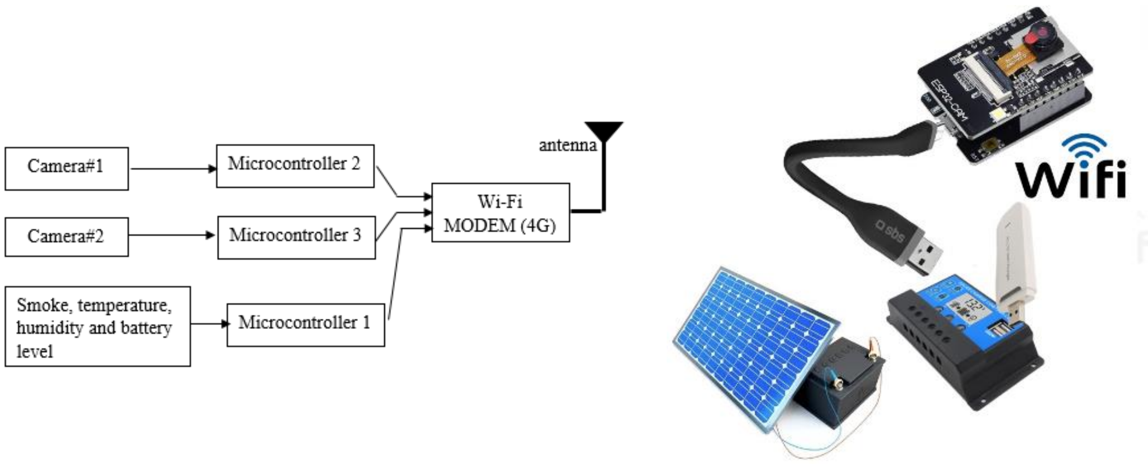


Figure 2. Sensor node design concept



(a) (b)

Figure 3. The prototype kit of (a) block diagram of the proposed sensor node and (b) wiring diagram of camera and WiFi module

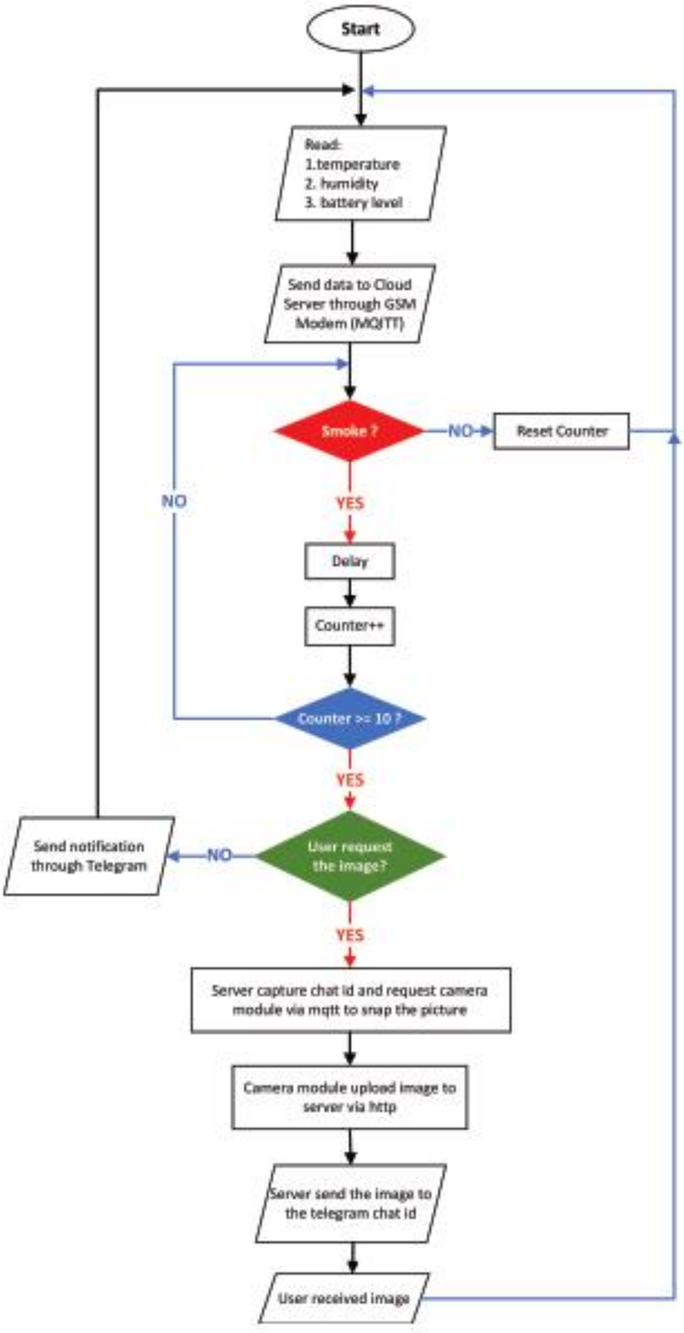


Figure 4. The overall system operation

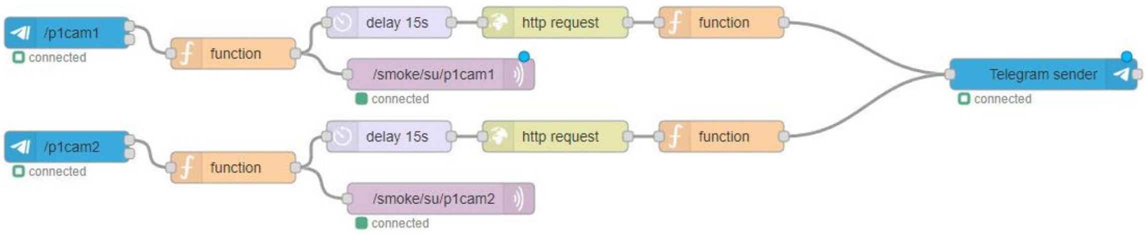


Figure 5. Flow-based programming tool using Node-RED software Nodered flow for camera 1 and camera 2

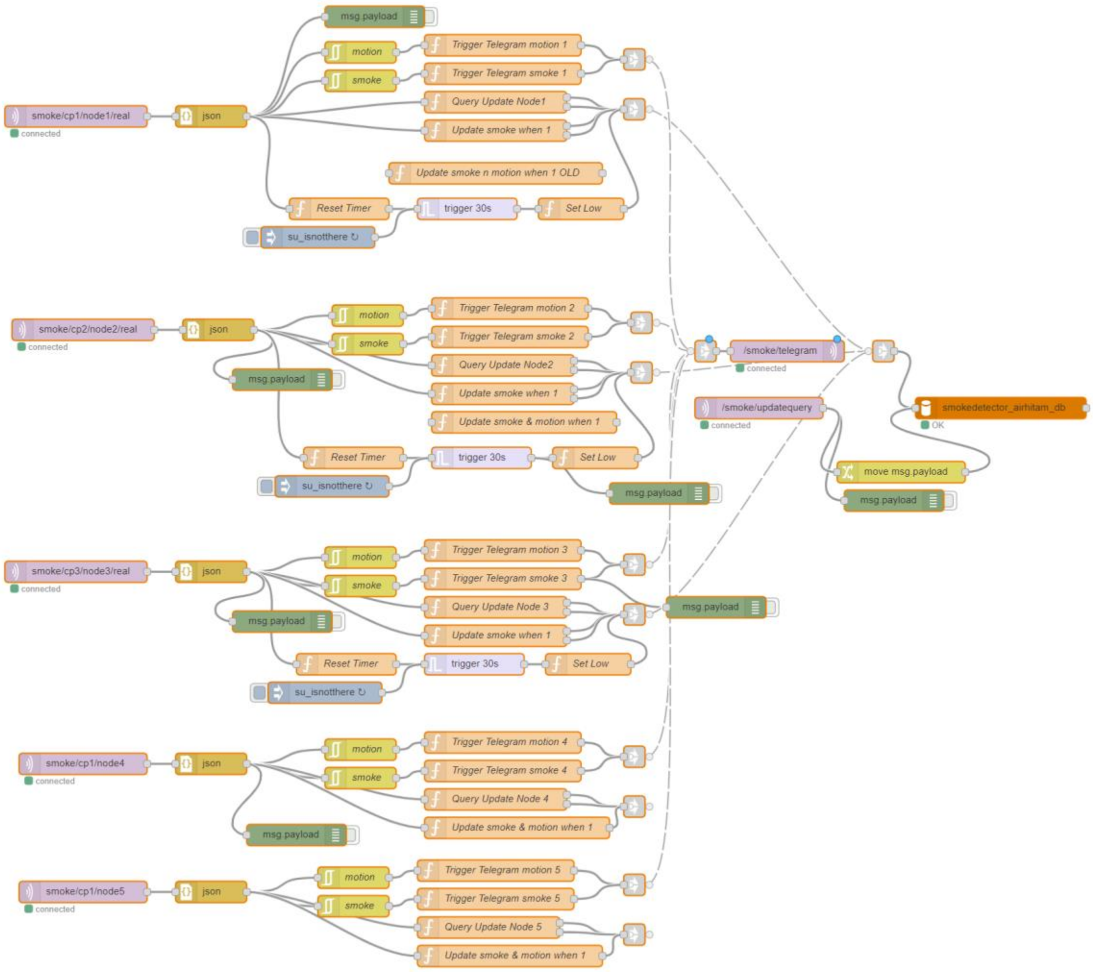


Figure 6. Flow-based programming tool using Node-RED software for all SN

3. RESULTS AND DISCUSSION

Users can monitor the readings of this prototype kit via the Telegram channel using a smartphone or laptop. With command /help, Telegram quick menu will give a display on the phone screen as seen in Figure 7. Through the /p1cam1 and /p1cam2 commands, the image display of camera 1 and camera 2 is obtained as shown in Figures 8(a)-(b). Command /status1, /status2 and /status3 also give users the reading values of temperature, humidity, smoke and battery for node 1, node 2 and node 3 as stated in Figures 9-11, respectively.

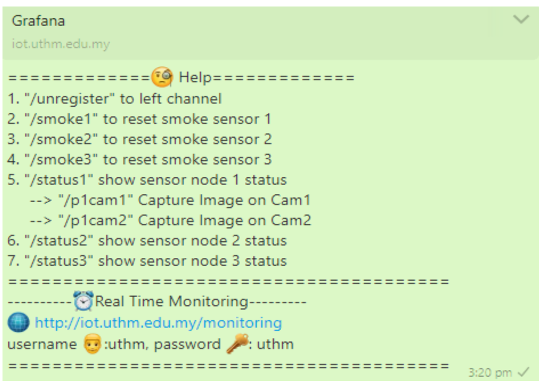
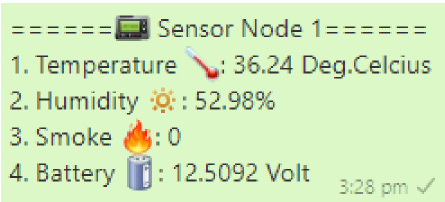


Figure 7. Telegram quick menu

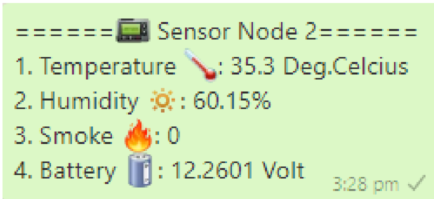
(a) (b)

Figure 8. Image notification in Telegram channel (a) camera 1 and (b) camera 2



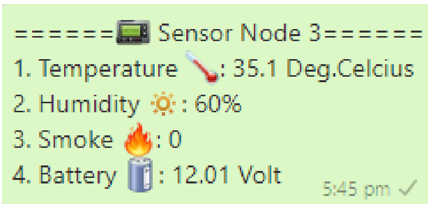
======Sensor Node 1======
1. Temperature : 36.24 Deg.Celcius
2. Humidity : 52.98%
3. Smoke : 0
4. Battery : 12.5092 Volt 3:28 pm

Figure 9. Node 1 status



======Sensor Node 2======
1. Temperature : 35.3 Deg.Celcius
2. Humidity : 60.15%
3. Smoke : 0
4. Battery : 12.2601 Volt 3:28 pm

Figure 10. Node 2 status



======Sensor Node 3======
1. Temperature : 35.1 Deg.Celcius
2. Humidity : 60%
3. Smoke : 0
4. Battery : 12.01 Volt 5:45 pm

Figure 11. Node 3 status

Figure 12(a) to (e) shows the display of smoke status, temperature, humidity, voltage level and images from camera 1 and camera 2 of sensor node 1 via Grafana software dated 10 January 2022 at 3:45 pm. The temperature, humidity and voltage levels readings are 37.26 °C, 51.01% and 12.55 V respectively while no smoke has been detected. The real time graphs of temperature and humidity are also displayed. Images from camera 1 and camera 2 are shown in this GUI displayed as node1camera1 and node1camera2, respectively. The presence of smoke through status and pictures as well as critical values of temperature and humidity can be obtained through this web-based GUI display. The kits developed in this article can increase the accuracy of the kit while detecting smoke through the images.

Figure 12. GUI display of (a) smoke status, (b) temperature, humidity and voltage level in number, (c) temperature and humidity in graph, (d) image from camera, 1 and (e) image from camera

4. CONCLUSION

The prototype kit developed in this article is able to help the authorities detect forest fires more accurately. Users can request the system to send smoke images or pictures around the sensor node at any time when necessary. This feature is an addition from the original system that is capable of distinguishing real smoke or non-real smoke. This kit can take clear pictures of smoke using two cameras and can even operate consistently. The use of this camera has improved the accuracy of the smoke detection system through the smoke images received by the user. The system is equipped with two ESP32 digital camera units that are capable of capturing images based on requests from the users. Users can confirm the presence of smoke and can help the authorities monitor forest fires more effectively and systematically. In the future, the system will be equipped with a video camera that will record the presence of smoke in real time and a water level sensor to measure the water level in the ground which in turn can further improve the performance of the node sensor kit.

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