Fire Detection Using Unmanned Aerial Vehicle

Mays Mohammed Nabeel [*], Shaymaa W. Al-Shammari [**]

[*] Department of Computer Engineering, College of Engineering, AL-Nahrain University, Baghdad, Iraq
Email: eng.mays12@gmail.com
https://orcid.org/0009-0002-2394-9326

[**] Department of Computer Engineering, College of Engineering, AL-Nahrain University, Baghdad, Iraq
Email: shaymaa@nahrainuniv.edu.iq
https://orcid.org/0000-0003-1720-5486

Abstract

Fire is one of the most dangerous types of accidents that can occur and may cause huge harm to people's lives and threaten environmental resources by spreading quickly, which makes it out of control. This critical aspect requires an intelligent system to control it correctly and as soon as possible. To achieve this, a platform has been proposed for a fully automated fire detection system to overcome fire spreading, this goal has been achieved by utilizing the UAVs (Unmanned Aerial Vehicles) as an IoT service role equipped with Pixhawk4 as a flight controller and an onboard fire detection system using Raspberry-Pi4 equipped with a camera to detect the fires using Convolutional Neural Network (CNN) algorithm. The drone systems' particular properties of high speed, flexible movement, and easy control, as well as the embedded sensors in flight controller like gyroscope, accelerometer, and compass, make it the best choice for the real-time monitoring system. The whole system was tested and the real-time fire video was detected using the MobileNetv2 as a CNN pre-trained model which has trained and achieved an accuracy 99.79% .

Keywords- UAV, Fire detection, deep learning, Pixhawk, and Raspberry-Pi4.

I. INTRODUCTION

Fire accidents usually cause huge economic damage and endanger people's lives. Depending on the National Fire Protection Association (NFPA), an estimated 1,319,500 fires during 2017 as a United States fire department responded, resulting in 3,400 civilian fire fatalities, 14,670 civilian fire injuries, and an estimated $23 billion in direct property loss [1]. So, the ability of fire detection systems needs improvement according to the development of technology over time to overcome this problem; where in the beginning, they used the manned aerial vehicle for observation with a pilot, and it produced excellent results in preventing the fire from spreading, but it is considered a costly and risky way [2]; this is why the unmanned aerial vehicles started to be used for this purpose to save human lives and reaching the fire accident situation easily and quickly. On the other hand, many early fire-detection methods and sensors have been used to avoid fire disasters. Most are based on temperature and humidity sampling and air transparency testing. However, those detectors either must be very close to the fire or cannot provide the ground station with enough information about the burning process [3]. In addition, it needs a large scale of fire to trigger an alarm, which is impossible because these devices cannot be deployed in large-scale outdoor environments, e.g., forests, wild places, and high buildings, etc. also, using the infrared camera is unreliable because it does not work well with cloudy weather [4]. As object detection and classification in images, voice recognition, and other fields have succeeded with deep learning, so, it helps in preventing the fire from growing and detecting it at a specific time.

The research problem of this paper is the difficulty to reach the fire situations in the meantime of fire, besides the time consumed to obtain accurate detection results to confirm whether there is a fire or not and the location. The wasted time would save human lives. These points are considered one of the most important things in fire detection problems.

The main contribution of the presented work is the fully automated fire detection system with real-time processing, when the flight plan is received, the UAV flies off autonomously, and at the same time, the software platform sends an SMS message from the burning area to the fire station. This makes the whole process not require human interaction. In addition, on drone decision-making, while flying without the need to send a video to the station to check if there is a fire. This can help avoid the tedious and time-consuming process during the detection process.

The remaining parts of this paper are organized as follows. Section II presents the background and related work. Section III introduces the system architecture and requirements. In addition, section IV presents the proposed work. Section V introduces the final experiment results and analysis. Section VI discuss the system evaluation. Finally, VII concludes this paper by discussing the results and possible future research directions.

II. RELATED WORK

In literatures, many fire detection methods using UAVs have been proposed. The authors in [5] Proposed Forest fire detection in real-time using UAV with Ardu pilot Mega as flight controller to control the UAV from the ground station using telemetry 433 MHZ. The Raspberry Pi3 was utilized with onboard sensors to measure the temperature of the collected data from the fire location and deploy the result when a fire is detected to the database server. Whereas [6] presented a fire/smoke detection system by training YOLOv2 Convolutional Neural Network (CNN) detector, R-CNN, and Fast R-CNN models on MATLAB using indoor and outdoor fire/smoke images with 128x128 as input size and tested the models on real-time video, the camera installed in closed-circuit television surveillance systems were used. In the research introduced in [7], a six-rotor drone (DJI S900) equipped with Sony A7 camera was used to acquire forest fire images using CNN architecture. The study considered 950 images for training, testing, and validation sets. Kinaneva et al. 2019 [8] used two types of drones: Fixed Wing and rotary wings. Where the fixed wings drone can flies at medium altitude (350 m to 5500 m), while the rotary wings drone flies at a much lower altitude (10 m to 350 m) compared to fixed-wing UAVs by flying closely inspects to the area, which would have better and more detailed visibility of the area. By using optical camera type Zenmuse X4S 4K. The model used to train these input images was ssd_mobilenet-v1_coco. The research in [9] focused on forest fire by utilizing the six-rotor drone (DJI900) with a SONY A7 camera to collect images, CNN-based forest fire detection methods were used. The input dataset for training was collected from a real forest fire, while the test images were obtained from the internet. Another study introduced in [10] used a rotary-wing UAV with a limited time, which is not enough to observe a large area, they also used fixed-wing UAVs with vertical take-off and landing for long-term observation of the area. The researchers used TensorFlow to train the pre-trained R-CNN model to avoid a huge number of computational resources and a lot of time. They tested the model on video feeds from UAV as images to the operators by its software, then an alarm triggered by a system when a fire in an image was detected. Nithyavathy, et al. 2021 [11] proposed forest fire detection using a thermal camera on a quadcopter at 10 meters altitude controlled by Ardupilot. The image was captured and sent to the fire station for processing. The thermal camera used infrared radiation to create a heat zone image. The study in [12] focused on wildfire detection using UAV and deep learning software with TensorFlow and Keras library, through DJI Phantom 3 Professional and DJI Matrice 200 drones. A drone took 10 videos with a different duration to collect the dataset for the CNN algorithm. Finally, the authors in [13], presented a review of the main uses of UAVs in fire detection, where the authors used the infrared computer technique as the fire detection algorithm by changing the real-time frame's color from RGB to HSV. Deploying this algorithm on a drone using a Raspberry Pi3 to achieve the best fire detection in the forest area.

Table 1 presents a comparison summary of the research presented in the literature review. This helps in lighting the shed on the main differences between this study and previous studies.

Table 1 Summary of literature survey

Reference	UAV	Camera	Status	Environment	Method
Diw et al., 2018 [5]	Yes	No	Real-time	Forest fire	Sensors
Hu and Lu, 2018 [6]	No	Yes, Static camera	Realtime	Indoor and outdoor smoke images	CNN(ConvNet) 97.0% detection rate
Chen et al.,2018 [7]	Yes DJI S900	Yes, SONY A7	Real-time	Forest fire	CNN
Kinaneva et al., 2019 [8]	Yes Fixed Wing and rotary wing drone	Yes	Offline	Forest fire	ssd_mobilenet-v1_coco
IEEE Industrial Electronics Society. et al.,2019 [9]	Yes, Six-Rotor UAV	Yes, SONY A7	Real-time	Forest fire	CNN
Georgiev et al.,2020 [10]	Yes	Yes	Real-time Video from the thermal and optical camera and send an email	Forest fire	R-CNN
Nithyavathy et al.,2021 [11]	Yes Quadcopter	Yes, Thermal camera	Real-time Send to fire station	Forest fire	It uses infrared radiation to create a heat zone image
Bouguettaya et al., 2022 [12]	Yes DJI Phantom 3 and DJI Matrice 200	Yes	Realtime	Wildfire	CNN

P. Chamoso et al., [13]	Yes	Yes	Realtime	Forest fire	Infrared computer technique
Proposed Work	Yes	Yes, a digital camera	Real-time	Forest and Urban dataset	MobileNetv2

III. SYSTEM ARCHITECTURE AND REQUIREMENTS

This section introduces the proposed system architecture and requirements. The proposed system shown in Figure (1) has been implemented to achieve accurate real-time fire detection.

Figure 1. Fire detection system.

The proposed system requires collecting images using a camera placed on the drone, processing the collected data, making onboard decisions, and sending the fire's location through SMS messages, as shown in Figure (2). The following subsections introduce the main components of the architecture in details:

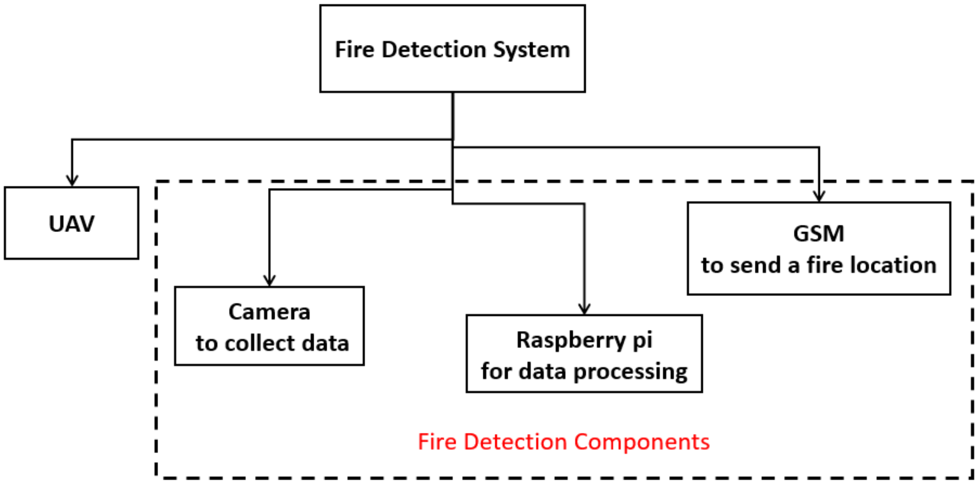

Figure 2. The requirements to implement the proposed system.

A. The UAV

The quad-copter drone has been built, as shown in Figure (3), by collecting the components shown in Figure (4).

Figure 3. The Drone

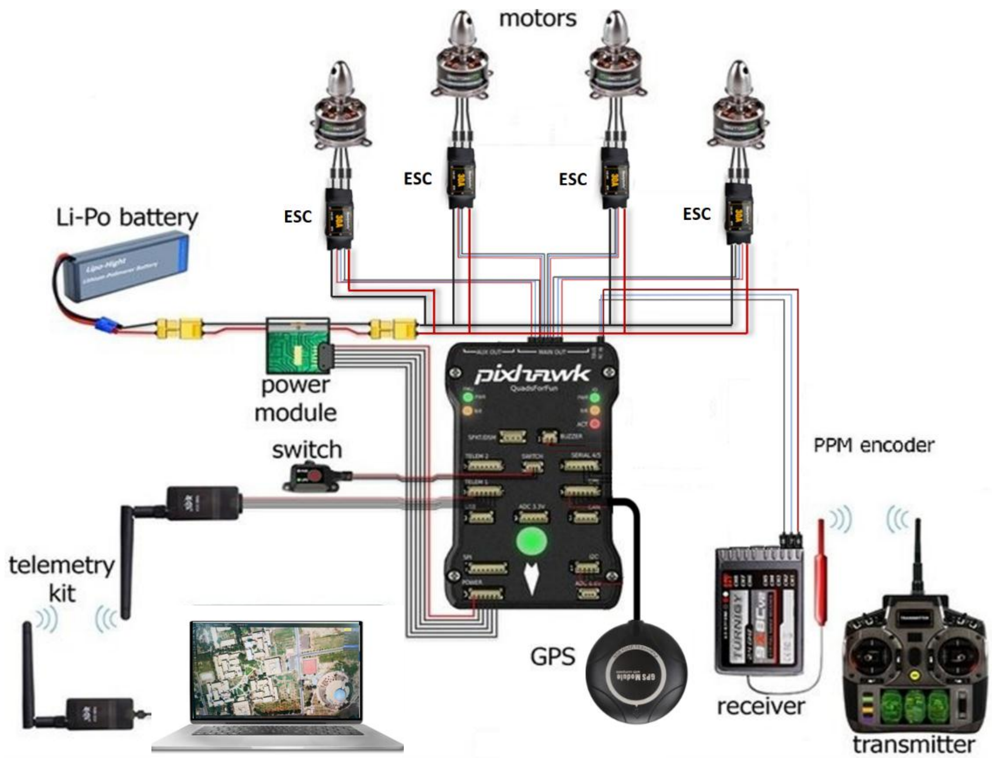

Figure 4. Drone components circuit diagram connection.

The following points describe each component used to build the UAV:

1- Frame

The frame of the drone consists of a Power Pistribution Board (PDB) type (S500) and four fibre arms, where Carbon rods are impregnated into the arms. Specially designed angled arms increase flight stability while minimizing power loss; cost-effective choice for entry-level aerial video shooting.

2- Brushless Motor:

The DJI 2212 920KV Brushless Motor is a DC electric motor for Quadcopter. Known as Electronically Commutated Motors (ECMs). The motors are powered by a DC electric source via ESC (Electronic Speed Control), which produces an AC electric signal to drive the motor. The setup of motors in the drone is as follows: 1 and 3 motors rotating in a clockwise direction. While 2 and 4 motors are set to rotate in a counter-clockwise direction, as shown in Figure (5) [14].

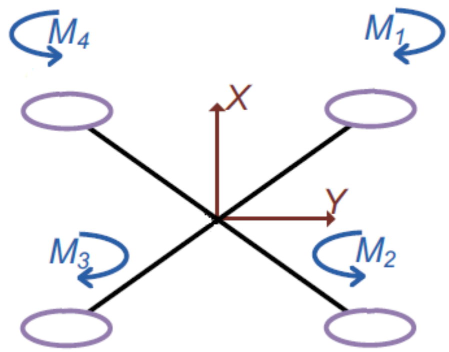

Figure 5. Setup the motor's direction in the UAV[14].

3- ESC (Electronic Speed Control):

It is an electronic circuit, which provides a controlled current to each motor to achieve the correct speed and direction. It obtains the input signal from Pixhawk4 and raises its current to 30A, which feeds to the motor. It works on 7.4V - 11.1V as an input voltage range, size: 40 X 24 X 7 (mm), and weight: 12 grams (excluding lines). [15].

4- Battery:

It is a Lithium polymer battery with 3500 mAh used due to its great power density and ability to recharge for a flight at least 20 minutes. It has a three-power cell with 25C local capacity, where each cell provides 3.7 V. So, the total voltage supply to the drone is 11.1 V. It feeds the power to the PDB of the drone and the Pixhawk flight controller [15].

5- Pixhawk 4:

Many applications have widely used Pixhawk hardware to drive the UAV, which is considered the heart of the drone. It is an advanced Autopilot 32-Bit Flight Controller architecture with low-cost, high-end and availability. It has three sensors: a compass, a gyroscope, and an accelerometer. In addition, there are two modes to control the UAV through Pixhawk: manual flight mode (by remote control,) and mission flight mode (by Q-Ground control program). The UAV components require to connect to the flight controller [14] [16].

6- Telemetry:

It is a radio module for wireless transmission data used to send and receive the main information to control the quadcopter with air data rates up to 250kbps. The radio telemetry consists of two parts, the first one connects to the PixHawk4 flight controller on the drone by telemetry pins, while the second one is for the ground station connected to the computer by USB port. The radio telemetry type used in this proposed system is 915 MHZ, 500 mw: For 100-150 M transmission data distance range [17].

7- GPS Module:

The Global Positioning System, is a new M8N GPS module that includes a digital compass, with dimensions (45mm X 45mm). It does not require an internet or user to transfer data; the main use of the GPS was in military and civil departments. It is connected to the quadcopter by GPS pins on a Pixhawk flight controller [18].

After collecting all the components presented in this section together and building the drone, the setup for the drone's flight controller (Pixhawk) was implemented using the Q-ground control program, version 3.5.5. by calibrating the compass, gyroscope, accelerometer, and radio controller. Then, the setup of all calibration results was saved in Pixhawk's SD RAM. Figure (6) shows the accelerometer calibration to achieve a good drone's stability.

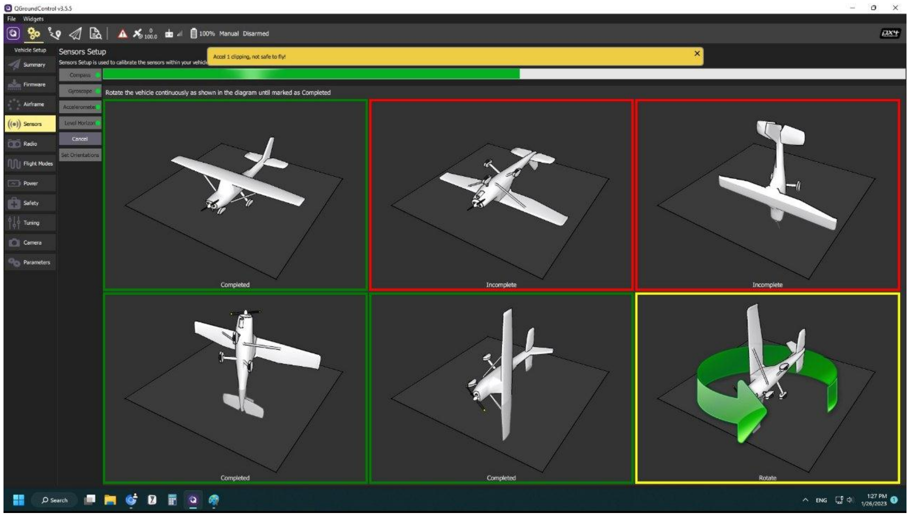

Figure 6. The calibration process of the drone's accelerometer.

B. Fire Detection Components

The fire detection part consists of Raspberry Pi4, camera, and GSM connected, as shown in Figure (7). The Raspberry Pi4 is connected to the GSM through UART TTL pins serial interface, and it is also connected through a USB port with Logitech Camera, as shown in the pin diagram in Figure (8).

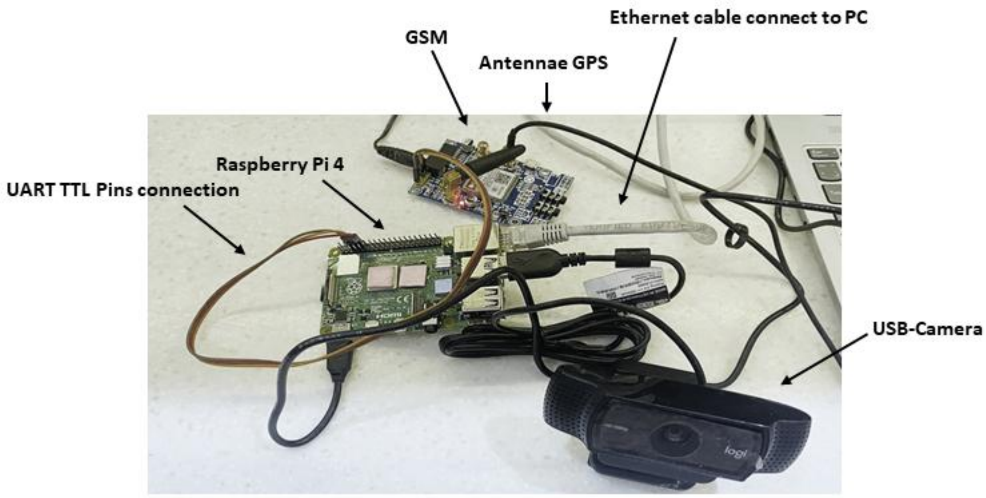

Figure 7. The Raspberry pi4, Camera, and GSM circuit connection

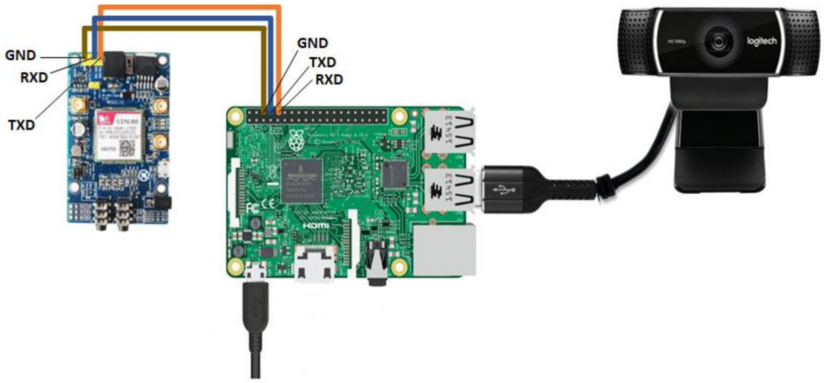

Figure 8. The Raspberry pi4, camera, and GSM Pin Diagram connection.

IV. PROPOSED WORK

Experiments have been applied to test the system, check the functionality of the proposed work and show the real-time fire detection system performance. The test process for the proposed work includes both testing the functionality of the drone's components and checking the fire detection system components. Figure (9) presents a flowchart that shows the test process of the drone's main components:

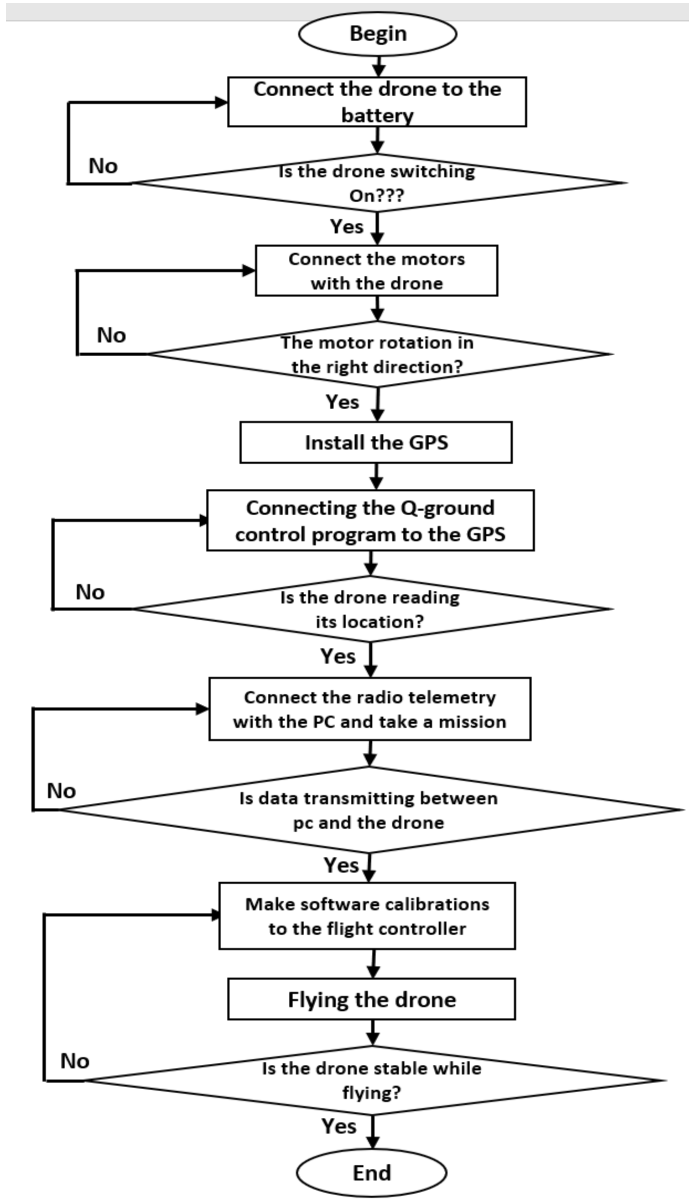

Figure 9. Installing and testing the drone's components

More details about collecting the drone's components and the test process are shown in the following points:

1- Testing the motors by connecting them to the battery and testing their rotation in the right direction.

2- When the drone is off, install propellers and check it is in the right direction and freely moving.

3- Install the GPS and open the Q-Ground control software program and check the GPS is working.

4- After connecting the flight controller (Pixhawk4) with the required components as shown in Figure (4), open the Q-Ground control software program and set the calibration steps to calibrate the drone stability, Compass, Gyroscope, Exylometer, telemetry, Radio, and fly mode (hold, return, position, altitude, manual and mission, etc.) and save all the calibration results in its RAM to apply this setup when the Pixhawk is powered on.

5- Connect the radio telemetry air module with the PC to test the data transmission when taking a mission to the drone.

The test process for the fire detection system components is depicted in Figure (10) which shows the test steps.

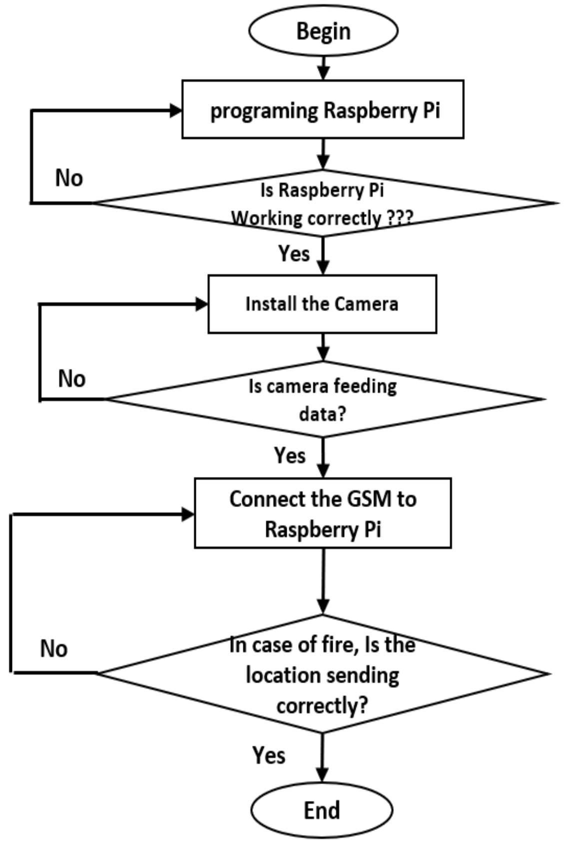

Figure 10. Installing and testing fire detection componants

After achieving the Security approvals, the experiment was conducted at Al-Nahrain University at different altitudes reach to 25 meters to test the whole proposed system, as shown in Figure (11).

Figure 11. A figure shows the drone tested at 15m altitude.

V. FINAL EXPERIMENT RESULTS

The proposed fire detection system was tested successfully, as shown in Figure (12) in Iraq-Baghdad. This experiment was held using a CNN pre-trained model (MobileNev2), which was previously presented in [19] and achieved the highest accuracy in the study, which is 99.79%. Conducting the experiment with a Six-meter altitude, 4 m/s speed, and 36 Sec time response from catching the fire to sending the location by an SMS message with no error noticed in a fire location received. The drone flight was stable and successfully flown for 10 minutes with full motor speed.

Figure 12. Final fire detection experiment

VI. SYSTEM EVALUATION

In this section, the main parameter used in this paper is evaluated, which are:

1- Data processing speed: this is achieved by using Raspberry Pi4 which provides a high speed performance compared with other researchers [13], who have used Raspberry Pi3.

2- Controlling the drone: Using the Pixhawk4 as a flight controller which has a compass, accelerometer, and gyroscope. Also, The architecture of the Pixhawk 4 is 16 bit while the ardupilot is 8 bit, this aspect can affect the speed of controlling the drone.

3- Camera performance: it is worth mentioning that the camera used in the proposed work is a full HD recording, with a resolution of 1920x1080 pixels, 30 frames per second, and a lens angle of 78 degrees.

From the above-mentioned points and by comparing them with other researches mentioned in the literature review section, refer to Table 1 for more details. The proposed system in this paper is more efficient and has higher speed performance and processing speed. This is considered the main point in a fire detection system as it is a critical disaster and time is a very important aspect.

VII. CONCLUSION

This paper has explored the design and implementation of a real-time and accurate fire detection system using a UAV and CNN pre-trained model (MobileNev2). The proposed work has been implemented using a Pixhawk4 and Raspberry-Pi4 with the Python programing language. The developed Quadcopter drone provides onboard decision-making. The onboard decision-making can be an effective tool with the fire systems to achieve an immediate response. The main points for future work are by developing the quality of the camera specifications and other drone components like the battery type to increase the flight time which could help in covering a larger area during the detection process. In addition, adding sensors on the drone beside the camera would be useful to confirm the detection results.

REFERENCES

[1]B. Kim and J. Lee, “A Video-Based Fire Detection Using Deep Learning Models,” *Applied Sciences*, vol. 9, no. 14, p. 2862, Jul. 2019, doi: 10.3390/app9142862.

[2]R. Bailon-Ruiz and S. Lacroix, “Wildfire remote sensing with UAVs: A review from the autonomy point of view.” International Conference on Unmanned Aircraft Systems (ICUAS 2020), Sep 2020, Athens, Greece. hal-02614975

[3]K. Muhammad, J. Ahmad, Z. Lv, P. Bellavista, P. Yang, and S. W. Baik, “Efficient Deep CNN-Based Fire Detection and Localization in Video Surveillance Applications,” *IEEE Trans Syst Man Cybern Syst*, vol. 49, no. 7, pp. 1419–1434, Jul. 2019, doi: 10.1109/TSMC.2018.2830099.

[4]O. M. Bushnaq, A. Chaaban, and T. Y. Al-Naffouri, “The Role of UAV-IoT Networks in Future Wildfire Detection,” *IEEE Internet Things J*, Dec. 2021, doi: 10.1109/JIOT.2021.3077593.

[5]E. Dwi *et al.*, “Real-time forest fire monitoring system using unmanned aerial vehicle,” Journal of Engineering Science and Technology Vol. 13, No. 6 (2018) 1587 - 1594 © School of Engineering, Taylor’s University 1587

[6]Y. Hu and X. Lu, “Real-time video fire smoke detection by utilizing spatial-temporal ConvNet features,” *Multimed Tools Appl*, vol. 77, no. 22, pp. 29283–29301, Nov. 2018, doi: 10.1007/s11042-018-5978-5.

[7]Y. Chen, Y. Zhang, J. Xin, Y. Yi, D. Liu, and H. Liu, “A UAV-based Forest Fire Detection Algorithm Using Convolutional Neural Network.” Proceedings of the 37th Chinese Control Conference July 25-27, 2018, Wuhan, China

[8]D. Kinaneva, G. Hristov, J. Raychev, and P. Zahariev, “Early Forest Fire Detection Using Drones and Artificial Intelligence,” MIPRO 2019, May 20-24, 2019, Opatija Croatia.

[9]IEEE Industrial Electronics Society., Xi’an li gong da xue, IEEE Singapore Section, IEEE Singapore Section. Industrial Electronics Chapter, and Institute of Electrical and Electronics Engineers, “UAV Image-based Forest Fire Detection Approach Using Convolutional Neural Network,” *2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA)*

[10]G. D. Georgiev, G. Hristov, P. Zahariev, and D. Kinaneva, “Forest Monitoring System for Early Fire Detection Based on Convolutional Neural Network and UAV imagery,” in *28th National Conference with International Participation, TELECOM 2020 - Proceedings*, Oct. 2020, pp. 57–60. doi: 10.1109/TELECOM50385.2020.9299566.

[11]N. Nithyavathy, S. Arun Kumar, D. Rahul, B. Satheesh Kumar, E. R. Shanthini, and C. Naveen, “Detection of fire prone environment using Thermal Sensing Drone,” *IOP Conf Ser Mater Sci Eng*, vol. 1055, no. 1, p. 012006, Feb. 2021, doi: 10.1088/1757-899x/1055/1/012006.

[12]“A review on early wildfire detection from unmanned aerial vehicles using deep learning-based computer vision algorithms | Elsevier Enhanced Reader.” 0165-1684/© 2021 Elsevier B.V.

[13]P. Chamoso, A. González-Briones, F. De, L. Prieta, and J. M. Corchado, “Computer vision system for fire detection and report using UAVs.” Proceedings of the RSFF’18 Workshop, L’Aquila, Italy, 19-20-July-2018, published at http://ceur-ws.org.

[14]K. D. Nguyen and C. Ha, “Development of Hardware-in-the-Loop Simulation Based on Gazebo and Pixhawk for Unmanned Aerial Vehicles,” *International Journal of Aeronautical and Space Sciences*, vol. 19, no. 1, pp. 238–249, Mar. 2018, doi: 10.1007/s42405-018-0012-8.

[15]S. Ahirwar, R. Swarnkar, S. Bhukya, and G. Namwade, “Application of Drone in Agriculture,” *Int J Curr Microbiol Appl Sci*, vol. 8, no. 01, pp. 2500–2505, Jan. 2019, doi: 10.20546/ijcmas.2019.801.264.

[16]K. Yang, G. You Yang, and S. Isi Huang Fu, “Research of control system for plant protection UAV based on Pixhawk,” in *Procedia Computer Science*, 2020, vol. 166, pp. 371–375. doi: 10.1016/j.procs.2020.02.082.

[17]“UrukTech Electronics.” https://www.uruktech.com/ (accessed Feb. 03, 2023).

[18]N. Nithyavathy, S. Arun Kumar, D. Rahul, B. Satheesh Kumar, E. R. Shanthini, and C. Naveen, “Detection of fire prone environment using Thermal Sensing Drone,” *IOP Conf Ser Mater Sci Eng*, vol. 1055, no. 1, p. 012006, Feb. 2021, doi: 10.1088/1757-899x/1055/1/012006.

[19]M. M. Nabeel and S. W. Al-Shammari, “A Comparison Study for applying Different Deep Learning Models On Fire Detection method,” 2022 Iraqi International Conference on Communication and Information Technologies (IICCIT), 26–31, Jan. 2023, doi: 10.1109/IICCIT55816.2022.10010