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IoT-based Autonomous Search and Rescue Drone for Precision Firefighting and Disaster Management

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***Abstract*—Disaster management is a line of work that deals with the lives of people, such work requires utmost precision, accuracy, and tough decision-making under critical situations. Our research aims to utilize Internet of Things (IoT)-based autonomous drones to provide detailed situational awareness and assessment of these dangerous areas to rescue personnel, firefighters, and police officers. The research involves the integration of four systems with our drone, each capable of tackling situations the drone can be in. As the recognition of civilians and protecting them is a key aspect of disaster management, our first system (i.e., Enhanced Human Identification System) to detect trapped victims and provide rescue personnel the identity of the human located. Moreover, it also leverages an Enhanced Deep Super-Resolution Network (EDSR) x4-based Upscaling technology to improve the image of human located. The second system is the Fire Extinguishing System which is equipped with an inbuilt fire extinguisher and a webcam to detect and put off fire at disaster sites to ensure the safety of both trapped civilians and rescue personnels. The third system (i.e., Active Obstacle Avoidance system) ensures the safety of the drone as well as any civilians the drone encounters by detecting any obstacle surrounding its pre-defined path and preventing the drone from any collision with an obstacle. The final system (i.e., Air Quality and Temperature Monitoring system) provides situational awareness to the rescue personnel. To accurately analyze the area and its safety levels, inform the rescue force on whether to take precautions such as wearing a fire proximity suit in case of high temperature or trying a different approach to manage the disaster. With these integrated systems, Autonomous surveillance drones with such capabilities will improve the equation of autonomous Search and Rescue (SAR) operations to a great extent as every aspect of our approach considers both the rescuer and victims in a region of disaster.**

Keywords—Search and rescue; firefighting; internet of things; disaster management

I. INTRODUCTION

India has a history of being particularly susceptible to natural disasters due to its geo-climatic conditions. Landslides, cyclones, earthquakes, floods, and droughts have been frequent occurrences. Every single year from 1990 to 2000 [1], there were approximately 4344 calamities and over 30 million people were greatly affected by disasters followed by a significant increase in frequency and extremity of natural disasters between 2000 and 2020. The government has initiated steps to improve its rescue support and approach to responding to disasters, but there is lots of room for improvement to protect the vulnerable and significantly reduce the impact of natural disasters in this densely populated country. Over the past few decades, Unmanned Aerial Vehicles (UAV) have increased in popularity rapidly. Drones are UAVs that are controlled using remotes or can fly autonomously [2]. They can be made to perform Search and Rescue (SAR) operations, provide early disaster warnings to humans, analyze the damage, deliver important supplies to isolated or inaccessible locations, and aid in communication with blacked-out areas. This paper deals with providing a sophisticated drone for autonomous search and rescue operations during disasters with the motive to rescue the lives of both the victims and the rescue personnel with the added capabilities of firefighting. This is achieved by the integration of multiple precision IoT sensors and cameras for completely utilizing the drone's position in a zone of disaster that is unsafe for any human. Apart from transmitting real-time sensor data to the ground rescue team, it is also integrated with a sophisticated Enhanced Human Identification System to keep track of all humans encountered during the drone’s SAR operation. The paper also explains how inbuilt fire extinguishers installed in drones can be utilized to extinguish dangerous fires located at disaster sites, thereby providing a safe entry/exit path for rescue personnel, and hence improving the rescue effectiveness and efficiency.

In the past several researchers have worked on the various potential applications of drones in disaster management, such as Search and Rescue (SAR), damage assessment and communication. As discussed in study [3] the benefits to explore a range of applications of drones in disaster management and how they can change the entire aspect to solve key challenges involved. Similarly, in [4] presents the design and creation of a low-cost, autonomous drone that is capable of communication, surveillance, and transportation of medical supplies utilizing an integrated GPS and real-time video streaming. In [5], the author conducts a brief survey of video surveillance using drones and highlights the challenges that come along with the technology, such as battery life, data transmission, image processing, and privacy concerns. The high-rise buildings have less accessibility, but when sensors are set up and in case any fire is detected, it is meant to send a message to the control room and give the GPS location to the cloud-enabled drone can be piloted to the affected spots and give situational awareness to firefighters, was the idea given by the author of [6]. Similarly, drones can be used for assisting in rescues during times of disasters [7]. The authors of [8] present the idea of integrating fire-fighting drones that will act as first respondents and will ensure enhanced response time and send necessary details to the control center. [9] presents a similar approach for the early detection of forest fires using two sets of drones, i.e., Fixed wing Unmanned

Aerial Vehicles (UAV) and Rotary-wing UAV with the assistance of artificial intelligence. In study [10] the author gives a brief insight into the concept of using drone as a technology-driven solution that highlights the potential to revolutionize this domain by providing improvised access to healthcare services during times of disaster. In research [11], the authors provide a conceptual framework of drone swarms for fire suppression activities. The framework consists of various stages, such as fire detection, decision-making, and intervention. The results of study [12] indicate the approach of utilizing UAVs as aerial base stations to help in providing reliable communication coverage and connectivity in disaster scenarios. Low-cost-drone-borne synthetic-aperture radar imaging system that can generate high-quality images in various scenarios, including complex terrain and urban environments. The proposed system has the potential range of applications, disaster management, agriculture, and urban planning are a few examples [13]. The study in [14] presents a similar hybrid drone-based radar system for vital sign imaging in disaster management scenarios. Lastly, the development of an Enhanced Deep Super-Resolution Network (EDSR) [15] that can upscale images to make their resolution better can be used to identify humans with utmost precision after locating them.

Overall, the previous and related works show that drones have significant potential for firefighting and disaster-management applications. However, many challenges must be addressed to fully realize the potential of drones in disaster management. Most of the papers have been seen to implement a single task with the help of multiple drones which is not cost-effective and brings in the complication of maintaining them and having to always keep track of their coordination. Similarly, another challenge that was noticed in a few papers was that the overall features for disaster management were not implemented. Keeping these ideas and the demerits of the previous works in mind, this paper implements the integration of a single drone with the concepts of deep learning and the Internet of Things, the drone is infused with multiple systems such as the Air quality and temperature monitoring system, Active Obstacle Avoidance system and most importantly the Fire Extinguishing system. This brings novelty into the research in the implementation approach that has not been explored yet until now.

The rest of this paper is organized as follows. Section II explains the methodology of the proposed work where we introduce a system that has four systems integrated with our drone which consist of an Enhanced Human Identification system, Fire Extinguishing system, Active Obstacle Avoidance system and Air Quality and Temperature Monitoring system. In Section III, we will delve into Hardware setup, Section IV provides the results. The paper ends with Section V and Section VI respectively where we have written concluding remarks on the potential capabilities of the research and future scope.

II. METHODOLOGY

This research work depends on the strong autonomous capabilities of the drone. Being autonomous is the foundation and is achieved by the integration of a companion computer Raspberry Pi 3B which is connected to the flight controller, the Pixhawk 2.4.8 as shown in Fig. 1. The connection is made via the telemetry port on the Pixhawk. All the data is communicated using appropriate MAVLINK protocols. With this setup, we have achieved Raspberry Pi-controlled drone movements.

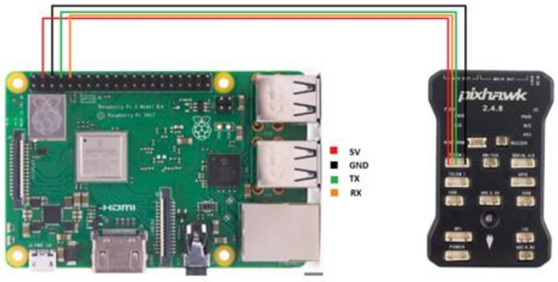


Fig. 1. Connections from raspberry Pi to Pixhawk 2.4.8.

Now the drone is capable of autonomous takeoff, landing, and maneuvering based on both a predefined path, as well as the surrounding conditions perceived by the sensors and cameras used. These main functionalities have been explained in detail in the following system:

1) *Enhanced* human identification system
2) *Fire* extinguishing system
3) *Active* obstacle avoidance system
4) *Air* quality and temperature monitoring system

A. *Enhanced Human Identification System*

The drone is equipped with an inbuilt webcam to provide rescue personnel with live footage to keep them regularly updated on the surrounding environment of the affected disaster site. However, the main purpose of this system is to provide a human detection system to identify trapped victims in disaster sites. This enables us to keep track of all the humans encountered in the drone's path during its flight. Unfortunately, the drone is expected to be recording subpar images in harsh situations where surroundings are filled with smoke, dust, fire, and relative movement of the drone and human. Hence, we are leveraging a EDSR based image resolution enhancement architecture to be able to identify the human with increased ease after the face detection system stores the faces in the database. Therefore, we are able to achieve a resulting output image with a four times Scaling Factor.

1) Advanced face detection: We have implemented the human identification by deploying a face detection feature that uses OpenCV and Deep-Learning technique called Single Shot Detector (SSD), where once a face is identified, the image of that face is clicked and saved in a database which is accessible only to rescue personnels. Once the image is stored, an alert message is sent to the rescue personnel with a prompt, informing them that a victim has been identified. This feature uses the "Twilio" API to send messages which uses a secure authentication token and a specific SSID which makes this a highly secure communication line as seen in Fig. 2. Using this information, rescue personnel can keep track of the victim's location and carry out their rescue operation more efficiently.

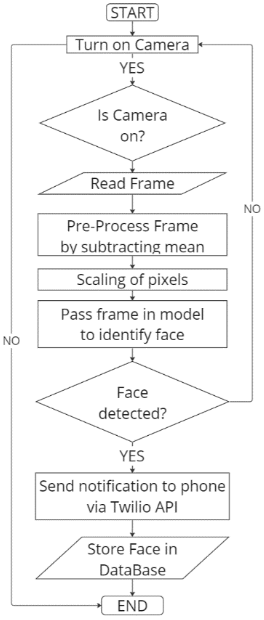


Fig. 2. Workflow of advanced face detection.

In the Algorithm 1, we have explained the Single Shot Detector which is used to identify the human face from an input frame.

Algorithm 1: Single Shot Detector

a) Load the pre-trained model and define the input size.

b) For each image in the input:

- Preprocess the image.
- Feed the image through the network.
- Obtain the predicted class scores and bounding box coordinates.
- Apply non-maximum suppression to remove overlapping boxes.
- Draw the remaining boxes on the image and output the result.

2) EDSR x4 image enhancement: The Enhanced Deep Super Resolution (EDSR) x4 architecture is based on a sophisticated CNN specifically designed to upscale low-resolution images to specifically bring out the hidden details. It is inspired by the ResNet architecture that is characterized by a deeply stacked layers which leverages residual connections. The architecture initially employed a scaling factor of 2, subsequently 3 and then finally 4 in order to reaching a x4 scaling factor. This accelerates both the training and the overall performance of the model. The images form the database are retrieved to process through EDSR and the Layers and Components for EDSR x4 as seen in Fig. 3 is explained as follows:

a) Input Layer:

- Accepts the low-resolution image as input.

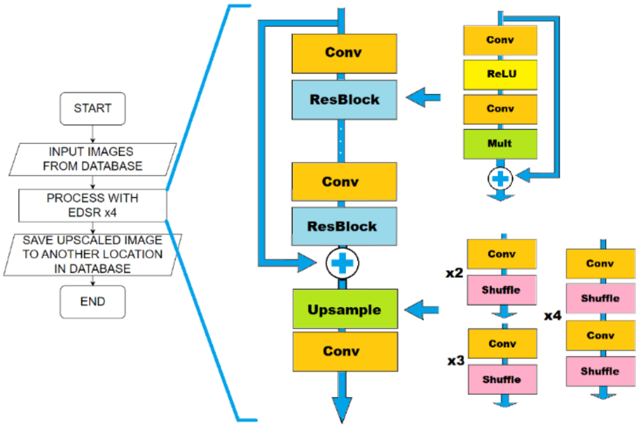


Fig. 3. Workflow of EDSR x4 image enhancement.

b) Feature Extraction Layers:

- Utilizes convolutional layers without batch normalization and ReLU activation to extract relevant features from the input image.
- ResNet-style architecture is employed for feature extraction.

c) Residual Blocks:

- These are the core building blocks of EDSR x4, following the ResNet style.
- Each residual block consists of:
  - Convolutional layers without batch normalization and ReLU activation.
  - Skip connections that bypass one or more convolutional layers and are added to the output.
  - Constant scaling layers placed after the last convolutional layers in each residual block with a factor of 0.1.
- The absence of batch normalization allows for greater range flexibility in the features' networks.

d) Skip Connections:

- These connections enable the network to learn residual details, facilitating the learning of high-frequency details.

e) Upsampling Layers:

- Utilizes techniques like nearest-neighbor interpolation or transposed convolution to upscale the feature maps.
- These layers increase the spatial resolution while preserving the learned features.

f) Output Layer:

- Produces the high-resolution image as the final output.
- By processing the human face images from the database using this technique, we can overcome the drawback of blurred images taken by the drone and

hence identify the human with ease due to its higher resolution resulting image.

B. Fire Extinguishing System

This system mainly deals with the detection and extinguishing of fire at disaster sites to ensure safety of both trapped civilians and rescue personnel. These outcomes are achieved by utilizing Raspberry Pi for on-board computations required to detect fire through an inbuilt Raspberry Pi camera along with servo motor to activate the fire extinguisher at the bottom of the drone. First, the armed drone monitors a particular area in its pre-defined path to check for any fires. Once the fire is detected, the drone lowers its altitude to get an effective range to carry out extinguishing process by using the inbuilt fire extinguisher after which it returns to optimum altitude to resume its surveillance process. The entire workflow of the fire extinguishing system is shown in Fig. 4.

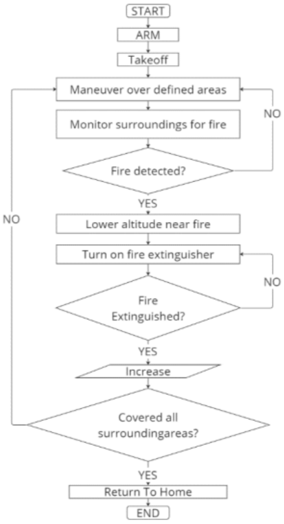


Fig. 4. Workflow of fire extinguishing system.

This classifier contains patterns of fire in images that have been previously trained, and it is used to identify potential fire regions in the video frames. Initialize Camera:

The cv2.VideoCapture() function is used to initialize the camera and establish a connection to capture live video feed. The camera is set to capture frames continuously in a loop.Process Video Frames: The code captures video frames from the camera in a loop using vid.read() function. For each frame, it performs the following operations:

1) Convert to grayscale: The frame is converted to grayscale using cv2.cvtColor() function. This step reduces the computational complexity and simplifies the fire detection process as the color information is not needed for fire detection.

2) Detect fire regions: The grayscale frame is passed to the loaded cascade classifier using fire_cascade.detectMultiScale() function. This function detects potential fire regions in the frame based on the patterns learned by the classifier.

3) Draw rectangles: For each detected fire region, a rectangle is drawn around it uses cv2.rectangle() function. This visually highlights the detected fire regions in the frame.

4) Display processed frame: The frame with highlighted fire regions is displayed using cv2.imshow() function. This allows visual inspection of the processed frame with detected fire regions.

5) Exit the loop: The code continues capturing video frames, applying fire detection, playing the alarm sound, and displaying processed frames until the 'q' key is pressed. Once the 'q' key is pressed, the loop is exited, and the code terminates.

Overall, the code continuously captures video frames, detects fire regions in the frames, plays an alarm sound, and displays processed frames with highlighted fire regions, providing a guide to the fire extinguishing system using a cascade classifier and a camera.

C. Active Obstacle Avoidance System

The active obstacle avoidance system is the main backbone of the autonomous flying aspect of the drone; it is to ensure the safety of the drone as well as any civilians the drone encounters. The system works primarily with the help of the four HC-SR04 sensors on each side of the drone as seen in Fig. 5, which are connected to the Arduino-Uno which is in turn connected to the Pixhawk flight controller. The drone’s front and back movement is controlled by the Pitch. If the Pitch increases the drone moves backwards and if it decreases the drone moves forward. Similarly, the roll of a drone refers to the rotation of the drone around its longitudinal axis. When a drone rolls, it tilts to the left or right while keeping its heading unchanged. Roll controls the drone's left and right movements. If the roll increases the drone moves towards the right and if it decreases the drone moves towards the left.

Fig. 5. Representation of the front, back, right, and left sensors on the drone.

The Pixhawk flight controller controls the movement of the drone and receives commands from the remote control through its radio receiver. The Arduino-Uno is linked to the Pixhawk's RX and TX ports to integrate the active obstacle avoidance system with the flight controller. This is done to enable communication between the two devices. The Arduino-Uno sends obstacle detection information to the Pixhawk flight controller via the TX pin, which the Pixhawk interprets to adjust the drone's flight path to avoid the detected obstacles. The reason why digital pins 10 and 11 are used for this connection is that they are designated as hardware serial communication pins on the Arduino-UNO board. By using hardware serial communication, the communication between the Arduino-Uno and the Pixhawk flight controller is fast, reliable, and minimizes the risk of communication errors

The first step in the methodology is to acquire the data from the ultrasonic sensors. The ultrasonic sensors are used to detect obstacles in the immediate vicinity of the drone and calculate the distance of the obstacle from the drone. The data acquired from the sensors is processed using algorithms that calculate the distance of the obstacles from the drone. Once the distance from the ultrasonic sensors has been acquired the sensors change the Pitch or roll value of the drone depending on which sensor has detected an obstacle.

The equation for the change in Pitch when an obstacle is detected by the FRONT SENSOR within its range is given by Eq. (1):

$$PITCH\_BACK = 1500 + 30 + ((100 - FRONT\_SENSOR) * 6) \quad (1)$$

where PITCH_BACK = the Pitch value to make sure the drone moves back,

1500 = Mid Term,

30 = initial increment when object detected at 99cm,

100 = Range of the sensors(cm),

FRONT_SENSOR = Front sensor distance (cm).

The relation between the Pitch and the distance is given by the following graph in Fig. 6.

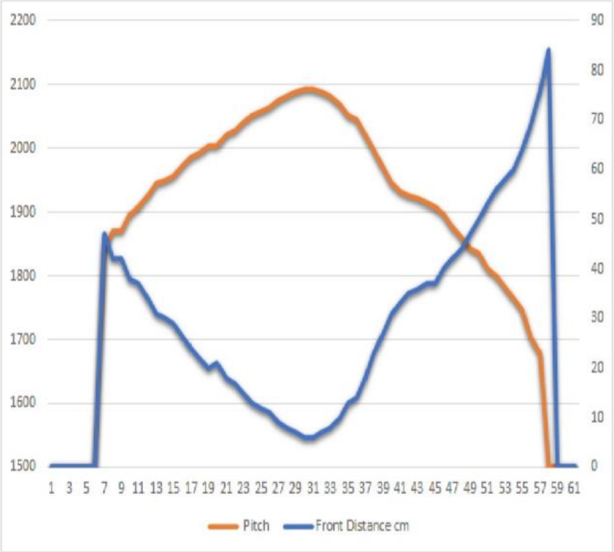


Fig. 6. Graph depicting the relation between pitch and the front distance.

Fig. 7 shows the working of the active obstacle avoidance system wherein we can see, once the ultrasonic sensors start operating, they start detecting any obstacle within the radius of 100 centimeters around it. Then through the digital pin number, they get to know which sensor has detected an obstacle and depending on that the roll or the Pitch must be changed, and then it either increases or decreases Pitch if the object is detected in the front or back respectively. The roll is changed by either decreasing or increasing it when the obstacle is detected on the right or left side respectively.

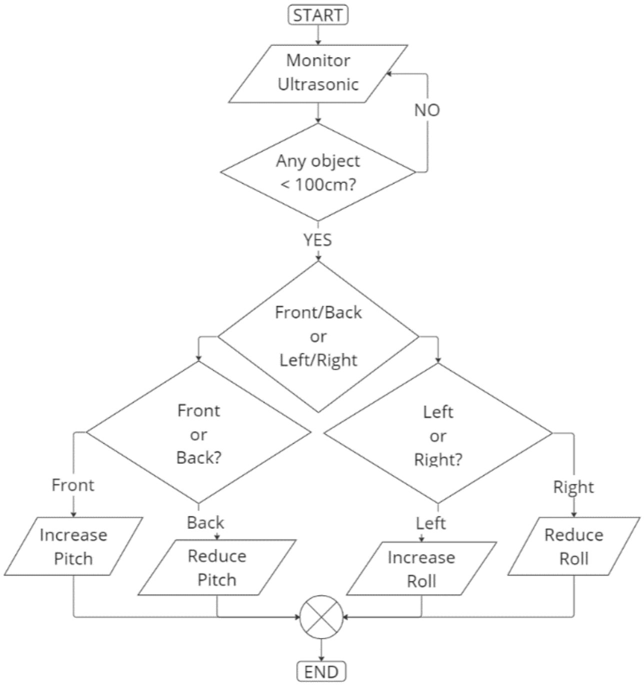


Fig. 7. Workflow of active obstacle-avoidance system.

D. Air Quality and Temperature Monitoring System

This system takes advantage of the drone's position in a region of disaster prior to the arrival of the rescue team. Alerting the rescue teams is done based on current environment conditions which are determined by several factors like temperature, humidity and air quality. To monitor these factors regularly our drone is equipped with a Temperature and smoke sensor which is seamlessly integrated into smartphones through an application called Blynk.App which obtains the data through the NodeMCU ESP8266 module and stores the data in Blynk.Cloud. Blynk.App is a mobile application to prototype, deploy and manage connected electronic devices at any scale. Real-time data are obtained by these connected devices and are stored in the Blynk.Cloud. Using an API, the devices easily connect to the platform and take advantage of all its advance features. The live values of the surrounding environment are being read by this system and can be viewed through the application for monitoring purposes.

1) Air quality monitoring: The sensor used to perceive data is the MQ2 sensor, which is sensitive to H_2, LPG, CH_4, CO, alcohol, smoke, propane, and air. Fig. 8 explains the step-by-step working of this monitoring system. The toxicity of the air and the presence of smoke is what we are interested in this Air Quality System. Once the sensor starts, the toxicity of the air is calculated by the concentrations of methane, ethane, butane, propane, and hydrogen present in the surrounding environment. The final toxicity value has to be perceived in terms of parts per million (ppm) for the convenience of easily making decisions. The ppm calculation is based on the resistance ratio (RS/R0). RS is calculated using Eq. (2). Using the RS value calculated in Eq. (1) we find the R0 value using Eq. (3).

$$RS = [(VC - RL)/ Vout] - RL \tag{2}$$

$$R0 = RS/\text{Fresh air ratio value from the datasheet} \tag{3}$$

Where RS = Change in resistance on detecting gas,

R0 = Stable sensor resistance in the fresh air,

V_C = Voltage Current,

V_{out} = Output voltage,

RL = Load Resistance.

Now that we have access to the live ppm values, we are able to conveniently perform analysis. In this research work, we have assumed three values of the threshold for monitoring purposes (i.e. 500 ppm, 700 ppm, and 800 ppm) for feasible testing. These values can be changed and set accurately for real-life scenarios. So, based on these three threshold values we generate appropriate response messages which will be uploaded to the Blynk.Cloud from where the message is sent to the user's phone via the Blynk.App. This way the rescue team can utilize appropriate safety gears and precautions based on the severity of the situation determined by this system.

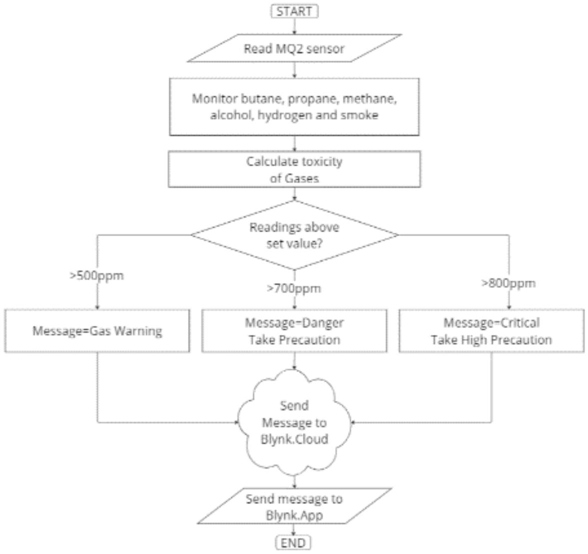


Fig. 8. Workflow of air quality monitoring system.

2) Temperature monitoring system: We are using the DHT11 sensor to monitor the temperature in the surrounding area. This sensor is connected to both the Raspberry Pi and the NodeMCU 8266 module. The workflow of this system is shown in detail in Fig. 9. Once the DHT11 Sensor starts, we obtain the temperature value in Celsius. Based on what temperatures the human body can bear or withstand, we have taken into consideration 35°C and 40°C as threshold values.

Based on the temperature threshold, the response message will help the rescue team to take appropriate safety measures. These appropriate response messages will be uploaded to the Blynk.Cloud from where the message is sent to the user's phone via the Blynk.App. These messages generated are sent to the rescue team and ground station to provide awareness about the situation in the disaster zone. Alerts are sent to the smartphone in several ways such as Blynk application as a popup alert, phone notification with the alert message and Sent as a mail to the recipient of choice with relevant information obtained from Blynk.Cloud.

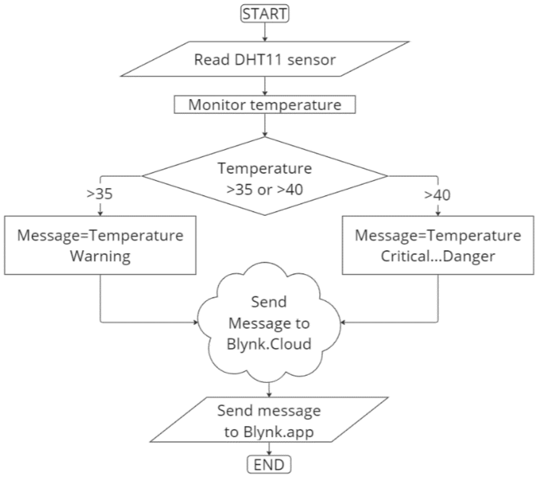


Fig. 9. Workflow of temperature monitoring system.

In real life scenarios, there are possibilities where there exists a high temperature environment where the content of smoke in the area might be less or even negligible, likewise, even the possibility of high smoke presence without the presence of fire as shown in Fig. 10.

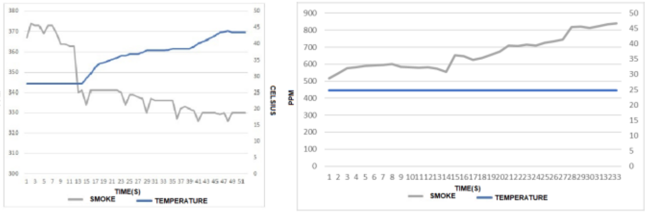


Fig. 10. Sensor readings for cases of high smoke / temperature.

Alerts are based on predefined safety values to ensure a safe and assessed environment as seen in Table I.

TABLE I. SPECIALIZED ALERT MESSAGES BASED ON ENVIRONMENTAL CONDITIONS

Parameter	Condition	Alert Message
Temperature	Temperature is greater than 30°C.	"Temp Over 30°C."
Temperature	If the temperature is greater than 45°C.	"Take Precaution!! Temp Over 45°C."
Gas Toxicity/Smoke	If greater than 500 ppm.	"Gas Conc Over 500 Ppm."
Gas Toxicity/Smoke	If greater than 700 ppm.	"Take Precaution!! Conc Over 700 Ppm."
Gas Toxicity/Smoke	If greater than 800 ppm.	"Condition Critical Gas Conc Over 800 Ppm."

III. HARDWARE SETUP

The various components required to establish the four systems have to be placed on the drone accordingly. The Fig. 11 shows how the Enhanced Human Identification system where the camera that is attached to the Raspberry Pi is placed in front of the drone such that we get the exact look at the Drone's view. The Active Obstacle Avoidance system consisting is placed on all four sides of the drone as seen in Fig. 11.

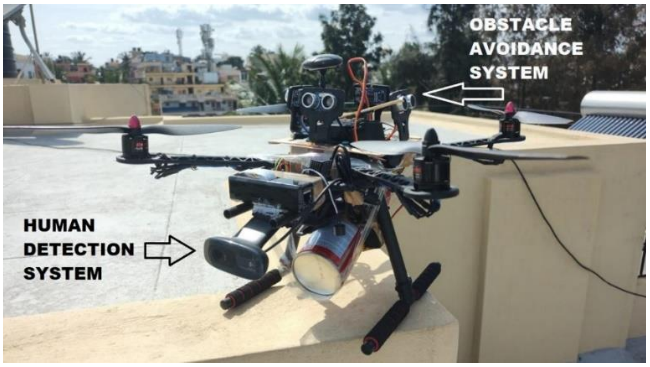


Fig. 11. Setup of the enhanced human identification system and the active obstacle avoidance system.

Fig. 12 shows the setup of the Fire Extinguishing system where the Fire extinguisher is placed under the drone and connected to a servo motor that presses on the spray when fire is detected.

Fig. 12. Setup of the fire extinguishing system.

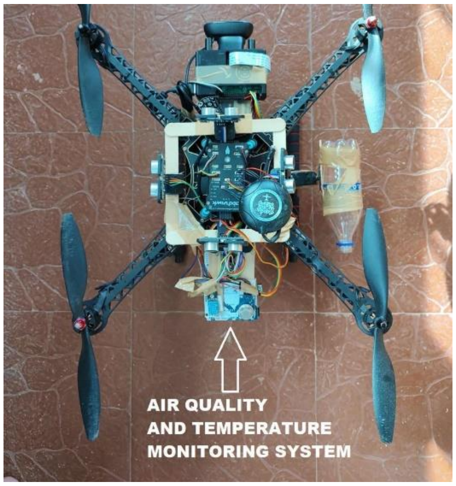


Fig. 13. Setup of the air quality and temperature monitoring system.

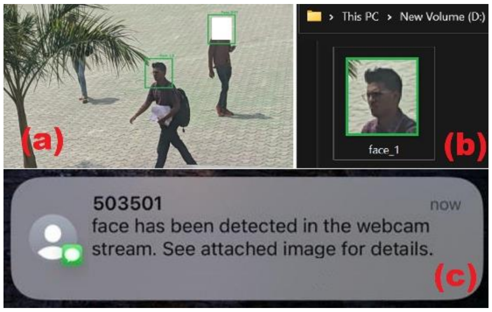
Lastly, Fig. 13 shows the setup of the MQ-2 sensor and DHT-11 sensors which are a part of the Air Quality and Temperature Monitoring system is attached over the drone's length such that the sensor readings are not affected by the heat generated by the components.

IV. RESULTS

The IoT-based autonomous drone has the true potential to revolutionize aid and relief in the field of disaster management. The drone's advanced capabilities to collect real-time data, analyze complex situations and facilitate well-informed decision-making can make a huge impact in the effectiveness of emergency response efforts, leading to an efficient method with increased safety measures to minimize the impact of disasters. To explain the working of our proposed solution, we have divided the following explanations into each of the dedicated systems of our proposed model which includes Enhanced Human Identification System, Fire Extinguishing System, Active Obstacle Avoidance System and Air-Quality and Temperature Monitoring System.

A. Enhanced Human Detection Identification System

1) Advanced face detection: The face detection system is used to keep track of the civilians encountered by the drone during its surveillance operation. This system works in real-time and continuously monitors the surroundings for humans. This happens as shown in Fig. 14. The Face Detection System uses Single Shot Detector Algorithm to detect trapped victims as seen in Fig. 14(a) and is stored into a dataset to keep track of the trapped victim as seen in Fig. 14(b). Once the victim is detected an alert message is sent to the rescue personnel to notify them of the trapped victim as seen in Fig. 14(c).



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face has been detected in the webcam stream. See attached image for details.

Fig. 14. (a): Detection of facial features in real time (b) Detected faces stored at dedicated location (c) Push notification alerts when face is detected.

2) EDSR x4 image enhancement: Once the image is stored in the database, by the Advanced Face Detection, it is enhanced to achieve a better resolution to identify the human easily. In Fig. 15(a), we can see the original image, and Fig. 15(b) shows the enhanced image using the EDSR Super-Resolution. It is evident that the enhanced image is more detailed and the facial features are brought up. Additionally, it has enhanced the 100 pixel x100 pixel image into a 400 pixel x 400 pixel image. This enhancement is done after its stored in the database because this process is resource intensive and therefore not viable to be a part before its stored in the database in the Advanced Face Detection System.

B. Fire Extinguishing System

This system utilizes a pre-trained cascade classifier-based fire detection system which can accurately detect the fire shown. Since we could not replicate large scale fires, we used images from online resources for testing purposes before deploying it on the drone. This image given as input can be seen in Fig. 16(a) and the camera's perspective of it is given in Fig. 16(b).

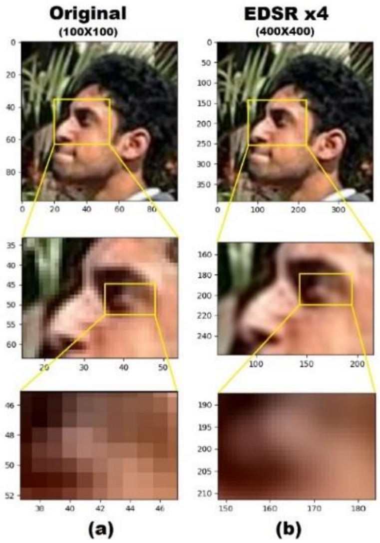


Fig. 15. (a): Original image from the database (b) EDSR x4 scaled image.

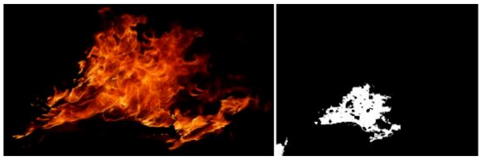


Fig. 16. (a) Sample fire used for testing fire detection (b) Camera's perspective of the fire.

The drone in on the ground as shown in Fig. 17(a), and it begins to take off and surveil in the defined areas. Once the drone encounters the fire region, it begins to extinguish the fire as shown in Fig. 17(b). We have been able to come up with an approach that effectively detects fire in the presence of high temperatures and smoke and tries to extinguish it. In our testing and evaluation phase, it was found that the system detected the fire with huge accuracy and precision.

Fig. 17. (a) Drone on ground with paper on fire in front (b) Drone extinguishing the fire.

C. Active Obstacle Avoidance System

Obstacle avoidance is an add-on feature to the autonomous maneuverings of the drone to ensure the drone does not collide with anything. The Arduino-Uno is used for this specific purpose, with it we have placed HC-SR04 ultrasonic sensors in all four directions of the drone to consider obstacles from any of the four sides. This system has multiple use cases, let us consider a civilian running away from disaster in a state of panic, and may not notice a drone in the field due to several reasons such as loud surroundings, too much smoke to look around, etc. Collision with the drone will cause injuries to the civilian which is against the objective of the drone's mission. Hence by using ultrasonic sensors, we overcome this problem. Another such use case can be the possibility of a building wall breaking down towards the drone where it must move away to protect itself. Hence, this system is programmed to consider all the obstacles at any given time and prioritizes the obstacle closer to the drone over the obstacle further away from it. Hence, we shall now consider these cases and understand the working of the active obstacle avoidance system. Hence, from the below cases considered it is observed that various combinations of sensor input are being given, the reaction of the drone is consistent and prioritizes the closer obstacle ensuring the safety of the objects surrounding it.

Case 1 - Obstacle in the Front and Back of the Drone.: There is an obstacle in the front and back of the drone. In this case, as we can see in Fig. 18(a), as the front distance increases the Pitch decreases and as the back distance increases the Pitch increases.

Case 2 - Obstacle in the Front and Right of the Drone: As we can clearly see from the graph below in Fig. 18(b), when there is an object in the front the pitch changes and the roll remain unchanged, while when there is an object detected in the left the pitch remains unchanged while the roll changes. Finally, when there is an obstacle detected both in the front and back the object changes both its pitch and roll which makes it move diagonally and the graph in Fig. 18(b) depicts the relationship between them.

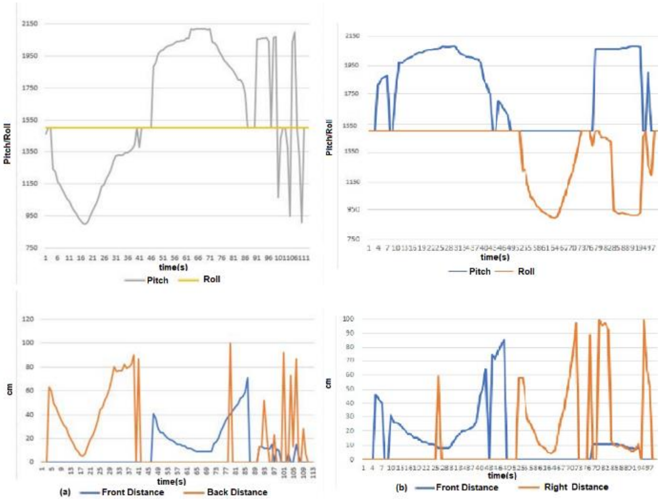


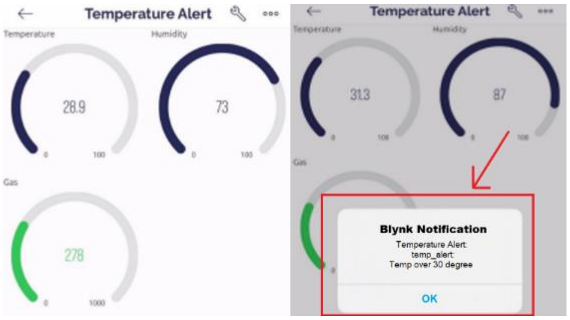
Fig. 18. Graph depicting the relation between Pitch, roll, and front and right distance for Case 1 (18 (a)), Case 2 (18 (b)).

Let us consider a situation as shown in Fig. 19(a) wherein the drone detects an obstacle with its FRONT SENSOR within the set range, now the drone has to move backwards and that can be achieved by increasing the Pitch of the drone as per the Eq. (3) as seen in Fig. 19(b).

D. *Air Quality and Temperature Monitoring System*

This system consists of sensors integrated with the drone to monitor the temperature, humidity and toxicity levels of the surrounding area to alert rescue personnel of the need to prepare themselves with high safety measures with the required precaution that can save their lives.

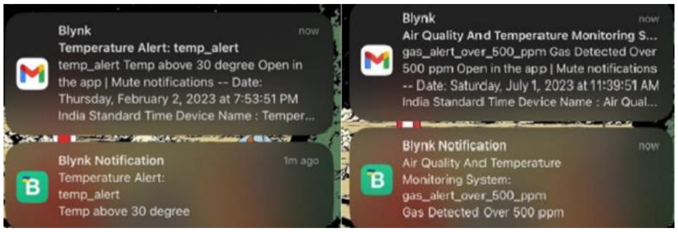
Fig. 19. (a): Obstacle introduced in front of the drone (b) Drone moving away from the introduced obstacle.



Blynk Notification
Temperature Alert:
temp_alert:
Temp over 30 degree

Fig. 20. (a): Live monitoring of sensor values on smartphone (b) Illustration of blynk.app alerting the user in case of high temperature.

The values read by the sensors are processed and shown in an easy minimalist way on the Blynk application for easy understanding by the user as seen in Fig. 20(a) which has gauges for temperature, humidity and gas. The depicted gas value is the combined toxicity of the composition of Butane, Methane, LPG, Smoke, Alcohol, Propane, and Hydrogen which is measured in ppm. If there is a spike in any of these levels, then the smartphone is alerted regarding the critical status based on the scenario in the following methods: Firstly, as seen in Fig. 20(b), the Blynk.App notifies the user with a popup alerting the user about the increased temperature conditions at the current location of the drone and similarly displays popups for unusually high gas toxicity. Secondly, As phone notification with the alert message. Fig. 21(a) shows the alerts for temperatures above 30 °C. Similarly, notifications will be provided for higher temperatures as well. As seen in Fig. 21(b), the notification system ensures the user is alerted even when not using the Blynk application by providing a push notification feature which demonstrates the different notifications sent to the phone based on our tested gas toxic levels of 500ppm, 700ppm and 800ppm as per Table I and finally, Sent as a mail to the recipient of choice with relevant information.



Blynk now
Temperature Alert: temp_alert
temp_alert Temp above 30 degree Open in the app | Mute notifications -- Date: Thursday, February 2, 2023 at 7:53:51 PM India Standard Time Device Name : Temper...

Blynk Notification 1m ago
Temperature Alert:
temp_alert
Temp above 30 degree

Blynk now
Air Quality And Temperature Monitoring S...
gas_alert_over_500_ppm Gas Detected Over 500 ppm Open in the app | Mute notifications -- Date: Saturday, July 1, 2023 at 11:39:51 AM India Standard Time Device Name : Air Qual...

Blynk Notification now
Air Quality And Temperature Monitoring System:
gas_alert_over_500_ppm
Gas Detected Over 500 ppm

Fig. 21. (a): Blynk.app notification and mail sent to users for high-temperature.(b): Blynk.app notification and mail sent to users for high-toxic levels.

These alerts to the user are purely based on the readings from the sensors used. Hence, we are successfully able to accurately analyze the environmental situation using the onboard sensors and provide the rescue team with appropriate alert messages which will allow them to decide their approach to rescue. They can also opt to wear fire proximity suits in case of high temperatures, or chemical mask suits for protection against breathing toxic gases during the rescue. Due to a lack of testing with real toxic gases, we have set the temperature and gas threshold to ideal values to show output alerts. However, these values can be tuned as per real-life conditional levels easily.

V. CONCLUSION

In conclusion, the use of IoT-enabled drones for disaster management has enormous potential for enhancing the efficiency of emergency services during natural disasters and other emergencies. Rescue teams can quickly survey disaster-affected areas, find survivors, evaluate damage, and give first responders, on the ground real-time, situational awareness by utilizing these four systems namely Enhanced Human Identification System, Fire Extinguishing System, Active Obstacle Avoidance System and Air-Quality and Temperature Monitoring System. These systems provide added capabilities to these unmanned aerial vehicles solving major problems faced by rescue personnel. Emergency rescue personnel can use this knowledge to make wise decisions in saving the victims. With added Deep Learning model, the drone is more efficient in detecting human and fire, so that we can identify the trapped victims in disaster sites and extinguish dangerous fires, thereby creating an effective rescue process which ensures safety of victims and the rescue personnel involved.

VI. FUTURE WORK

Our current implementation of the method was designed with careful consideration of our economic constraints. The proposed solution adopts a cost-effective approach, employing a Raspberry Pi 3B as a companion computer and a basic Pixhawk 2.4.8 flight controller. However, the reliability of our obstacle avoidance system, utilizing the SR04 sensor, falls short of industrial standards due to its low resolution in distance input. Furthermore, the software approach employed for face detection, utilizing the Single Shot Detector, though faster, lacks accuracy. To enhance the overall efficiency of our methodologies, acquiring industry-standard components for drones is imperative. The following outlines the future scope of the project:

1) Incorporating a Nvidia Jetson Nano as a companion computer will enable us to integrate more sophisticated and resource-intensive algorithms, thereby enhancing computational capabilities.

2) The integration of thermal cameras is proposed as a more effective alternative to traditional cameras. Thermal cameras demonstrate improved capability in detecting humans through smoke, dust, and debris, making them invaluable in challenging environments.

3) Exploring more effective and lightweight alternatives to traditional fire extinguishing techniques is a potential avenue for improvement. This could involve adopting innovative approaches to firefighting that align with the latest industry standards.

By implementing these advancements, we anticipate a significant improvement in the overall efficiency and performance of our proposed methodologies for drone applications in various scenarios.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] UNICEF. "Disaster Risk Reduction." UNICEF India. [Accessed on June 17, 2023]. Available at: https://www.unicef.org/india/what-we-do/disaster-risk-reduction.

[2] Tanzi, Tullio Joseph, Madhu Chandra, Jean Isnard, Daniel Camara, Olivier Sebastien, and Fanilo Harivelo. "Towards" drone-borne" disaster management: future application scenarios." In XXIII ISPRS Congress, Commission VIII (Volume III-8), vol. 3, pp. 181-189. Copernicus GmbH, 2016.

[3] Daud, Sharifah Mastura Syed Mohd, Mohd Yusmiaidil Putera Mohd Yusof, Chong Chin Heo, Lay See Khoo, Mansharan Kaur Chainchel Singh, Mohd Shah Mahmood, and Hapizah Nawawi. "Applications of drone in disaster management: A scoping review." Science & Justice 62, no. 1 (2022): 30-42.

[4] Saha, HimadriNath, Srijita Basu, Supratim Auddy, Ratul Dey, Arnab Nandy, Debjit Pal, Nirjhar Roy et al. "A low cost fully autonomous GPS (Global Positioning System) based quadcopter for disaster management." In 2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC), pp. 654-660. IEEE, 2018..

[5] Dilshad, Naqqash, JaeYoung Hwang, JaeSeung Song, and NakMyoung Sung. "Applications and challenges in video surveillance via drone: A brief survey." In 2020 International Conference on Information and Communication Technology Convergence (ICTC), pp. 728-732. IEEE, 2020.

[6] Jayapandian, N. "Cloud enabled smart firefighting drone using internet of things." In 2019 International Conference on Smart Systems and Inventive Technology (ICSSIT), pp. 1079-1083. IEEE, 2019..

[7] Apvrille, Ludovic, Tullio Tanzi, and Jean-Luc Dugelay. "Autonomous drones for assisting rescue services within the context of natural disasters." In 2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS), pp. 1-4. IEEE, 2014.

[8] Mnaouer, Hajer Ben, Mohammad Faieq, Adel Yousefi, and Sarra Ben Mnaouer. "FireFly Autonomous Drone Project." arXiv preprint arXiv:2104.07758 (2021)..

[9] Kinaneva, Diyana, Georgi Hristov, Jordan Raychev, and Plamen Zahariev. "Early forest fire detection using drones and artificial intelligence." In 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), pp. 1060-1065. IEEE, 2019.

[10] Pathak, Pankaj, Madhavi Damle, Parashu Ram Pal, and Vikash Yadav. "Humanitarian impact of drones in healthcare and disaster management." Int. J. Recent Technol. Eng 7, no. 5 (2019): 201-205.

[11] TAusonio, Elena, Patrizia Bagnerini, and Marco Ghio. "Drone swarms in fire suppression activities: A conceptual framework." Drones 5, no. 1 (2021): 17.

[12] Panda, Kirtan Gopal, Shrayan Das, Debarati Sen, and Wasim Arif. "Design and deployment of UAV-aided post-disaster emergency network." IEEE Access 7 (2019): 102985-102999.

[13] Bekar, Ali, Michail Antoniou, and Christopher J. Baker. "Low-cost, high-resolution, drone-borne SAR imaging." IEEE Transactions on Geoscience and Remote Sensing 60 (2021): 1-11.

[14] Yan, Jiaming, Zhengyu Peng, Hong Hong, Hui Chu, Xiaohua Zhu, and Changzhi Li. "Vital-SAR-imaging with a drone-based hybrid radar system." IEEE Transactions on Microwave Theory and Techniques 66, no. 12 (2018): 5852-5862.

[15] Lim, Bee, Sanghyun Son, Heewon Kim, Seungjun Nah, and Kyoung Mu Lee. "Enhanced deep residual networks for single image super-resolution." In Proceedings of the IEEE conference on computer vision and pattern recognition workshops, pp. 136-144. 2017.