

Face Recognition and Tracking System for Rescue Operation in Fire Emergency

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ABSTRACT

Fire incidents remain one of the major threats to human life and property, making effective rescue operations critical during emergencies. This project presents the development of a system designed to assist rescue workers in identifying and tracking individuals inside a building during a fire. The system integrates an ESP32-CAM module for real-time video streaming and facial recognition, combined with motion (PIR) and smoke (MQ2) sensors to detect human presence and potential hazards. Recognized faces and sensor data are transmitted to Firebase Realtime Database and displayed on a mobile application to provide live updates for rescue teams. This real-time monitoring enables responders to locate trapped individuals more quickly, even in smoke-filled environments where visibility is limited. The system complements traditional rescue methods by providing additional information to improve response speed and accuracy. Limitations include reduced face recognition accuracy in crowded scenes and lower performance under poor lighting conditions. Overall, the system demonstrates promising potential to enhance the effectiveness of fire rescue operations.

Keywords: Fire emergency, face recognition, real-time monitoring, Firebase, mobile application, rescue operation.

1. Introduction

Fire emergencies can happen unexpectedly and often create dangerous situations where it is difficult to see and locate people inside a building. In these moments, having fast and accurate information about who is still inside can make a big difference in saving lives. This project introduces a real-time system that helps rescue teams identify and track people during a fire. The system uses an ESP32-CAM to stream live video and perform face recognition, along with a PIR motion sensor and MQ2 smoke sensor to detect movement and fire hazards. All this information is sent to Firebase and shown in a mobile app, giving rescue workers a clear view of the situation even in rooms filled with smoke. By providing timely updates and helping responders know where people are, this system supports and improves traditional rescue efforts during fire emergencies.

2. Related Work

Fire incidents continue to be one of the leading causes of loss of life and property globally [1], and improving the efficiency of rescue operations remains a major priority [2], [3]. Traditional rescue methods rely heavily on manual searches, which can be slow and dangerous, especially when visibility is reduced due to smoke. To address this, recent research has explored the use of facial recognition technology to help locate and identify individuals during fire emergencies [4], [5]. Studies show that integrating face recognition systems with emergency response tools can provide faster and more accurate information for rescue teams [6], [7]. However, these systems often face limitations in low-light environments, when faces are partially obstructed, or when multiple people are present [7], [8]. In parallel, IoT technologies have made it possible to enhance fire monitoring and emergency response through the use of real-time sensors and cloud-based data sharing [9], [10], [11]. Combining devices such as motion detectors and smoke sensors with cloud platforms allows live updates to be shared with emergency responders [9], [12]. Many existing solutions, however, rely on expensive or complex hardware that is not suitable for small-scale or low-cost deployments. To overcome these challenges, this project proposes a simple and affordable system that integrates an ESP32-CAM, PIR motion sensor, and MQ2 smoke sensor with real-time face recognition and a mobile app, providing an effective tool to support rescue operations during fire emergencies.

3. Methodology

This section focuses on the hardware and software utilized to develop the tracking system for a rescue operation in fire emergency. Figure 1 shows the flowchart of the proposed system, from input gathering to output operations. There are three essential input devices; first is camera, second is smoke detector, and lastly is motion sensor.

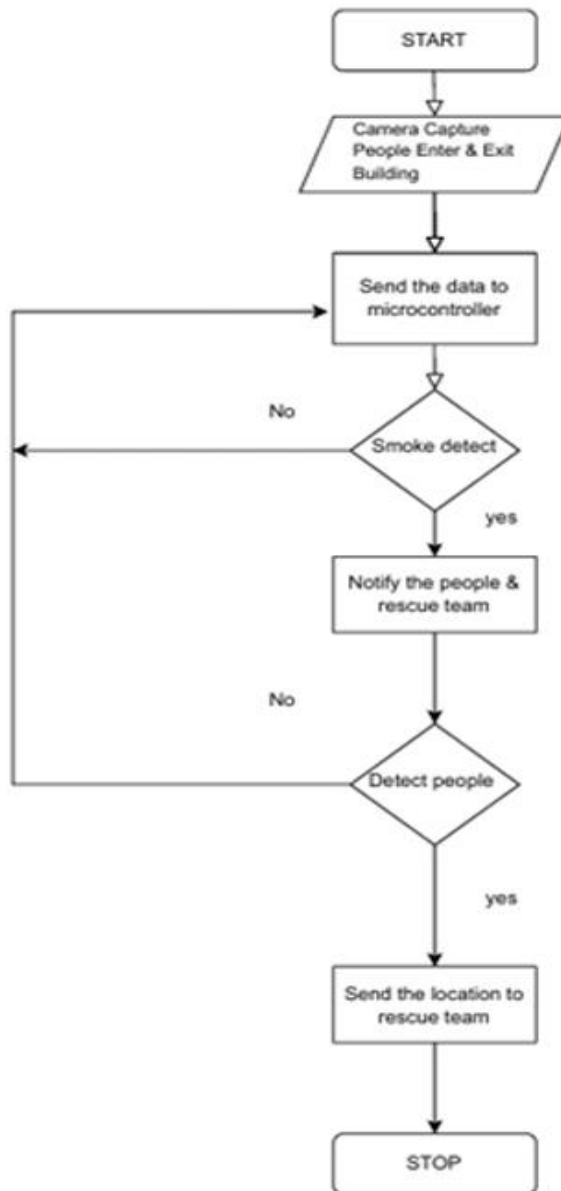


Figure 1. Basic flow in Face Recognition & Tracking System

Based on the flowchart, the system starts by monitoring people entering and exiting the building using camera. The captured data is then sent to a microcontroller for processing. The system checks for the presence of smoke. If smoke is detected, it immediately alerts the occupants and notifies the rescue team. If no smoke is detected, the system proceeds to check for people still inside the building. If people are found, their location is sent to the rescue team to ensure a swift response. If no people are detected, the process stops, completing the cycle. Figure 2 illustrates the block diagram of the proposed system.



Figure 2. Block Diagram of The Hardware Integration in the Proposed System

The block diagram shows the hardware integration in the proposed system in completing the face recognition and tracking system. It starts with a camera capturing data, which is processed by the microcontroller. The smoke detector identifies fire hazards, while the motion sensor detects movement. Finally, the application tracking monitors and records the results for emergency management.

The hardware configuration of the system has been designed to provide real-time tracking, identification, and monitoring of people in the event of a fire, as shown in Figure 3. To ensure a rescue team can immediately find the people within a building, the system combines several components, such as motion sensors, smoke detectors, camera systems, and an ESP32 microcontroller.

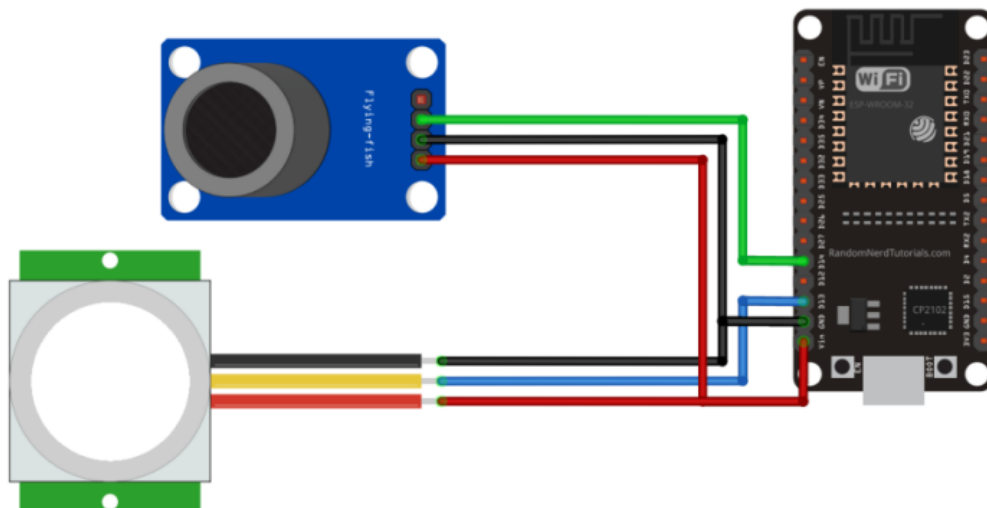


Figure 3. Hardware Connection of ESP32 to PIR and MQ2 Modules

Real-time pictures are captured by the camera, and facial recognition system is used to identify people. Smoke detectors continuously monitor indications of fire, while motion sensors detect any movement, particularly in smoke-obscured regions. As the central processing unit, the ESP32 manages sensor connection and controls components like emergency lighting and alarms. The system is made to function properly in challenging situations, providing rescue crews with essential support in situations of need.

To ensure smooth communication between hardware and end users, several software platforms have been integrated into the system. Python was used for processing real-time video and performing face recognition, while the Arduino IDE was used to program the ESP32 board to send sensor readings to the cloud. Firebase Realtime Database served as the central platform for storing and sharing face recognition and sensor data. A mobile application built with MIT App Inventor allowed users to access this information remotely. The architecture of the entire system is illustrated in Figure 4.

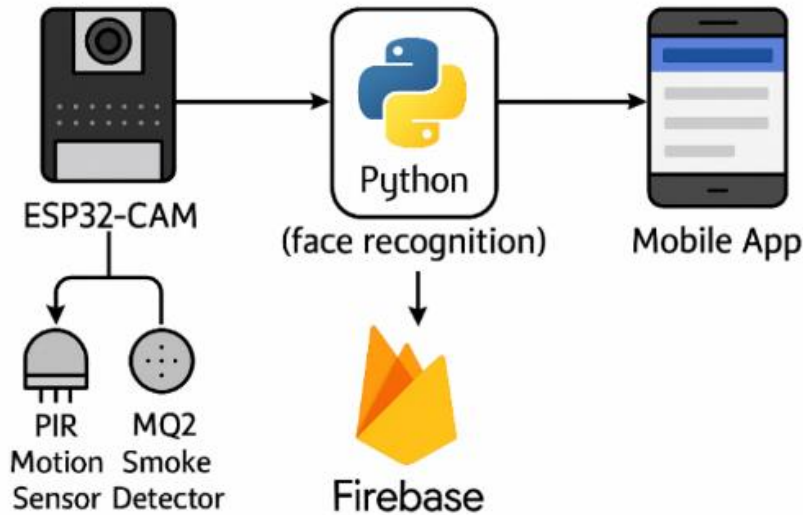


Figure 4. System architecture of the face recognition and tracking system for fire emergency rescue

This architecture highlights how each software component interacts to support real-time monitoring. By linking the Python-based face recognition system and sensor data with Firebase, and displaying the output through a mobile app, the system ensures timely alerts and effective communication during fire emergencies.

4. Results and Discussion

The ESP32-CAM streams live video to the Python-based face recognition system to be processed. The recognized face data are then sent to the Firebase Realtime Database. Meanwhile, the ESP32 microcontroller reads inputs from the PIR motion sensor and MQ2 smoke detector and transmits the data to Firebase as well. A mobile application built in MIT App Inventor continuously reads from Firebase and displays real-time updates.

Figure 5 shows multiple test results where the system successfully recognized different individuals under normal lighting conditions. The ESP32-CAM captured clear images, and the Python program accurately identified each person with a high confidence level. The recognized names were then sent to Firebase and displayed in the mobile app along with motion and smoke sensor status.

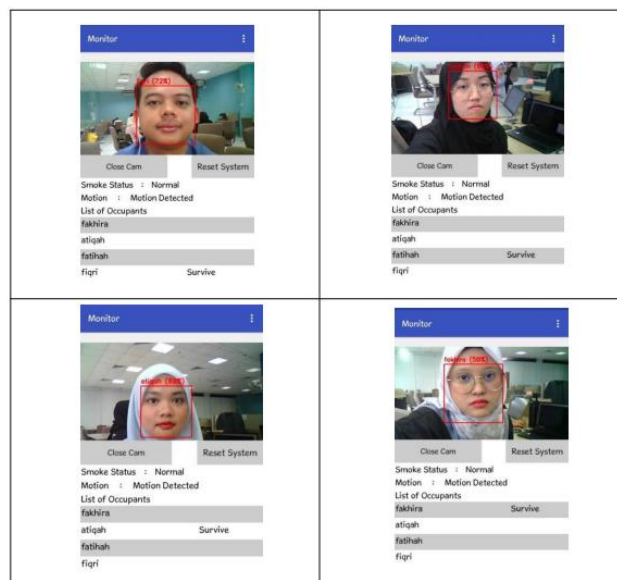


Figure 5. Face Recognition Test in Normal Lighting

In low lighting conditions, the system was tested to see how well it could recognize faces when the environment was dim. The results showed that it could still detect and recognize individuals, but with much lower confidence compared to normal lighting. In this test, the lowest recognition confidence recorded was 54%, which indicates a drop in accuracy under poor lighting. The result is shown in Figure 6 where the system successfully recognized the face but with reduced certainty. This highlights the need for better lighting to improve overall recognition performance.

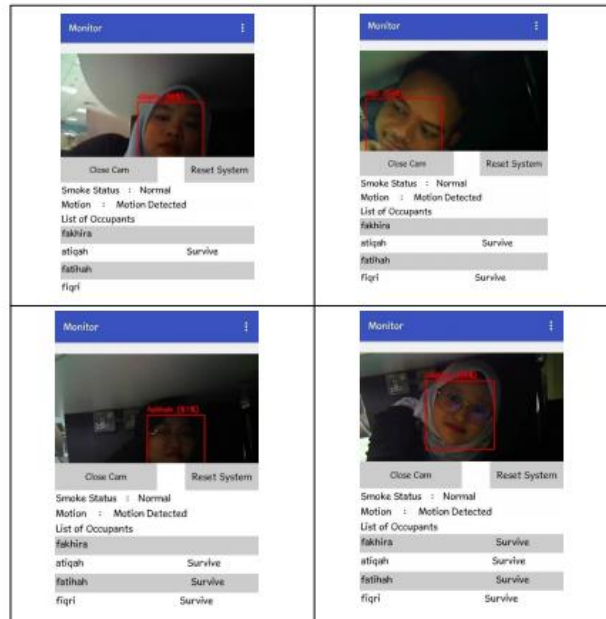


Figure 6. Face Recognition Test in Low Lighting

The system was also tested with faces turned slightly to the side to evaluate how well it could recognize non-frontal angles. In this condition, the system still managed to detect and identify individuals, but with reduced accuracy compared to a front-facing view. Some faces were recognized successfully, but the confidence levels were lower. The results, shown in Figure 7, demonstrate that while side angles are supported, the system performs best when faces are directly facing the camera.

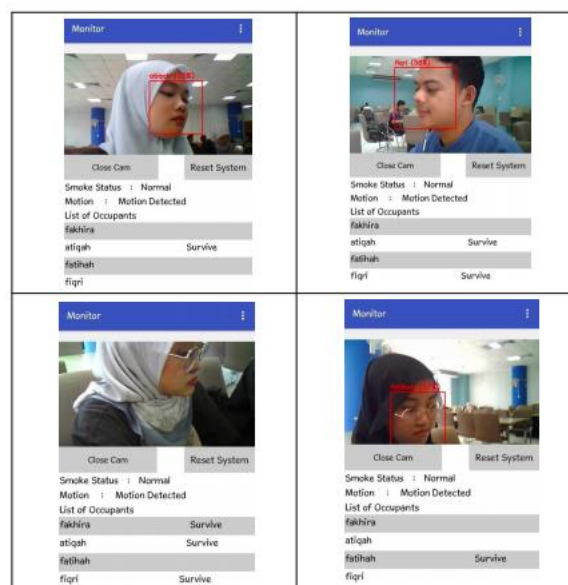


Figure 7. Face Recognition Test in Side Face Angle

To test the system face recognition in longer distance, subjects were standing approximately 2 meters away from the ESP32-CAM. At this distance, the camera was still able to capture clear facial features, and the system successfully recognized the individuals with slightly reduced confidence as depicted in Figure 8. The results showed that the system remains effective at longer distances, although accuracy may decrease slightly compared to closer range.

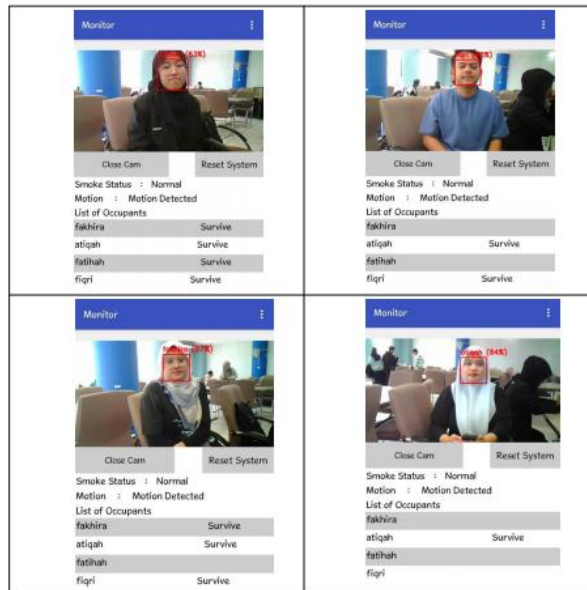


Figure 8: Face Recognition Test in 2 Meters Distance

To evaluate the system performance in detecting multiple individuals at once, face recognition was performed with several subjects positioned together within the camera frame. As shown in Figure 9, the system successfully detected and identified all faces present, although recognition confidence varied slightly depending on the angle and distance of each subject from the camera. To analyze the detection accuracy more thoroughly, the positions of the individuals were changed during the test. This allowed observation of how the system responds to different placements, such as overlapping faces or partial side views.



Figure 9. Face Recognition Test at Multiple Face in Frame

Table 1 summarizes the results from each of the test conditions.

Table 1. Face Recognition System Performance Under Different Test Conditions

Condition	Tested	Recognized	Accuracy
Good Lighting	4	4	100%
Low Lighting	4	4	100%
Side Face Angle	4	3	75%
2 Meter Distance	4	4	100%
Multiple Face in Frame	4	4	100%

The motion and smoke detectors were tested to determine how well they could respond in real time. The PIR motion sensor could swiftly and accurately detect motion in the test. Update notifications were observed on the serial monitor on each detection, evidencing that the sensor was able to discern the difference between multiple captures without latency as listed in Figure 10. This nimble response can be critical for fires, when it’s important to determine whether someone is inside.

The MQ2 smoke sensor was also examined by blowing smoke close to it to create a fire scenario. As we can see from Figure 11, whenever smoke occurred, we saw clear “Smoke: Detected” messages appear on the serial monitor. This indicates that the sensor successfully detected changes in air quality. Both sensors functioned well together to reinforce the system’s purpose is to provide accurate, real-time information that boosts a rescue team’s ability to act more quickly in emergency situations.

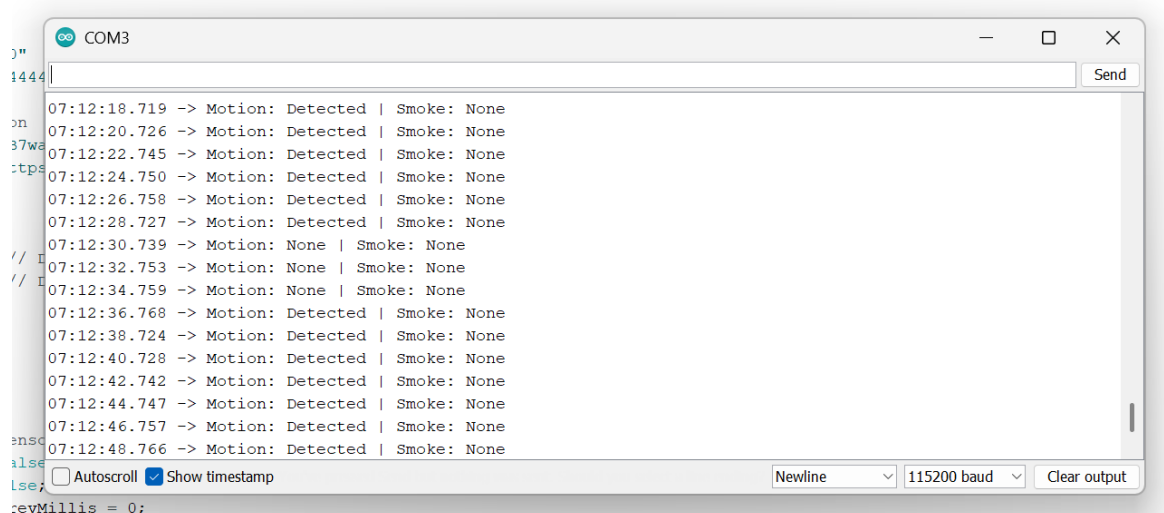


Figure 10. Real-Time Motion Sensor on the Serial Monitor

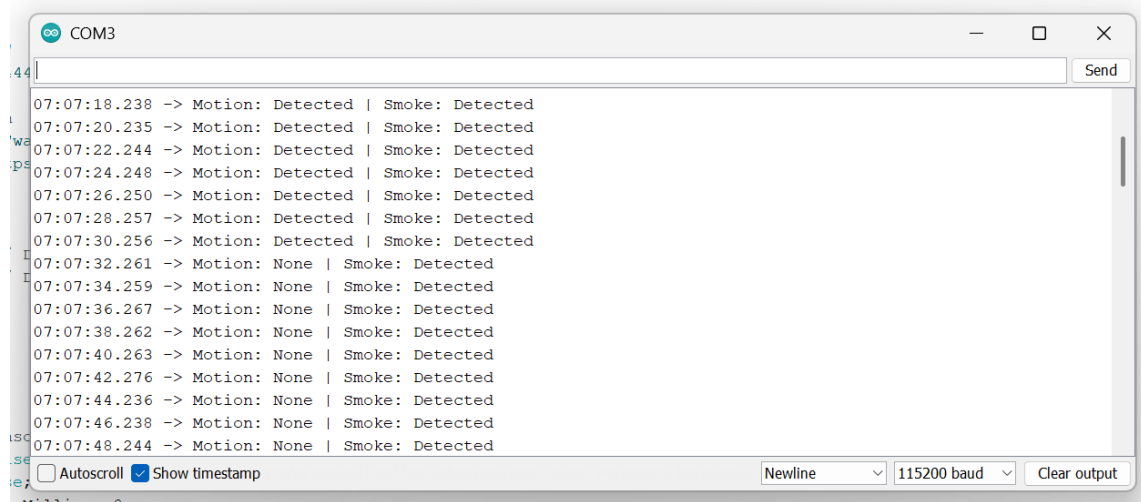


Figure 11. Real-Time MQ2 Sensor on the Serial Monitor

5. Conclusions

This project successfully developed a real-time face recognition and tracking system that helps identify and track people during fire emergencies. By combining face recognition, motion and smoke detection, and real-time data sharing through a mobile app, the system provides useful information that can support rescue teams when quick decisions matter most. It was able to detect faces, sense movement and smoke, and send that data to the Firebase database, where it could be viewed instantly on a mobile device. The system worked well in normal conditions, showing quick responses and accurate face recognition. However, it faced challenges in situations with low lighting and multiple people in the camera frame, where recognition accuracy dropped. Despite these limitations, the system shows great potential as a tool that could assist in real-life emergencies. With some improvements, it could become an even more reliable and helpful part of emergency response systems.

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