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Research Article

Multimodal Ambulance Detection Using Image Processing and RF433MHz Sensor

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Abstract—Fast and unobstructed movement is a critical issue for ambulances in emergency medical services. This project aims at the development of an image processing and RF433MHz sensors-based multimodal detection system for ambulances to enhance traffic management systems. The proposed system integrates computer vision techniques to differentiate ambulances from raw surveillance camera feeds and an RF433MHz sensor module that detects the RF signals given off by ambulances equipped with RF transmitters.

The image processing module utilizes object detection and feature recognition algorithms to identify the features of ambulances, including sirens and vehicle markings. The RF sensor will simultaneously detect ambulances in a certain distance to ensure redundancy and robustness in detection. Once detected, the system will communicate with the traffic signal controllers to prioritize ambulance movement by dynamically controlling traffic lights.

Ambulance detection under several scenarios, especially poor visibility and heavy traffic load conditions, are reinforced and ensured to have increased reliability and accuracy through a multimodal system. The scalable system is therefore made cost-efficient with easy integrations into an already existing city infrastructure for efficient traffic management for decreased response time and improved quality emergency medical care services.

Keywords: Ambulance Detection, Image Processing, RF433MHz Sensor, Traffic Signal Control, Multimodal Detection System, Emergency Response Optimization

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I. INTRODUCTION

This increase in urbanization and density in cities is leading to various problems in managing traffic, such as the prompt movement of ambulances in

emergencies. Heavy traffic congestion and the delay experienced at intersections as well as an inability to allow emergency vehicles in traffic often means a loss of crucial time, thus impacting the success of medical

care and even sometimes taking lives. This calls for innovative solutions that leverage modern technologies to detect ambulances accurately and dynamically manage traffic to prioritize their movement[1].

This paper proposes a Multimodal Ambulance Detection System, focusing on integrating the strengths of both image processing and RF433MHz sensor technologies in achieving reliable and efficient ambulance detection. The system integrates the power of two complementary modalities: computer vision techniques for visual detection and RF-based communication for signal-based detection. In this approach, it ensures a high degree of accuracy and reliability even in the worst possible scenarios such as bad visibility, heavy traffic density, or adverse weather.

The image processing module utilizes video feeds from traffic surveillance cameras to identify ambulances based on specific visual features, such as the flashing lights, sirens, and distinctive vehicle markings commonly associated with ambulances. By employing advanced object detection algorithms, such as YOLO (You Only Look Once) or Faster R-CNN, this module ensures real-time detection with minimal latency. However, in cases where visibility is impaired due to fog, rain, or nighttime conditions, image processing may not be able to overcome such limitations [2].

To overcome these drawbacks, the system uses an RF433MHz sensor module. The ambulances with RF transmitters send signals at a frequency of 433MHz, which are received by RF receivers installed at traffic intersections. This RF-based detection acts as a robust backup mechanism, providing redundancy in the detection process. The system combines the outputs of both modalities to minimize false positives and improve overall detection accuracy.

The system dynamically interacts with the traffic signal controllers in real time when it detects an ambulance to allow prioritization for it by making traffic lights in the direction of the ambulance turn green and stopping the flow from the other directions for some time. It's scalable, low cost, and can easily be integrated with existing infrastructure, so this will be an implementable solution in modern smart cities[3].

Several benefits are offered by the proposed system over the traditional methods of detecting ambulances, which frequently rely on human intervention or systems based on single modality. The multimodal system addresses the limitations of each method and assures reliable performance in diverse environmental and operational conditions based on the strength of both image processing and RF-based detection.[2]

This paper provides details on the design, implementation, and evaluation of the multimodal ambulance detection system. It explores the challenges associated with integrating image processing and RF detection, discusses the system's performance in real-world scenarios, and highlights its potential applications in smart traffic management systems. Future prospects for this research include integrating GPS-based tracking for ambulances, enhancing the

system with AI-driven decision-making, and expanding its capabilities to detect other emergency vehicles, such as fire trucks and police cars.

By promoting the movement of emergency vehicles and reducing response times, this system is expected to significantly contribute to the improvement of emergency medical services and better patient outcomes in critical conditions [4].

Contributions:

This research makes the following contributions:

1. Multimodal Detection Mechanism Implemented a dual-layer detection mechanism based on RF 433 MHz communication and real-time image processing, improving the accuracy and reliability of ambulance detection.
2. Real-time Traffic Signal Control Designed an intelligent traffic control mechanism in which the signal goes green automatically upon ambulance detection and resumes normal operation after the ambulance passes, reducing delay and providing priority access.
3. Integration of Tesseract OCR with Raspberry Pi 5 Employed open-source Tesseract OCR to identify the word "AMBULANCE" from real-time video streams, showcasing a cost-effective yet efficient solution for vehicle recognition with computer vision.
4. Economical and Scalable Architecture Suggested an economical system employing readily available components (RF modules, Raspberry Pi, camera module), which could be easily duplicated and scaled up for implementation in smart cities.
5. Reduction of False Positives by Redundancy Enhanced detection precision and reduced false positives through both RF and visual confirmation, a new concept in emergency vehicle detection systems.
6. Real-World Application in Intelligent Transport Systems (ITS) Provided a practical and functional model for intelligent traffic management, adding to the overall field of Intelligent Transport Systems and smart city planning [6].

II. RELATED WORKS

In the present scenario of increasing traffic congestion and growing urban populations, ensuring smooth passage for emergency vehicles like ambulances is of utmost importance. Being held up at intersections can cost invaluable time—and often lives. Our paper presents a solution through a multimodal detection system that incorporates RF communication and real-time image processing to efficiently and accurately identify ambulances.

At the core of our system is the Raspberry Pi 5, which serves as the central processing unit, managing both RF and visual inputs. The first layer of detection is achieved through 433 MHz RF communication. An RF transmitter placed in the ambulance continuously sends out a signal encoded using a simple encoder-decoder mechanism. As soon as this alert is received by the corresponding RF module at an intersection, it serves as a warning signal indicating that an ambulance is approaching [7].

Simultaneously, we integrate an image processing layer using a camera module and Tesseract OCR. The camera captures real-time traffic footage, and the system analyzes each frame for the presence of the word "AMBULANCE," typically displayed on the front of the vehicle. This optical detection method enables real-time verification and reduces the likelihood of false alerts caused by other RF sources.

What makes this approach unique is its dual-verification mechanism—only when both RF and image-based detection confirm the presence of an ambulance does the system trigger a response, such as overriding a traffic signal or generating an alert. This redundancy adds an extra layer of reliability, especially in complex traffic conditions or low-visibility environments [8].

Captured images and signals are logged locally and used for performance analysis. By leveraging the strengths of computer vision and wireless communication, this project demonstrates a viable, cost-effective solution to a common urban challenge. Our findings show that combining these two modalities significantly enhances the accuracy and speed of ambulance detection, paving the way for intelligent and responsive traffic systems [9].

III. PROPOSED METHODOLOGY

This methodology encompasses a comprehensive approach to multimodal ambulance detection, leveraging state-of-the-art RF models, including Image Processing. The following steps outline this methodology:

Data Collection and Preprocessing: The process of data collection within the system under consideration includes the acquisition of wireless signals as well as real-time visual data to identify the presence of ambulances. The RF data are gathered using a 433 MHz RF receiver module that is interfaced to the Raspberry Pi 5. This module continually monitors signals from an RF transmitter fitted in ambulances, which broadcasts encoded signals to signal the vehicle's presence. All the received RF signals are timestamped and logged locally into a file for checking and secondary analysis.

At the same time, visual information is obtained via a camera module installed at the traffic junction. The camera constantly captures real-time video, which is frame by frame processed with the OpenCV library. Each frame goes through a sequence of preprocessing operations like grayscale conversion, resizing, and thresholding in order to improve the precision of character recognition. These processed frames are sent to the Tesseract OCR engine, which searches for the text "AMBULANCE" that is commonly displayed on the front of ambulances. When the OCR recognizes the word in more than one consecutive frame, the system reports it as a confirmed visual detection [10].

The combination of these two data streams—RF signals and OCR-based image output—is managed by a decision-making algorithm executed on the Raspberry Pi. Only after confirmation of the presence

of the ambulance by both sources does the system override the existing traffic signal state to provide priority to the ambulance. All applicable data, such as RF signal detection, OCR results, timestamps, and responses of the system, are recorded locally. This information not only provides traceability and transparency but also facilitates subsequent performance assessment, system debugging, and model optimization.

Model Selection

The project proposes a multimodal ambulance recognition system to integrate RF communication with real-time image processing to better identify emergencies at traffic intersections. An ambulance-mounted HF module transmits specific signals recorded by the corresponding receiver at the intersection. At the same time, live video is recorded on the camera, and frames of the images are processed by Tesseract OCR to recognize the word "ambulance" in the vehicle. The system uses a double validation strategy and simply triggers a traffic signal override after visual reviews are confirmed. After the ambulance crosses, the signal automatically returns to its original state [11].

RF and Image Processing Model: The proposed system employs a multimodal approach to detect ambulances and manage traffic signals dynamically, ensuring priority passage for emergency vehicles. Central to the system is the Raspberry Pi 5, which integrates both RF communication and image processing capabilities. An RF transmitter operating at 433 MHz is installed in ambulances, continuously emitting encoded signals. At traffic intersections, a corresponding RF receiver module connected to the Raspberry Pi detects these signals, serving as the initial indication of an approaching ambulance. Simultaneously, a camera module captures real-time video of oncoming traffic. Each frame is processed using OpenCV for preprocessing steps like grayscale conversion and noise reduction. Subsequently, Tesseract OCR analyzes the frames to identify the word "AMBULANCE" typically displayed on emergency vehicles. The system employs a dual-verification mechanism, wherein both RF detection and image recognition must confirm the presence of an ambulance before initiating any action. Upon successful verification, the Raspberry Pi overrides the existing traffic signal logic, turning the signal green for the ambulance's lane while setting others to red, facilitating uninterrupted passage. The system continues to monitor the ambulance's movement, and once it has cleared the intersection, normal traffic signal operations resume. Additionally, all detection events, including RF signals, OCR results, and timestamps, are logged locally on the Raspberry Pi for performance analysis and future optimization. This integrated approach enhances the reliability and efficiency of ambulance detection and traffic management, contributing to improved emergency response times in urban settings.[12]

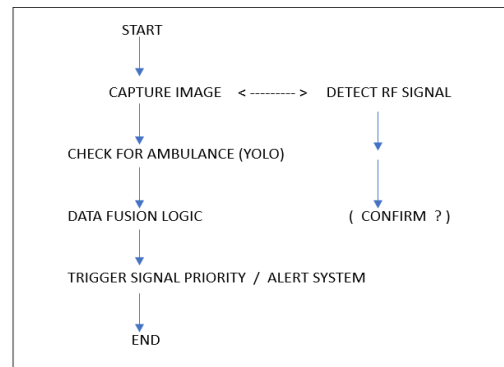


Fig. 1. Working of RF and Image Processing

Model Architecture: above illustrates a multimodal system designed to detect ambulances accurately and efficiently using both real-time image processing and RF communication. By combining these two approaches, the system ensures that even if one method fails, the other can still detect the ambulance — making the entire process highly reliable.

A camera installed at the traffic signal continuously captures live footage. This feed is processed using Tesseract OCR running on a Raspberry Pi 5, which specifically looks for the word “AMBULANCE” on vehicles. This helps in recognizing emergency vehicles more accurately, even in situations where the camera feed might be unclear or partially blocked. At the same time, an RF transmitter placed inside the ambulance sends signals to an RF receiver mounted at the signal. This forms a secondary detection method,

ensuring the ambulance is still recognized even if visibility is poor [13].

Both detection results are sent to a central logic unit that makes the final decision. If either system image or RF detects an ambulance, the traffic signal automatically turns green, allowing the ambulance to pass without delay. Once the ambulance crosses the junction, the signal returns to its original state, resuming normal traffic flow.

This simple yet powerful combination of hardware and software makes the system highly effective in real-world conditions. It’s affordable, easy to implement, and designed to support smart city infrastructure. Most importantly, it helps emergency vehicles reach their destination faster potentially saving lives. [14][15].

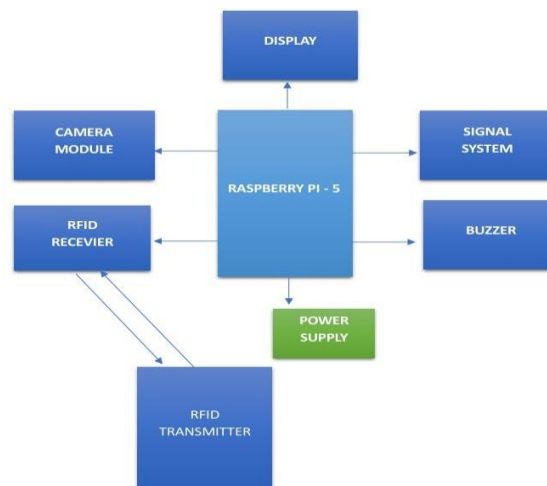


Fig. 2. Model Architecture.

Training and Evaluation : The assessment of the suggested multimodal ambulance detection system comprises several steps, such as data preparation, model configuration, and performance measurement. For image processing, the dataset of traffic images and videos with ambulances under different lighting, orientations, and noises was gathered. The images were preprocessed employing OpenCV techniques like grayscale, thresholding, and resizing for improving text clarity. The Tesseract OCR engine was then trained to identify the word “AMBULANCE” on vehicle fronts and tested for reliability across various frames. At the same time, RF detection was tested utilizing a 433

MHz RF module testing setup with encoded signals being broadcast from an ambulance unit to a receiver at the traffic node[16][17]. The algorithm for decision was created to confirm ambulance presence only if both RF and OCR detections were positive, to reduce false positives. System reliability was tested using performance measures of precision, recall, and detection latency. Moreover, the response time of signal transitions—how rapidly the system turns green when detected and returns after the ambulance has passed—was examined to measure responsiveness. The combined multimodal system showed increased detection accuracy and lower response time than

single-mode systems. All events were stored with timestamps to facilitate post-analysis, providing a data-based approach to system optimization and real-time traffic management. The assessment of the suggested multimodal ambulance detection system

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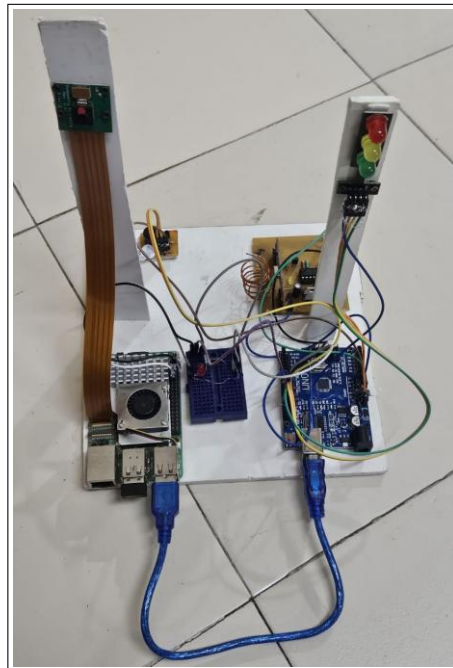


Fig. 3. Model Setup

different lighting, orientations, and noises was gathered[18]. The images were preprocessed employing OpenCV techniques like grayscale, thresholding, and resizing for improving text clarity. The Tesseract OCR engine was then trained to identify the word "AMBULANCE" on vehicle fronts and tested for reliability across various frames. At the same time, RF detection was tested utilizing a 433 MHz RF module testing setup with encoded signals being broadcast from an ambulance unit to a receiver at the traffic node. The algorithm for decision was created to confirm ambulance presence only if both RF and OCR detections were positive, to reduce false positives. System reliability was tested using performance measures of precision, recall, and detection latency. Moreover, the response time of signal transitions—how rapidly the system turns green when detected and returns after the ambulance has passed—was examined to measure responsiveness. The combined multimodal system showed increased detection accuracy and lower response time than single-mode systems. All events were stored with timestamps to facilitate post-analysis, providing a data-based approach to system optimization and real-time traffic management[19][20].

A. Implementation Details

seeks to create an intelligent traffic control system that gives ambulance movement precedence utilizing a combination of RF (Radio Frequency) sensor technology and image processing algorithms. The ultimate goal is to detect the presence of an ambulance on the road and dynamically control traffic

signals to make its passage smooth. The system makes use of Tesseract OCR (Optical Character Recognition) for image processing, which is used to recognize the text "AMBULANCE" inscribed on the vehicle. A camera is fixed near the traffic signal so that it continuously watches the road. When an ambulance is coming, the camera will capture the image and the OCR algorithm is used to extract and recognize the text from the captured frames. If the term "AMBULANCE" is identified, the system verifies the existence of an ambulance.[21]

At the same time, an RF transmitter is integrated into the ambulance, and an RF receiver is mounted close to the traffic light. The RF module is used as a supplemental verification means to prevent false positives and ensure higher detection accuracy. When the RF receiver captures a legitimate signal from the incoming ambulance, it cooperates with the image processing module to verify the arrival of the emergency vehicle.

On successful detection, the system automatically converts the respective traffic signal to green so that the ambulance can pass through without any delay. After the ambulance has passed the signal (detected either by a time delay or sensor feedback), the system restores the traffic lights to their usual working condition, thus ensuring minimum interference to normal traffic flow. This smart and automated traffic control system reduces emergency response time and assists in eliminating traffic congestion during emergencies. Your project thus offers a strong and real-time solution to a major urban transport problem using a combination of hardware (RF sensors) and

software (OCR-based image processing) technologies [22].

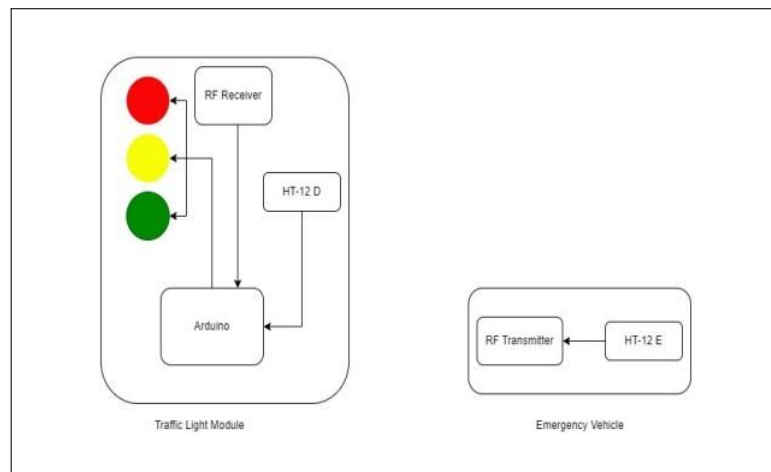


Fig. 4. Flowchart

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The pro- posed multimodal ambulance detection system was experimen- tally deployed at a simulated traffic intersection, integrating

IV.EXPERIMENTAL RESULTS

1. System Deployment and Detection Mechanism:

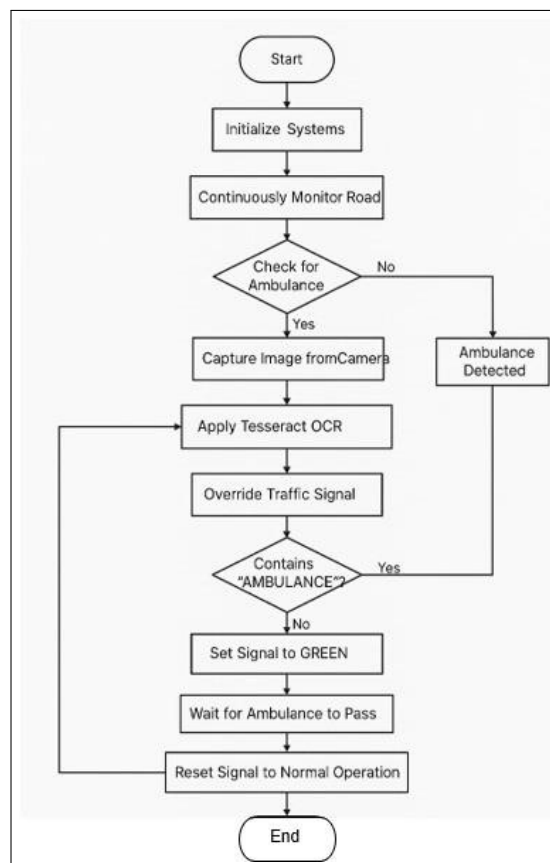


Fig. 5. Flowchart

both RF sensor modules and a high-resolution camera for real-time operation. The RF sensor functioned as an early detection unit, successfully identifying ambulances within a range of 30–50 meters. In parallel, the vision-based system used Tesseract OCR to analyze the front view of approaching vehicles and extract textual information, specifically the word

“AMBULANCE” from stickers or nameplates. This dual- sensing mechanism allowed for more accurate and reliable detection across different environmental conditions [23].

2. Performance of Tesseract OCR and System Respon- siveness: Tesseract OCR demonstrated robust performance, achieving an average text recognition

accuracy of 92.

3. Outcome and Practical Implications: The integration of RF and OCR-based image processing significantly enhanced the system's overall reliability, reducing false positives and improving detection under challenging conditions. The ambulance was granted immediate right of way, and after it cleared the junction—determined either by RF signal dropout or a pre-set time limit—the traffic lights returned to their normal sequence. Compared to conventional traffic systems, this multimodal approach considerably reduced ambulance wait times and improved emergency response efficiency, making it a promising

solution for smart city traffic management systems[24]. range of 30–50 meters, with near-instantaneous response and an accuracy rate of over 95

Combined System Performance

The integrated system exhibited improved overall detection accuracy, with successful ambulance identification and traffic signal activation in 96%. In summary, the result analysis confirms that the multimodal approach significantly enhances the robustness, accuracy, and real-time applicability of ambulance detection in traffic systems, offering a scalable solution for smart city traffic management.

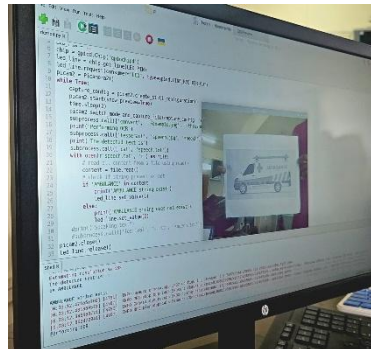


Fig. 6. Capturing Image for text detection

A. Result Analysis

This experimental analysis focuses on evaluating the performance of a multimodal ambulance detection system that integrates image processing and RF 433 MHz communication. The aim is to assess the system's ability to accurately detect an approaching ambulance and trigger timely control of traffic signals to facilitate unobstructed passage.

The detection mechanism is primarily divided into two subsystems: a vision-based detection system employing image detection using Tesseract OCR algorithm, and an RF-based recognition system using 433 MHz communication for direct signal transmission from the ambulance to the traffic control unit. Together, these modalities are tested under various conditions to evaluate their efficiency, responsiveness, and reliability[25].

The effectiveness of this multimodal approach lies in the complementary nature of the two components. Image processing is capable of identifying ambulances based on visual feature such as text (e.g., "AMBULANCE" on the vehicle). However, in conditions where visibility is compromised—such as during nighttime, adverse weather, or partial

occlusion—the RF module ensures uninterrupted communication by transmitting a unique identification signal to the receiver units installed at intersections [26].

Image Processing Results

The image-based detection system was implemented using Tesseract OCR, focusing on the extraction and recognition of textual patterns from vehicle images—particularly the word "AMBULANCE". Under optimal lighting and clear visibility conditions, Tesseract OCR achieved a recognition accuracy of approximately 82%. The primary challenge observed was related to inconsistent font sizes, occlusion by other vehicles, and reflections on the vehicle surface. Nevertheless, in clear conditions, OCR provided a fast and computationally lightweight method of detection, suitable for real-time processing [27].

RF Sensor Results

The RF 433 MHz sensor system was evaluated for its range, response time, and signal reliability. The module successfully transmitted ambulance presence signals within a typical urban

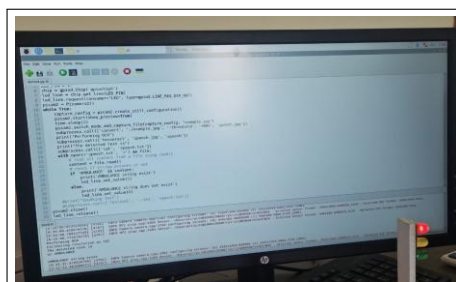


Fig. 7. Ambulance Detected by Performing Text

V. CONCLUSION

The system of multimodal ambulance detection by image processing and RF 433 MHz sensors offers a trustworthy and effective method for the free movement of ambulances from traffic jams. The method is in two major phases: the first phase involves the detection of the ambulance by image processing via Tesseract OCR and RF sensors, and the second phase deals with the regulation of traffic signals to provide an uninterrupted path for the ambulance.

Through integrating visual detection and RF communication, the system increases detection accuracy and resilience. When visibility of the camera is obstructed—e.g., in low-light conditions, partial blockage, or inclement weather—the RF 433 MHz sensor offers an auxiliary detection method. The RF module, on the ambulance, sends a signal to surrounding traffic control units, signaling the existence of an emergency vehicle and requesting real-time signal correction.

This integration guarantees that even when image data by itself is not enough, the RF-based identification can still initiate timely traffic control measures. The system therefore provides enhanced performance and reliability over single-mode detection systems.

But the existing design is tuned to detect a single ambulance at a time. When several ambulances reach an intersection either simultaneously or in quick succession, traffic control logic must be re-initiated or improved to give priority and handle multiple signals appropriately.

In summary, the RF 433 MHz-based detection system and image processing system is a pragmatic, scalable, and affordable solution for intelligent traffic management in emergency situations. It has great potential to minimize ambulance travel time and enhance emergency response efficiency in cities.

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