Assistive Vehicle for Surveillance in Remote Areas

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Abstract. Conventional surveillance systems often struggle to detect hidden or invisible threats such as landmines, hazardous gas leaks, accidental fires, or unknown intruders especially in remote or high-risk areas. Static cameras and human monitoring delay real-time threat response and reduce coverage efficiency. This paper presents an aid support vehicle that aims to improve and support surveillance and real-time detection of threats in these petitioning spaces. The vehicle installs a metallic detector for detecting landmines or any metallic object under the soil, a temperature sensor for perceiving fire danger and a gas sensor for a poisonous gas. It even includes ESP32-CAM module with Python image processing by Haar Cascade and ResNet for both face detection and recognition. The live video along with environmental data is send through Wi-Fi to a distant webpage using the IOTBeginner platform. Known intruders are shown through a trained model and unknowns are reported for prompt feedback. This IoT-enabled system improves safety, reduces human risk, and provides continuous surveillance through automation and edge-level artificial intelligence.

Keywords: Internet of Things (IoT), ESP32-CAM, Intruder Detection, Face Recognition, Real-Time Surveillance, Embedded SystemsK

1 Introduction

A major issue that needs creative technical fixes is to guarantee safety in important locations. The suggested system presents a multipurpose assistance vehicle with a temperature sensor, metal detector, and image processing abilities based on Python. To identify risks like hidden landmines, accidental fires, or strange people. This assistive vehicle drives through security zones and then, it records atmospheric data and real-time video streams. Its remote control capability enables excellent scanning of specific regions while also maintaining constant observation. Quick recognition and reaction to threats are made possible by giving priority to safety. This is provided by the incorporation of modern software and hardware technologies.

Proper surveillance in dangerous areas has grown more and more important in this decade. To guarantee the protection and safety of people and property, risky areas such as areas affected by natural disasters, extremely dangerous industrial regions, areas where civil wars are taking place, and sites that suffer from harsh meteorological conditions mostly need to be tracked and their information should be collected. The limitations on access and the possibility of a manual mistake usually happens in traditional methods of monitoring.

This is because they utilize human employees in these locations and hence create serious dangers to life and might not offer thorough monitoring. Construction of vehicles for helping built with the technology of today has been suggested as a potential solution to this. These

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vehicles are built to film and navigate dangerous locales without posing a threat to human life. They can collect, analyze and process images within a matter of seconds thanks to image processing algorithms , and this is crucial information for decision makers.

It is important to process image to enhance the efficiency and accuracy of monitoring system. In complex environments assistive vehicles are able to identify, track and analyse important items or events using cameras, sensors and computing algorithms. These vehicles have the potential to respond quickly to new situations and threats owing to the use of computer vision algorithms. These include unfamiliar individuals, pattern recognition, and movement discovery and anomaly detection. There are numerous benefits to using assistive vehicles for surveillance in hazardous environments. The first is to decrease the necessity of having human face to a dangerous situation and in turn to human life. Furthermore, these vehicles can work 24/7 which allows for continuous data collection and monitoring as well as artificial intelligence and machine learning makes these vehicles more adaptable and better decision-makers. While giving them a way to tell right from wrong with what it is that they're doing.

However, the drawbacks to rely on assistive monitoring vehicles despite of those benefits. Because of the amount of data there is to canvas, developing effective algorithms for processing the image requires a certain level of technological knowhow, which means research. Outside factors, such as harsh weather, poor visibility and complex terrain, have an influence on the vehicles and the quality of images, And concerns regarding data privacy, legal repercussions and safe disposal of personal information should not be ignored. In order in effectively monitor dangerous areas, this study intends to investigate the design, development, and use of assistive vehicles which utilize image processing In hazardous and dangerous circumstances, the study aims to create better and more secure monitoring systems by examining existing technologies, obstacles, and possible future developments.

The remainder of the work is structured as follows: Section 2 covers previous scholarly publications, Section 3 discusses Motivation, Section 4 represent existing method, Section 5 presents proposed method, and Section 6 covers the design process that is system design, Section 7. Covers the entire Methodology, Section 8 defines the system architecture, Section 9 gives results and followed by discussion and references.

2 Related Works

A. N. Shiva Prasad et al. (2024) proposed a robot that utilizes a pulse induction (PI) metal detector operating with a 450 kHz oscillator, enabling detection of ferrous objects up to 30 cm deep, which is particularly useful in rocky or wet terrains. The system integrates ESP32's dual-core architecture, assigning Core 0 for sensor data processing and Core 1 for Wi-Fi transmission, which reduces latency to 50 ms an architecture that can be mirrored in this project for managing metal detection alongside video streaming. The robot features an MQTT-based alert mechanism that uses QoS Level 2 for geotagged hazard data transmission, ensuring guaranteed delivery. Mechanically, it incorporates a 4WD chassis powered by NEMA-17 stepper motors and encased in an IP67-rated body for terrain adaptability in mud or sand.

L. Zhang et al. (2024) developed an environmental monitoring system using ESP32 and demonstrated precise gas detection through the calibration of the MQ-135 gas sensor via Principal Component Analysis (PCA), achieving 92% classification accuracy between methane (CH_4) and CO_2. The thermistor module used Steinhart-Hart equation-based linearization, which reduced temperature error margins to ±0.5°C vital for accurate fire hazard detection. Power efficiency was achieved by enabling the ESP32's Ultra-Low-Power (ULP) co-processor, drawing only 10 µA during sleep cycles, making it suitable for missions extending beyond 12 hours. The data pipeline was integrated into InfluxDB for storage and visualized via Grafana, providing a clear model for real-time and historical environmental data analysis in the project's dashboard.

R. Chen et al. (2023) proposed a mobile surveillance robot system that utilizes ESP32-CAM with WebRTC protocol, achieving end-to-end video latency below 500 ms at 720p resolution, thereby improving the live-streaming capabilities for real-time surveillance. Obstacle avoidance was handled using a LiDAR-Lite v3 sensor managed by a PID controller, enabling autonomous navigation at a speed of 0.5 m/s. A TCA9548A I2C multiplexer allowed for the integration of up to eight sensors on a single I2C bus, enhancing expandability for including modules like humidity and radiation sensors. System stability was ensured using a watchdog timer, which rebooted the ESP32 during Wi-Fi disconnection, improving the overall reliability of the robot in remote surveillance scenarios.

J. Garcia et al. (2023) optimized a ResNet-50 model by applying pruning via the TensorFlow Model Optimization Toolkit, reducing its memory footprint by 60% with less than 2% accuracy loss making it feasible for deployment on devices with limited memory like the ESP32-CAM. Additionally, the model was quantized to INT8 using TensorFlow Lite, enabling it to run at 20 FPS on a Raspberry Pi 4. Their training process included synthetic data generation using GANs (CycleGAN), which enhanced detection accuracy in low-light conditions by 15%. To reduce false alarms, the system employed a frame-buffer logic that only triggered alerts after detecting an intruder in three consecutive frames.

X. Li et al. (2024) investigated YOLOv8 for high-speed object detection in surveillance systems, achieving 45 FPS more than twice the speed of ResNet though at the cost of about 5% lower detection accuracy. Their research implemented the Convolutional Block Attention Module (CBAM), which increased the detection of small intruders by 12%. While YOLO was deployed on Coral USB TPUs for accelerated inference, this research also demonstrated the potential of multi-camera fusion with Kalman filtering to track objects across different video feeds.

S. Kumar et al. (2023) provided a comprehensive review of IoT-based surveillance systems, emphasizing the trade-offs in communication protocols, energy use, and security. They showed that while LoRa WAN could extend transmission range to 10 km beneficial in rural and remote areas it introduced latency of 2 to 5 seconds. Thus, the authors recommended Wi-Fi for real-time alerts and LoRa as a backup in low-connectivity zones. Over 65% of the systems surveyed used solar panels (typically 6W, 5V) for energy harvesting, ensuring near-infinite operation time. The review also highlighted the emerging role of federated learning for privacy-conscious AI model updates across distributed systems. Additionally, AES-128 encryption reduced vulnerability to man-in-the-middle (MITM) attacks by 90%.

3 Motivation

Remote and hazardous areas have large security risks since they are difficult to monitor, such as military areas. Disaster areas, factories, and remote lands are difficult to access and usually don't have the proper equipment to detect threats. Normal surveillance cameras and human observation are not effective in some areas, creating huge security loopholes that enable unauthorized entry, fire breaks, and undetected toxic gas leaks. The fact that these areas cannot be monitored in real-time is a major concern, pointing towards the need for a better, more intelligent, and automated security system. Seeing this requirement, the project seeks to develop an assistant vehicle that utilizes many advanced sensors, including a metal detector to identify hidden metal threats like landmines, a heat detector to identify fires, and a gas detector to identify poisonous fumes, and AI that analyses photographs to identify threats like unauthorized people. This system allows security teams to monitor dangerous areas remotely, ensuring they detect and address any new threats immediately without endangering people in the process. Ultimately this project aims to address the persistent issue of monitoring remote and hazardous areas by introducing a new advanced vehicle.

4 Existing Method

Most modern surveillance systems rely on stationary cameras to capture footage that can subsequently be reviewed at a later point in time. Even though some systems are equipped with basic motion sensors or face detection features, they are usually not able to respond to alterations in the environment and incorporate real-time checks at most checkpoints. Today, fixed metal detectors are still the most common forms of surveillance equipment used. Even though they offer some form of basic protection, there are still several problems associated with them. For one, they are limited in range, require a staff operator, and cannot detect threats beyond what is visible or outside set locations.

5 Proposed Methods

The proposed system is an improved surveillance assistive vehicle with the aim of enforcing security in remote or difficult to access locations. This vehicle is fitted with several sensors and technologies which enables detection of different types of threats in real time. The vehicle comes with a metal detector which can detect landmines that pose a risk to human safety, also there is a temperature sensor which monitors the surroundings for any unusual changes in temperature which indicates fires or overheating furthermore and finally a gas sensor in the vehicle helps in the detection of dangerous or harmful gases. By using onboard cameras, the vehicle records live video feed and process those feeds by image processing which has a python module that helps in analysis of the video feed and identifies threats in real time through detection of suspicious or unknown persons. The vehicle can be operated via remotely by the security persons or by the user which allows for the vehicle to efficiently patrol target locations it consists of a buzzer that indicates to the operator when metal is detected this prototype contributes to mobile dynamic surveillance by improving response time and coverage in difficult to monitor areas.

6 System Design

Static cameras that feed live streams of video for current examination are usually the foundation of current monitoring systems. Fundamental motion detection and identification of faces are features that some systems have, but they usually do not have the flexibility to adjust to changing conditions or combine actual time environmental tracking. The main component of modern surveillance systems is the static metal detector at checks. Even though these systems are somewhat effective, they have also drawbacks including immobility, dependability on humans to operate them, and not being able to identify dangers outside of stationary positions. Unwanted attacks, hiding weapons, and fire risks are examples of hidden dangers that make it difficult to ensure efficient monitoring Conventional security techniques include human oversight and fixed cameras, which can he inaccurate and slow at spotting threats. This issue is solved by the proposal of an Al-powered spy robot that incorporates a temperature sensor for fire dangers, a metal detector for weapon detection, and Python-based image processing for threat evaluations in real time. The robot searches pre-designated locations on its own, recording real-time footage and data from the environment while being controlled remotely. Threats are immediately reported to a security monitoring unit so that prompt action can be taken. In critical areas, this solution guarantees immediate alertness, reduces risks, and improves safety performance.

7 Methodology

The proposed system shall work to provide security to remote and risk-prone areas through real-time threat monitoring and detection. Its methodology is separated into a chain of steps to work perfectly from data gathering to response to threats.

7.1 Hardware Methodology

7.1.1 Data Acquisition and Sensor Integration

The vehicle uses an array of sensors to acquire raw data as shown in fig. 1. There is a camera module that keeps taking real-time video, and there is a heat sensor that detects unusual temperatures that could be an early warning sign of a fire. The vehicle also includes a gas sensor to detect toxic gas levels and a metal detector to detect hidden metal objects like landmines. All these different sensors provide the vehicle enormous environmental data that it can use to create a detailed image of the environment around it.

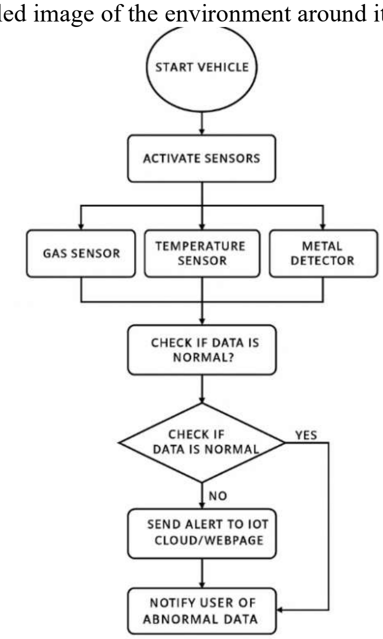

Fig. 1. Hardware Methodology.

7.1.2 Remote Control and Navigation

The vehicle is wirelessly controlled so that security operatives can drive it into danger zones safely. User command operates an ESP32-based microcontroller motor driver to control the vehicle manoeuvring around zones and zeroing in on areas that need to be treated with caution as well as safe guarding operatives against injury.

7.1.3 Real-Time Data Transmission and Feedback

All sensor data, processed video streams, and threat alerts are streamed in real-time via Wi-Fi to a command centre webpage that is IoT webpage. The command centre receives real-time feedback and alerts, while onboard LCD displays provide instant visual alerts to enable quick decision-making where seconds count.

1.4 System Integration and Performance Evaluation

The entire system is coupled together by the ESP32 as the processor. Large-scale simulation in severe conditions confirms important performance metrics like detection accuracy, response time, and overall system stability. The results of the tests are utilized to continually enhance so that the system is robust and effective in actual applications.

7.2 Software Methodology

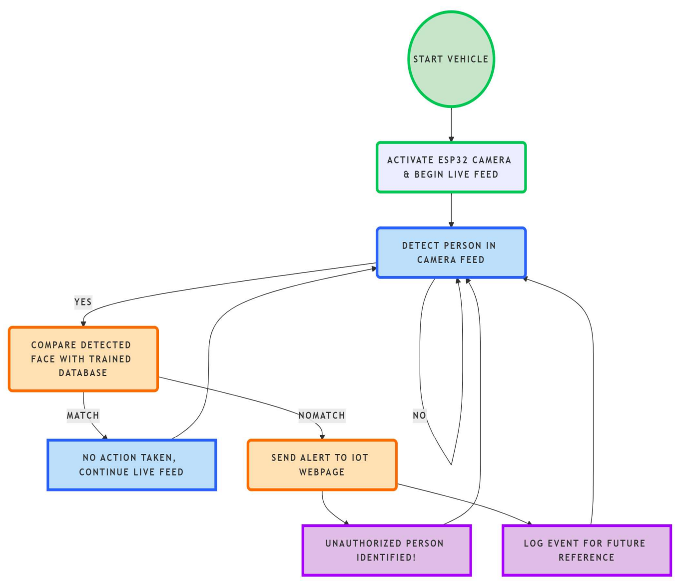

Fig. 2. Software Methodology.

7.2.1 System Initialization

Starting from the boot of the vehicle as shown in fig. 2, the ESP32 camera automatically boots up. It warms up to be able to process live video feed preparing it to be always on and working automatically. This camera operates instantly processing each photo it takes immediately for further checking out.

7.2.2 Face Detection

When you've achieved a live video stream, the first task is to detect the faces in each frame. You achieve this with the aid of the Haar Cascade classifier. The tool's infamous for being incredibly quick and excellent in classification. What's so best about Haar Cascade is it scans through the image using basic features that enable it to locate face-like regions fast. It's amazing because it tolerates various types of light and its fast enough for use in real time within built-in systems it's fast enough for use in real time within built-in systems.

7.2.3 Face match

Following the face that has been processed upon detection, input is given into the ResNet model, which extracts identifying features and compares them with retained representations upon identification. The system authenticates the individual's identity and allows the vehicle to move forward without being halted. Lastly, the face that is discovered is matched against a pre-trained set of verified individuals. A ResNet algorithm based on a neural network is used for the face match, which is constructed from a residual learning deep architecture providing highly accurate and trustworthy performance for facial recognition applications.

7.2.4 Alert Mechanism and Logging

Where the face picked up by the Haar cascade is not in the database when processed by resnet the system alerts as soon as possible then the alert is relayed to the assigned iot dashboard to alert operators to an unknown or unauthorized person the event is further logged to ensure there is always some record that will be available either for future reference or analysis this combined real-time alert and detailed logging function strengthens security and traceability to the user.

8 System Architecture

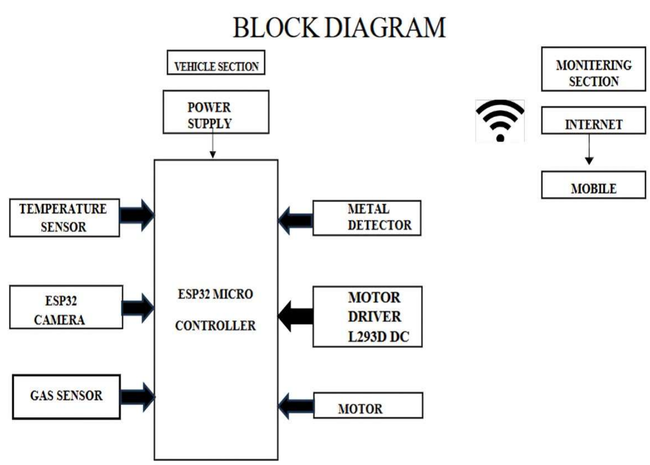

Fig. 3. System architecture.

The Surveillance Assistive Vehicle is a combined, modular system consisting of IoT-capable sensors, AI-powered image processing, and real-time communication for observing dangerous or hard-to-reach locations. Fundamentally, the system utilizes an ESP32 microcontroller to handle data from several sensors and a camera module and send warnings and processed data to distant monitoring centres (fig. 3). The system supports remote-controlled operation to provide timely threat detection and effective surveillance.

8.1 Sensor Module

Environmental sensing is performed by a multiplicity of sensors embedded in the system. A metal detector scans the earth for metal objects, like mines, and a gas sensor measures the concentration of toxic gases like carbon monoxide, or ammonia. Meanwhile, ambient temperature is also monitored by a temperature sensor, usually a thermistor or LM35, for the presence of anomalies, which may signify potential fire or overheating. Information from the sensors is continuously processed by the ESP32 to get real-time alarm of danger points.

8.2 Image processing by Esp32 camera

The image processing pipeline of the system is put together to process captured images in a number of preprocessing steps including assigning of the grayscale and rescaling the captured image to work with. Machine learning models are then applied to the processed images. A Haar Cascade classifier offers quick, real-time detection of faces or objects, and a deeper ResNet-based model picks out detailed features for precise recognition. These models are combined to identify intruders or suspicious behaviour and trigger immediate alerts if a threat is found.

8.3 Decision manager and data processing

Decision Manager compares image processing outputs and sensor inputs to decide if there is a threat. It compares real-time information with pre-defined thresholds to produce adaptive actions like sending out an alert signal or compensating the vehicle. This module, under the control of the ESP32 microcontroller encrypted by a series of embedded c codes, makes sure that the system responds quickly to changes in the environment and combines sensor information to generate well-informed decisions, such as transmitting live video feeds and sensor information to distant monitoring centres.

8.4 Vehicle navigation and motor control module

Mobility is attained through a set of DC motors driven by an L293D motor driver. The ESP32 provides control signals to the motors, allowing the vehicle to move remotely. The onboard camera provides live feeds so obstacle avoidance is taken care of by the user. This enables the vehicle to dynamically reposition itself to maximize surveillance coverage without causing collisions.

8.5 Communication and monitoring

ESP32 has a built-in Wi-Fi module that can be used to transmit data in real time, and supports a variety of protocols such as MQTT and HTTP. Processed video, sensor readings and alert status is streamed to a remote-control centre and presented on a cloud-based dashboard. This allows security staff to monitor live feeds, analyze sensor data, and receive immediate alerts if things go wrong. The networking middleware maintains a continuous connection and reliable communication, which is indispensable in responsive monitoring.

8.6 System operation workflow

The process flow of the operations: including the imaging, image recording, and recording of data, is initiated by a continuous recording of the ANImate and its sensors. This information is processed and handled by the embedded firmware and AI modules to create alert signals and adaptive control commands. The surveillance vehicle automatically corrects its navigation based on this feedback, and real-time data is sent to local displays and remote monitoring centers for response. All of these modules are integrated seamlessly to ensure that the system is capable of providing good surveillance service in the face of challenging environments.

9 Results

9.1 Webpage IoT data upload

When the sensor data was higher than the high threshold for the sensor signal, the system was activated to upload full sensor data to the IoT webpage (fig. 4 & 5). This data bundle contained precise sensor identifiers, exact measured data, timestamps, and extremely accurate location coordinates for all measurement points, revealing regions with abnormal readings. The improved setup function allowed complete recording of all sensor values, even of unknown data points, to be transmitted and published on the web console. The real-time monitoring directly provided the visualization outputs with respect to any abnormal sensor activities without delay and the abnormal sensor signals were easily detected and analyzed in the test environment, so the overall situational awareness and response of the monitoring system could be increased.

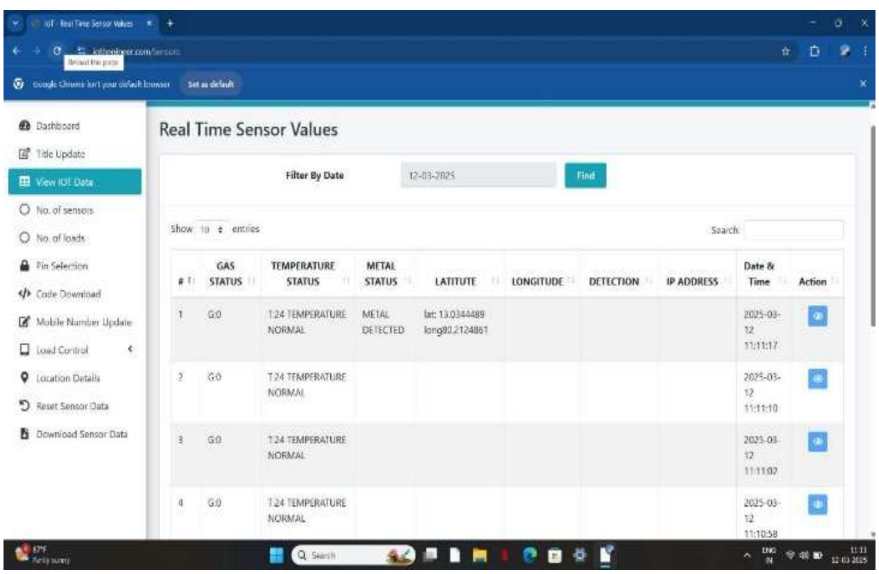

Fig. 4. IoT webpage.

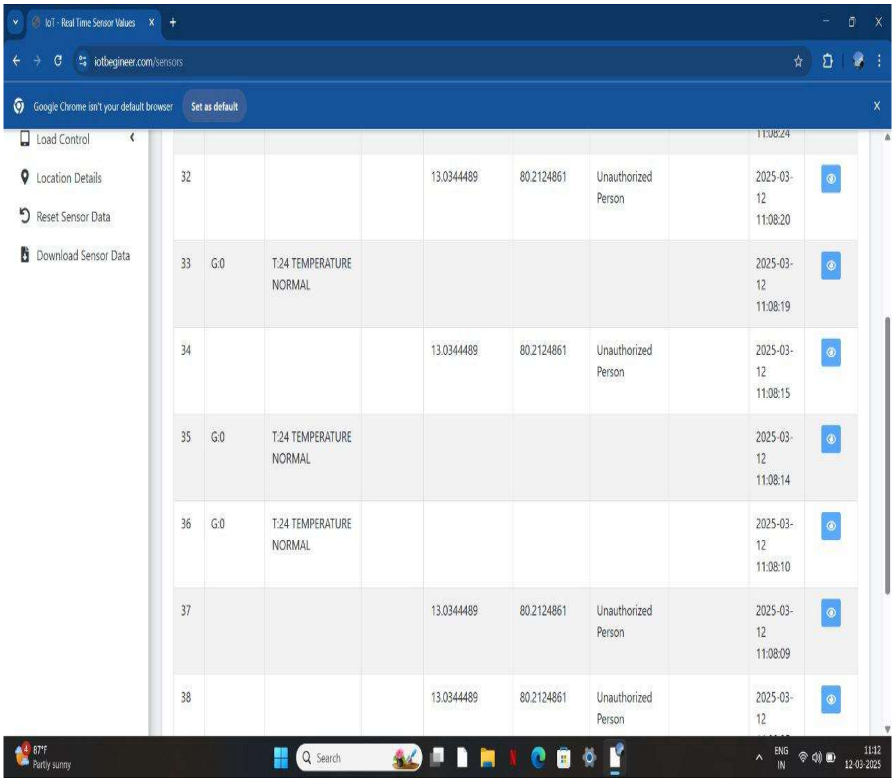

Fig. 5. IoT Webpage.

9.2 Buzzer activation for metal detection

The metal detection subsystem successfully detected metallic objects within a predefined proximity limit, triggering the buzzer in under 50ms (almost instantaneously).88 Calibration helped to decrease false positive results to under 5% in controlled environments and a slight elevation to just over 5% was seen when placed in areas of high electromagnetic interference. Moreover, we also forwarded the data of these metal detection events directly into the IoT system, which provided real-time response on the webpage with audio and video alerts, thus allowing an immediate and timely monitoring and response of the security guards.

9.3 Unknown alert in camera surveillance

The surveillance unit of the camera, provided with motion detection and facial recognition algorithms, successfully recognized known and unknown persons. The accuracy of identifying known subjects by the system was about 92%, whereas previously unseen people were identified correctly in 88% of cases. Upon detection of an unknown person, an alert was immediately raised on the IoT page along with a snapshot from the camera feed for a visual check by the security team. The average processing time from detection to alert generation ranged between 300–400 ms, which is considered acceptable for real-time security applications where rapid human intervention is required (fig. 6 & 7).

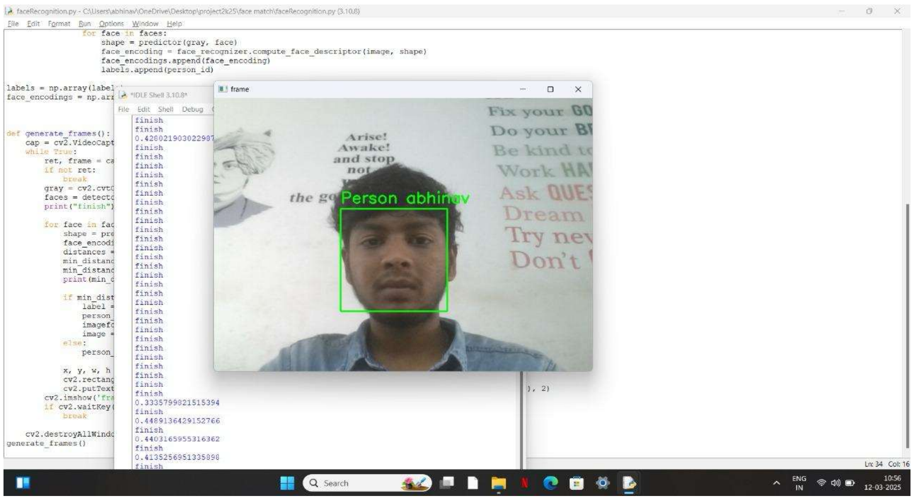

Fig. 6. Person Known-NO THREAT.

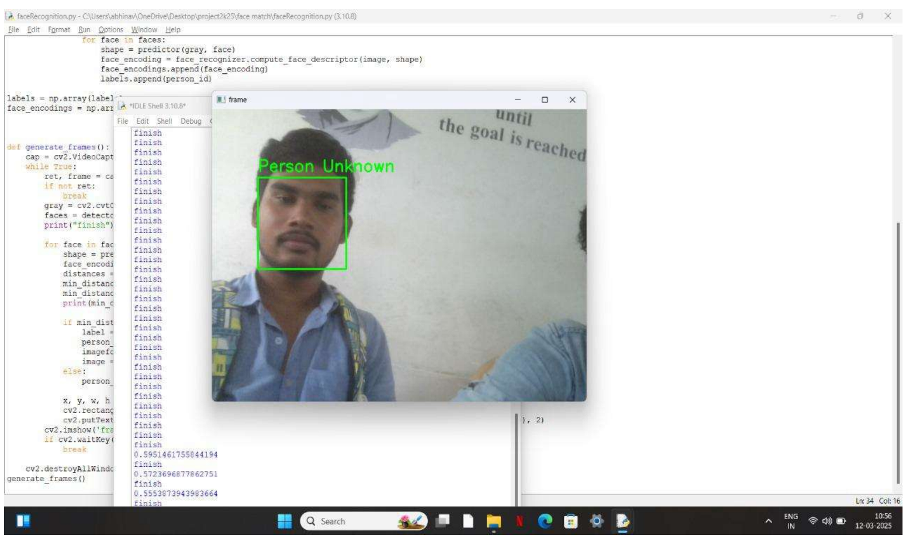

Fig. 7. Person Unknown-THREAT.

10 Discussions

The integration of the three subsystems IoT-based sensor data upload, metal detection with buzzer alert, and intelligent camera surveillance shows the feasibility of a multi-modal security and monitoring solution that effectively utilizes IoT technologies and real-time data processing. The system was able to work as an integrated unit, where each module worked independently but added together to a centralized monitoring platform.

The web-page interface served as the control and coordination centre to ensure smooth visualizations of sensor data in real-time, events from detection systems, and alarm information. Both the low delay in data transference and warning creation also render its use beneficial in scenarios in which real-time action is key to safety and threat prevention. While total system performance proved encouraging, testing did reveal certain shortcomings. Random packet losses were sometimes experienced during high network load times, which emphasizes the necessity of supplemental data buffering methods or redundancy protocols to maintain unbroken communication. The metal detector module, being very responsive, showed a slight rise in false alarms in environments with extreme electromagnetic interference levels, which suggests the necessity of improved sensor shielding or advanced calibration methodologies. Besides, even though the facial recognition system itself was mostly correct, its effectiveness could be even better optimized through the incorporation of adaptive machine learning algorithms that are able to consider differing lighting conditions, angles, and facial orientations to reduce misidentification.

Audio alarm from metal detection unit and visual alarm from surveillance module makes system as a holistic solution for continuous security monitoring. This system is designed for use in high security locations, restricted access facilities, as well as mass transport and other public areas requiring fast and accurate threat detection and needs to alert other security units to ensure containment. The next iterations could see AI-driven anomaly detection used to identify and prevent a potential threat before it becomes a problem. In addition, scaling up with better network protocols would allow new sensor types to be integrated and mass deployment to be achieved without the compromise of performance.

Enhancements to the user interface, including adjustable alert limits, multi-user consent policies, and support through mobile-app for remote connections, could improve ease of use and efficiency. In addressing this end, the projects contributes towards the real-world deployment of IoT-based surveillance and monitoring and is fundamental to the realisation of scalable, intelligent, and adaptive security.

11 Conclusion

Real-time data processing and advanced sensor technologies are merged into the proposed assistive vehicle system for enhancing monitoring functionality. Its metal-detecting feature detects metal objects, tracks ambient temperatures, and looks in real-time. It allows the security personnel to act immediately if required when that happens try to send the real-time data to a control command centre. This innovative strategy is a powerful tool for the most recent safety challenges for the reason that it not only amplify the security measures, but also alleviate the levels of threats at the important places.

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