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AMultimodal Smart Street Light System for Enhancing Women's Safety at Night

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Abstract—*Safety of women at night has become a major social issue in modern cities and semi-urban areas. The reasons for numerous crimes include inadequate lighting, surveillance infrequently, sluggish emergency response, and the absence of live monitoring systems. The primary function of conventional streetlights is to provide light, but it does not contribute to public safety or crime prevention. CCTV systems currently on the market are self-contained and require manual monitoring, making them less suitable for emergency situations. This research suggests that streetlights could be designed as smart safety units to enhance women's safety at night. Artificial Intelligence (AI) and Internet of Things (IoT) are combined with a range of other sensors, such as cameras equipped with built-in microphones, motion sensors or panic buttons, to create the system. The combination of these components identifies suspicious activities, distress sounds, unusual movement patterns, and manual emergency signals in real-time. Upon detection of an imminent risk the system will increase the brightness of the streetlight, sound alarms, capture visual evidence and immediately notify emergency contacts or local authorities. Using multiple data sources and making smart decisions, the proposed system allows for faster responses, better surveillance, and increased safety for women traveling at night. As part of smart city initiatives, this solution provides a flexible and proactive approach to safeguard public safety. Women Safety, Smart Street Lighting, Multimodal Sensors, IoT, Artificial Intelligence, Surveillance System, Emergency Alert are the key areas of focus.*

Keywords— Women's Safety, Smart Streetlight, Multimodal Sensors, IoT, Artificial Intelligence, Edge Computing, Emergency Alert System, Smart City

I. INTRODUCTION

Many regions still grapple with the issue of women's safety in public, especially at night. The absence of immediate assistance, inadequate lighting and remote areas, sluggish police response, and limited resources are all significant factors that increase the risk of harassment, assault, or other crimes against women. Even as cities embrace smart technologies, they still lack safety- focused infrastructure that is responsive and proactive. Static solutions are available for conventional street light systems. Our roads are illuminated by these elements, but they remain unchanged despite changes in the environment or human activities.Furthermore, this paper, we present an intelligent smart streetlight system we are gifted with the responsibility of providing constant human assistance to CCTV surveillance systems, which often does not prevent incidents[1].The outcome of this is a disparity between our infrastructure and safety achievements With the rise of Artificial Intelligence, edge computing, and the Internet of Things, autonomous intelligent systems that can detect, analyze (and eventually react) to real-world scenarios have become a reality. With the right combination of multimodal sensors and AI-based decision making, smart streetlights can be turned into real time safety street lights. In this paper, they outline a proposal for an innovative streetlight system that can actively monitor the environment, detect potential threats, and provide situational assistance to women at night[9].

II. PROBLEM STATEMENT

Even with modern technology, public safety systems still require improvement. The conventional street lights are capable of providing the necessary illumination, but they lack the technical expertise and adaptability to handle environmental conditions. Similarly, surveillance systems tend to rely on manual intervention, which results in delayed response to emergency situations. It is a particular issue that women in remote or underserved areas face when they are in distress, which is also the case for not receiving immediate help.Most systems fail to analyze their environment, which can result in issues such as not detecting distress sounds, sudden movements, or aggressive behavior.This is also a widespread issue. No automatic means is available to enhance visibility and focus on pressing issues, thereby eliminating the need to notify authorities in real-time. These concerns advocate for a safety mechanism that is intelligent, self- regulating, and operates independently without human intervention.[10]

III. LITERATURE REVIEW

Several studies have examined the potential of technology to enhance public safety and women's security. Wearable panic buttons and mobile applications are examples of IoT-based women's safety devices that can be used to send emergency alerts. These solutions are primarily dependent on the user's input, and they may fail if the victim is unable to activate the device.[1] Motion detection and closed-circuit television (CCTV) cameras have been integrated into smart surveillance systems. Despite their ability to enhance monitoring, these systems frequently operate in isolation and lack automated response mechanisms. High levels of false alarm in single-sensor systems are a result of differences in environment noise or lightning. The use of various data sources, including video, audio, and motion, has led to an increase in multimodal sensing technology, which is improving accuracy and reliability. The inadequate implementation of multimodal systems in streetlight infrastructure is a concern for women's safety that combines sensing, analysis, and response in one package.

IV. PROPOSED SYSTEM OVERVIEW

The proposed multimodal smart streetlight system aims to convert traditional street lights into intelligent safety nodes that can monitor public areas and react to potential threats in real time. The proposed solution differs from traditional street lighting systems in that it incorporates sensing, intelligence, communication, and automated response mechanisms to enhance women's safety during night-time hours. The smart streetlights come equipped with a variety of sensors, such as directional sensor, motion sensor (PIR) technology, and panic button. Continuously, these sensors amass environmental data, including visual activity, sound patterns, human movement, and manual distress signals. Depending on system requirements and network connectivity, Artificial Intelligence (AI) algorithms are used to process the data, either locally at the edge using embedded controllers like ESP32 or Raspberry Pi, or through a cloud-based platform.[2]

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By utilizing multiple sensors, the system analyzes data in unison through multimodal analysis. Suspect movements and abnormal behaviors can be detected using visual data, while audio signals are used to detect distressing sounds like screams or sudden loud noises, and motion sensors can detect unusual movement patterns. When people feel unsafe, they can simply manually request assistance by pressing the panic button, which guarantees immediate system intervention. Sensor fusion techniques are employed by the system to combine data from various sources and improve detection accuracy.Essentially, this method minimizes the potential for false alarms in single-sensor systems and enhances overall reliability. Predetermined rules, AI model outputs, or a combination of both are used to confirm threats.When this detects a potential threat, the system takes appropriate precautionary steps and then acts automatically. A few measures include elevating the brightness of street lights to enhance visibility, activating sound alarms or sirenses when necessary to deter criminals, collecting photographs or videos for evidence collection, and sending alerts in real-time to emergency contacts at local law enforcement agencies.It is a proactive and effective way to improve public safety by automating the response process, which allows for rapid intervention without human intervention. The system detects potential danger and then automatically brightens the streetlight, triggers an alarm to alert the public, and collects images or videos for evidence.

A. System State Classification

The system operates in three states: Normal, Alert, and Emergency.

The classification function is defined as:		
$C(T) = \{$	Normal, Alert, Emergency,	$T < \alpha, \alpha \leq T < \beta, T \geq \beta$

where $\alpha$and $\beta$are predefined threshold values.

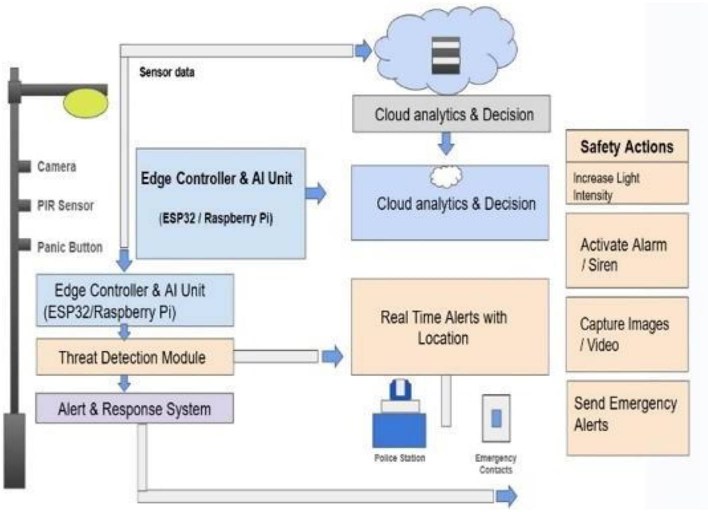

Fig. 1. Operational Workflow of the Smart Streetlight System

V. SYSTEM ARCHITECTURE

The proposed Multimodal Smart Street Light System is designed to be both scalable and adaptable, making it suitable for urban and semi-urban locations. It is built on layers that enable efficient data collection, intelligent processing, reliable communication and rapid emergency response. The four main layers of architecture are the sensor layer, processing layer (e.g, ASICs), communication layer and response layer. The sensor layer gathers both real-time environmental and user-generated data.Within the streetlight unit, there is a layer that comprises primarily consists of recessed cameras, microphones, PIR motion sensors, and panic buttons. The camera records visual information, such as human presence and movement patterns, while the microphone picks up audio signals, like disturbance sounds or unusual noise levels. The PIR motion sensor can detect nocturnal disturbances and human movement, while the panic button is designed to automatically trigger an emergency alert when people feel unsafe by triggering it manually. When taken together, these sensors offer comprehensive situational awareness[4].

Data analysis and decision-making are carried out by the processing layer. It comes with models that are based on AI and includes an edge processor or microcontroller, such as an ESP32 or Raspberry Pi. Additionally, The processing unit uses machine learning algorithms to analyze visual, audio and motion data in order to identify suspicious behaviour or emergency conditions. The layer employs sensor fusion techniques to merge the inputs from various sensors, which enhances detection accuracy and reduces false alarms. This is crucial for safety reasons. The system's configuration can determine whether processing is performed on a local level or with the help of cloud-based analytics for advanced calculations.[5]. To ensure prompt response to emergency calls and traffic, the communication layer utilizes wireless technologies such as GSM, Wi-Fi, or LoRa to send alerts like crowbars, images, and weather conditions directly to the user interfaceThis layer is a response layer that responds immediately after an individual becomes aware of terrorism or other dangers, using lights up to make the situation more visible, alerting people and making emergency alerts via video recording, and responding accordingly.

A. Multimodal Sensing Model Let the sensor inputs be defined as:

- V— Visual threat probability from camera
- A— Audio distress probability.
- M— Motion abnormality score
- P— Panic button status (0 or 1)

The combined multimodal threat score $T$is calculated using weighted data fusion:

$$T = w_v V + w_a A + w_m M + w_p P$$

Where

w_v, w_a, w_m, w_prepresent the weights assigned to each modality such that:

$$w_v + w_a + w_m + w_p = 1$$

An emergency condition is triggered when:

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$$T \geq \theta$$

where θ is the predefined threat threshold.

B. Audio Distress Detection Model

The energy of the audio signal is computed as:

$$E = \sum_{n=1}^{N} x[n]^2$$

where $x[n]$ represents the sampled audio signal. Audio threat probability is defined as:

$$A = \begin{cases} 1, & E > E_{th} \\ 0, & \text{otherwise} \end{cases}$$

where E_{th} is the energy threshold.

C. System Decision Model		
Risk level classification is defined as		
	Low,	$T < 0.3$
	R = {Medium, High,	$0.3 \leq T < 0.6$ $T \geq 0.6$

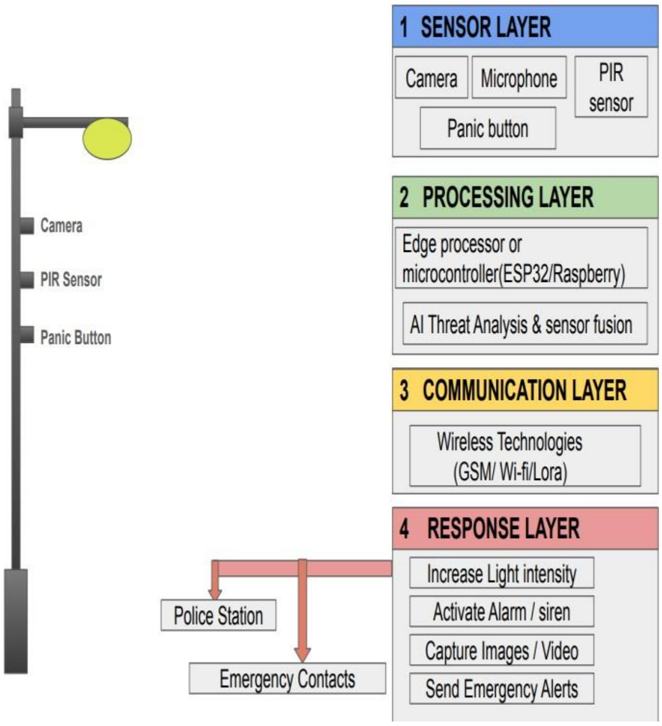

Fig. 2. Overall Architecture of the Proposed System

VI. OBJECTIVES OF THE PROPOSED SYSTEM

The multi-modal smart streetlight system is being developed to enhance women's safety at night by converting traditional street lights into intelligent and responsive safety units. In contrast to the past, we have a system that is aware of its surroundings and can detect potential dangers without human intervention.The primary objective of the system is to construct a multimodal sensing mechanism that includes various sensors, including cameras and microphones. It also includes motion sensor and panic button components. The use of various sensor types can enhance reliability and decrease the likelihood of false alarms, which enable us to detect different visual, auditory, and motion-based indications of distress or suspicious activity.The creation of AI- based threat detection features that are capable of processing real-time sensor data is a crucial factor. These systems can identify specific types of abnormal behaviors/activities, such as aggression, crowd behavior, distress sounds, and emergency button activation. The system will scrutinize information at the boundary to expedite reaction time and minimize requiring constant human observation.When an imminent threat is identified, the system can automatically activate safety measures/ responses. Instances of this can be heightened lighting for the nearby street lamps, activating an emergency sign or soundproofed siren, and recording a video to be used as evidence in case of an accident. Another key goal is to deliver immediate notifications and alerts to local law enforcement, emergency services personnel or designated emergency contacts. It uses wireless communications technologies such as GSM, Wi-Fi or LoRa to ensure that critical information is being transmitted immediately for emergency response and support.[3]

In conclusion, the suggested scheme endeavors to aid smart citysafety infrastructure by offering a practical, affordable and technologically advanced solution. The system's potential to enhance urban and semi-urban areas by integrating with existing smart city platforms can result in safer public spaces and increased urban security.

VII. THREAT DETECTION AND DECISION MAKING

The system processes data from multiple sensors in real time using AI algorithms, which enables it to identify threats and make decisions quickly.The system monitors events using computer vision, identifying potentially problematic behaviors such as aggressive behavior, stalking, or odd crowd dynamics.[11]. Simultaneously, audio processing models listen to their surroundings and filter out sounds to detect emergency alerts, panic calls, or distress signals.Motion sensors track a person's movements and can identify any oddities, such as abrupt behavioral changes, loitering in inappropriate areas, or intruding into prohibited areas.A central decision engine receives all of these sensor inputs and uses the combined data to determine the threat's level of seriousness. Responses are prompt but consistent because the system looks at multiple indicators before deeming something a threat in an effort to reduce false alarms.The system promptly initiates emergency procedures, alerts the authorities, and begins the prearranged safety measures when multiple sensors identify danger or a panic button is pressed.By enhancing the accuracy of threat detection and ensuring prompt and coordinated responses in actual emergencies, this multimodal decision-making framework contributes to the safety and security of monitored environments.

A. Decision Function

The decision-making process is based on threshold comparison:

$$D = \begin{cases} 0, & T < \theta_1 \\ 1, & \theta_1 \le T < \theta_2 \\ 2, & T \ge \theta_2 \end{cases}$$

where:

- $D = 0 \rightarrow$ Normal condition
- $D = 1 \rightarrow$ Suspicious condition
- $D = 2 \rightarrow$ Emergency condition

and θ_1, θ_2 are predefined thresholds.

VIII. MULTIMODAL SENSING APPROACH

Multimodal streetlight, a proposed multimodal system, uses multiple sensing methods to detect threats with accuracy and dependability. It works by combining visual, audio, motion, and manual inputs rather than just one sensor, maintaining heightened situational awareness and decreasing false alarms.The multifaceted approach involves using duct tape or coiled wire to monitor street lights, video, actuators, sensors, etc.Besides automatic sensing, it also includes an integrated panic button that can be used for manual emergency situations. The system can be dependable even if the sensors fail to detect danger or prompt immediate assistance, and women can immediately press the panic button to alert the system.Combining visual, audio, motion and manual sensing methods through sensor fusion techniques improves accuracy, reliability, and response time. The multimodal approach transforms the system into a robust means of improving women's safety in public spaces.[12]

IX. RESPONSE MECHANISM

The system immediately initiates a series of safety measures designed to lower the risk and ensure that assistance arrives promptly when it detects a potential threat.In addition to making it easier for anyone walking through to feel safe, streetlights automatically brighten the area to help people see better and deter potential troublemakers.In order to draw attention from anyone in the vicinity and increase the likelihood that someone will intervene and assist, a loud alarm or voice alert is simultaneously activated, making the area safer.Cameras simultaneously take pictures or videos of the scene, which can be helpful as proof for the police and future inquiries. In addition to responding locally, the system instantly notifies control rooms, local police stations, and pre-registered emergency contacts of the precise location.This coordinated approach increases the likelihood of preventing serious issues or minimizing harm to people, helps authorities stay informed of what's happening, and gets help to where it's needed quickly.[6]

X. TECHNOLOGY STACK

The system makes use of a strong and interconnected technological configuration that combines edge computing, IoT devices, AI analytics, and communication networks to ensure that threats are reliably identified and addressed.IoT sensors are installed throughout the area to continuously collect data, including cameras for visual inspections, microphones for listening in, and Passive Infrared (PIR) sensors for motion detection.These sensors connect to controllers such as Raspberry Pi or ESP32, which process the initial data on-site.For speedy reactions, sophisticated AI models for computer vision and audio classification can be configured directly on the controller. When more thorough analysis is required, these models can also operate on cloud platforms. In order to maintain seamless communication, technologies such as GSM, Wi-Fi, and LoRa are used to transmit sensor data and alerts to central servers or emergency services.Servers in the backend infrastructure manage data storage, perform analytics, and establish connections with external systems, such as registered emergency contacts or police control rooms.In order to create a reliable safety network, this technology stack manages data as it enters the system, keeps it operating smoothly, and promptly sends out alerts and responses, creating a comprehensive and reliable safety network[15].

A. AI Model Efficiency Inference latency for the deployed CNN model is:

$$T_{inf} = \frac{FLOPs}{Throughput}$$

To ensure real-time monitoring:

$$T_{inf} \le T_{frame}$$

where T_{frame} is the camera frame interval

.

B. Edge Processing Model

Let the computational workload of the edge device be defined as:

$$C_{total} = C_v + C_a + C_m$$

where:

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- C_v= Visual processing complexity
- C_a= Audio processing complexity
- C_m= Motion detection complexity

The processing time at the edge node is:

$$T_{proc} = \frac{C_{total}}{f_{cpu}}$$

where f_{cpu}represents processor frequency. The objective is:min (T_{proc})
ensuring real-time threat detection.

XI. ADVANTAGES OF THE PROPOSED SYSTEM

The suggested system functions well in contemporary urban environments because it offers numerous advantages over conventional safety measures.The system reduces the time between an incident and action by using real-time data from multiple sensors to identify threats immediately and ensure a prompt emergency response.By eliminating the need for human oversight and manual monitoring, this automated system improves accuracy and dependability.Combining cameras and audio sensors improves evidence collection and provides law enforcement with valuable data for their investigations.Without requiring significant setup adjustments, the system can readily expand to cover larger areas or more locations.Over time, it reduces operating expenses through automation, and it integrates seamlessly with smart city systems to enhance connectivity and administration.In order to make women feel safer when traveling at night, the system is crucial. They feel safer and less anxious because it watches over them and issues alerts when necessary.[7]

XII. LIMITATIONS

The high initial installation cost, privacy concerns, network dependence, and the actual accuracy of the AI model are some of the main obstacles this study must overcome.Addressing privacy issues requires having clear ethical standards and protecting data.

XIII. FUTURE ENHANCEMENTS

Women's safety at night is effectively enhanced by the suggested multimodal smart streetlight system, although there are still certain areas for improvement and expansion.Future enhancements have the potential to significantly increase the system's sustainability, coverage, and intelligence.Adding a mobile safety app is a significant improvement.Users can see nearby safe zones, receive immediate alerts, and contact emergency services directly from their phone when the smart streetlight system connects to a mobile app.The system functions beyond the fixed infrastructure thanks to the mobile application, which enables users to manually send alerts, share their current location, and request assistance in an emergency.Future additions should include facial recognition technology[10.]As long as it complies with legal and ethical guidelines, the system can identify repeat offenders or those with a criminal history by looking through recorded images and video.This feature aids law enforcement in monitoring high-risk areas more closely and preventing recurrence of incidents.To ensure that everything is used appropriately, we must implement privacy-preserving strategies and secure data handling.[13].The system can also be enhanced by incorporating solar-powered smart streetlights. The addition of solar panels and energy storage components will make the system more environmentally friendly and economical, especially in areas that are far away or lack adequate power. The use of solar power reduces our dependence on the power grid and helps to support environmentally friendly smart city initiatives. The creation of city-wide safety analytics dashboards can provide valuable information about crime patterns, hotspots, and peak crime times. Crime data from multiple smart streetlights can be analyzed collectively to assist in crime prediction, resource allocation, and city development planning. The dashboards can assist in making informed decisions to enhance public safety on a larger scale.The aim is to enhance the system so that it becomes smarter, more comprehensive, and is able to protect cities in the long run.The smart streetlight system can become better at providing safety and support to women in public spaces as AI, IoT, and data analytics continue to enhance.[14]

A. System Architecture

The proposed system involves placing several sensing units directly into the streetlight system.The motion, sound, and camera sensors are all connected to a central microcontroller.Communication modules enable you to send information directly to the authorities and emergency contacts.The system operates throughout the night to monitor public areas.

B. Components Used

- Motion Sensor (PIR)
- Sound Sensor / Microphone
- Camera Module
- Microcontroller (Arduino / ESP32)
- Communication Module (Wi-Fi / GSM)
- LED Street Light

C. Working of the System

The system is always monitoring the area through the use of motion and sound sensors that are connected to the street lights. When the microcontroller detects unusual movements or sounds of distress, it activates the camera module to capture images. In addition, they increased the brightness of the streetlight to improve visibility. An alert message containing the location and details of the event is sent to the nearby authorities and the emergency contacts that are stored. This is done to ensure that the issues are caught quickly and that emergencies are responded to promptly.

XIV. CONCLUSION

This research focuses on a smart street lighting solution that incorporates different technologies to enhance women's security at night.The solution combines different sensors and smart alerting capabilities to monitor everything in real-time and respond immediately in case of an emergency.The solution is cost-effective, scalable to meet the needs of the city, and suitable for a smart city environment.Additional features may be incorporated using AI.

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