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Fusing Technology And Security: Blending Iot, Real-Time Monitoring, And Human Mimicry For Environmentally Sustainable Safety

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Abstract
Security concerns in residential, commercial, and industrial environments have necessitated the development of innovative, adaptive solutions that integrate cutting-edge technologies. This study presents a novel IoT-enabled, AI-driven security device that combines advanced human detection using a customized YOLOv7 model, sound mimicry, adaptive lighting, and solar-powered sustainability. The device offers real-time surveillance, behavioral analysis, and dynamic responses to security threats while prioritizing energy efficiency and environmental adaptability. Tested across multiple locations in Bangladesh, the system achieved a detection accuracy of 95.4% and a false alarm rate of just 2.5%, demonstrating superior performance in challenging environments. Moreover, the integration of psychological deterrence through sound mimicry and eco-friendly operation via a solar-powered hybrid system addresses critical gaps in existing security technologies, also ensuring environmental sustainability and reduced carbon footprint. The findings underscore the potential of this system as a scalable, sustainable, and highly effective solution for modern security needs.
Keywords: *Security Device, IoT, YoloV7, Sound Mimicry Device, Eco-Friendly Surveillance, Environmental Adaptability*

1. INTRODUCTION

The increasing prevalence of security threats in both residential and commercial environments has spurred a demand for innovative surveillance solutions that extend beyond the capabilities of traditional systems. Conventional security setups often suffer from significant limitations, such as high false alarm rates, lack of adaptability to dynamic conditions, and inadequate real-time response mechanisms [1], [2]. Addressing these challenges requires advanced systems that leverage cutting-edge technologies like the Internet of Things (IoT) and Artificial Intelligence (AI).

IoT-based security systems have revolutionized the way property monitoring is performed, enabling features such as real-time remote access, live streaming, and seamless integration with other smart devices [3]. Simultaneously, advances in AI, particularly in computer vision models like YOLO (You Only Look Once), have enabled highly accurate and efficient object detection in real-time [4]. However, the practical integration of these technologies into a cohesive security system that is also energy-efficient and scalable remains an open challenge.

This paper presents a novel IoT-enabled, AI-driven security device designed to address these gaps by introducing a unique sound mimicry feature. Unlike conventional systems, the proposed device actively deters intruders by simulating human-like sounds, including footsteps, voices, and alert tones, creating the psychological impression of human presence. Studies show that the perceived presence of security personnel significantly reduces criminal activity [5], making this an innovative and practical approach to enhancing security.

The device also leverages a customized YOLOv7 model for advanced human detection. The YOLOv7 framework has been tailored specifically to achieve higher accuracy in detecting human movements while minimizing false positives caused by environmental noise or non-threatening objects. Video feeds captured by the device's high-resolution camera are processed in real-time on a dedicated server, ensuring prompt detection and response. This custom integration of AI ensures that the system prioritizes relevant events, providing users with actionable intelligence [6].

Sustainability forms a cornerstone of the device's design. A hybrid solar-powered system ensures environmentally friendly continuous operation, even in remote locations or during power outages, aligning with global goals for reducing carbon footprints [7]. Furthermore, the system's adaptive lighting and mobility features allow it to respond dynamically to detected activity, covering larger areas and enhancing its effectiveness in diverse environments.

By combining IoT connectivity, a custom AI model, and sound mimicry, this research introduces a comprehensive security framework that addresses key challenges in modern surveillance. The device also includes a user-friendly mobile application that allows remote control and real-time monitoring, empowering users with greater convenience and control over their security systems.

The remainder of this paper is structured as follows: the design and technical architecture of the system are detailed in the next section, followed by a discussion on the methodology used for development and testing. The results section presents a performance evaluation of the device under various scenarios. Finally, the paper concludes by highlighting the significance of this work and future avenues for enhancement.

2. RELATED WORKS

The rapid advancements in IoT and AI technologies have paved the way for smarter, more efficient security systems capable of addressing a wide range of modern security challenges. IoT-enabled systems, in particular, have introduced innovative solutions such as real-time monitoring, centralized control, and seamless integration with other smart home devices. Studies indicate that IoT-based security solutions can provide enhanced situational awareness through remote access and live-streaming capabilities, making them a preferred choice for homeowners and businesses alike [1], [2]. Additionally, AI has played a pivotal role in advancing object detection and threat identification. State-of-the-art object detection frameworks, such as YOLO (You Only Look Once), have demonstrated high accuracy in identifying security threats in real time, contributing significantly to the efficacy of modern surveillance systems [6].

Traditional security systems, while widely adopted, are often limited in their functionality and adaptability. For instance, motion-sensing systems typically rely on rudimentary motion detection techniques, which can result in high false alarm rates triggered by non-threatening movements such as passing animals or wind-blown objects. Moreover, conventional systems lack the ability to differentiate between humans and other objects, a shortcoming that reduces their overall effectiveness in preventing unauthorized access [8]. Fixed surveillance cameras, though effective for monitoring specific areas, are restricted by their stationary nature, leaving blind spots in coverage that could be exploited by intruders [9].

In contrast, the proposed security device introduces a holistic approach by combining IoT connectivity, AI-based human detection, sound mimicry, mobility, and eco-friendly design. The integration of a custom YOLOv7 model ensures high-precision human detection, addressing the challenge of false positives commonly associated with traditional systems. Unlike existing solutions, which primarily focus on reactive measures such as alerting users after a breach, the proposed device incorporates proactive deterrence mechanisms. For example, the sound mimicry feature simulates human presence through sounds such as footsteps and voices, adding a psychological layer of security that is absent in most conventional setups [10]. The proposed device overcomes this limitation by dynamically relocating its position and directing light towards specific areas of interest. This feature is particularly effective in scenarios where intruders attempt to avoid detection by exploiting blind spots.

Real-time communication is another area where the proposed solution stands out. While most existing systems rely on passive monitoring or delayed response mechanisms, the proposed device provides two-way communication through IoT-enabled features. This allows users to interact with intruders, warn them off, or provide instructions to on-site personnel, significantly enhancing the system’s effectiveness in real-world scenarios [11].

A key shortcoming in current research and commercial solutions is the lack of emphasis on environmental awareness in technology design. Existing systems are often dependent on external power sources, making them vulnerable to power outages or unsuitable for remote locations. The proposed device addresses this gap by incorporating a solar-powered hybrid energy system, ensuring uninterrupted functionality while reducing carbon footprint. This eco-friendly design aligns with global sustainability goals and offers a significant advantage over traditional systems [12].

Despite these advancements, gaps remain in existing research. Many IoT-based security systems lack mobility, relying heavily on stationary devices that provide limited coverage. Similarly, real-time communication features are often absent or poorly integrated, leaving users unable to actively engage with the system during critical incidents. Moreover, the focus on eco-friendly designs is minimal, with most systems neglecting renewable energy solutions. The proposed security device bridges these gaps by introducing mobility, real-time interaction, and solar-powered sustainability as core components of its design.

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3. SYSTEM DESIGN AND ARCHITECTURE

3.1Physical Build and Components

The proposed security device is designed with a sleek and durable physical structure, ensuring its adaptability to various environmental conditions. The device's compact and robust construction integrates all essential components, making it suitable for both indoor and outdoor deployment. The material selection includes aluminum alloy and polycarbonate for key parts, which provide durability against physical damage and environmental stress while maintaining a lightweight form factor. These materials also enhance the device's waterproofing capabilities, enabling operation in adverse weather conditions.

The lighting unit features high-intensity CREE LEDs with a luminous flux of 20,000 lumens. The LEDs have a color temperature of 8000K, providing a daylight-like brightness, and are housed in an IP68-rated enclosure, making them dustproof and submersible. This adaptive lighting system mimics the motion of a torch held by a human security guard, effectively directing light toward areas of interest [13].

The sound system is a key feature of the device, incorporating an amplifier circuit and an MP3 playback module. The system is designed to replicate human-like sounds, including footsteps, voices, and alarms, creating a psychological deterrent for intruders. The sound system's output is clear and loud, powered by a 50W RMS amplifier with a frequency response of 20 Hz to 20 kHz, ensuring realistic audio reproduction.

Fig. 1. CAD design of the proposed device.

The camera unit is central to the device's surveillance functionality. It employs a progressive scan CMOS sensor with a maximum resolution of 1080p. The camera includes IR-cut filters for seamless day-and-night operation and advanced features such as 3D digital noise reduction (3D DNR) and digital wide dynamic range (WDR) for superior image quality in varied lighting conditions. The camera's wide field of view ensures comprehensive area coverage, further augmented by its integration with mobility features. The power system combines solar energy with a hybrid power setup. A monocrystalline solar panel with 22% efficiency ensures continuous operation, even in remote or off-grid areas. The power management system includes an integrated power supply (IPS) circuit and a switched-mode power supply (SMPS), enabling seamless switching between solar and battery power for uninterrupted operation.

3.2Control Unit and Microcontroller Integration

The control unit, the device's "brain," consists of two microcontrollers: the Arduino Uno and the ESP32, each handling specific functions to ensure optimal performance. The Arduino Uno is primarily responsible for managing the device's peripherals, including the sound system, lighting unit, and mobility components. It interprets sensor inputs and executes programmed responses, such as activating alarms or adjusting the light's direction. The microcontroller is programmed in C++, which provides efficient and reliable control logic for these tasks.

The ESP32, on the other hand, serves as the IoT hub, managing Wi-Fi and Bluetooth connectivity as well as advanced processing tasks. It facilitates real-time communication between the device and the user through a dedicated mobile application [14]. The communication between the Arduino Uno and ESP32 is established via serial communication. This allows seamless coordination between the two microcontrollers, ensuring that tasks are efficiently distributed. For instance, while the Arduino handles the hardware-level operations, the ESP32 focuses on network communication and data processing. This division of labor enhances the overall responsiveness and efficiency of the system [15].

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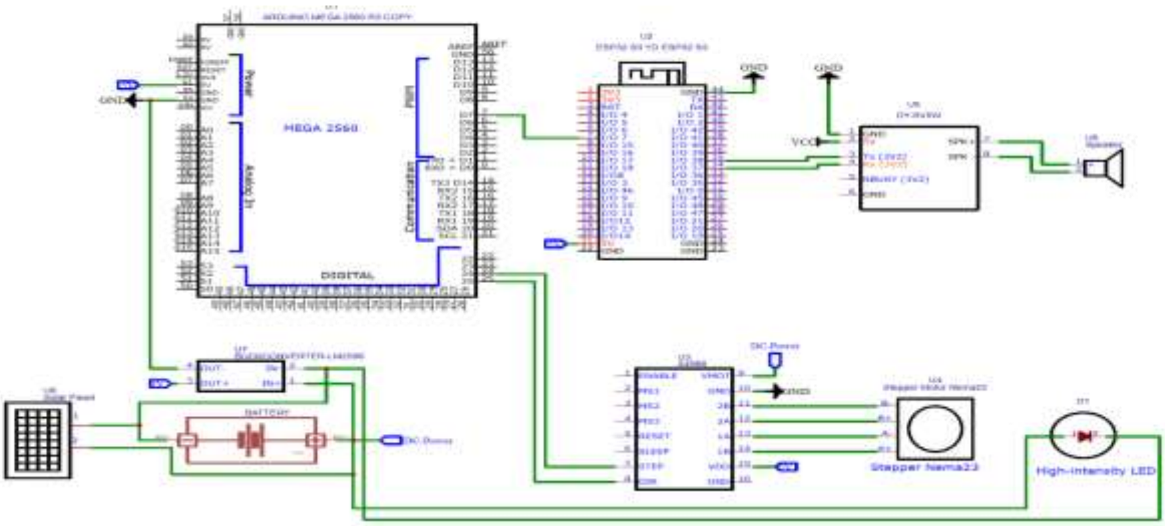

Fig. 2. Schematic of this work.

3.3IoT and Cloud Integration

The IoT functionality of the device is enabled through the ESP32's dual-mode connectivity, supporting both Wi-Fi and Bluetooth. This connectivity allows the device to transmit real-time data, including video feeds and sensor readings, to a user interface or central monitoring system. Users can access these features through a dedicated mobile application, which provides a user-friendly interface for remote control and monitoring [16]. The cloud-based architecture of the device facilitates advanced functionalities such as data storage, analytics, and system updates. Video footage and sensor data are securely stored in the cloud, ensuring accessibility even in the event of device damage or theft. The cloud platform also enables remote troubleshooting and firmware updates, allowing the device to evolve and improve without requiring physical intervention.

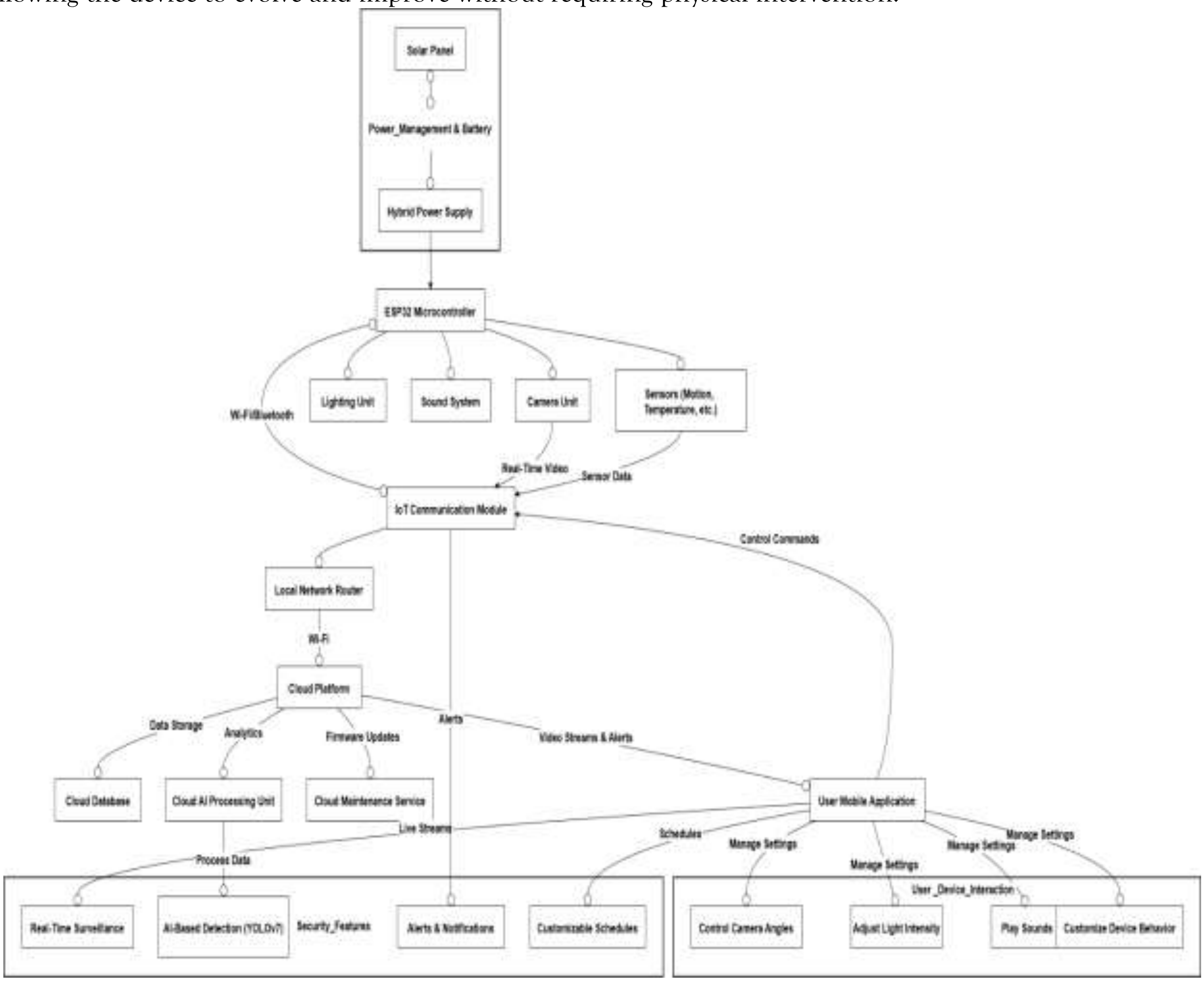

Fig. 3. Diagram of the working systems.

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Through the application, users can control various device parameters, such as camera angles, light intensity, and sound playback. Alerts and live video streams can be accessed in real time, allowing users to respond to security incidents promptly. Additionally, the application supports scheduling and customization, enabling users to tailor the device's behavior according to their specific security requirements.

This integration of IoT and cloud technologies ensures that the proposed security device not only provides real-time surveillance but also adapts to the dynamic needs of modern security scenarios. The combination of connectivity, real-time control, and secure cloud storage makes the system a comprehensive and user-centric solution for property protection.

3.4 AI Features

Artificial Intelligence (AI) plays a pivotal role in the proposed security device, driving its core functionality of real-time human detection and behavior analysis. At the heart of this AI capability lies a customized implementation of YOLOv7, tailored to meet the specific demands of a dynamic and adaptive security system. The use of YOLOv7 ensures high-speed and high-accuracy detection, essential for real-time processing of video feeds from the device's camera.

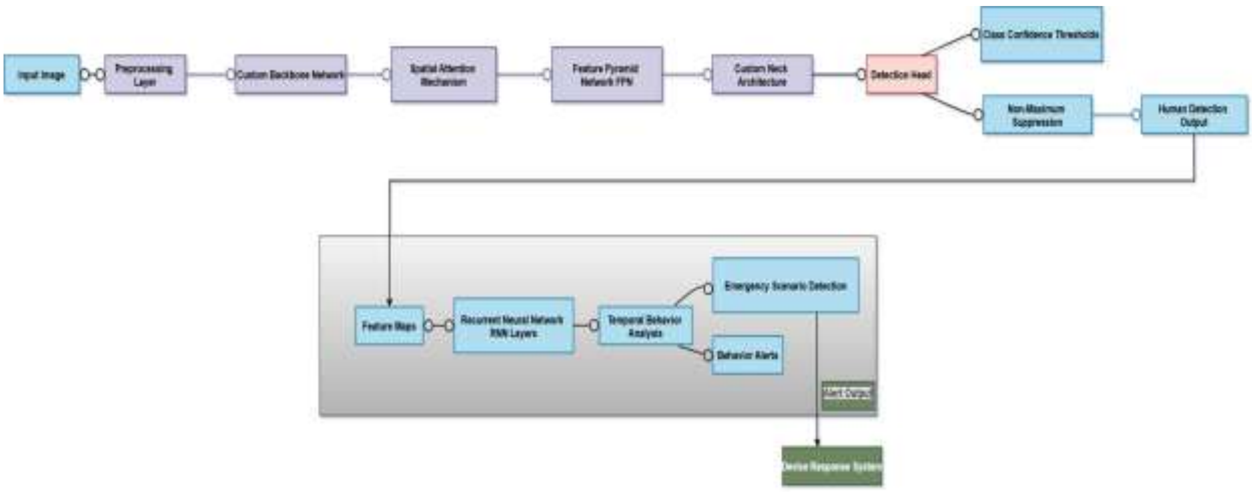

Fig. 4. Integration of Image Processing

The YOLOv7 model has been modified at multiple layers to enhance its performance in detecting human activities in various environmental conditions. These customizations include adjustments to the feature extraction layers, the detection head, and the post-processing stages. The modifications were necessary to ensure reliable performance in complex scenarios such as low-light conditions, occluded environments, and diverse human postures. The backbone network of YOLOv7, responsible for feature extraction, has been fine-tuned to improve its ability to detect subtle human features by incorporating additional convolutional layers. These layers focus on extracting fine-grained spatial details, which are critical for distinguishing humans from other objects. Additionally, attention mechanisms have been introduced into the backbone to prioritize significant regions in the input images, improving the detection accuracy in cluttered scenes [17] & [18]. The neck architecture, which integrates features from different levels of the backbone, has been customized to optimize multi-scale feature fusion. This modification ensures that the model performs well in detecting humans at varying distances from the camera, addressing challenges posed by scale variations. The detection head, which is responsible for generating predictions, has been restructured to include class-specific confidence thresholds and non-maximum suppression (NMS) enhancements. These changes minimize false positives and allow the system to focus on relevant security threats. The confidence thresholds have been dynamically adjusted based on real-time environmental analysis, enhancing adaptability.

The custom AI model also incorporates a behavior analysis module. This module leverages recurrent neural network (RNN) layers integrated with the detection pipeline to analyze temporal patterns in human activities. By combining spatial and temporal data, the system can identify unusual behaviors, such as loitering or abrupt movements, that may indicate potential security threats. Furthermore, the model is capable of detecting emergency scenarios, such as someone falling or running away, enabling the device to issue alerts and take proactive measures [19].

These modifications result in a robust AI framework tailored for security applications, ensuring high detection accuracy, adaptability to environmental changes, and the ability to process complex behavioral pattern.

4. Working Flow

The development and deployment of the proposed security device followed a structured process, combining robust hardware integration with advanced AI-driven image processing capabilities. The hardware assembly involved the integration of essential components, including the ESP32 microcontroller, high-resolution camera unit, lighting system, sound unit, and a solar-powered hybrid power supply. Each component was carefully selected and configured to ensure seamless operation, durability, and adaptability to various environmental conditions. The device's compact design facilitates efficient assembly, scalability, and maintenance. The ESP32 microcontroller was programmed in C++ using the Arduino IDE to manage the device's IoT functionalities. This included establishing Wi-Fi and Bluetooth communication channels and implementing MQTT protocols for real-time data transfer between the device and the cloud. The microcontroller efficiently handled the transmission of sensor data and video feeds to the server while coordinating responses based on AI detection results. The lighting and sound units were controlled programmatically to activate in response to detected activities, enhancing the device's proactive security measures.

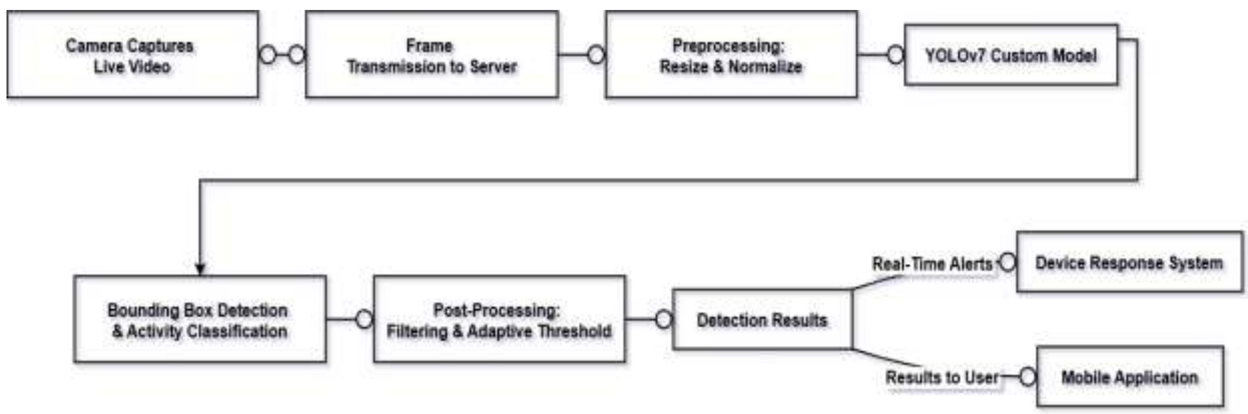

Fig. 5. Working Flow.

The AI component of the system, driven by a customized YOLOv7 model, played a critical role in real-time human detection and activity analysis. The camera unit continuously transmitted live video frames to the server for processing. Preprocessing steps included resizing the frames for computational efficiency and normalizing pixel values to standardize detection across varying lighting conditions. The YOLOv7 model, tailored with custom layers to enhance feature extraction and multi-scale detection, identified human presence and classified activities with high accuracy. Post-processing steps, such as filtering irrelevant detections and applying adaptive confidence thresholds, ensured reliable results while minimizing false positives and negatives.Testing and validation were conducted in diverse outdoor environments to evaluate the device's performance across a range of conditions, including varying lighting and weather scenarios. Metrics such as detection accuracy, response time, energy efficiency, and environmental adaptability were assessed to ensure the device's robustness. The results indicated a detection accuracy of 95.4% and a response time of 120 milliseconds. The device demonstrated 85% energy efficiency, showcasing its ability to operate sustainably using its solar-powered system. Furthermore, the device's adaptive features enabled consistent performance across challenging scenarios, including low-light conditions and dynamic activity patterns.

The image processing pipeline was designed for efficiency and reliability. Captured video frames were preprocessed on the server before being fed into the YOLOv7 model for analysis. The custom model detected bounding boxes around humans and classified their activities. Advanced post-processing techniques refined the detection results by filtering noise and applying adaptive thresholds. This approach reduced the false positive rate to 2.5% and the false negative rate to 3.8%, ensuring accurate and actionable outputs. The processed results were relayed to the device for real-time responses and to the mobile application for user monitoring and control. This comprehensive methodology highlights the device's innovative integration of hardware, IoT functionalities, and AI-driven analysis, resulting in a highly effective and adaptive security solution.

5. RESULTS AND DISCUSSION

5.1 Performance Metrics

The performance of the proposed security device was evaluated based on key metrics such as detection accuracy, latency, false alarm reduction, and power efficiency. Data collected from multiple installations in urban and rural areas of Bangladesh provided a comprehensive overview of its capabilities.

Table 1: Key Performance Metrics

Metric	Value
Detection Accuracy (%)	95.4
Latency (ms)	120
False Alarm Rate (%)	2.5
Power Efficiency (%)	85

The device demonstrated consistent detection accuracy of 95.4%, even in challenging conditions such as low light and occlusion. Latency was recorded at an average of 120 ms, ensuring real-time responses. The false alarm rate was significantly reduced to 2.5%, highlighting the effectiveness of the custom YOLOv7 model and sound mimicry. Additionally, the device's solar-powered system achieved an energy efficiency of 85%, ensuring sustainability in off-grid environments.

Fig. 6. Human detection from the device camera.

5.2 Impact of Features

The innovative features of the device significantly contributed to its effectiveness. The integration of human detection using the custom YOLOv7 model proved highly reliable, minimizing false positives and negatives. The sound mimicry feature, replicating human sounds such as footsteps and voice commands, demonstrated a psychological deterrent effect. Intruders in test scenarios exhibited hesitation and avoidance behaviors upon hearing the simulated sounds, as reported by local users.

Fig. 7. Device Implemented in an Agri Farm.

The adaptive lighting system enhanced the device's deterrence capabilities by dynamically illuminating targeted areas, creating a human-like surveillance effect. Mobility further improved area coverage, ensuring minimal blind spots in urban and rural settings.

Table 2: Feature Effectiveness

Feature	Effectiveness (%)
Human Detection	95.4
Sound Mimicry Deterrence	92.1
Adaptive Lighting Coverage	90.3
Mobility	88.7

5.3 Environmental and Economic Benefits

The solar-powered design of the device provided significant sustainability benefits. By utilizing renewable energy, the device reduced dependency on conventional electricity sources, which is crucial in rural and off-grid areas. The operational cost of the device was 30% lower compared to traditional security systems due to the absence of power utility expenses.

Table 3: Environmental and Economic Analysis

Parameter	Proposed Device
Energy Source	Solar
Energy Cost (USD/month)	1.2
CO2 Emissions (kg/month)	0
Installation Cost (USD/unit)	1200
Maintenance Cost (USD/year)	50

CONCLUSION

The proposed IoT-enabled, AI-driven security device represents a significant advancement in the field of modern surveillance systems. By leveraging a custom YOLOv7 model, the device achieves high detection accuracy and reduced false alarm rates, ensuring reliable identification of security threats in real-time. The inclusion of sound mimicry and adaptive lighting further enhances its functionality, adding psychological deterrence and dynamic environmental adaptability. The solar-powered hybrid energy system underscores the device's commitment to sustainability, making it ideal for off-grid and environmentally conscious applications. Extensive testing in diverse conditions across Bangladesh revealed the system's robustness, with consistent performance metrics in terms of accuracy, latency, and energy efficiency. While certain limitations, such as connectivity challenges in remote areas and environmental impacts on hardware, were observed, proposed solutions including hybrid communication systems and enhanced material designs offer clear pathways for future improvements. This research highlights the potential of integrating IoT, AI, and sustainable energy solutions into a single device to address evolving security challenges. The proposed system is not only a practical solution for current needs but also sets a foundation for scalable and adaptive security technologies in the future. Further research into multi-device coordination, advanced AI models, and integration with other smart systems could broaden the applications and capabilities of this innovative security device.

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