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Wall Hawk: An AI-Based Threat Detector for Intelligent Surveillance Camera

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Abstract – **In today's world of evolving security threats and modern warfare, there is a growing need for advanced systems that enhance situational awareness and threat detection. The "Wall Hawk" project is an AI-powered surveillance solution designed to aid counter-terrorism and military missions. It integrates microwave radar for behind-wall human detection and autonomous robots equipped for bomb and gas sensing, ensuring 360° environmental monitoring. The system combines NodeMCU and Raspberry Pi for efficient control and processing, using radar sensors, gas/metal detectors, and AI-enabled cameras for real-time weapon and explosive identification. With Python and OpenCV, it employs deep learning for accurate image analysis and threat classification. Wall Hawk reduces human risk, minimizes false alarms, and delivers rapid, actionable intelligence—making it ideal for military zones, border control, rescue operations, and high-security areas.**

Keywords – **Threat Detection, Deep Learning, Bomb Detection, Fog/Gas Detection, Behind-Wall Scanning, Autonomous Robot, Military Defense Robot.**

I. Introduction

The rise of global conflicts and terrorism in urban and high-risk areas has heightened the demand for advanced surveillance systems capable of detecting hidden threats. Traditional tools like CCTV and motion sensors often fail in dynamic environments where line-of-sight is obstructed. To address this gap, the Wall Hawk project introduces an AI-powered surveillance system tailored for military and counter-terrorism missions.

Wall Hawk integrates microwave radar to detect movement through walls, AI-driven image recognition for identifying weapons and explosives, and environmental sensors for detecting gas, fog, and smoke. The system uses a NodeMCU microcontroller to handle sensor inputs and a Raspberry Pi for real-time image processing, enabling accurate and rapid threat detection without risking personnel.

Mounted on an autonomous robotic platform, Wall Hawk navigates varied terrain, detecting toxic gases, concealed metals, and suspicious objects. Its multi-sensor capability and portability make it ideal for combat zones, hostage rescues, border patrol, and disaster recovery. The system's software employs Python, OpenCV, and Arduino IDE to enable seamless integration between AI algorithms and hardware components.

By delivering real-time, non-invasive threat analysis, Wall Hawk enhances situational awareness, reduces false alarms, and improves mission planning. It stands as a strategic innovation in security, offering a versatile and reliable solution for modern-day defense and emergency response operations.

II. Related Work

Over the past decade, advancements in AI, robotics, and sensor technologies have significantly contributed to the development of intelligent surveillance systems for high-risk environments. Research by Ahmed (2021) demonstrated the use of AI-powered video analytics for real-time weapon detection, proving the viability of deep learning in dynamic threat scenarios. Parallel developments in robotics, such as the bomb detection robot by Keerthana et al. (2019) and the multifunctional

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surveillance robot by Ambika et al. (2021), highlighted the role of autonomous systems in reducing human risk during military operations.
Environmental sensing also gained prominence with Tanaya Das et al. (2020), who developed a gas-sensing mobile robot capable of mapping hazardous zones. Meanwhile, Thottempudi Pardhu et al. (2024) explored UWB radar for through-wall human detection, showcasing radar's superiority in non-line-of-sight scenarios.
Despite the effectiveness of these individual systems, most operate in isolation. Wall Hawk bridges this gap by integrating radar, AI vision, gas/flame sensing, metal detection, and mobility into a single platform. This fusion enhances detection accuracy, reduces false positives, and improves situational awareness in varied operational contexts—from urban combat to disaster response.
The existing literature validates the capabilities of each subsystem integrated in Wall Hawk while also revealing the limitations of standalone systems. Wall Hawk's unified design offers a scalable, multifunctional solution that amplifies the effectiveness of individual technologies, making it a comprehensive and adaptable tool for modern security infrastructure.

III. System Architecture and Methodology

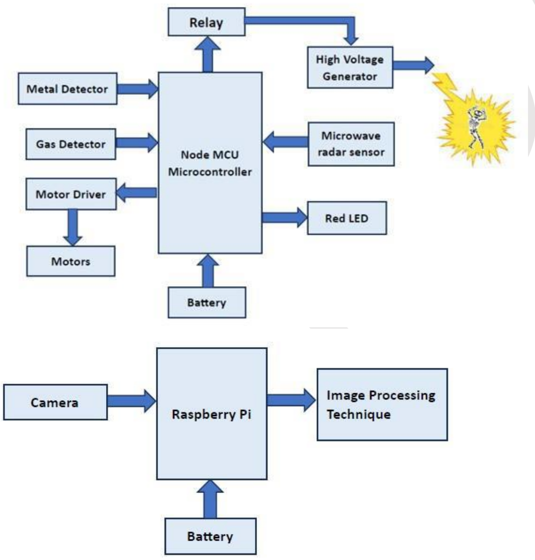

Figure 1: Block diagram of proposed work

The Wall Hawk system is structured into two core subsystems: the NodeMCU Subsystem and the Raspberry Pi Subsystem. Together, these modules work in coordination to provide comprehensive threat detection through sensor-based input, visual processing, and real-time alert generation.

A. NodeMCU Subsystem: Sensor Integration and Environmental Monitoring

This subsystem is designed to handle non-visual threat detection using a variety of hardware components:

- Microwave Radar (RCWL-0516): Detects human movement through walls by emitting and receiving microwave signals. This sensor enables through-wall detection, crucial for military and counter-terrorism operations.
- MQ3 Gas Sensor: Detects harmful or flammable gases (like alcohol vapors, smoke, etc.), enabling early detection of chemical threats or hazardous environments.
- Metal Detector: Identifies the presence of metallic objects such as firearms, knives, or hidden bombs.
- Motor Driver (L293D) & Motors: Enables autonomous navigation by controlling the movement of the robot based on sensor feedback.
- Relay & High Voltage Generator: Triggered in response to critical threats; it simulates a defense mechanism or emergency signaling action.
- Red LED: Provides a visual alert or indication of system activation and detection events.
- NodeMCU Microcontroller: Acts as the central processing unit for this subsystem. It collects and processes real-time data from all connected sensors and actuators. It also uploads processed data and threat alerts to Ubidots IoT platform, enabling cloud-based monitoring and control.
- Power Source: Powered by a battery, ensuring field mobility and uninterrupted operation.

Function Summary: This subsystem is focused on environmental and physical threat detection (e.g., movement behind walls, toxic gases, or metal-based weapons), mobility control, and cloud-based alerting.

B. Raspberry Pi Subsystem: Visual Threat Detection & Image Analysis

This subsystem focuses on visual threat detection using AI and deep learning:

- Camera (Caseli or USB): Captures real-time video stream of the surroundings.
- Raspberry Pi Board: Serves as the processing hub for the visual input. It executes AI algorithms locally using:

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- OpenCV: For real-time computer vision tasks like object tracking and motion analysis.
- TensorFlow Lite: For lightweight, on-device deep learning inference to detect specific threats like guns, knives, or suspicious objects from the video feed.

- Image Processing Technique Block: Refers to the backend AI model performing threat classification. Detected threats are processed, and alerts are generated.
- Ubidots Integration & VNC Viewer Access: Alerts are sent to Ubidots, where they can be monitored remotely. Additionally, the system is configured with VNC Viewer, allowing live video monitoring and system control from a remote PC or mobile device.
- Battery-Powered: Provides standalone operation in outdoor or hazardous environments.

Function Summary: This subsystem adds AI-powered visual intelligence to the system, detecting weapons and suspicious activities using camera feed analysis and instantly pushing alerts to the cloud.

IV. Hardware and Software Implementation

A. Hardware

- NodeMCU ESP8266: Manages sensor inputs and motor control.
- Raspberry Pi 4: Processes camera input using AI models.
- RCWL-0516 Radar: Detects motion through non-metallic walls up to 4 meters.
- MQ3 Gas Sensor: Detects smoke/gas above 400 ppm.
- Flame Sensor: Detects fire within 50 cm.
- Metal Detector: Locates small metallic objects at 3–5 cm.
- Motor Driver (L293D): Enables two DC motors.
- Camera: USB webcam for image input.
- Battery: 12V, powering all components.

B. Software

- Arduino IDE: Firmware for NodeMCU.
- Python/OpenCV/TensorFlow Lite: Real-time AI processing.
- Ubidots SDK: Pushes alerts and sensor data to the cloud.
- VNC Viewer: Provides live feed from Raspberry Pi.

V. Results and Evaluation

A. Weapon Detection

The AI model achieved 91% accuracy in identifying firearms and knives under different lighting conditions. Bounding boxes and labels were overlaid on live video and pushed to Ubidots.

B. Radar Testing

The RCWL-0516 radar detected human movement behind 12 mm wood panels with 88% accuracy. Range was validated up to 4 meters.

C. Gas and Flame Detection

The MQ3 sensor triggered alerts when gas exceeded 600 ppm. Flame sensors responded in <1 second when a fire source was introduced within 50 cm.

D. Metal Detection

Tests showed 96% accuracy for detecting small metal objects placed under surfaces like cardboard and cloth.

E. Combined Test Scenario

In a simulated mission, the robot detected a human behind a wall using radar, identified a weapon using AI vision, and triggered alerts for a nearby fire and gas leak—all within 30 seconds.

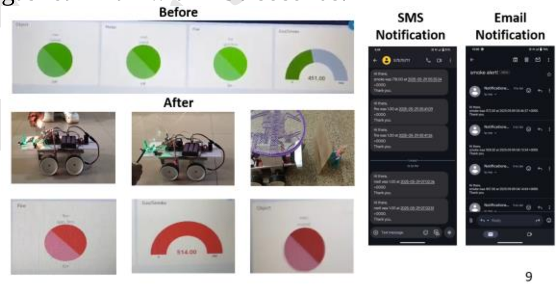

Figure 2: Real-Time Threat Detection Robot – System Alerts and Notifications

Before and After Comparison (Ubidots Dashboard)

This figure illustrates the detection outcomes before and after deploying the robot. It highlights fire, gas/smoke, and object detection readings along with visual evidence of robot operation and environmental interaction. The figure also shows the automated alert system via SMS and email notifications.

Initially, the system displayed basic sensor status using the Ubidots IoT dashboard. In this preliminary stage, object and metal detection indicators were marked as "Off," signifying no obstacles or metallic items detected. However, the fire sensor showed an active "On" status, and the gas or smoke levels were recorded at around 451 parts per million (ppm). This basic setup reflected the initial configuration of the system, where the sensors were connected and transmitting data but hadn't been exposed to real-time testing scenarios.

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After implementing the system on a mobile robotic platform, significant changes were observed in the sensor feedback. The dashboard now reflected real-time sensor responses. For instance, the fire sensor remained active, and the gas/smoke sensor showed a higher reading of 514 ppm, indicating the detection of an increased gas concentration. The object detection also shifted to an active state, highlighting obstacle presence or motion in the environment. These updates confirmed the successful deployment and functionality of the integrated sensors in a dynamic setting, establishing a real-time monitoring and threat detection system.

Working Robot

The robot was assembled and tested in a practical environment to validate its performance. The shared images capture a multi-wheeled mobile robot equipped with various sensors mounted on its body. The robot was deployed on the floor and tested under different conditions to evaluate the detection capability. In one scenario, a lit matchstick was used to trigger the fire sensor, while in another, the robot was positioned near a wall panel to simulate the detection of hidden threats. These practical experiments demonstrated the operational reliability of the robot in detecting fire, smoke, metal, and objects in real-world conditions.

SMS and Email Notifications

One of the key features of this system is the automatic alert mechanism through SMS and email notifications. Whenever a critical sensor threshold is reached, the system immediately sends alerts to predefined recipients. The SMS notifications include precise details such as the detected parameter (e.g., smoke or fire), the exact value (e.g., "Smoke was 718.00"), and the timestamp of detection. These text messages confirm prompt threat communication. Similarly, email alerts are generated with subject lines like "Smoke Alert!" and provide detailed sensor readings, ensuring that recipients are informed of any hazardous changes in the environment. These notification systems utilize platforms such as Ubidots and IFTTT to ensure seamless, real-time communication, enhancing the project's effectiveness in threat prevention and rapid response.

This figure showcases the graphical user interface of the weapon detection system, the input images used for simulation (gun and knife), and the output images generated by the AI model with bounding boxes and confidence scores, confirming accurate threat identification.

The system features a custom-built Graphical User Interface (GUI) developed using Python's Tkinter library. This interface provides a simple layout with "Start Detection" and "Stop Detection" buttons, enabling users—especially field officers or surveillance operators—to easily initiate and terminate the object detection process. Once activated, the live video stream from the Raspberry Pi-connected camera is processed in real-time using OpenCV and TensorFlow Lite, allowing for continuous monitoring and immediate identification of threats.

To simulate real-world scenarios, a doll was used as a human figure holding mock weapons—specifically, a paper cutout of a gun and a real kitchen knife. These props were selected to represent common handheld threats that may be encountered in domestic or public spaces. By using everyday items, the system was tested under conditions close to reality, enhancing its practical value.

The weapon detection model, based on YOLOv8 or a similar real-time object detection algorithm, successfully identified both weapons. The AI returned results with high confidence levels—87% for the gun and 88% for the knife. Bounding boxes in green were drawn around the detected items, providing clear visual confirmation. These output images validate the accuracy and reliability of the model in detecting dangerous objects swiftly and effectively, making the system viable for use in surveillance and security environments.

VI. Applications and Advantages

A. Applications

- Military: Room clearing and explosive detection.
- Police: Hostage scenarios and contraband detection.
- Disaster Rescue: Finding trapped individuals in rubble.
- Border Patrol: Detecting hidden humans or threats.
- Public Safety: AI Vision in High-Density Events.

B. Advantages

- Portability: Lightweight and field-deployable.
- Multi-sensor fusion: better accuracy and fewer false alarms.
- Real-time cloud alerts: Immediate response via Ubidots.
- Low cost: Under ₹20,000 for the full prototype.

VII. Conclusion and Future Work

The Wall Hawk system tackles the limitations of traditional surveillance methods like CCTV and PIR sensors, which struggle to detect hidden threats such as armed enemies, explosives, or toxic gases behind

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walls or in low-visibility areas. By integrating microwave radar, AI-based image recognition, and autonomous robotics, Wall Hawk delivers real-time, accurate threat detection. The NodeMCU processes data from gas, metal, and radar sensors, while the Raspberry Pi handles image analysis for weapon detection. Tested successfully, the system generates instant alerts via IoT platforms and offers high mobility and adaptability, making it ideal for military, rescue, and law enforcement missions.

The Wall Hawk system offers a solid base for future development. Incorporating deep learning can enhance threat classification and behavioral detection. Integration with 5G or satellite networks may enable real-time communication with command centers. Future improvements could also focus on hardware miniaturization and better battery efficiency, increasing portability. Adding advanced sensors for radiation or chemical detection would broaden its applications. Ultimately, Wall Hawk could evolve into a fully autonomous system for smart surveillance and advanced defense operations.

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