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NexusGuard AI System: An AI and IOT-Enabled Integrated Smart Infrastructure for Campus Safety and Sustainability

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***Abstract*—NexusGuard AI is an Artificial Intelligence (AI) and Internet of Things (IoT)-based integrated smart infrastructure system designed to improve safety, monitoring, emergency response, and energy efficiency in college campuses. The proposed system combines multiple independent campus facilities such as surveillance, environmental monitoring, emergency warning, smart lighting, and communication into a unified smart pole. An ESP32 microcontroller collects sensor data and performs device-level control, while a Raspberry Pi 4 processes camera data for AI-based object detection and event analysis. The system incorporates an AI camera, PIR motion sensor, smoke and gas sensors, flame sensor, temperature and humidity sensor, air-quality sensor, sound sensor, LDR, and emergency SOS button. Abnormal conditions can trigger a siren, speaker, warning lighting, display, and remote notification. Sensor and event data are communicated using Wi-Fi and MQTT, stored through Firebase, and presented on a dashboard or mobile application. Solar power with battery backup supports autonomous operation. The proposed system provides a scalable approach for campus safety, environmental monitoring, energy management, and future smart-campus integration.**

***Keywords*—Artificial intelligence, Internet of Things, smart campus, edge computing, campus safety, smart infrastructure.**

I. INTRODUCTION

Modern educational campuses consist of several independent facilities such as surveillance systems, campus lighting, environmental monitoring, emergency-response systems, communication infrastructure, and electrical equipment. In many conventional arrangements, these facilities operate separately, which increases infrastructure complexity, maintenance requirements, energy consumption, and difficulty in centralized monitoring. Traditional systems may also depend on continuous human observation, resulting in delayed identification and response to security, fire, environmental, and equipment-related problems. NexusGuard AI is proposed as an integrated Artificial Intelligence (AI) and Internet of Things (IoT)-based smart infrastructure system intended to address these limitations by combining multiple campus facilities into a single intelligent smart-pole platform. The proposed system integrates intelligent surveillance, environmental sensing, emergency detection, smart lighting, communication, cloud monitoring, and renewable energy support into a common infrastructure. The main objective is to provide a safer, smarter, more responsive, and more energy-efficient campus environment.

The development of smart-campus technologies has been supported by the rapid growth of IoT, embedded computing, edge computing, wireless communication, and artificial intelligence. IoT enables physical sensors and devices to communicate with software platforms, while AI allows collected data, particularly camera information, to be processed intelligently. In NexusGuard AI, these technologies are combined to create an integrated monitoring architecture in which physical events are sensed locally, processed through embedded controllers and AI hardware, communicated over a network, stored in a cloud platform, and presented through a dashboard or mobile application. This approach allows the system to provide both local automatic responses and remote monitoring capabilities.

The body of this paper describes the design and implementation of the NexusGuard AI system, an AI- and IoT-enabled smart infrastructure developed for campus safety and sustainability. It explains the proposed system architecture, including the ESP32-based sensor and control unit, Raspberry Pi 4 for AI-based camera processing, environmental and safety sensors, smart lighting, emergency alert devices, communication through Wi-Fi and MQTT, Firebase cloud monitoring, and the solar-powered backup system. It also discusses the working principle of the system, in which sensor and camera data are collected, processed, and analyzed to detect abnormal conditions and generate local and remote alerts. The paper further presents the advantages, applications, limitations, and future scope of integrating multiple campus safety and energy-management functions into a single smart infrastructure platform.

II. Proposed System and Architecture

A. Proposed System

NexusGuard AI is an Artificial Intelligence (AI) and Internet of Things (IoT)-enabled integrated smart infrastructure system developed for improving safety, monitoring, emergency response, and energy efficiency in college campuses. The proposed system combines several functions that are generally implemented through separate systems, including surveillance, environmental monitoring, emergency detection, smart lighting, communication, and cloud-based monitoring. The system is implemented in the form of a smart pole, which provides a common platform for installing sensors, controllers, communication devices, and physical alert mechanisms. This integrated approach reduces system fragmentation and provides a centralized method of monitoring campus conditions.

The proposed architecture consists of two major layers: the Intelligent Sensing and Actuation Layer (ISAL) and the Intelligent Monitoring and Analytics Layer (IMAL). The hardware layer is responsible for sensing, local processing, actuation, communication, and power management, while the software layer handles AI processing, IoT communication, cloud storage, monitoring, alerts, and control logic. The combination of both layers allows the system to detect events locally and communicate important information to remote users.

B. System Architecture

The overall block diagram of the proposed system is shown in Fig. 1.

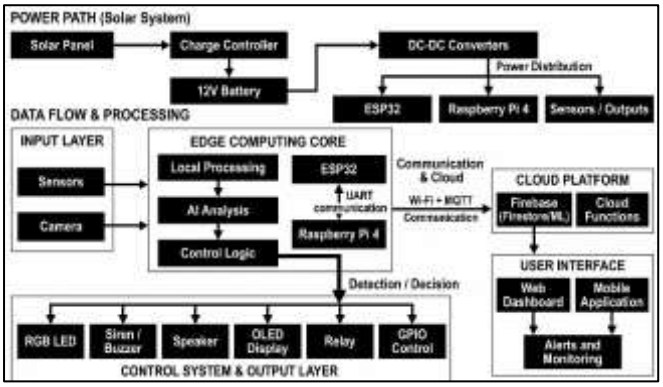


Fig. 1. Block diagram of the NexusGuard AI system.

C. Software Architecture

The software system is based on AI processing, IoT communication, cloud services, and a monitoring interface. Raspberry Pi 4 processes camera information for object detection and event analysis. The AI component is intended to identify relevant visual events and provide information that can be combined with sensor readings. The ESP32 collects data from the sensors and controls the connected hardware. The use of edge processing through Raspberry Pi 4 allows camera information to be processed locally before relevant event information is transmitted to the remote platform.

For communication, Wi-Fi is used to connect the smart pole to the network, while MQTT is used to transfer IoT sensor data and alerts. Firebase is used as the cloud platform for storing and managing real-time information. The dashboard and mobile application provide users with access to sensor status, alerts, and system information. The control logic processes the sensor and AI results and generates commands for the connected hardware. This creates a complete communication path between physical sensors, local processing units, the cloud platform, and end users.

III. Hardware-Based System

A. ESP32 Microcontroller

The ESP32 acts as the main controller of the NexusGuard AI smart pole (Fig. 2). It collects data from multiple sensors, performs local processing and control decisions, and operates connected output devices. It also provides Wi-Fi connectivity and communicates with the Raspberry Pi 4 through UART for exchanging sensor and AI-related information.

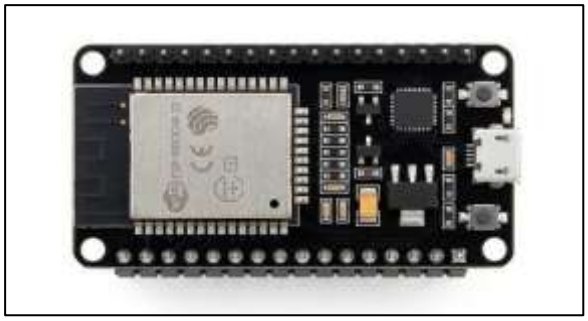


Fig. 2. ESP32 microcontroller.

B. Raspberry Pi 4

The Raspberry Pi 4 functions as the higher-level processing unit of NexusGuard AI (Fig. 3). It receives camera information and performs AI-based computer-vision processing, object detection, and event analysis. It works with the ESP32 through UART, allowing the system to combine sensor information with camera-based intelligence for improved campus monitoring.



Fig. 3. Raspberry Pi 4.

C. AI Camera

The AI camera (Fig. 4) is used to capture images or video from the campus surroundings and provide visual information to the Raspberry Pi 4. Its primary purpose is to support AI-based object detection and event analysis. The camera helps the system identify relevant visual activities or unusual events as part of intelligent campus surveillance.

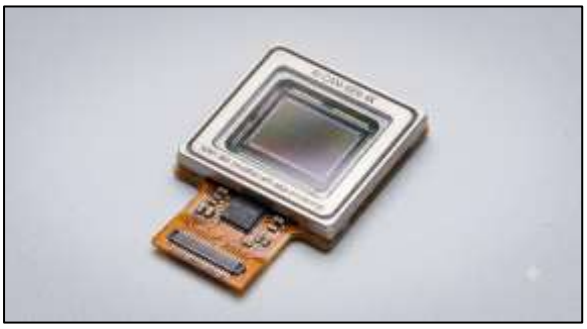


Fig. 4. AI camera.

D. PIR Motion Sensor

The Passive Infrared (PIR) motion sensor (Fig. 5) is used to detect movement or activity in the monitored area. It provides information about possible human movement and can support security monitoring. The PIR sensor can also assist the smart-lighting system by helping determine when movement occurs and when lighting may be required.



Fig. 5. PIR motion sensor.

E. MQ-135 Gas/Air-Quality Sensor

The MQ-135 sensor (Fig. 6) is used to monitor gas-related and air-quality conditions around the smart pole. It provides environmental information to the controller and can help identify abnormal air conditions. The collected data can be processed locally and transmitted through the IoT communication system for monitoring and possible safety alerts.



Fig. 6. MQ-135 gas/air-quality sensor.

F. Flame Sensor

The flame sensor (Fig. 7) provides an additional safety mechanism for identifying fire-related conditions by detecting the presence of flame. It works alongside the smoke sensor to improve fire monitoring. When a possible flame event is detected, the information can be processed by the ESP32 and used to activate warning devices and generate a remote alert.



Fig. 7. Flame sensor.

G. DHT22 Sensor

The DHT22 sensor (Fig. 8) is used for environmental monitoring by measuring temperature and relative humidity. The sensor provides data to the ESP32, allowing the system to continuously observe surrounding environmental conditions. These measurements can be displayed and transmitted through the IoT platform, providing useful information for campus environmental monitoring and system analysis.

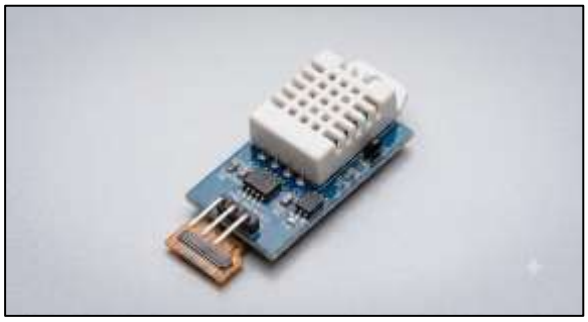


Fig. 8. DHT22 temperature and humidity sensor.

H. Light-Dependent Resistor (LDR)

The Light Dependent Resistor (LDR) (Fig. 9) is used to measure ambient light intensity in the surrounding environment. It helps the system determine whether conditions are sufficiently bright or dark and supports automatic LED-lighting control. By combining LDR information with movement detection, the system can operate lighting more intelligently and reduce unnecessary energy consumption.

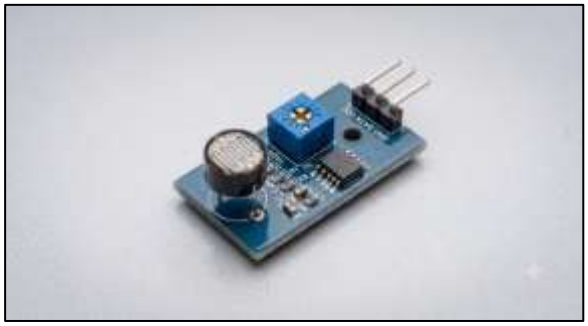


Fig. 9. Light-dependent resistor (LDR).

IV. Working of the System

The operation of NexusGuard AI begins with continuous data collection from the installed sensors and camera. The ESP32 receives information from sensors such as the PIR, MQ-2, MQ-135, flame sensor, DHT22, sound sensor, and LDR. At the same time, the AI camera captures visual information and sends it to the Raspberry Pi 4. The Raspberry Pi processes camera data for object detection and event analysis, while the ESP32 handles sensor processing and device control. Information between the two controllers is exchanged through UART.

When an abnormal condition is detected, the system can generate a suitable local response. For example, smoke or flame detection can result in activation of the siren or buzzer, warning lights, speaker, and display. Similarly, an emergency event initiated through the SOS button can generate an immediate alert. Movement information obtained from the PIR sensor and camera can also be used for security monitoring and smart-lighting decisions. Sensor information and alerts are transmitted through Wi-Fi and MQTT to the cloud platform, where the information can be monitored through Firebase and the dashboard or mobile application.

The smart lighting function uses the LDR and movement information to improve energy efficiency. During low-light conditions, the system can use movement information to determine whether lighting is required, reducing unnecessary operation. In this way, the system combines safety monitoring with energy management instead of treating lighting as an independent system. The solar panel and battery backup further support continuous operation of the smart infrastructure.

V. Conclusion

NexusGuard AI presents an integrated approach to campus safety and sustainability by combining artificial intelligence, Internet of Things technologies, embedded controllers, environmental sensors, camera-based surveillance, smart lighting, emergency response, cloud monitoring, and renewable power into a unified smart-pole architecture. The ESP32 functions as the main sensor and control controller, while the Raspberry Pi 4 performs AI-based camera processing. A collection of sensors provides information about movement, smoke, gases, flame, temperature, humidity, sound, and ambient light, while the actuator section enables local warning and control through LEDs, siren or buzzer, speaker, OLED display, and relay devices. Wi-Fi and MQTT provide network communication, Firebase provides real-time cloud management, and the dashboard or mobile application allows remote monitoring. Solar power, battery storage, and DC-DC conversion support autonomous operation. Overall, the proposed architecture aims to overcome the limitations of fragmented campus systems by providing a centralized, intelligent, scalable, and energy-conscious infrastructure for safety and sustainability.

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