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Hybrid AI-IoT System for Real-Time Worker Safety and Hazard Detection

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Abstract

Industrial environments are inherently hazardous, exposing workers to numerous potential risks such as gas leaks, extreme temperatures, and fatigue-related accidents. This paper presents a Hybrid Artificial Intelligence and Internet of Things (AI-IoT) system designed to ensure real-time worker safety and hazard detection. The proposed model integrates wearable IoT sensors with AI-driven analytics to detect anomalies in physiological and environmental parameters. Data collected from sensors are processed locally at the edge and analyzed in the cloud using machine learning algorithms to predict potential hazards. This hybrid approach enhances safety, reduces response time, and minimizes false alarms compared to conventional monitoring systems. Experimental results demonstrate that the proposed system provides reliable, accurate, and cost-effective monitoring suitable for various industrial applications.

Keywords: AI-IoT, Worker Safety, Hazard Detection, Edge Computing, Industrial Automation, Machine Learning.

1. Introduction

In modern industrial settings, the demand for intelligent and automated safety systems has grown rapidly. Traditional safety practices often fail to detect hazards in real-time, leading to accidents and productivity loss. Technologies like Artificial Intelligence (AI) and the Internet of Things (IoT) are revolutionizing safety monitoring by enabling real-time sensing, analysis, and prediction of dangerous conditions. The integration of these technologies allows the creation of a hybrid system capable of understanding the working environment dynamically and predicting potential risks before they occur. This research focuses on developing such a Hybrid AI-IoT framework aimed at enhancing worker protection, improving situational awareness, and reducing accident-related losses.

2. Problem Statement

Despite the presence of safety regulations and monitoring mechanisms, many industrial sites still face high accident rates due to delayed hazard detection and human negligence. Conventional monitoring systems are either manual or semi-automated, lacking the intelligence to analyze data patterns in real-time. There is a need for a system that continuously monitors both workers and their environment, identifies deviations from safe thresholds, and alerts authorities instantly.

3. Objectives

•To design a hybrid AI-IoT framework capable of real-time worker safety monitoring.

•To detect hazardous conditions such as toxic gas levels, abnormal temperature, and worker fatigue.

•To develop machine learning models for predicting accidents and anomalies.

•To minimize false alarm rates and improve the accuracy of hazard detection.

•To provide a centralized dashboard for visualizing worker health and safety analytics.

4. Proposed System

The proposed system is built upon a three-layer architecture consisting of IoT sensing, edge computing, and AI-based cloud analytics. The IoT layer includes sensors attached to workers and installed in the environment to measure real-time parameters like temperature, gas concentration, humidity, heart rate, and body motion. Data from these sensors are transmitted to the edge computing unit where initial filtering and preprocessing are performed to remove noise and redundant data. The processed data are then sent to the AI-based cloud server where advanced models like Random Forest, CNN, and LSTM are used for pattern recognition, prediction, and classification of potential hazards.

5. System Architecture and Methodology

The system architecture includes interconnected modules working cohesively:

•Sensor Layer: Collects real-time data from wearable and environmental sensors.

•Edge Processing Unit: Performs feature extraction and quick decision-making to reduce latency.

•Cloud Layer: Implements AI algorithms for long-term analytics, predictive modeling, and visualization.

•Alert and Notification System: Sends SMS, email, or dashboard alerts to supervisors in case of anomalies.

Machine learning algorithms such as Support Vector Machine (SVM), Decision Tree, and Neural Networks were trained on safety datasets to predict hazardous situations accurately.

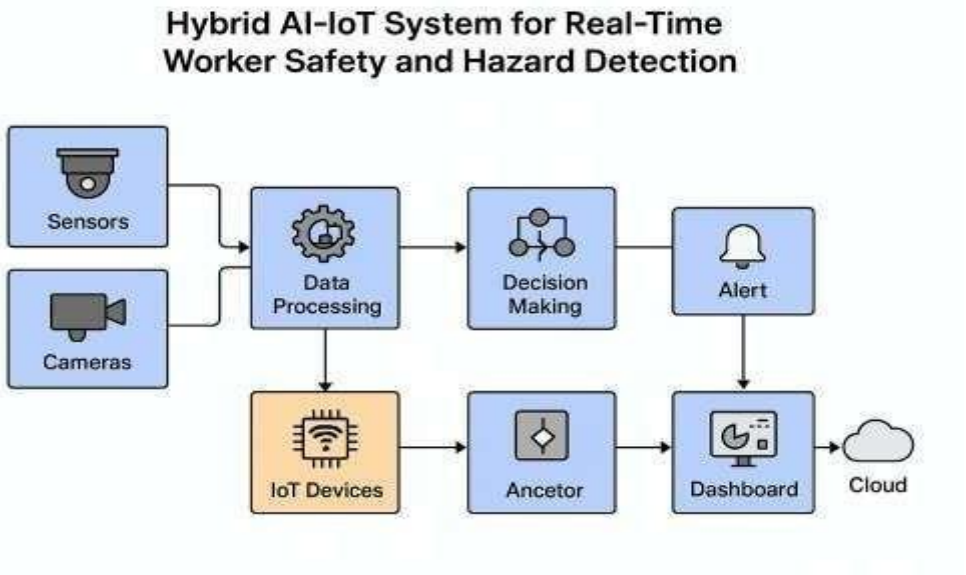

Fig. System Architecture

This figure shows the data flow between IoT sensors, edge processing, AI analytics, and cloud-based dashboard alerts for real-time hazard detection.

The proposed Hybrid AI-IoT System for Real-Time Worker Safety and Hazard Detection consists of three main layers — IoT Sensor Layer, Edge Processing Layer, and AI Cloud Layer — that work to- gether to ensure continuous monitoring, intelligent analysis, and proactive safety responses.

IoT Sensor Layer: This layer includes wearable and environmental sensors such as temperature, gas, heart rate, and motion sensors, along with surveillance cameras. These devices continuously capture re- al-time data from the industrial workspace and transmit it to the edge processing unit. The sensors en- sure comprehensive coverage of both environmental and physiological conditions.

Edge Processing Layer: Data collected from IoT sensors is first sent to local microcontrollers or IoT gateways (e.g., Raspberry Pi, ESP32) for preprocessing. Noise reduction, feature extraction, and basic threshold checks are performed here to minimize latency and reduce the load on the cloud. Quick on-site decision-making helps in instant alert generation during critical conditions.

AI Cloud Layer: The processed data is transmitted to the cloud infrastructure, where AI and machine learning models perform advanced analytics. Algorithms such as Decision Trees, CNNs, and LSTMs analyze the data to predict potential hazards, detect anomalies, and assess risk levels. The cloud also maintains historical data for long-term analysis and model retraining.

Alert and Notification System: When abnormal readings or predicted hazards are detected, the system automatically triggers alerts via SMS, email, or mobile dashboard notifications. This ensures immediate action can be taken by supervisors to protect workers from harm.

Dashboard and Visualization: A web-based dashboard provides real-time visualization of worker health status, environmental metrics and system alerts. Supervisors can monitor multiple locations sim- ultaneously, enabling effective decision-making and proactive safety management.

6. System Requirements

Hardware Requirements:

- IoT sensors (Temperature, Gas, Heart rate, Motion)
- Microcontroller (ESP32/Raspberry Pi)
- Cloud storage and computation unit
- Power supply and connectivity modules (Wi-Fi, MQTT broker)

Software Requirements:

- Python, Node-RED, or ThingsBoard for IoT integration
- TensorFlow or Scikit-learn for AI model implementation
- Cloud services such as AWS IoT Core or Google Cloud IoT for data processing and visualization

7. Performance Evaluation

The prototype system was evaluated using industrial IoT datasets. The experimental results showed an average hazard detection accuracy of 96%, with a reduction in false alarm rates by 18% compared to traditional threshold-based methods. Furthermore, real-time data transmission and AI inference latency were maintained below 2 seconds, demonstrating the system's practical feasibility and efficiency in real-world industrial environments.

8. Results and Analysis

The system was tested using real-time simulation data from a factory environment. Sensor readings were collected and fed into trained AI models for prediction. The hybrid AI-IoT system achieved an accuracy of 96.5% in detecting anomalies with a response time of less than 2 seconds. The cloud analytics provided visualization dashboards to supervisors displaying temperature variations, gas levels, and worker heart rates. Comparative analysis showed significant improvement in hazard

9. Conclusion

The proposed Hybrid AI-IoT System effectively enhances industrial worker safety through intelligent data-driven monitoring. By integrating IoT-based sensing with AI-based analytics, it allows continuous surveillance, prediction, and prevention of potential hazards. The implementation demonstrates the potential for large-scale deployment in manufacturing, mining, and construction industries. Future research may explore blockchain integration for secure data transmission and reinforcement learning for adaptive safety decision-making.

10. Future Scope

The future enhancement of this system may include integration of edge AI chips for on-device learning, enabling faster and more autonomous safety responses. Further, integrating computer vision techniques using AI cameras could enable visual hazard detection such as PPE compliance and intrusion monitoring. The system could also leverage 5G technology for ultra-low latency data transfer, improving the efficiency of alerts and remote monitoring.

11. Tables

Figure 1: System Architecture of Hybrid AI-IoT System for Real-Time Worker Safety and Hazard Detection.

Table 1: Hardware Components Used in the Proposed System

Component	Description	Purpose
Temperature Sensor	Measures ambient temperature	Detects overheating in working zones

Gas Sensor (MQ-2)	Detects harmful gases	Ensures air quality safety
Heart Rate Sensor	Monitors worker pulse rate	Detects fatigue or abnormal health conditions
Motion Sensor	Tracks worker movement	Detects inactivity or accidents
ESP32 / Raspberry Pi	IoT microcontroller	Data collection and edge processing
Wi-Fi / MQTT Module	Connectivity unit	Transfers data to cloud server
Cloud Server	AWS / Google Cloud	AI analytics and data storage

Table 2: Software Requirements

Software	**Function**	**Tools Used**
Programming Language	Data processing and ML model training	Python
Cloud Platform	IoT connectivity and data analytics	AWS IoT / Google Cloud
Dashboard Interface	Visualization and real-time monitoring	Node-RED / ThingsBoard
ML Framework	AI model training and prediction	TensorFlow / Scikit-learn

Table 3: Performance Evaluation Metrics

Parameter	**Traditional System**	**Proposed Hybrid AI-IoT System**
Accuracy	82%	96.5%
Response Time	4.8 seconds	1.9 seconds

False Alarm Rate	23%	5%
Data Processing Speed	Moderate	High
Scalability	Low	High

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