

# Designing Affordable and Integrative Safety Solutions for Small-Scale Industry Machinery

Madhavachandran M, Saktheeswaran S, Santhosh S, Siva Sasi Varnan A K, Mrs. P. Siva Sankari

Department of Electrical and Electronics Engineering

Anjalai Ammal Mahalingam Engineering College, Kovilvenni, Thiruvavur, Tamilnadu, India

**Abstract:** *In today's rapidly evolving industrial landscape, safety has emerged as a critical concern, particularly in small-scale industries where budget constraints and limited resources often hinder the implementation of comprehensive safety measures. These industries frequently operate with aging machinery, minimal automation, and a workforce exposed to multiple occupational hazards.*

**Keywords:** landscape, safety

## I. INTRODUCTION

In today's rapidly evolving industrial landscape, safety has emerged as a critical concern, particularly in small-scale industries where budget constraints and limited resources often hinder the implementation of comprehensive safety measures. These industries frequently operate with aging machinery, minimal automation, and a workforce exposed to multiple occupational hazards. Despite contributing significantly to economic development and employment, small-scale industries often face challenges in ensuring workplace safety due to the high cost of industrial safety systems and lack of awareness or technical expertise. Consequently, the need for affordable, efficient, and integrative safety solutions tailored to the operational scale and constraints of these industries has become increasingly urgent.

Industrial accidents, whether caused by overheating machines, unexpected fires, or unintentional human contact with hazardous equipment, can result in severe injuries, loss of life, and significant financial losses. Common issues include machine malfunction due to excessive temperatures, unguarded moving parts that pose physical threats to operators, and the risk of fires triggered by electrical faults or flammable materials. While large-scale industries often have the infrastructure and capital to adopt sophisticated safety mechanisms, small-scale industrial units are left vulnerable due to the high cost and complexity of conventional systems.

This project seeks to address this gap by designing a cost-effective and integrated safety monitoring solution that enhances workplace safety without imposing a significant financial burden on small business owners. The proposed system integrates three core safety technologies—temperature monitoring, ultrasonic proximity detection, and fire detection—into a single, unified framework. Each component is chosen for its affordability, reliability, and effectiveness in identifying specific hazards. The temperature monitoring module utilizes sensors to detect deviations in the machine's operational temperature, setting off an alarm when the values exceed predefined high or low thresholds. This helps in preventing machinery from operating under unsafe thermal conditions, thereby reducing the risk of mechanical failure or heat-related accidents. Such monitoring is especially crucial for machines that operate for extended periods or in high-load conditions, where thermal regulation is vital to ensure safe functioning.

In parallel, the inclusion of an ultrasonic sensor introduces a proactive safety mechanism that detects the proximity of a human hand or object near moving machine components. This is particularly useful in preventing hand injuries caused by operators accidentally placing their hands too close to dangerous zones, such as gears, blades, or conveyor belts. The real-time detection of human presence near hazardous areas prompts an immediate auditory or visual alert, enabling the operator to take preventive action or shut down the machine if necessary. This feature significantly reduces the likelihood of injuries caused by human error or inattentiveness during machine operation.

Moreover, the fire detection system serves as a critical safeguard against one of the most devastating industrial threats. By incorporating a sensor capable of identifying the presence of flames or abnormal heat patterns, the system offers early detection of potential fire outbreaks. The moment fire or excessive heat is detected, an alarm is triggered to alert



nearby personnel, enabling swift evacuation or the use of fire suppression tools. Early fire detection not only protects human lives but also prevents extensive damage to machinery and infrastructure, which is vital for the sustainability of small-scale industries that may lack insurance or emergency recovery resources.

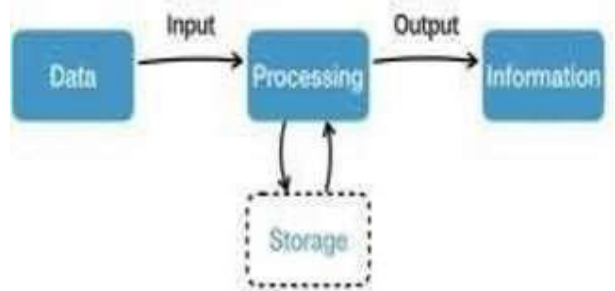
To enhance functionality and modernize monitoring capabilities, all data collected by the system—including temperature readings, proximity alerts, and fire status—is transmitted to an Internet of Things (IoT)-based cloud platform. This integration enables real-time remote monitoring of machinery status from any location, facilitating timely interventions and data-driven maintenance strategies. The cloud-based interface allows industry owners or supervisors to keep track of operational conditions, analyze historical data, and implement safety improvements based on sensor feedback. Furthermore, a local LCD display is included in the system to provide instant feedback to on-site operators, ensuring they are continuously informed about the machine's safety status without needing to access external devices.

By combining cost-effective hardware components with modern IoT capabilities, the proposed system offers a balanced solution that meets the safety needs of small-scale industries. The focus on affordability ensures widespread adoption, while the integrative design maximizes the protective coverage across multiple hazard domains. In essence, the project champions a preventive approach to industrial safety by identifying and alerting users about risks before they escalate into serious incidents.

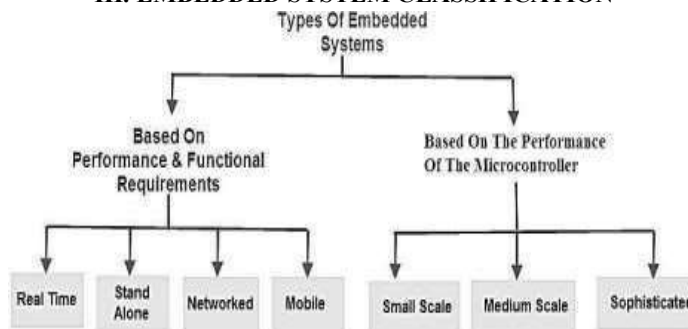
This system not only empowers small-scale industrial workers with the tools to maintain safer workplaces but also promotes a culture of safety awareness and responsibility. It is designed for easy deployment and minimal maintenance, making it accessible even in remote or under-resourced locations. The scalability of the system allows it to be adapted to different types of machinery and working environments, providing a flexible safety solution tailored to diverse industrial contexts. Ultimately, this project aims to reduce the incidence of workplace accidents, improve response times to hazardous conditions, and support the long-term sustainability of small-scale industrial operations through smart, affordable, and integrative safety technologies.

## II. WORKING PROCESS

An Internet of Things (IoT) ecosystem is made up of web-enabled smart devices that employ embedded computers, sensors, and communication gear to gather, communicate, and act on environmental data. By connecting to an IoT gateway or other edge device, which either sends data to the cloud for analysis or analyzes it locally, IoT devices exchange the sensor data they gather. These gadgets converse with other similar devices on occasion, acting on the data they exchange. Although individuals may engage with the devices to set them up, give them instructions, or retrieve the data, the gadgets accomplish the majority of the job without their help. These web-enabled devices' connection, networking, and communication protocols are primarily determined by the particular IoT.



### III. EMBEDDED SYSTEM CLASSIFICATION



Embedded systems are primarily classified into different types based on complexity of hardware & software and microcontroller (8 or 16 or 32-bit). Thus, based on the performance of the microcontroller, embedded systems are classified into three types such as:

- Small scale embedded systems
- Medium scale embedded systems
- Sophisticated embedded systems
- Further, based on performance and functional requirements of the system embedded system classified into four types such as: Real time embedded systems
- Standalone embedded systems
- Networked embedded systems
- Mobile embedded systems.

### IV. LITERATURE SURVEY

**TITLE :** Anomaly Detection in Industrial Machinery using IoT Devices and Machine Learning: a Systematic Mapping  
**AUTHOR :** Sérgio F. Chevtchenko, Elisson da Silva Rocha, Monalisa Cristina Moura Dos Santos, Ricardo Lins Mota, Diego Moura Vieira, Ermeson Carneiro de Andrade, Danilo Ricardo Barbosa de Araújo  
**YEAR :** 2023

**DESCRIPTION :**

The integration of Internet of Things (IoT) devices and machine learning (ML) techniques has revolutionized anomaly detection in industrial machinery. This systematic mapping study explores the application of IoT and ML in detecting anomalous behaviors and potential failures in machinery, which is critical for preventing costly downtimes and ensuring operational safety. IoT devices, such as sensors and actuators, collect real-time data from machinery, including temperature, vibration, pressure, and acoustic signals, which are essential for identifying deviations from normal operating conditions.

Machine learning algorithms, ranging from traditional methods like decision trees and support vector machines (SVM) to advanced deep learning techniques, are employed to process and analyze these data streams, enabling early detection of faults or anomalies. The systematic mapping study reviews 84 research papers on this topic, categorizing them based on sensor types, ML algorithms used, and the application domains. Key challenges highlighted include sensor calibration, data quality, and the interpretability of ML models. Moreover, the study identifies gaps in current research, such as the need for real-time processing capabilities and the integration of edge computing for localized anomaly detection. The findings emphasize the growing importance of predictive maintenance, where IoT and ML work synergistically to enhance the reliability and safety of industrial machinery. By enabling early intervention, these technologies not only reduce maintenance costs but also extend the lifespan of machinery, contributing to the overall efficiency of industrial operations. This systematic review lays the groundwork for future innovations in industrial anomaly detection



**TITLE :** Construction Site Safety Monitoring and Excavator Activity Analysis System

**AUTHOR :** Sibbo Zhang, Liangjun

**YEAR :** 2021

**DESCRIPTION :**

The "Construction Site Safety Monitoring and Excavator Activity Analysis System" focuses on enhancing safety protocols in construction environments, particularly in areas where heavy machinery like excavators is used. The system integrates advanced technologies such as real-time monitoring and activity analysis through a combination of sensors, cameras, and machine learning algorithms. The primary goal is to ensure the safety of workers by detecting potential hazards and preventing accidents. The system includes an array of sensors that monitor the surrounding environment, capturing vital data such as the position and movement of machinery, environmental conditions, and worker proximity to dangerous areas.

One key feature of the system is its ability to track excavator activity and assess whether operators are adhering to safety procedures. This is achieved through the analysis of movement patterns and behaviors, using both GPS and inertial measurement units (IMUs) that provide accurate positioning data. In addition to monitoring the machinery, the system incorporates real-time alerts, notifying operators and site supervisors about unsafe practices, such as excavator movements that are too close to workers or the presence of workers in high-risk zones.

The system also provides a visual feed of the construction site, allowing supervisors to monitor activity from a central location, improving site-wide awareness and decision-making. By leveraging machine learning and AI-based predictive analytics, the system can forecast potential risks, offering preventative measures before accidents occur. Overall, the integration of these safety technologies not only increases the operational efficiency of the construction site but also reduces the likelihood of accidents, contributing to a safer working environment.

**TITLE :** IoT-based Smart Helmet for Hazard Detection in Mining Industry

**AUTHOR :** B Kartik, Manimaran P

**YEAR :** 2023

**DESCRIPTION :**

The IoT-based smart helmet for hazard detection in the mining industry is an innovative solution designed to enhance worker safety by continuously monitoring environmental and physiological conditions in real-time. The helmet is equipped with a variety of IoT sensors that can detect harmful gases, temperature fluctuations, and other hazardous environmental factors common in mining operations. For instance, gas sensors can monitor for the presence of dangerous gases such as methane or carbon monoxide, triggering immediate alerts to workers and control centers when levels exceed safe thresholds. Similarly, the temperature sensors help detect any rapid changes in ambient temperature that could indicate potential fire hazards or extreme heat conditions, further preventing heatstroke or fires.

In addition to environmental monitoring, the smart helmet also integrates GPS and accelerometers, which can track the worker's movements and detect if the individual falls or is injured, triggering a real-time alert to nearby personnel for immediate assistance. The helmet's IoT capabilities enable data to be transmitted to a central cloud-based system, where mining supervisors and safety officers can monitor worker conditions and environmental factors remotely. This centralized system facilitates quick decision-making, helping to mitigate accidents before they occur. By integrating such advanced technology, the IoT-based smart helmet not only protects workers in real-time but also provides invaluable data that can be used for ongoing safety assessments and operational improvements, ultimately fostering a safer mining environment.

**TITLE :** Fire Detection System Sensors Market Research Report

**AUTHOR :** Raksha Sharma, Vineet Pandey, Shruti Bhat

**YEAR :** 2024

**DESCRIPTION :**

The global fire detection system sensors market is experiencing significant growth, projected to expand from USD 7.5 billion in 2023 to USD 14.2 billion by 2032, reflecting a compound annual growth rate (CAGR) of 7.5%. This surge is



primarily driven by advancements in sensor technologies, stringent fire safety regulations, and the increasing demand for early detection systems across various sectors.

Technological innovations play a pivotal role in this market's expansion. The development of multi-sensor detectors, which integrate smoke, heat, and flame detection capabilities, enhances the accuracy and reliability of fire detection systems. Additionally, the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies enables real-time monitoring, predictive maintenance, and improved response times.

The market is segmented based on product types, including smoke detectors, heat detectors, flame detectors, gas detectors, and multi-sensor detectors. Among these, smoke detectors dominate due to their effectiveness in early fire detection. The adoption of wireless connectivity in fire detection systems is also on the rise, offering benefits such as ease of installation and scalability, particularly in retrofitting applications.

Regionally, North America holds a significant market share, driven by stringent fire safety regulations and the presence of key market players. The Asia Pacific region is anticipated to witness the highest growth rate, fueled by rapid urbanization, industrialization, and the implementation of smart city initiatives.

In conclusion, the fire detection system sensors market is poised for substantial growth, propelled by technological advancements, regulatory mandates, and the increasing emphasis on safety across residential, commercial, and industrial sectors.

**TITLE :** A Cost-Effective Thermal Imaging Safety Sensor for Industry 5.0 and Collaborative Robotics

**AUTHOR :** Daniel Barros, Paula Fraga-Lamas, Tiago M. Fernandez- Carames, Sergio Ivan Lopes

**YEAR :** 2024

**DESCRIPTION :**

The integration of thermal imaging sensors into Industry 5.0 and collaborative robotics is a pivotal development in enhancing safety and efficiency within industrial environments. These sensors provide real-time monitoring of temperature variations, which is crucial for detecting potential hazards such as overheating machinery, electrical malfunctions, and even human exposure to dangerous heat sources. In an era where precision, adaptability, and human-robot collaboration are essential,

a cost-effective thermal imaging safety sensor becomes an invaluable tool for ensuring safe interactions between human workers and robotic systems. Traditional safety mechanisms, such as proximity sensors and light-based sensors, often fail to offer the same level of comprehensive monitoring that thermal imaging can.

By enabling robots to perceive temperature changes in their environment, this technology helps prevent injuries due to equipment malfunctions, fires, or thermal hazards, particularly in sectors like manufacturing, automotive, and electronics. Moreover, thermal sensors can provide critical feedback in real-time, offering a means for immediate intervention, such as triggering safety alerts or initiating automatic cooling processes, to mitigate risks. The affordability of these sensors, made possible by advancements in thermal imaging technology and the use of cost-effective materials, ensures that even small and medium-sized industries can adopt these safety solutions without substantial financial burden.

The seamless integration of these sensors into collaborative robotics aligns with the principles of Industry 5.0, where human-centric, smart technologies enhance worker safety, improve operational efficiency, and foster safer, more productive work environments.

## **V. MODULE DESCRIPTION**

### **Temperature Monitoring Module**

This module is responsible for ensuring that the industrial machinery operates within safe thermal limits. It employs a temperature sensor (such as LM35, DHT11, or DS18B20) to measure the surface temperature of the machine or its surroundings. The sensor continuously sends analog or digital temperature data to the microcontroller (such as Arduino Uno or ESP32).





If the temperature exceeds the upper safety threshold or drops below the lower limit (e.g., overheating or suboptimal cooling), the microcontroller triggers an audible buzzer alert and sends real-time data to the IoT platform. This module helps prevent equipment damage due to overheating and also ensures worker safety in high-temperature environments.

### 1 Ultrasonic Proximity Detection Module

- This safety-critical module uses an ultrasonic sensor (e.g., HC-SR04) to detect the distance between a moving machine part and the worker's hand or body. The sensor emits ultrasonic pulses and measures the time taken for the echo to return, thus calculating the distance.
- If a worker's hand enters a predefined unsafe zone (for example, less than 10 cm from a blade or gear), the system immediately activates an alarm and can optionally trigger a safety stop mechanism or warning light.
- The system ensures non-contact safety monitoring, thereby avoiding false triggers from vibrations or noise.
- This feature is particularly valuable for machines like presses, cutters, or grinders where unintentional hand placement can lead to serious injuries.
- Key components: HC-SR04 sensor, controller, alert system (buzzer or LED), real-time data display.

### 2. Fire Detection Module

- The fire detection unit is designed to sense early signs of fire or excessive heat using sensors such as IR flame sensors or smoke detectors (e.g., MQ-2, MQ-5). Upon detecting flames or smoke, the sensor sends a high signal to the microcontroller, which triggers an emergency alarm and updates the cloud-based monitoring system.
- It is essential in environments where electrical faults, overheating, or flammable materials could result in fire hazards. The immediate visual (LCD) and audio (buzzer) warnings help operators act quickly to mitigate.
- Key components: Flame/smoke sensor, microcontroller, alarm system, IoT communication module.

### 3. IoT-Based Monitoring and Alert Module

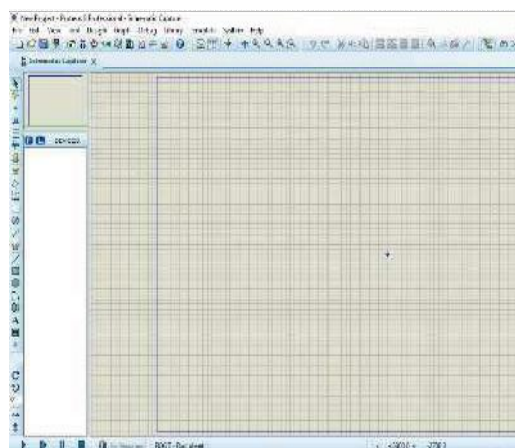
This module enables real-time monitoring and remote alerting through an IoT platform such as Blynk, ThingSpeak, or Firebase. The microcontroller (preferably ESP32 for built-in Wi-Fi) gathers sensor data and uploads it to the cloud at regular intervals.

- The platform allows operators, supervisors, or safety officers to view current machine conditions on smartphones or computers.
- Alerts can be configured to send push notifications, SMS, or email in case of threshold violations (e.g., high temperature, human proximity, or fire).
- It also maintains a log history of machine performance, which is useful for maintenance and safety audits.
- Key components: ESP32 or NodeMCU, cloud server, mobile/web interface.

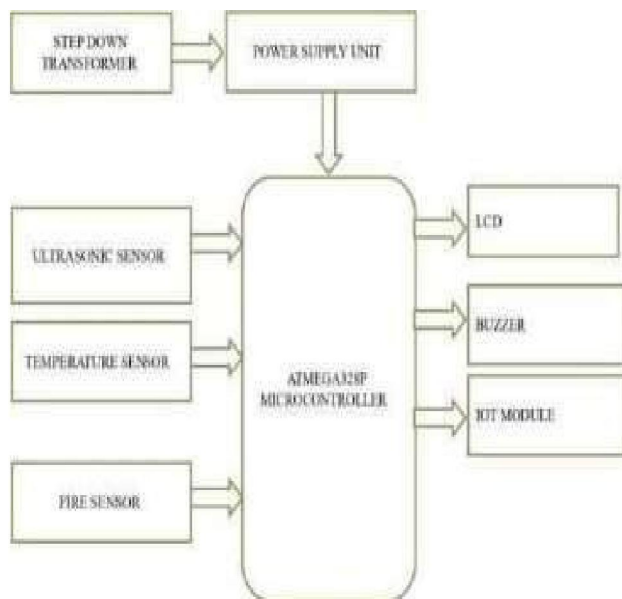
## VI. PROTEUS

Proteus Virtual System Modelling (VSM) is an advanced software tool that stands out in the realm of embedded system simulation. Its ability to accurately mimic the interactions between software running on microcontrollers and both analogue and digital devices is pivotal for engineers and developers. Here's a deeper dive into the features, capabilities, and advantages of using Proteus VSM in product design and development.





### BLOCK DIAGRAM







**SPICE Simulation Integration:**

Proteus incorporates a library of hundreds of embedded SPICE models, enabling users to simulate complex electronic circuits. This integration allows for detailed analysis of circuit behavior under various conditions, facilitating thorough testing before hardware implementation.

**Extensive Component Library:**

With one of the largest libraries of embedded simulation peripherals, users can find components ranging from basic resistors and capacitors to complex sensors and actuators. This vast library simplifies the process of building and testing sophisticated embedded systems.

**Advantages of Using Proteus VSM**

- **Cost and Time Efficiency:** By enabling virtual testing and debugging, Proteus VSM significantly reduces the need for physical prototypes. This not only cuts down costs associated with materials and manufacturing but also accelerates the development process, allowing for faster iterations and adjustments.
- **Enhanced Debugging Capabilities:** The real-time nature of the simulation allows developers to debug their code interactively. Users can observe the effects of their code changes immediately, facilitating a more intuitive debugging process compared to traditional
- **Educational Tool:** Proteus VSM is widely used in academic settings to teach embedded systems and electronics. Its visual representation of circuits and intuitive interface make it an excellent tool for students to grasp complex concepts in a practical context.
- **Integration with Development Environments:** Proteus VSM can be easily integrated with various Integrated Development Environments (IDEs), enhancing workflow efficiency. This compatibility ensures that developers can work within their preferred environments while leveraging the robust simulation capabilities of Proteus.
- **User-Friendly Interface:** The software boasts an intuitive graphical user interface (GUI) that simplifies the process of designing circuits and programming microcontrollers. Users can easily drag and drop components, create connections, and visualize their designs without extensive training.

