

AI-Powered Smart Safety Jacket for Industrial Application

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ABSTRACT— Industrial workers are frequently exposed to hazardous conditions such as gas leakage, poor air quality, physical accidents, excessive temperature, and delayed emergency response. Conventional safety equipment mainly provides passive protection and does not continuously monitor the health and surrounding conditions of workers. To address this problem, this paper presents an AI-powered smart safety jacket designed for real-time worker monitoring and emergency assistance. The proposed system integrates multiple sensors with an ESP32 microcontroller to continuously collect physiological and environmental information. A MAX30102 sensor is used for heart-rate and blood-oxygen monitoring, while a DS18B20 sensor measures body temperature. MQ-2 and MQ-135 sensors are used to detect combustible gases, smoke, and changes in air quality. An MPU6050 inertial measurement unit is incorporated for detecting abnormal motion and possible worker falls. A GPS module provides the worker's location, while a GSM module enables emergency communication through SMS. In addition, a buzzer, LED indicators, and vibration motor provide immediate local alerts to the worker.

Keywords: *Smart Safety Jacket, Artificial Intelligence, ESP32, Worker Safety, Fall Detection, Health Monitoring, Gas Detection, GPS, GSM, IoT, Anomaly Detection.*

I. INTRODUCTION

Worker safety is an important concern in industries where workers are continuously exposed to hazardous working conditions. Construction sites, manufacturing plants, mining areas, chemical industries, and other industrial environments involve risks such as accidental falls, gas leakage, poor air quality, abnormal body temperature, and sudden health-related problems. In such situations, the time required to identify an accident and inform the responsible person can have a direct effect on the safety of the worker. Therefore, there is a need for safety systems that can monitor the worker continuously and provide an alert when an unsafe condition occurs.

Conventional safety jackets and personal protective equipment mainly provide physical protection to workers. However, they generally do not have the capability to monitor the worker's health condition or the surrounding environment in real time. Some existing wearable safety systems are designed to monitor individual parameters such as body temperature, heart rate, or movement. Similarly, gas detection systems are commonly used for identifying hazardous gases in industrial areas. Although these approaches are useful, using

separate systems for different safety parameters can increase the complexity of monitoring and may not provide complete information during an emergency.

II. RELATED WORK

With the development of wearable electronics and IoT technologies, several researchers have focused on improving worker safety through continuous monitoring of health, environmental conditions, movement, and location. Wearable systems have been increasingly studied because they can collect information directly from the worker and provide safety-related information without requiring the worker to remain near a fixed monitoring system. A review of industrial wearable systems classified their applications into monitoring, supporting, training, and tracking, and also discussed the use of communication and localization technologies for workplace safety.

Several studies have focused on the use of wearable devices for detecting worker falls. In [1], a real-time wearable fall detection system was developed using MEMS sensors and narrowband IoT communication. The proposed system used a multilevel threshold method to identify fall events and provided communication with a remote monitoring system. The experimental evaluation was carried out using volunteers performing daily activities and simulated falls. The results showed that the system was able to detect falls with high accuracy. However, the work mainly focused on fall detection and did not combine the detection process with several environmental and physiological parameters required for industrial safety.

In [2], a wearable-based monitoring system was proposed for linemen working in power utilities. The system was intended to monitor workplace health and safety risks using wearable technology. Such systems are useful in situations where workers operate in areas where direct supervision is difficult. The use of wearable monitoring provides an additional method for observing the worker's condition during field activities. However, a broader combination of environmental hazard detection, fall detection, location tracking, and emergency communication can further improve the usefulness of such systems..

III. PROPOSED SYSTEM

The proposed system is an AI-powered smart safety jacket designed to monitor the health condition of a worker and the surrounding working environment in real time. The system combines different sensors, an ESP32 microcontroller, GPS, GSM, and alert devices in a single wearable platform. The main purpose of the system is to identify unsafe conditions at an early stage and provide an immediate warning to the worker as well as an emergency notification to a predefined contact.

A. SYSTEM ARCHITECTURE

The overall system consists of five main stages: data collection, data processing, decision making, emergency action, and notification. The sensors continuously collect information from the worker and the surrounding environment. This information is provided to the ESP32, which acts as the central controller of the system.

The ESP32 receives the sensor readings and checks the collected data for abnormal conditions. The MAX30102 is used to obtain heart-rate and SpO₂ information, while the temperature sensor is used to monitor temperature. The MQ-2 and MQ-135 sensors provide information about smoke, combustible gases, and air-quality changes. The MPU6050 provides acceleration and gyroscope data that can be used for detecting a possible fall.

B. HEALTH MONITORING

The health-monitoring part of the jacket is intended to observe important physiological parameters of the worker. The MAX30102 sensor is used for measuring heart rate and SpO₂. The sensor is positioned in a location where it can maintain suitable contact with the worker for obtaining readings. Body temperature is monitored using a temperature sensor such as the DS18B20. The temperature reading is periodically sent to the ESP32 and compared with the selected safety conditions. The health parameters are not considered independently. The collected values can be observed together to identify unusual changes in the worker's condition. This information can also be used as input for the anomaly-detection part of the proposed system.

C. ENVIRONMENTAL MONITORING

The working environment is monitored using MQ-series gas sensors. The MQ-2 sensor is used for detecting smoke and combustible gases, whereas the MQ-135 sensor is used to monitor changes related to air quality. The sensors continuously provide readings to the ESP32. If the sensor value increases beyond the selected safety limit, the system considers it a possible hazardous condition and activates the warning mechanism. The gas sensors are intended for detecting changes in the surrounding environment. Their readings depend on factors such as sensor calibration, placement, temperature, humidity, and the gases present. Therefore, suitable calibration

is required before using the system in an actual industrial environment.

D. FALL DETECTION

Fall detection is implemented using the MPU6050 accelerometer and gyroscope. The sensor measures the movement and orientation of the worker along different axes. During normal activities, the acceleration and orientation values generally remain within changing but recognizable ranges. A fall can produce a sudden change in acceleration followed by a change in body orientation and reduced movement. These parameters can be analyzed to identify a possible fall.

E. AI-BASED DATA PROCESSING

The sensor data collected by the jacket is processed by the ESP32. The purpose of the AI-based processing is to identify abnormal patterns in the collected data instead of depending only on a single sensor value. For example, in fall detection, acceleration, angular movement, orientation, and inactivity can be considered together. Similarly, changes in environmental sensor readings can be observed over a period of time rather than using only one instantaneous value. The AI model used in the final implementation should be selected according to the available training data and the processing capability of the ESP32. A lightweight model is suitable for this application because the system is intended to operate on a portable microcontroller. The model can classify the incoming sensor information into normal and abnormal conditions.

F. DECISION-MAKING MECHANISM

After collecting and processing the sensor data, the ESP32 determines whether the current condition requires an emergency response. If all monitored parameters remain within their acceptable ranges, the system continues monitoring the worker. If an abnormal condition is identified, the system moves to the emergency-action stage.

The decision process can be summarized as:

Sensor Data → Processing → Safety Check → Normal/Abnormal Decision

For a normal condition:

Normal → Continue Monitoring

For an abnormal condition:

Abnormal → Alert → GPS Location → GSM Notification

This arrangement allows the system to continuously operate without requiring manual interaction during normal working conditions.

G. EMERGENCY ALERT SYSTEM

When an unsafe condition is detected, the jacket provides an immediate warning through three local mechanisms. The buzzer produces an audible alarm, the LED indicators provide a visual indication, and the vibration motor provides tactile feedback. The combination of these alerts is useful in industrial environments because the worker may not always be able to hear an alarm due to machinery and surrounding noise.

H. GPS-BASED LOCATION TRACKING

After an emergency condition is detected, the GPS module is used to obtain the worker's geographical location. The proposed design uses a NEO-6M GPS module. The GPS module provides latitude and longitude information to the controller. This information can be included in the emergency message sent to the predefined contact. Location information is particularly useful for workers operating in large industrial areas, construction sites, mines, or other locations where the exact position of an incident may not be immediately known.

I. GSM-BASED NOTIFICATION

The GSM module provides communication between the safety jacket and the supervisor or emergency contact. The proposed design uses a SIM800L GSM module. After an emergency event is detected and the worker's location is obtained, the ESP32 sends the required information to the GSM module. The GSM module then transmits an SMS containing the emergency condition and location information.

A typical notification can contain information such as:

“ALERT: Worker in danger. Emergency condition detected. Location: GPS coordinates.”

The use of GSM allows the system to send notifications through the cellular network without depending entirely on a local Wi-Fi connection.

IV. IMPLEMENTATION

The proposed smart safety jacket was implemented by integrating the sensing, processing, alert, power, and communication components into a wearable safety jacket. The implementation was carried out in such a way that the components remain protected inside the jacket while the sensors are positioned at suitable locations for collecting the required data. The ESP32 is used as the main controller for collecting sensor data, processing the information, and controlling the alert and communication modules.

a. Hardware Implementation

The hardware implementation consists of an ESP32 microcontroller, MAX30102, DS18B20, MQ-2, MQ-135, MPU6050, GPS module, GSM module, SOS button, LED indicators, buzzer, vibration motor, battery, charging module, and boost converter.

The ESP32 is connected to the sensors and output devices according to their communication requirements. I2C communication is used for suitable digital sensors, while analog inputs are used for the gas sensors. Serial communication is used for the GPS and GSM modules. The complete circuit is powered using a rechargeable battery placed inside the jacket.

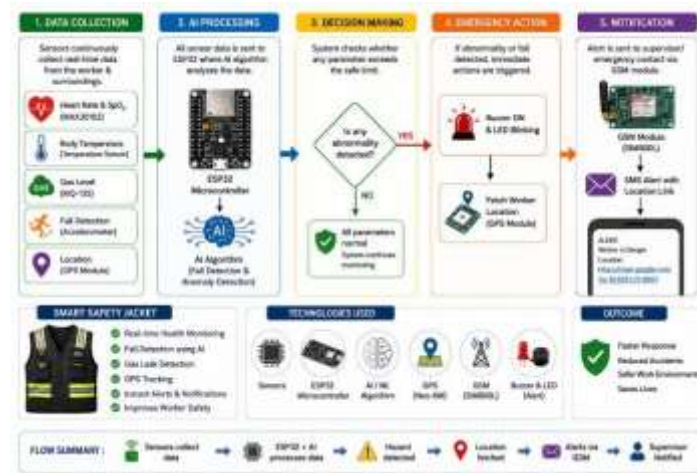
b. Sensor Integration

The MAX30102 is connected to the ESP32 for obtaining heart-rate and SpO₂ readings. The sensor is positioned on the front side of the jacket where suitable contact with the worker can be maintained. The DS18B20 temperature sensor is connected to the controller to obtain temperature readings. The

temperature data is periodically read by the ESP32 and stored for further processing.

c. ESP32-Based Processing

The ESP32 acts as the central unit of the jacket. After the system is switched on, the controller initializes the connected sensors and communication modules. Sensor readings are then collected at regular intervals.



K. Overall Implementation Procedure

The complete implementation procedure is carried out in the following sequence:

1. The ESP32 and all sensors are connected according to their communication interfaces.
2. The individual sensors are tested separately.
3. The MQ-2 and MQ-135 sensors are calibrated before testing.
4. The MAX30102 and temperature sensor are tested for health-related measurements.
5. The MPU6050 is tested using normal movement and simulated fall conditions.
6. The GPS module is tested for obtaining latitude and longitude.
7. The GSM module is tested for sending SMS messages.
8. The buzzer, LEDs, vibration motor, and SOS button are connected to the controller.
9. The sensor-processing and decision logic is implemented on the ESP32.
10. The AI/anomaly-detection model is integrated where applicable.
11. All components are mounted inside the jacket according to the proposed placement.
12. The complete jacket is tested under normal and abnormal operating conditions.



V. CONCLUSION

This paper presented an AI-powered smart safety jacket for monitoring industrial workers and detecting unsafe conditions. The proposed system combines health monitoring, environmental sensing, fall detection, GPS tracking, and GSM-based emergency communication using an ESP32. The jacket monitors heart rate, SpO₂, temperature, gas, air quality, and worker movement. When an abnormal condition is detected, the buzzer, LED, and vibration motor provide an immediate warning. In an emergency, GPS provides the worker's location and GSM sends an alert to a predefined contact. The proposed system provides an additional safety layer for workers and can help reduce the delay in emergency response. Future work can focus on improving AI-based detection, increasing battery life, and testing the system under different industrial conditions.

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