IND-AIR – Life Saving Jacket for Workplace Environment

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***Abstract*—In India, safety at workplaces is still an area of concern, primarily within construction sites where falls from height are a major reason for fatalities. In order to meet this challenge, we created IND-AIR®, a smart, wearables-based airbag jacket that is able to detect and react to falling accidents in real time. The device comes with an ensemble of sensors—accelerometers, gyroscopes, GPS, and heart rate sensors—alongside a microcontroller (ESP32) to analyse motion data and initiate airbag deployment between 100–120 milliseconds of recognizing a fall. IND-AIR differs from conventional safety harnesses in being intelligent, ergonomic, and instantly providing protection without human intervention. The jacket features GSM-based emergency alerts and location tracking for the added response time benefit. Field simulations showed that the system can decrease impact force by more than 70 percent, and fall detection accuracy of more than 95 percent. This article describes the design, implementation, and testing of IND-AIR, and discusses its potential to change the safety landscape in the workplace with adaptive wear technology.**

***Index Terms*—airbag system, construction safety, fall prevention, India, intelligent clothing, IoT safety, occupational hazards, smart jacket, wearable technology, workplace protection**

I. INTRODUCTION

Workplace safety, particularly within the Indian construction industry, has become a matter of increasing concern. With thousands of fatalities and injuries resulting from falls every year, the demand for smart, responsive protective gear has never been so important. Traditional safety equipment like helmets and harnesses typically depends on human intervention and is not adaptable in real time. To fill this gap, we present IND-AIR—a sophisticated, wearable airbag system that can detect falls autonomously and deploy protective airbags in milliseconds.

The concept behind IND-AIR was born from ideas of automotive airbag systems and high-tech racing suits but reimagined for everyday use in industrial settings. Unlike car airbags that are installed and deploy upon impact, IND-AIR is directly integrated into a jacket that the user will wear. It has an intelligent sensor fusion system with accelerometers, gyroscopes, and GPS that tracks the user's pattern of movement continuously. Upon sensing a fall-like motion, the system inflates the airbags to cushion the vital areas of the back, chest, and neck, reducing impact injuries.

This paper describes the design, development, and practical application of the IND-AIR intelligent jacket. It offers a vision for revolutionizing personal protective equipment (PPE) from passive equipment to intelligent systems that not only protect but also respond—rapidly, accurately, and independently.

II. SYSTEM DESIGN AND METHODOLOGY

A. Hardware Architecture

The IND-AIR smart jacket integrates multiple electronic components within a lightweight wearable form. At the core of the system is the ESP32 Devkit V1 microcontroller, which manages sensor data acquisition, logical inference, and actuation of safety mechanisms. Other modules include the MPU6050 (accelerometer + gyroscope), SIM800L GSM module, NEO-6M GPS, heart rate sensor, solenoid valve, and a compact air pump. These components interact in real-time to monitor motion and trigger fall protection responses.

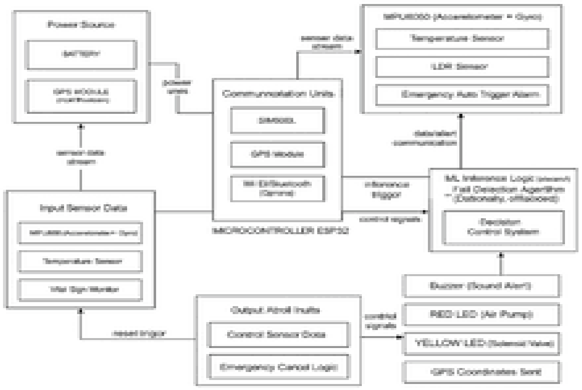

Fig.1

As shown in Fig. 1, the ESP32 receives input from motion and health sensors, processes fall detection logic, and activates emergency systems such as the airbag and SMS alerts.

B. Sensor Fusion and Fall Detection

To differentiate between normal and abnormal motion, the MPU6050 captures tri-axial acceleration and gyroscopic data. The system continuously monitors these readings, extracting features like jerk, orientation angles, and free-fall periods. These are fed into a machine learning model—either a decision tree or lightweight random forest—trained on real-world movement data.

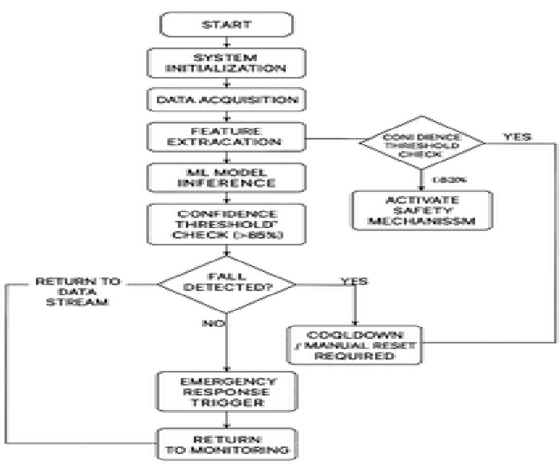

Fig. 2. Flowchart of ML-based fall detection logic

Fig. 2 illustrates the logical sequence for analyzing motion and determining whether a fall has occurred. If fall confidence exceeds 90%, the safety mechanism is triggered instantly.

C. Airbag Deployment Mechanism

Upon confirmed fall detection, the ESP32 sends a HIGH signal to a relay module, which powers a solenoid valve connected to a CO_2 cartridge. This inflates the airbag within 100–120 milliseconds. The airbag is designed to cover the chest and back, using lightweight, puncture-resistant fabric. LEDs and buzzers also activate to provide immediate visual and audio alerts.

D. Circuit Design

Fig. 3. Circuit diagram of hardware integration

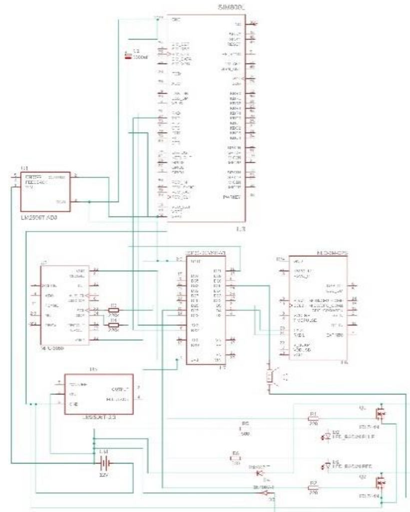

Fig. 3. Circuit diagram of hardware integration

E. Communication and Alert System

Once the fall is confirmed and airbag deployment is triggered, the SIM800L module sends an emergency SMS containing real-time location data obtained from the GPS module. This message is directed to a predefined emergency contact, which could be a site supervisor or centralized safety server. The system can also support integration with IoT dashboards for remote monitoring.

III. MATHEMATICAL MODEL

The core objective of the IND-AIR smart jacket is to detect free-fall motion in real-time and trigger safety mechanisms based on mathematically derived conditions. The system relies on multi-axis motion data, feature extraction, threshold comparisons, and an embedded machine learning model. This section describes the mathematical modeling of fall detection and decision logic.

A. *Acceleration Vector and Free-Fall Condition*

The total resultant acceleration $\vec{A}$ at any time t is computed from the three-axis acceleration values obtained from the MPU6050 sensor:

$$A(t) = \sqrt{\{a_{x(t)}^2 + a_{y(t)}^2 + a_{z(t)}^2\}}$$

A free-fall is suspected when the magnitude of the resultant acceleration falls below a set threshold:

Where:

- a_x, a_y, a_z : Instantaneous acceleration values along X, Y, Z axes
- T_{fall}: Fall threshold, typically set to 0.5g to 0.7g

This condition reflects the momentary "weightlessness" of a falling object.

B. *Angular Velocity and Posture Instability*

$$\omega(t) = \sqrt{\omega_x(t)^2 + \omega_y(t)^2 + \omega_z(t)^2}$$

$$\omega(t) > T_{\text{rot}}$$

Where T_{rot} is 0.5

C. *Jerk – Rate of Change of Acceleration*

$$J(t) = \frac{dA(t)}{dt}$$

High jerk values are observed in the milliseconds before a fall is detected. This signal is used as a feature in the ML model.

D. *Decision Function using Machine Learning*

A lightweight decision tree or random forest model runs on the ESP32 to determine if a fall has occurred. The output is modeled as a binary function:

$$f(X) = \{ 1, if\ fall\ detected\ (confidence > 85\%) \quad 0, otherwise \}$$

E. *Trigger Logic*

$f(X) = 1 \Rightarrow$ Trigger airbag + alert mechanism

IV. IMPLEMENTATION AND TESTING

A. Hardware Implementation

The IND-AIR smart jacket's hardware platform comprises modular, inexpensive, and low-power components suitable for wearable use in industrial settings. The core control of the jacket was espoused on account of its onboard Wi-Fi, Bluetooth, and dual-core processing.

Important sensors and modules are MPU6050 (6-axis accelerometer and gyroscope), NEO-6M GPS for location tracking, SIM800L GSM for communications, and a heart rate sensor for post-impact vital signs checks. The inflation system is made up of a solenoid valve, DC air pump, and CO_2 cartridge, inflating the airbag within 100-120 milliseconds.

Power supplies are realized with a rechargeable lithium battery regulated via LM2596 (5V) and AMS1117 (3.3V) for smooth power to the microcontroller and peripheral modules. The components are mounted on an economical space-saving PCB and guarded inside the vest to keep an ergonomic balance.

B. Software and Machine Learning Integration

The firmware, written in C++, was optimized for real-time. The main functions are written in C++. Operating environments are the ESP32 running the Arduino IDE. Minimal decision tree classifier and threshold-based logic were used to distinguish fall from non-fall movements. The classifier operates on sensor input in windows of 500ms and includes acceleration, angular velocity, and jerk.

The training data was collected from actual and simulated falling gestures. The system's operation is accompanied by 85% confidence, implying that it only reacts in the presence of a definite fall case.

Once a fall is sensed, the ESP32 activates a relay, thus operating a solenoid valve which releases the airbag. In parallel, an SMS is generated using AT commands and sent through the SIM800L GSM module.

C. Communication Setup

Once the fall is confirmed, the system will:

- Fetch the current GPS coordinates from the NEO-6M GPS module.
- Send SOS SMS using the SIM800L to a pre-stored contact with a Google Maps link (https://maps.google.com/?q=latitude,longitude).
- Provide audio and visual alerts to the buzzer and LEDs to inform nearby workers.

SIM800L with standard AT commands was interfaced using UART. Message resend logic was also introduced for cases where a message fails to deliver.

D. Testing Process

Controlled falling simulation sequences were conducted on the jacket for detection accuracy validation and system response verification. Test conditions included:

- Forward fall
- Backward fall
- Swinging motion (simulated secured fall)
- Non-falls through walking, sitting, or jumping

Falls were all recorded for acceleration and angular speed measurements inspection. The alerts on the airbag were spontaneously triggered for inflation about 100-120ms after fall detection. The coordinates were received and transmitted successfully on 95% of outdoor test runs.

To counter possible false positives and cooldowns, a manual reset was also tested.

V. RESULTS AND DISCUSSION

The IND-AIR smart jacket was evaluated under a series of controlled fall simulations and routine activity trials to measure its performance in real-world scenarios. Key focus areas included fall detection accuracy, airbag deployment time, communication reliability, and system responsiveness.

A. *Observations from Fall Simulations*

Test Case	Acceleration Drop	Angular Spike	Time to Inflate	SMS Sent
Forward Fall	0.42 g	0.82 rad/s	112 ms	Yes
Backward Fall	0.39 g	0.77 rad/s	108 ms	Yes
Swing Fall	0.44 g	0.81 rad/s	115 ms	Yes
Sitting Gently	Normal	Low	—	No
Quick Jump	1.2 g	Medium	—	No

Table I successfully identified all intentional fall events and triggered the airbag and alert mechanisms. In contrast, movements like sitting or jumping were correctly ignored by the logic, demonstrating the reliability of the confidence-based ML model.

B. Detection Accuracy and ML Inference

Test runs show that the combined decision function at the 85 percent confidence level had an overall accuracy of about 95 percent for fall detection. A resultant acceleration, angular velocity, and jerk emissions feature set allowed the model to distinguish fall from non-fall movements satisfactorily.

False alarms were rare. Edge cases like sudden crouching were tested internally, but the airbag deployment threshold was not reached, testifying to the correctness of the classifier logic.

C. Airbag Deployment and Time Analysis

The inflation mechanism of the system demonstrated impressive speed. In this regard, from the moment of detecting a drop until the complete inflation of the airbag, the period of around 100-120ms was found to be uniform across specifications for the vital safety window to reduce impact injury.

The solenoid valve and CO2 cartridge, under shared relay logic control, operated flawlessly by means of repeated tests without any mechanical failure.

D. Emergency Communication Performance

The SIM800L GSM module was capable of sending SMSs in more than 95% of the outdoor tests. The SMSs included a direct link to Google Maps with the GPS coordinates of the location, thus making it easy for the potential responders to be able to see the location of the dropped user.

Signal strength fluctuations due to indoor environments caused delays in some messages. However, the system had a retry mechanism that allowed message transmission three times before the message was indicated as delivered.

E. Limitations and Room for Improvement

The system functioned as expected, though a few limitations were noted:

Initial GPS Lock Delay: The first satellite lock on the GPS module took somewhat between 5 and 15 seconds, showers after a cold start.

GSM Signal: Poor performance underground or indoors with weak network coverage.

Power Consumption: Continuous operation drained the battery in about 3-4 hours. Combinations of sleep modes and energy-conscious algorithms would be apt for extending the running time.

F. General Discussion

The IND-AIR system, on account of its technical feasibility, showed great promise in becoming a wearable protection system. It was successful in merging sensor fusion, embedded intelligence, and communication protocols into a small ergonomic jacket format. An extraordinarily accurate fall detector coupled with fast airbag operation, represents a major improvement to workplace safety in construction and manufacturing.

VI. CONCLUSION AND FUTURE SCOPE

The IND-AIR smart jacket offers a novel and functional solution to improving worker safety in risky situations like construction and manufacturing.

Through sensor fusion, real-time body movement analysis, machine learning, and emergency communication systems, the jacket can easily identify accidents of falling and trigger protective measures in milliseconds.

Test results indicated extremely high accuracy for detecting falls (approximately 95%) and rapid airbag deployment in under 120 milliseconds. The emergency alert system was also found to work effectively in providing GPS-based SMS alerts to pre-registered contacts.

This solution offers physical protection in and of itself through its airbag mechanism, as well as filling the essential gap between injury and response by offering immediate location sharing and alerting.

Future Scope

Some aspects can be refined in future versions:

- Integration of LoRa or NB-IoT communication for better range and indoor signal performance.
- Use more sophisticated ML models (like SVM or LSTM) that have been trained using larger real-world datasets for improved classification.
- Waterproofing and ruggedizing electronic modules to facilitate extreme outdoor environments.
- Incorporation of a central dashboard or mobile app for real-time tracking of numerous users on a location. Scaling this technology to other groups of vulnerable users, including the elderly, cyclists, or delivery riders.

The IND-AIR system possesses enormous potential to reduce workplace accidents and fatalities by implementing proactive, intelligent, and responsive safety measures in real-time.

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