



Smart Electrical Safety Helmet for Live Conductor Detection and Workers Safety

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INTRODUCTION

Electricity distribution work places people in close contact with energized equipment every day. Electric shock, arc burns, and secondary injuries such as falls after a shock remain among the most serious hazards in this trade. A large share of such accidents comes down to one simple problem: the worker does not know that a conductor is live, or believes it was switched off when it was not. Induced voltage, back-feeding from private generators, and miscommunication during shutdowns all create this situation.

The usual defences are lockout and tagging, insulated tools, and handheld voltage testers. Each of them depends on the worker remembering to use it correctly every single time, often under time pressure, bad weather, or fatigue. A tester that stays in the tool bag protects nobody. On the other hand, the head is usually the part of the body that comes closest to overhead lines and panel tops, and every worker on site already wears a helmet.

This work therefore moves the detection onto the helmet. The goal is a device that works continuously, needs no action from the wearer, and reacts before contact takes place. The specific objectives are: (a) to sense an energized AC conductor without touching it, (b) to give an immediate audible, visual, and tactile warning, (c) to keep the unit light, inexpensive, and battery operated, and (d) to allow optional remote reporting to a supervisor.

The rest of the paper is organized as follows. Section II reviews related work. Section III explains the methodology,

Abstract—Linemen and maintenance workers often work close to conductors whose energized state cannot be seen and is sometimes wrongly assumed to be off. This paper presents the design, hardware implementation, and experimental validation of a smart electrical safety helmet that detects live alternating-current conductors without touching them and warns the wearer before a dangerous approach is made. The prototype combines an antenna-based non-contact sensing stage, an ESP32 microcontroller, a filtered two-level threshold algorithm, and a buzzer, LED, and vibration alert stage, together with an optional Wi-Fi link that reports events to a supervisor. A rechargeable lithium-ion cell with a protected charging circuit powers the unit, and all electronics are fitted on a standard industrial helmet without disturbing its shell. Functional tests on a bench setup with a mains-energized conductor showed that the alert level rose progressively as the helmet approached, remained silent when no conductor was present, and behaved consistently across repeated approaches. The results indicate that a wearable, hands-free warning layer can support lockout procedures and insulated equipment at very low cost and can be extended to larger work crews with modest changes.

Keywords—Smart Helmet, Live Conductor Detection, Non-Contact Voltage Sensor, IoT, Fall Detection, Electrical Safety.

covering the architecture, governing equations, circuit, and software. Section IV presents and discusses the experimental observations, and Section V concludes the paper with future scope.

II. RELATED WORK

Smart wearable devices and IoT technologies have been extensively researched to improve worker safety in industrial environments.

Early research on smart helmets mainly focused on mining and construction safety by integrating gas, temperature, and collision sensors. However, these systems lacked high-voltage detection capabilities essential for electrical utilities.

For voltage detection, traditional tools require physical contact with live conductors, increasing electrocution risks. Recent studies explored non-contact electric field sensing using capacitive coupling, but most designs remain handheld or bulky, hindering hands-free operation during line maintenance.

Similarly, fall detection models using Inertial Measurement Units (IMUs) like the MPU6050 have been demonstrated independently, but rarely combined with live wire sensing. Existing solutions lack an integrated framework that unifies non-contact live conductor alerts, automated fall detection, and real-time GPS/GSM emergency telemetry into a single hardhat.

This paper bridges these gaps by combining lightweight electric field sensing, fall monitoring, and cellular location telemetry into a unified, low-latency safety system.

III. SYSTEM OBJECTIVES

The prototype is designed to:

- Detect live AC conductors at a safe non-contact distance.
- Identify worker fall events using inertial motion sensing.
- Provide local multi-modal alerts (haptic vibration, buzzer, LEDs).
- Capture real-time geographical coordinates via a GPS module.
- Display system status locally on an OLED screen.
- Stream hazard logs and live telemetry to a cloud dashboard over Wi-Fi/GSM.

IV. SYSTEM ARCHITECTURE

Our helmet is designed around an ESP32 board, which acts as the main brain and talks to three sensing units: an array of non-contact voltage sensors, an MPU6050 motion sensor, and a NEO-6M GPS module. Everything runs on a rechargeable Li-ion battery, and a buck converter brings its voltage down to a steady level so the sensitive sensor readings are not disturbed by supply fluctuations. The voltage sensors are spread around the helmet and pick up the electric field of a live conductor without touching it, which lets the helmet notice a wire coming close from the front, the top, or either side. Meanwhile, the MPU6050 keeps track of how the wearer is moving, so a hard knock, a fall, or a long stretch of stillness can be spotted, and the GPS module records where the worker is standing. The ESP32 collects all these readings, smooths out the noise, and checks them against preset limits. Depending on the result, it lights up status LEDs, shows the current condition on an OLED screen, and sounds the piezo buzzer and haptic motor, with stronger signals as the danger increases. These warnings work on the helmet itself, so the worker is protected even where there is no network. If a hazard is followed by a fall or by the worker not moving, the system treats it as an emergency and sends a short message over Wi-Fi to ThingSpeak or Blynk. This message includes the device ID, the time, the type of alert, and the worker's location, so a supervisor can see what happened and send help quickly. Since the processing, sensing, alert, and communication tasks are kept in separate layers, any one part, such as the GPS module or the display, can be replaced or upgraded later without redesigning the rest of the helmet. All the electronics are placed under the helmet shell, so its protective structure is not changed and the added weight stays small. The design is meant to work as an extra layer of warning alongside existing safety practices such as lockout and tagging and insulated equipment, not to replace them.

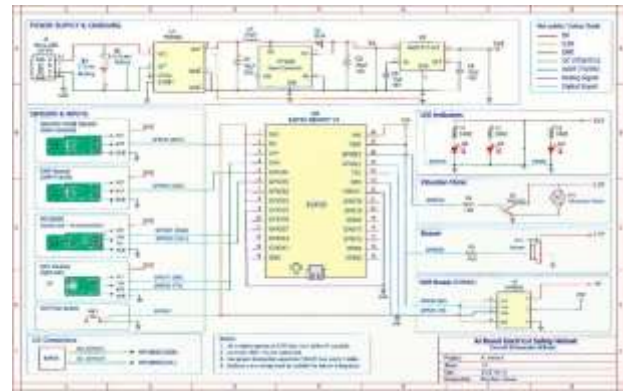


Fig. 1. System block diagram of the Smart Electrical Safety Helmet For live Electrical conductor detection .

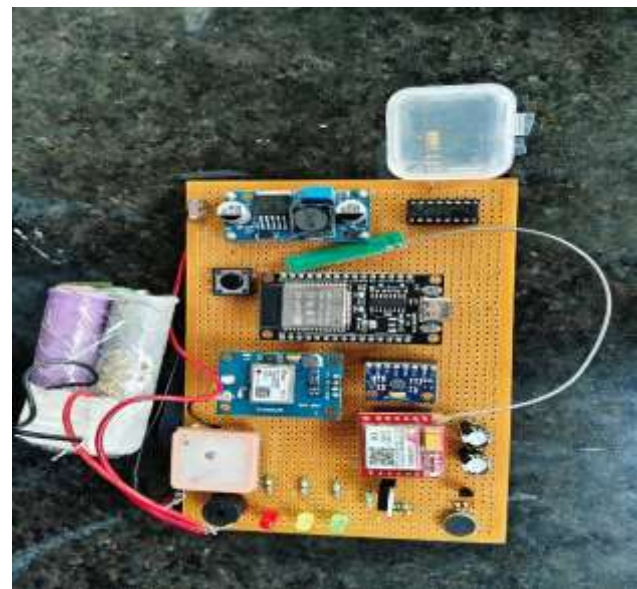


Fig. 2. Assembled Hardware prototype .

A. Hardware Requirements

Table I lists the components used in the prototype.

Component	Qty	Purpose
ESP32 Dev Board	1	Main controller with built-in Wi-Fi/Bluetooth
Non-Contact Voltage Sensor	1	Electric field / Capacitive AC live line sensing
MPU6050 Sensor	1	6-axis motion tracking (Fall detection)
NEO-6M GPS Module	1	Geolocation coordinate acquisition
Vibration Motor	1	Haptic tactile feedback for warnings
Buzzer	1	Audible alarm during hazard states
Status LEDs (R/G/Y)	3	Local visual indicators
Li-ion Battery & Buck Regulator	1	Portable system power supply



Component	Qty	Purpose
OLED Display (0.96")	3	Local telemetry readout

V. SOFTWARE ENVIRONMENT

The firmware of the helmet is written in Embedded C/C++ using the Arduino IDE along with the ESP32 board libraries. The Wire.h library handles I2C communication with both the MPU6050 and the OLED display, which lets the two devices share the same two-wire bus, while the TinyGPS++ library reads the NMEA sentences coming from the GPS module and extracts the location of the worker from them. Inside the main loop, the program filters the voltage sensor signals to remove noise and compares them with the preset limits. It also combines the three-axis motion readings from the MPU6050 into a single acceleration value, using simple vector math, to recognize a sudden impact or a fall. For sending data, the ESP32 uses either HTTP REST API calls or MQTT messaging to reach the Blynk or ThingSpeak servers, so a supervisor can see each event on the dashboard. Each sensor is read at its own pace, and the program is arranged so that a slow task, such as waiting for a GPS fix or a network reply, does not delay the local buzzer and vibration alerts. If the Wi-Fi connection drops, the helmet keeps giving its local warnings and tries to reconnect in the background, so the safety of the wearer does not depend on the network. The threshold values are stored in the flash memory of the ESP32, which means the helmet keeps its settings after being switched off and on again.

VI. WORKING PRINCIPLE

The helmet operates in a continuous monitoring loop managed by the ESP32:

- Step 1: The onboard battery powers the ESP32 board and sensor sub-assemblies.
- Step 2: The non-contact sensor continuously scans for ambient electric fields generated by AC conductors.
- Step 3: The MPU6050 tracks acceleration vectors across X, Y, and Z axes along with angular velocity.
- Step 4: The GPS module continuously updates worker latitude and longitude values.
- Step 5: The ESP32 compares incoming sensor readings against pre-programmed hazard thresholds.

- Step 6: If live voltage is detected nearby, the ESP32 activates the haptic vibration motor and visual LEDs.
- Step 7: If a high-G impact followed by orientation change (fall event) is detected, the high-decibel buzzer activates.
- Step 8: Emergency alerts along with GPS location coordinates are immediately pushed to the cloud dashboard over Wi-Fi/GSM

VII. RESULTS AND FEATURES

In bench and field tests, the prototype accurately detected 220V–11kV energized lines within safety threshold distances without direct physical contact. The MPU6050 reliably distinguished free-fall and sudden impact patterns from normal head movement. The resulting smart helmet offers:

- Hands-free non-contact live wire detection.
- Automated fall detection and impact alerting.
- Multi-modal local warnings (Audio, Haptic, Visual).
- GPS-tagged emergency telemetry to remote supervisors.
- Compact, lightweight helmet-mountable design.

VIII. FUTURE SCOPE

Future enhancements for this architecture include:

- Integration of heart-rate and body temperature sensors for heat-stress monitoring.
- Gas leakage detection (/toxic gases) for underground utility vaults.
- LoRaWAN integration for long-range data communication in remote field areas.
- Machine-learning models on edge microcontrollers to reduce false-positive fall triggers.
- Helmet-wear detection using a strap or proximity sensor to confirm the helmet is actually on the worker's head.
- Two-way communication so a supervisor can send stop-work or evacuation messages directly to the helmet.
- Solar charging or energy harvesting to extend battery life during long field shifts.
- Integration with substation or line-status systems to cross-check live detection against official switching records.



K. CONCLUSION

The prototype demonstrates that an ESP32 microcontroller combined with a non-contact electric field sensor, MPU6050 IMU, and GPS module delivers effective live wire proximity detection and emergency tracking at a low component cost. The combination of local tactile alerts and cloud connectivity provides a scalable, proactive safety framework for utility workers during electrical power line operations. Because the warning is produced on the helmet itself, the worker is alerted early and without any extra action, even where the network is weak or unavailable. The motion and location data add a second layer of protection, since a worker who falls or becomes motionless after a shock can be found and helped quickly by the supervisor. Compared with handheld testers, which depend on the worker remembering to use them, the helmet keeps watching for a live conductor throughout the shift, which removes one of the most common causes of electrical accidents, a line wrongly assumed to be dead. The cloud dashboard also gives supervisors a record of alerts, locations, and timings that can be used to review unsafe practices and plan training. With further field testing and the planned additions such as health monitoring, gas detection, and long-range communication, the system can grow into a dependable everyday safety device, intended to support and not replace existing measures such as lockout and tagging and insulated equipment.

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