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Designing an ESP-32 IoT-Based Fall Prevention Early Warning System for Workers' Safety

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ABSTRACT

This article presents a design and implementation of an ESP-32 IoT-based fall prevention system that combines sensor-based monitoring, computer vision, and real-time alerts to enhance worker safety in potential fall hazard situations. The system utilizes an altimeter to measure the worker's height relative to a reference point and a limit switch to detect the status of the hook for fall protection. Data acquisition and processing are performed by the ESP32 microcontroller, which acts as the central hub. The system also incorporates data filtering and noise reduction techniques to ensure accurate sensor readings. It integrates computer vision and sensor-based monitoring, providing a comprehensive solution for fall prevention. Real-time alerts are generated by the system, enhancing worker safety by prompting swift corrective actions in potential fall hazard situations. These outcomes emphasize the importance of educating workers on the proper use, maintenance, and limitations of the fall prevention system to ensure optimal utilization and effectiveness.

KEYWORDS: ESP-32, Fall prevention, IoT, Real-time, Sensor-based monitoring

1. INTRODUCTION

Workers in the construction business are exposed to a number of risks at work, which can result in tragic incidents. The most frequent construction-related accidents include electrocutions, falling from heights (FFH), getting trapped in machinery, and getting struck by an impediment. The most common reason for accidents at construction sites is FFH. Until 2017, over 20% of all industrial accidents were reported to be fatal in the construction industry of Japan, Korea, US, Hong Kong and the UK [1]. Thirty percent of all industrial fatalities were caused by ffh, with 376 deaths being related to the company[2]. The health and safety executive (HSE) reported that ffh is the main cause of mortality at construction sites in 2019–2020, accounting for 27% of all fatalities. To overcome this issue safety training sessions are conducted to educate workers and site managers on safety hazards and countermeasures in an effort to lower the frequency of ffh accidents at construction sites. These trainings on communication and fall prevention decreased workers' risky behaviours and strengthened safety laws[3]. However, the number of ffh incidents is still rising, which requires extraordinary precautionary measures to overcome the issues. Figure 1 shows a maturity model representing the use of fall prevention systems over time.

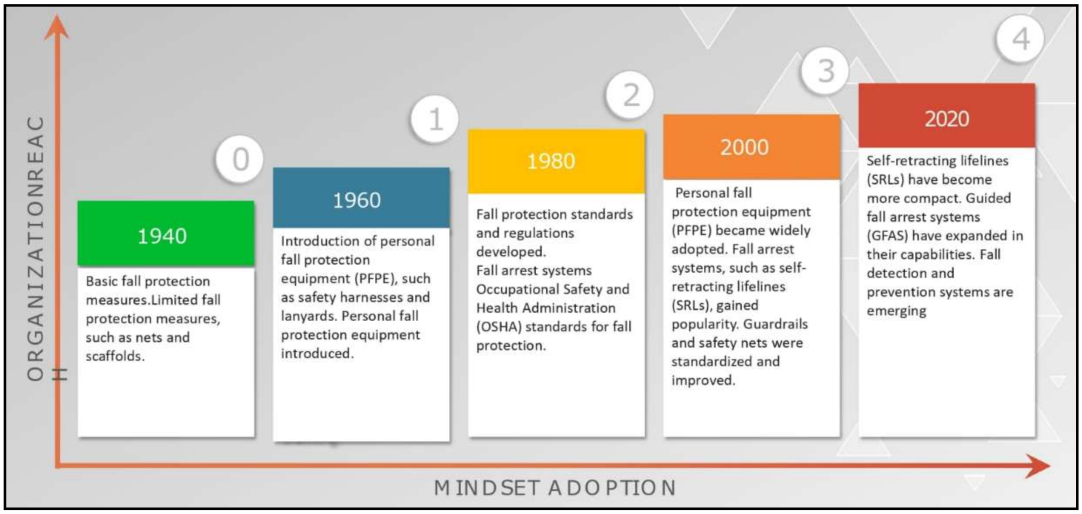

Figure 1: Maturity model of fall prevention system from 1940 to 2020s.

2. LITRATURE REVIEW

Construction projects are complicated, which means there are a lot of safety hazards when working [4]. The construction industry experiences a significantly higher rate of fatalities and injuries compared to other industries [5]. To address this issue, researchers are exploring the use of sensor-based safety systems, utilizing technologies such as machine learning, computer vision, and the internet of things, to enhance construction site safety. Shockingly, over half of the 7275 construction worker accidents in China between 2010 and 2019 involved falls from great heights [5]. To tackle this problem, researchers have put forth a proposal for an internet of things (IoT) system, specifically designed for fall prevention. This system would be able to track worker height, movements, and the condition of their safety hooks in real-time, using a user-friendly web-based platform and a compact, smart safety hook device [6].

Three deep learning models and k-nearest neighbor search optimization techniques have been developed to recognize personal protective equipment in photos and determine anchor placements. Sensor-based monitoring is another tool used to monitor workers at construction sites. Wearable sensors and barometers are used to detect work at height and safety hook attachments. A machine learning model was developed to detect safety hook attachments of workers with 96% accuracy level [7]. It implies that early detection of hazards offers valuable insights to mitigate risks and prevent injuries at construction sites [8]. The following difficulties must be addressed while developing a promising fall prevention system that utilizes an ESP32 microcontroller, an altimeter, and a limit switch to monitor and alert workers in potentially hazardous situations. A promising fall prevention system should be capable of (i) altitude monitoring, (ii) risk detection, (iii) safety confirmation and (iv) unclipped hook alert.

3. METHODOLOGY

The proposed framework for fall prevention system is as follows: an ESP32 microcontroller is employed as the central hub for data acquisition and processing. Utilize an altimeter to continuously measure the worker's height relative to a reference point. Integrate a limit switch to detect the status of the hook, indicating whether it is securely clipped or unclipped. Implement data filtering and noise reduction techniques to ensure accurate sensor readings. Develop algorithms to analyze altitude data and identify potential fall hazards based on predefined thresholds. Process limit switch data to determine the status of the hook and assess the overall safety of the working position. Activate a green LED when the altitude is below 1.6 meters, signaling a safe working range. Trigger a red LED when the altitude exceeds 1.6 meters, indicating a potential fall hazard and prompting the worker to take precautionary measures. Engage a buzzer if the limit switch detects an open state indicating the hook is unclipped, and immediately alerting the worker to the unsafe condition. Develop a user-friendly interface for configuring system parameters, viewing sensor data, and receiving safety alerts. Implement communication protocols to enable data transmission between the system and a central monitoring station or cloud-based platform for remote supervision and analysis. Integrate the fall prevention system with existing safety protocols and procedures such as fall protection systems and emergency response mechanisms. Provide comprehensive training to workers on the proper use, maintenance, and limitations of the fall prevention system. Establish a feedback mechanism to gather user input on system performance, usability and comfort, enabling continuous improvement.

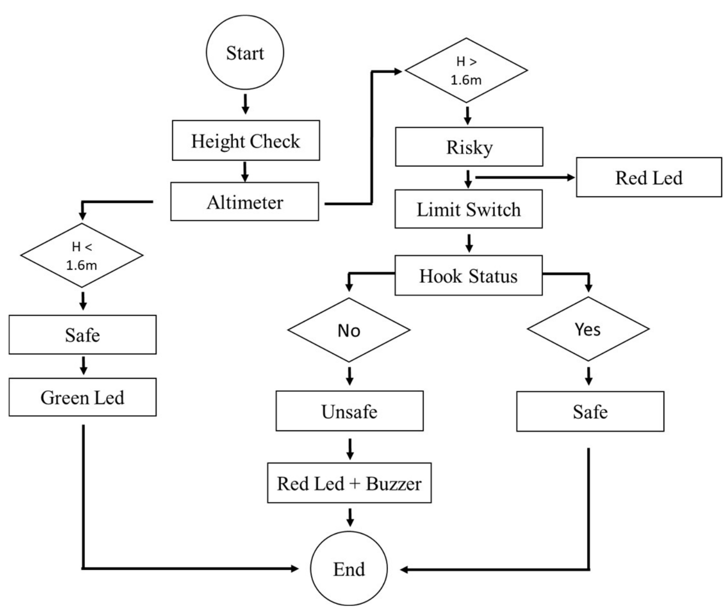

Figure 2: Algorithm of proposed framework.

Table 1: System components and associated costs.

Sr. No.	Components	Cost (Rs.)
1	Small Microswitch/Limit Switch SKU: B623	50
2	9 Volt Battery Snap Connector SKU: B192, IMP 1000, Th500, KRT49, S	25
3	10Cm Pin to Pin Jumper Wire Dupont Line 40 Pin Male to Male Arduino Jumper Wires SKU: B683, IMP300, Th150, S krt198	140
4	BMP280 Barometric Pressure Sensor Module SKU: B758, IMP50, Th25 A krt36	130
5	WROOM ESP32 Wi-Fi Based Microcontroller Development Board Nedelcu SKU: 899, IMP500, TH250, krt217, A	1075
6	KCD1 SPST Rocker Switch Mini Boat Switch 10A 125V 6A 250V Press Button Rocker Switch SKU: B671, L, TH25, IMP50	20
7	KENDAL 6F22 9V Heavy Duty Battery | Best Price in Pakistan SKU: B34, th50, L100, kr155	120

3.1 IMPLEMENTED MODELS

A system's model is essential to comprehending the intended appearance of the project. The majority of the time, the hardware does not perfectly match the model, but without the model, it is impossible to compare and identify areas for improvement. Both the hardware model and the simulation model are required to finish the project. Before the hardware model is implemented, the simulation model provides an idea of whether the project would work as intended or not.

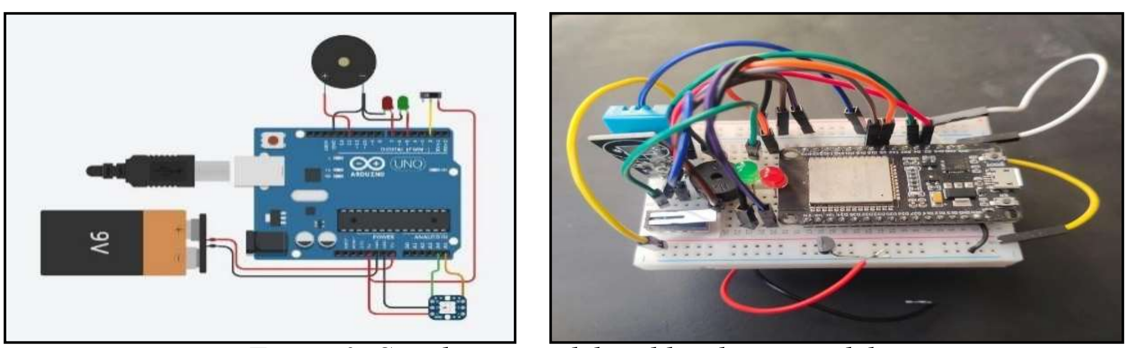

Figure 3: Simulation model and hardware model.

4. RESULTS

1	System performance	Rigorous testing of the prototype demonstrated accurate altitude monitoring and effective fall risk detection, validating the system's performance.

2	Real-time alerts	The visual and audible alert mechanisms including LED lights and a buzzer, effectively alerted workers to potential fall hazards.
3	Integration and Interoperability	Thorough integration testing demonstrated seamless communication between system components, thereby ensuring interoperability.
4	Communication Protocols	The developed communication protocols enabled secure data transmission between the fall prevention system and central monitoring stations or cloud platforms.
5	Overall system effectiveness	The implemented fall prevention system successfully addresses the objectives of accurate monitoring, timely alerting, and enhanced worker safety.

Table 2: Analytics

Sr. No.	Temperature	Altitude	Hook status	Buzzer	Red LED	Green LED
1	20	<1.6m	Not attached	OFF	OFF	OFF
2	20	<1.6m	Attached	OFF	OFF	OFF
3	22	>1.6m	Attached	ON	ON	OFF
4	22	>1.6m	Not attached	OFF	OFF	ON

4.1 HARDWARE RESULTS

The implemented hardware results represent: (i) Hook status, (ii) Discrete altitude level, (iii) Work environment temperature is shown below.

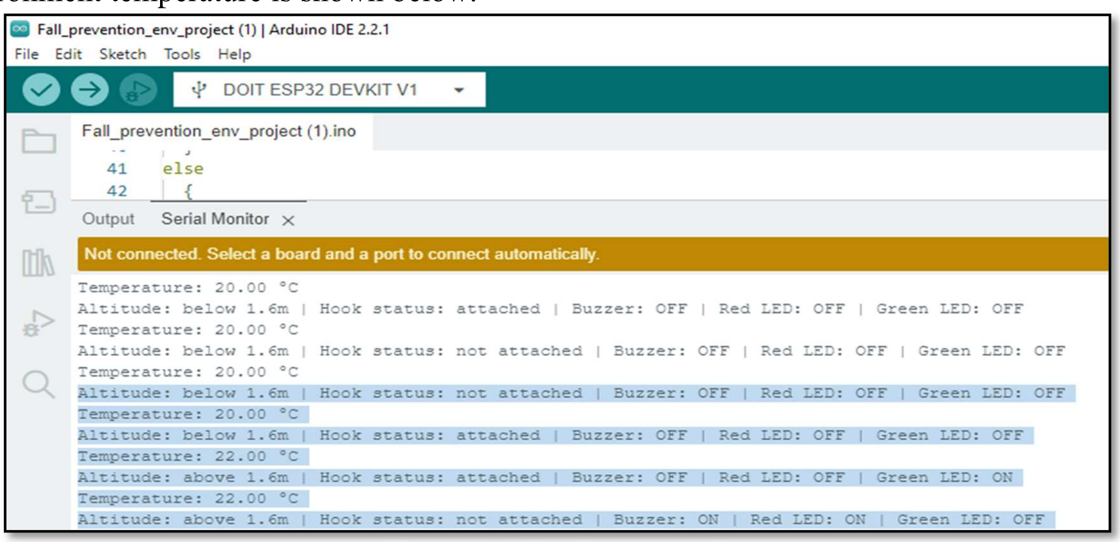

Figure 4: Hardware results

5. DISCUSSION

ESP-32 IoT-based fall prevention system combines sensor-based monitoring, computer vision, and real-time alerts to enhance worker safety in potential fall hazard situations. The importance of educating workers on the proper use, maintenance, and limitations of the fall prevention system to ensure optimal utilization and effectiveness. Rigorous testing of the prototype demonstrated accurate altitude monitoring and effective fall risk detection, validating the system's performance. The implemented fall prevention system successfully addresses the objectives of accurate monitoring, timely alerting, and enhanced worker safety. The developed communication protocols enabled secure data transmission between the fall prevention system and central monitoring stations or cloud platforms. Results shows that the worker falls in a safe zone which shows the green light followed by a buzzer.

6. CONCLUSION

In this study, a design has been proposed for the real-time surveillance of workers' hazardous activities through the amalgamation of vision and IoT sensor technologies. The envisioned solution not only identifies unsafe behaviours of workers at elevated risk heights but also ensures continuous monitoring of the hook status in real-time on scaffolding. This is achieved through the integration of intelligent sensors such as DHT11, BME 280 altimeter, buzzer, LED, and the ESP32 Board, which incorporates both Wi-Fi and Bluetooth modules. The proposed smart safety hook (SSH) monitoring methodology is orchestrated through a microcontroller-based control system, offering a comprehensive and effective means of enhancing safety measures in construction environments.

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