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LOCATION-BASED LAST JOB RISK ASSESSMENT AND REAL-TIME FALL ALERTS

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Abstract

Falls are among the most frequent and hazardous incidents in the construction industry, presenting significant challenges due to their unpredictability and severe consequences. Beyond fall-related accidents, construction sites face a wide range of other safety hazards, necessitating the adoption of advanced technological solutions. This study introduces two innovative safety technologies leveraging geofencing systems: (1) a smartphone-based alert system for fall hazard zones and (2) a location-based last job risk assessment tailored to specific work areas.

The proposed geofencing system utilizes CCTV footage to define fall hazard zones and work areas, automatically triggering and transmitting work risk analysis information to workers' devices upon entry into these zones. This integration enhances safety by providing real-time alerts and up-to-date risk assessments, empowering workers to make informed decisions.

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Keywords: Safety, Geofencing, Smart Construction, Fall protection

1. Introduction

1.1. Background

Falls from heights, including incidents involving ladders, scaffolding, roofs, and other elevated surfaces, are among the most significant causes of accidents in the construction industry (Mistikoglu et al. 2015). Despite enhanced safety measures such as training, fall prevention equipment, and compliance with safety regulations, falls remain a leading cause of injuries and fatalities at construction sites. According to the U.S. Occupational Safety and Health Administration (OSHA), falls accounted for 401 of the 1,102 construction-related fatalities reported in 2020. Similarly, Olcay et al. (2021) revealed that falls from roofs, platforms, and scaffolding were responsible for 32.42%, 25.32%, and 22.87% of accidents between 2012 and 2019, respectively.

Falls are often caused by environmental hazards such as unprotected openings, slippery surfaces, and exposed edges (Ojah et al. 2023). Data analysis indicates that over 70% of fall victims lacked adequate fall prevention measures (Kang, 2018). These incidents are influenced by factors such as construction site conditions, worker experience, weather, and enforcement of safety regulations. For example, disorganized or poorly maintained sites have higher fall rates, while experienced and well-trained workers are better equipped to identify and mitigate risks.

Construction companies and workers are increasingly aware of these risks, prompting the establishment of safety regulations and guidelines in many countries. Job hazard analysis (JHA) serves as an essential tool for identifying risks at various work stages and developing mitigation measures (Wang et al. 2011; Kjellen et al. 2017). However, studies show that many workplace risks remain unrecognized during actual operations (Jeelani et al. 2017). While JHA is ideal for risk awareness and safety training, its application is limited in rapidly changing construction environments where real-time updates are crucial.

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Real-time monitoring and supervision of worksites and workers represent a critical direction for advancing construction safety. Emerging technologies, including drones, digital twins, computer vision, automation, and deep learning algorithms, have been applied for real-time monitoring and hazard detection.

This study introduces a geofencing system integrated with computer vision and video analysis to enhance safety measures. The proposed system delivers fall hazard alerts and a dynamic, real-time Last Job Risk Assessment (LJRA) that reflects the evolving conditions of worksites. A case study demonstrates the system's ability to provide automated updates and real-time alerts to workers, offering significant potential to mitigate risks and improve safety management in the construction industry.

2. ACCIDENTS IN CONSTRUCTION SITE

This paper reviews and synthesizes recent research addressing fall accidents in construction, a leading cause of fatalities in the industry. A study in the United States analyzed 23,057 fall accidents, finding that most incidents occurred at heights below 9.15 meters, during roofing work, and on new commercial or low-cost residential projects, predominantly between 10:00–12:00 and 13:00–15:00, involving experienced older workers (Halabi et al. 2022). This study emphasizes proactive safety management to mitigate fall risks.

In Malaysia, an investigation of 108 fall accidents between 2010 and 2018 identified major factors such as financial constraints, work complexity at heights, unsafe procedures, unprotected edges, and open holes, proposing an Analytical Hierarchy Process (AHP) model to enhance safety awareness (Rafindadi et al. 2022).

New technologies, such as machine learning, have been utilized for fall risk prediction by testing models on factors including date, activity, location, and human elements (Zermane et al., 2023). Additionally, decision tree techniques, such as C5.0 and CHAID, have been employed to extract rules correlating fall probability with variables like fall distance and safety training (Mistikoglu et al., 2015).

Innovative systems like the Rapid Demountable Platform (RDP) have been developed to replace traditional scaffolding, providing benefits in urban areas like Hong Kong (Cheung 2012). Advances in technology, including inertial measurement units (IMUs), have enabled real-time monitoring of worker posture and movements, predicting fall likelihood and enhancing safety (Yang et al., 2014; Qi et al., 2014). Smartphones and artificial neural networks (ANNs) have shown potential in fall detection, identifying high-risk workers and environments (Zhang et al., 2019).

Robotics research has proposed multi-agent systems that autonomously detect and locate fall hazards, integrating path planning and computer vision (Ojah et al., 2023). Bayesian networks have been employed to model fall risk factors, offering probabilistic assessments for safety strategies (Nguyen et al. 2016). Prevention through Design (PTD) tools further integrate fall prevention into the design phase of construction projects (Qi et al., 2014).

Dynamic risk assessment frameworks combining computer vision with Bayesian networks dynamically evaluate fall risks by detecting environmental changes and worker activities, demonstrated through ladder climbing case studies (Piao et al., 2021). Machine learning approaches, such as decision trees and random forests, have identified interpretable safety rules and key factors behind slips, trips, and falls (STFs) (Sarkar et al., 2019).

This study contributes to the field by integrating geofencing technology with computer vision for real-time fall hazard alerts and dynamic risk assessments, providing updated safety information in evolving work environments. The proposed framework offers a comprehensive approach to enhancing worker safety, addressing both traditional and emerging risk factors in the construction industry.

3. CAUSES AND TYPES OF FALL ACCIDENTS

Fall accidents in construction sites are often the result of a combination of factors that compromise worker safety. One significant contributor is the lack of proper fall protection equipment, such as safety harnesses, guardrails, or safety nets, which leaves workers vulnerable to falls. Unsafe work practices also play a major role, as workers may neglect to use fall protection devices correctly or fail to follow established safety procedures, such as maintaining three points of contact while climbing.

Inadequate training further exacerbates the problem, as many workers lack sufficient knowledge of safety protocols and procedures for working at heights. The work environment itself can also pose significant risks, with hazards such as slippery surfaces, unstable scaffolding, or poorly maintained equipment contributing to accidents. Additionally, equipment failure, whether due to malfunction or improper use, can lead to falls, especially when ladders or scaffolding are involved.

A lack of supervision is another critical factor, as insufficient oversight often results in unsafe work practices going unchecked. Finally, fatigue or distraction among workers significantly increases the likelihood of accidents, as tired or unfocused individuals are more prone to making errors that lead to falls. Together, these factors underscore the importance of comprehensive safety measures and effective training to mitigate the risk of fall accidents on construction sites.

Fall accidents on construction sites can typically be classified as follows:

- Roof Falls: Occur when workers fall from roofs during construction, repair, or inspection. Hazardous areas include the entire roof surface, roof edges, and openings.
- Ladder Falls: Commonly occur when workers ascend or descend ladders. Hazard zones include ladder rungs, steps, and transition points between ladders and work surfaces.
- Scaffold Falls: Falling from scaffolding is particularly dangerous. Hazard zones include scaffold platforms, edges, and access points such as stairs or ladders.
- Elevated Platform Falls: Occur when workers fall from aerial lifts, scissor lifts, or other elevated work platforms. Hazard zones include the platform and open sides.
- Floor and Ground Falls: Falling on flat surfaces can be hazardous, especially when workers trip over objects, slip on wet surfaces, or fall into holes or trenches. Hazard zones include uneven terrain, holes, trenches, and cluttered workspaces.
- Edge Falls: Happen when workers approach unprotected edges of floors, decks, or balconies. Hazard zones include unguarded edges, open sides, and floor openings.
- Stairway Falls: Workers may lose balance or trip while ascending or descending stairs. Hazard zones include stair treads, steps, and railings.
- Shelf Falls: Occur when workers fall from shelves or other protruding structures. Hazard zones include shelves, railings, and unprotected edges.
- High Passageway Falls: Occur when workers use elevated walkways or passages without proper guardrails or fall protection devices. Hazard zones include the passageway itself and openings.

4. Statistical Analysis of Fall Accidents in Korea

According to the Korean Occupational Safety and Health Agency (KOSHA), the distribution of fall accidents by causative factors over a 10-year period (2010–2019) is as shown in Figure 1. Understanding these causes and types of falls is essential for developing targeted safety measures and reducing the frequency of such accidents in construction environments.

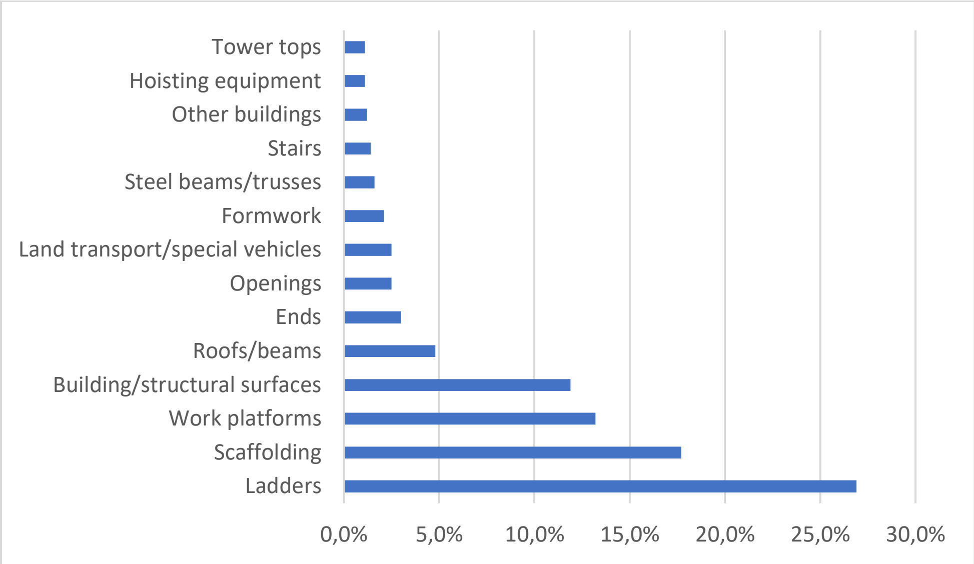

Figure 1. Status of Fall Accidents by Causative Factors

5. SAFETY MANAGEMENT SYSTEM USING GEOFENCING

5.1. GEOFENCING TECHNOLOGY

Geofencing technology, a location-based service utilizing GPS, RFID, Wi-Fi or cellular data, creates virtual geographic boundaries or "fences" around specific areas (Caggiani et al., 2023). These virtual boundaries, defined by latitude and longitude coordinates, can range from a few meters to several hundred kilometers. Once a geofence is established, it can automatically trigger task-related safety alerts when individuals enter or exit the defined area. This technology has found widespread applications across various industries. Research highlights include methodologies for urban geofencing, such as limiting e-scooter speeds in city areas, demonstrated in a case study in Bari, Italy, and mobile application-based geofencing platforms for monitoring worker movements and detecting potential biosecurity breaches in swine production systems (Black et al., 2022). Geofencing's usability for managing electric scooters and bicycles, addressing spatial occupancy and traffic safety, has also been investigated (Nikiforiadis et al., 2023).

In aviation, geofencing has been applied to enable automatic avoidance maneuvers for aircraft based on real-time conditions and performance constraints, validated through flight tests (Pinchetti et al., 2022). Similarly, airport geofencing systems incorporating inner threshold and outer buffer zones have been proposed for unmanned aerial vehicles (UAVs), offering practical applications for safety around major airports like Chongqing Jiangbei International Airport (Zhang et al., 2020).

Geofencing is also employed in human-wildlife conflict mitigation, such as limiting livestock movement within virtual boundaries and deterring elephants from human-dominated habitats using Automated Geofencing Devices (AGDs) (de Mel et al., 2023). Additionally, smartphone-based geofencing has been used for monitoring medical resident clinical work hours (Owei et al., 2021), logistics management through SafeTrack for route monitoring (Oliveira et al., 2015), and pedestrian safety at intersections by facilitating communication between pedestrians and drivers (Angulo et al., 2021) .

Other notable applications include energy management in HVAC systems during unoccupied periods in U.S. homes (Pang et al., 2021) and the development of virtual dynamic message signs (VDMS) for public transit information dissemination, which improved message comprehension and reduced driver reaction times (Ma et al., 2015).

This paper explores the versatility and effectiveness of geofencing technology across diverse fields, emphasizing its potential to enhance safety, optimize resource management, and improve user interaction through innovative applications. The findings underscore geofencing's role as a transformative tool for dynamic and adaptive systems.

5.2. Geofencing System Operation

Real-time alerts for fall hazard zones aim to prevent fall accidents by identifying potential fall hazards and their corresponding zones, then establishing geofencing boundaries for these areas. Common fall hazard zones and contributing factors include: Roofs, Ladders, Scaffolding, Elevated platforms, Unorganized floors and ground surfaces undergoing demolition or work, Edges of work zones, Stairs, Shelves, High passageways, Holes and other openings. When such fall hazard zones and contributing factors exist within the work area, geofencing can be implemented using video footage.

The geofencing safety management system operates as follows:

1. Defining the Main Area: The safety manager establishes a virtual boundary for the work zone (main area) using video footage.
2. Defining Sub-Areas: After defining the work zone, additional virtual boundaries (sub-areas) are set for regions with potential fall hazards.
3. Risk Analysis Information Delivery: When a worker enters the defined work zone (main area), job hazard analysis (JHA) information is provided to their smartphone.
4. Risk Information Update: If additional hazards are identified within the work zone, the JHA information is updated in real-time.
5. Final Risk Assessment and Information Sharing: After completing the updated final risk assessment and sharing the hazard information, workers proceed with the task.
6. Real-Time Fall Hazard Alerts: If a worker enters a fall hazard zone (sub-area) within the work zone during the task, a fall hazard alert is issued.

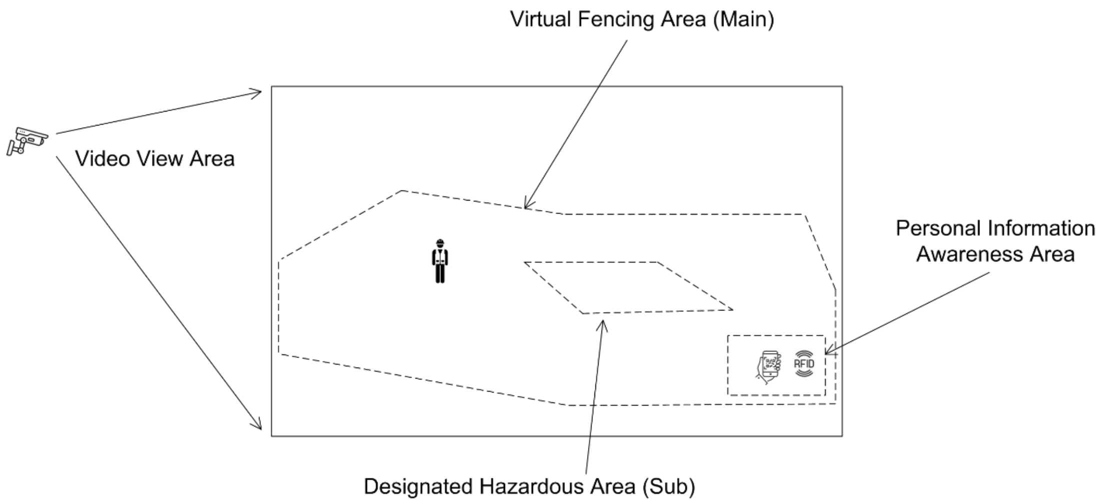

Figure 2. Conceptual Framework of Geofencing for Fall Prevention

The geofencing concept provides an innovative approach to construction safety by integrating advanced location-based services with hazard detection and communication technologies. The process begins with the identification of workers in the workplace through QR codes or RFID devices. Once a worker is recognized, their movements are monitored via location tracking to determine if they enter a fall hazard zone. If the identified worker enters a fall hazard zone, they receive hazard notifications on their smartphone or audio alerts through the speaker in their safety helmet. This system ensures real-time monitoring and immediate response to fall hazards, enhancing worker safety and reducing accidents.

6. ACTIVITY RISK ASSESSMENT

Identifying and sharing risk factors associated with a task is a core process in safety management. Job Hazard Analysis (JHA) typically involves breaking down the task into sequential steps, identifying risks at each stage, and outlining mitigation measures and training requirements. By linking JHA with defined work zones, it becomes possible to conduct risk analysis specific to a particular area. Using geofencing, work zones are defined, and when a worker enters the designated zone, the relevant JHA information is automatically triggered and delivered to them. Figure 3 illustrates the integration of work zones with corresponding JHA information, demonstrating a model for automatic hazard alerts and updates using geofencing technology.

In dynamic construction environments, new hazards frequently emerge due to constant changes on-site. As a result, the existing JHA information may not always reflect the current risks accurately. To address this, team leaders and workers can update the JHA information for their work zone as new hazards are identified. This updated information can then be shared among all participants involved in the task, ensuring that the latest safety measures are communicated and implemented effectively.

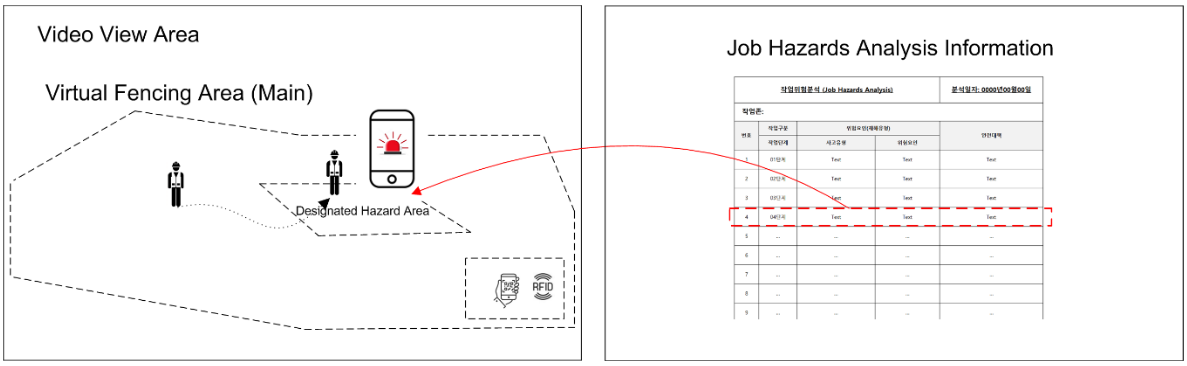

Figure 3. Hazard Area Information

7. CONCLUSIONS

Despite the critical importance of hazard awareness among construction workers, many risks remain unrecognized on-site. This study focuses on leveraging geofencing technology to enable real-time communication and hazard awareness for workers.

The geofencing-based safety management system developed in this research provides methods to warn against fall accidents—one of the most common hazards in construction—and supports enhanced recognition of various other construction risks. The case study demonstrates the system's capability to identify new hazards in dynamic work environments and share these hazards with participants in real-time.

Two key safety features of the geofencing-based system were validated in the study:

- Real-Time Hazard Alerts: Providing immediate warnings to workers entering fall hazard zones.
- Location-Based Final Job Risk Assessment: Delivering up-to-date risk evaluations based on the worker's location.

However, the case study also revealed limitations in the system, such as potential errors caused by overlapping video feeds during location tracking, leading to issues like incomplete personal data recognition or loss of information. These findings highlight the need for further improvements in the accuracy and reliability of location tracking and personal data recognition, which remain challenges to be addressed in future research.

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