DEEP LEARNING BASED POSE ESTIMATION OF SCAFFOLD FALL ACCIDENT SAFETY MONITORING

Seungsoo Lee, Seonwoo Son & Pa Pa Win Aung
Department of Global Smart City, Sungkyunkwan University, South Korea

Minsoo Park
Departm Sungkyun AI Research Institute, Sungkyunkwan University, South Korea

Seunghee Park
School of Civil, Architectural Engineering and Landscape Architecture, Sungkyunkwan University, South Korean

ABSTRACT: *According to the Ministry of Manpower, falling and slipping accidents are one of the most common accidents in addition, falls from heights (FFH), including accidents during scaffolding work, are still a major cause of death in the construction industry. Regular safety checks are currently being carried out on construction sites, but scaffold-related accidents continue to occur. Sensing technology is being attempted in many industrial sites for safety monitoring, but there are still limitations in terms of the cost of sensors and object detection, which are limited to certain risks. Therefore, this paper proposes a deep learning-based pose estimation approach to identify the risk of falling during scaffolding work in the construction industry. Through analysis of the correlation between unstable behavior during scaffold work and the angle of keypoints of workers, the proposed approach demonstrates the ability to detect the risk of falling. The proposed approach can prevent falling accidents not only by detecting construction site workers, but also by detecting specific risky behaviors. In addition, in limited work environments other than scaffolding work, the information on unstable behavior can be provided to safety managers who may not be aware of the risk, thus contributing to preventing falling accidents.*

KEYWORDS: *deep learning, pose estimation, keypoint angle calculate, construction site safe monitoring, falls from heights*

1. INTRODUCTION

According to the Ministry of Manpower, falling and slipping accidents are one of the most common accidents in addition, falls from heights (FFH), including accidents during scaffolding work, are still a major cause of death in the construction industry. Working at height on construction sites is associated with a major risk of falls that must be properly managed to prevent injury and death.

Statistics from the U.S. Department of Labor in 2021 indicate that nearly one in five workplace fatalities occurred in the construction industry, with over a third of these attributed to falls, slips, and trips. The construction industry was responsible for 46.2% of all deaths from falls, slips, and trips that year(U.S. BUREAU OF LABOR STATISTICS, 2023).

Based on data from Singapore's construction sector, construction accidents have been on the rise from 2020 to 2022, accounting for 171 incidents (26% of total accidents). Of these, FFH accounted for 55 incidents (32%), while slips and trips were responsible for 27 incidents (15.8%) (MOM, 2022).

Meanwhile, in South Korea, despite the implementation of the Major Accident Act in January 2022 aimed at reducing fatalities among construction workers, there has been a 0.01% increase in such incidents as of March 2023. Specifically, in 2022, out of 539 deaths, 268 were attributed to "falls," marking the highest cause. These statistics reconfirm that the construction sector is hazardous, with a pronounced risk of fall incidents.

While various personal protective equipment and safety devices have been developed to prevent accidents, a study by (Xia et al., 2018) highlighted that one of the main causes of fall incidents is the absence or insufficiency of worker behavior supervision. Information on the posture of construction workers can serve as valuable data for evaluating safety and productivity (Xu et al., 2022). Several studies have been driven based on this perspective.

(Khan et al., 2021) researched methods to detect unsafe behaviors of workers using IMU sensors, specifically by assessing the angle of attached hooks. Enrique (Valero et al., 2016) used wearable devices based on IMU sensors to analyze movement data and detect unsafe postures. There have also been significant strides in using computer

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vision for safety research. (MassirisFernández et al., 2020) proposed a method to assess work risks by analyzing joint angles of workers under limited visibility conditions.

Deep learning methodologies have also been applied to safety research. (Khan et al., 2021) utilized deep neural networks to classify and segment worker movements, detecting unsafe behaviors on moving platforms. Pinsheng (Duan et al., 2023) introduced a technique using OpenPose to detect personalized stability based on the individual characteristics and habits of workers at height.

However, a gap has been identified in safety monitoring research following the Standard Operating Procedure (SOP). This study aims to address this gap by proposing a method to monitor unsafe postures of workers during scaffolding operations based on their shoulder joint angles, in accordance with the SOP.

Furthermore, by actively incorporating such innovative technology at construction sites, it is possible to enhance worker safety and improve productivity. For instance, these posture detection systems can support workers in maintaining safe working postures and preemptively detect unsafe conditions to prevent accidents. This not only elevates safety standards in the construction industry but also enhances work efficiency while reducing fatigue and injuries during operations.

Moreover, the practical utilization of such technology in construction sites can lead to adherence to project schedules and cost savings. Real-time posture detection and analysis at the site are expected to contribute significantly to enhanced productivity and the creation of a safe working environment in the construction industry.

2. LITERATURE REVIEW

The construction industry has been a focal point of research on workplace safety, largely due to the high frequency of fall-related accidents (MOM, 2022; U.S. BUREAU OF LABOR STATISTICS, 2023). With a significant portion of accidents attributed to falls from heights (FFH), slips, and trips, it is clear that this is an area in need of targeted interventions and technological innovation.

Efforts have been made to mitigate the risk of falls in the construction industry by developing personal protective equipment and safety devices. However, studies suggest that the root cause of fall incidents often lies in inadequate supervision of worker behavior (Xia et al., 2018). Construction worker's postures are a valuable source of stability and productivity information that can be used to manage construction sites (Xu et al., 2022).

Monitoring changes in a worker's posture can provide information about whether the worker is in a safe or unsafe position. Numerous studies have been conducted to detect and analyze unsafe behaviors of workers using this approach. For instance, (Khan et al., 2021) conducted a study using IMU sensors to determine unsafe worker behavior through the angle of secured hooks. Similarly, Enrique (Valero et al., 2016) used wearable devices based on IMU sensors to measure movement data, detecting and characterizing the unsafe postures of workers. Other researchers have also leveraged computer vision to detect and analyze worker posture information. For instance, (MassirisFernández et al., 2020) evaluated job risk by inferring joint angles of workers under limited field of view conditions based on computer vision.

Deep learning has also found its applications in this context. (Khan et al., 2021) identified unsafe behaviors on mobile platforms through object correlation detection using deep neural network-based worker classification and segmentation. Also, (Duan et al., 2023) proposed a personalized stability detection technology based on high-altitude workers' body posture patterns by detecting individual physical characteristics and habits using the OpenPose method.

Amidst these technological advancements in detecting unsafe behaviors, there's a noticeable gap when considering overlapping or closely interacting workers in construction sites. Addressing this complexity, (Park et al., 2023) introduced a method for detecting small and overlapping workers at construction sites, emphasizing the intricate interactions and spatial relations of workers in crowded environments. Demonstrated significant potential in ensuring workplace safety by identifying such challenging scenarios with higher accuracy.

While these prior studies have inferred the results of unsafe worker behaviors using sensors and evaluated worker stability, they often lack in terms of monitoring safety during scaffolding work as per Standard Operating Procedure (SOP). Therefore, this study aims to monitor unsafe postures by detecting shoulder joint angles of workers during scaffolding work based on SOP, as an effort to prevent fall accidents in this context.

3. METHODS

3.1 Research framework

In the construction industry, the safety of workers holds paramount importance, especially with the rising concerns related to fall-related accidents. Traditional methodologies have primarily leaned towards sensor-based approaches to address these concerns. However, there's a growing interest in methodologies based on computer vision. In this framework, we utilize the YOLOv7 Pose algorithm to detect and assess the shoulder joint angles of construction workers to discern potential hazardous situations. As illustrated in Fig. 1 the framework to monitor the stability of construction workers working at elevated heights consists of five modules. First, data is collected from the construction site, encompassing a myriad of movements by the workers. From the collected video data, essential frames are extracted and major regions pertaining to the workers are labeled accordingly. Next, the YOLOv7 Pose algorithm is employed to detect the skeleton of the workers. Special emphasis is laid on the skeleton information around the shoulder joint to calculate the angle of the shoulder joint. Subsequently, an analysis is performed to determine if the current angle of the worker's shoulder joint poses any risk in comparison to a set standard angle. If any hazardous posture is detected, real-time alerts are displayed, urging the implementation of necessary safety measures.

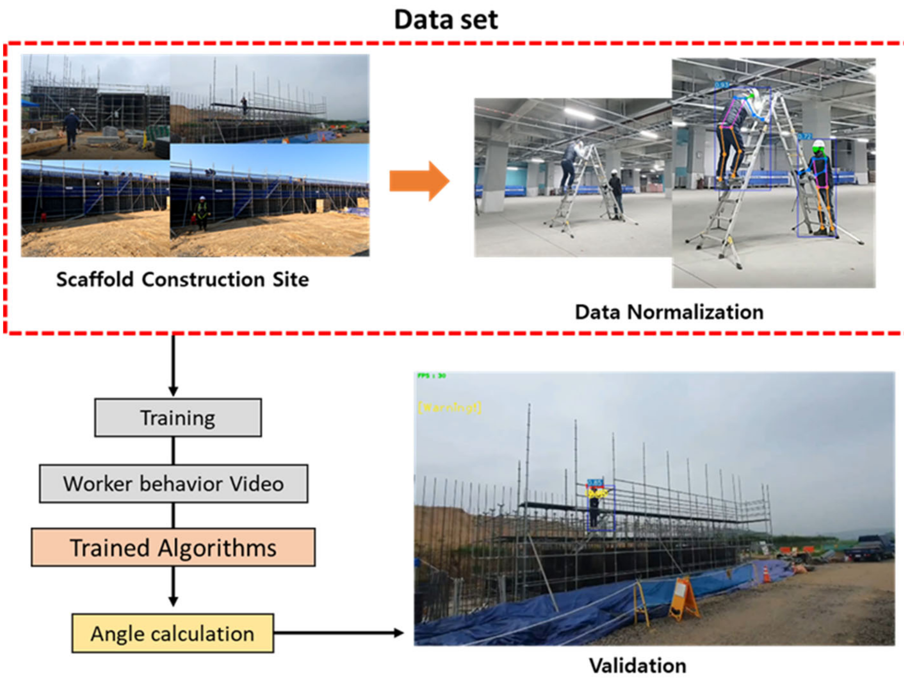

Fig. 1: Research Framework.

3.2 Identification method

Ensuring the safety of construction workers in high-risk environments, such as working at heights, has always been a top priority in the construction industry. Falls from heights are a common type of accident on construction sites, and many of these incidents occur when workers lose their balance and become unstable. In particular, scaffold work, which is frequently performed by construction workers, is associated with a high number of accidents. Therefore, in this study, the OpenPose method, which detects human postures from images and videos, was used to detect and analyze the postures and joint information of scaffold workers. The algorithm, trained using the MS COCO dataset and videos captured at construction sites, detects and represents human posture as shown in Fig. 2 It identifies a total of 17 joints, numbered from 0 to 16, as illustrated in Fig. 2, right image, and provides information about each joint. Table 1 illustrates unsafe postures that can occur during scaffold work. While various postures are possible during scaffold work, such as sitting, standing, bending, or bowing the head, there is a posture where both arms are raised simultaneously, lifting both the left and right shoulders, with a shoulder angle of less than 90 degrees. In this study, a posture involving the simultaneous elevation of both arms and shoulders with an angle less than 90 degrees is designated as an unsafe posture.

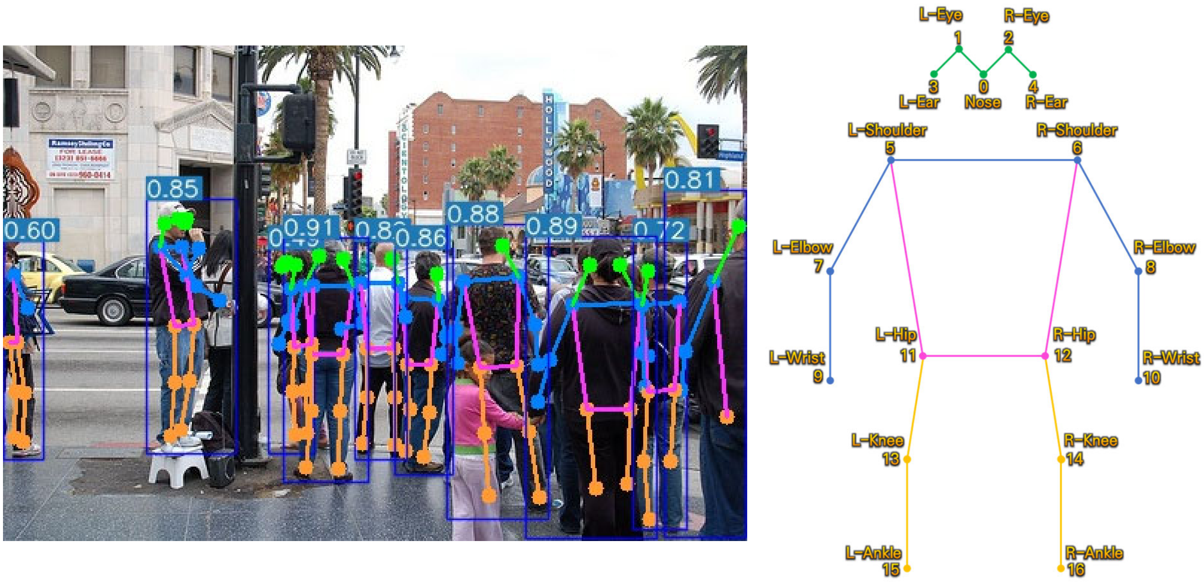

Fig. 2: Joint position information.

Table 1: Unstable behavior criteria for scaffolding operations

Unstable behavior description	Angle name	Angle numbers	Range	Threshold
Arm rasing	Left-Shoulder	∠7,5,6	0°~270°	∠LS ≤ 90°
	Right-Shoulder	∠8,6,5	0°~270°	∠RS ≤ 90°

3.3 Feature extraction

Algorithm 1 demonstrates a method for representing risk alerts based on angle calculations. This is employed to indicate stability alerts based on the angle when a worker raises their arm during operations. The algorithm consistently computes risk alerts based on shoulder angles, thereby continuously detecting workers and providing real-time notifications for risks associated with unsafe postures. It processes the input, detecting individuals in the video, and then delineates Bounding Boxes (BBox) and keypoints. Subsequently, it performs ongoing calculations for the angles of the R (Right) and L (Left) Elbows and R, L Shoulders. When the angle falls between 90 and 180 degrees, a warning notification is sent, while angles below 90 degrees trigger an Unsafe posture notification, which is visualized and transmitted.

Algorithm 1: Finding Angle between Three Points

Input: Detected Workers

Output: angle

1: Extract coordinates for p1, p2, p3 from kpts.

2: Calculate angle using atan2.

3: **if** angle >= 180.0 THEN label = '[safe!]', color = blue

4: **else if** 90 < angle < 180 THEN label = '[Warning!]', color = yellow

5: **else** label = '[Unsafe!]', color = red

6: **if** draw **then** visualize angle, label on image.

7: Return angle.

Fig. 3 demonstrates the method for detecting unsafe postures when the algorithm is applied during video recording. The YOLOv7 algorithm was utilized for its speed and capability to detect individuals while simultaneously detecting joints. The worker's joints are divided into 17 distinct points, from the head to the legs, each assigned an ID. To identify unsafe postures during scaffold work, the angles of the shoulders are crucial when the arms are raised. Therefore, angles for the joints L-Shoulder(5) and R-Shoulder(6) were detected and calculated. For angle calculation, a line connecting L-Shoulder(5) and R-Shoulder(6) was used as the baseline, and vectors were applied to the Elbow joint for angle calculation, as the calculation required angles for external rotation at each shoulder joint. Following the KOSHA GUIDELINE, when a worker raises their arm, an unsafe posture is determined based on a 90-degree threshold. The system alerts the user with three levels: over 180 degrees for safe, between 90 and 180 degrees for warning, and below 90 degrees for unsafe.

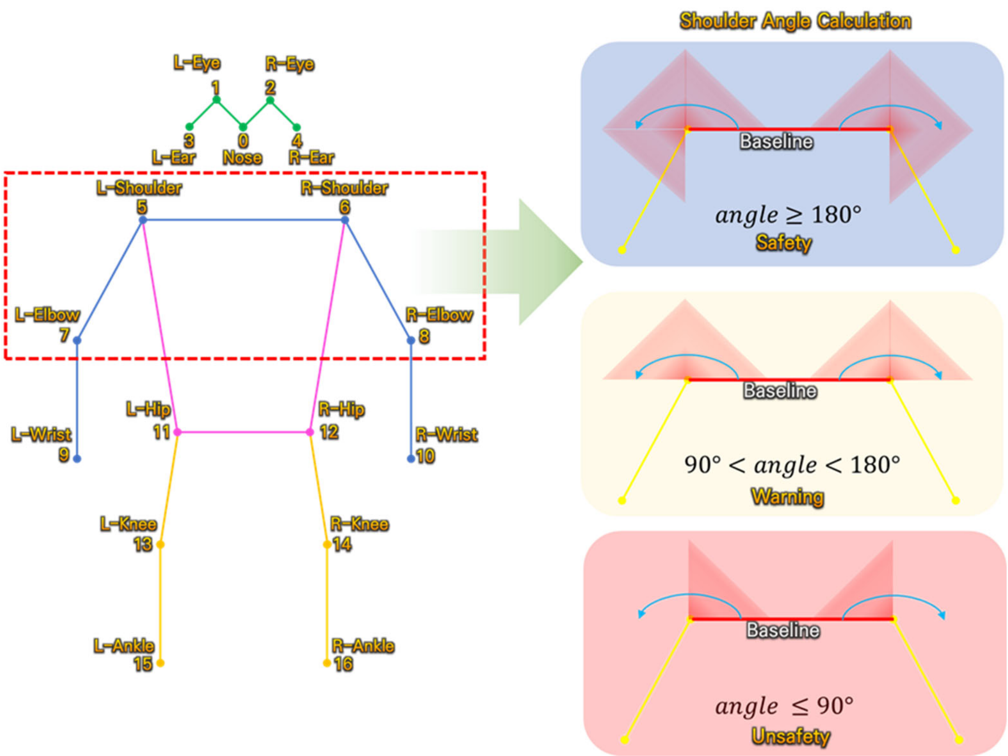

Fig. 3: Joint information and how to calculate shoulder joints

4. RESULTS

(a)

(b)

Fig. 4: Worker safety monitoring results during scaffolding operation. (a) Scaffolding installation work image taken diagonally, (b) Scaffolding installation site work image taken from the front

In Fig. 4 (a) presents the results of detecting a worker engaged in scaffold installation captured from a diagonal angle. When the worker raises their arms, the proposed angle-based criteria triggers a [Warning!] alert, indicating the detection of the worker and the activation of the alarm system. In (b), an image captured from the front showcases the construction site, not only identifying scaffold workers but also other workers engaged in different processes. As these workers are not in the arm-raised posture, no warning alerts are generated.

The proposed method for detecting unsafe postures during elevated work involves worker detection on construction sites and shoulder joint angle assessment for safety monitoring. This approach aligns with safety posture guidelines applied when workers raise their arms during elevated tasks, providing real-time warning notifications. This experiment validates the robustness of this study in facilitating easier site supervision and monitoring by administrators in complex and chaotic construction environments.

5. CONCLUSION

This study aims to contribute to the advancement of automated safety monitoring technology in the field of construction sites. The proposed method utilizes a Deep Learning-based OPENPOSE pose estimation model to estimate the postures of scaffold workers on construction sites. This estimation aims to provide real-time risk alerts to prevent falls from height (FFH) accidents. This research is expected to reduce the fatigue of construction site managers and decrease the occurrence rate of scaffold-related fall accidents.

However, during this research, limitations and areas for improvement have been identified. Due to the nature of construction sites, there are often obstacles and situations where workers are obstructed or difficult to detect due to equipment. Additionally, as objects move farther from the camera, issues were observed in joint angle calculations and false positives/negatives of worker detection. This indicates the need for further research and algorithm improvements. To address these challenges, future research aims to enhance detection accuracy based on distance and devise strategies to detect workers obstructed by obstacles. Furthermore, incorporating Multi-Camera setups is intended to calculate worker head angles.

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