COMPUTER VISION-BASED MONITORING FRAMEWORK FOR FORKLIFT SAFETY AT CONSTRUCTION SITE

Muhammad Sibtain Abbas, Aqsa Sabir, Nasrullah Khan, Syed Farhan Alam Zaidi, Rahat Hussain, Jaehun Yang & Chansik Park
ConTI Lab, Department of Architectural Engineering, Seoul, South Korea.

ABSTRACT:

Efficient forklift operation is critical for construction site safety and project progress; yet, the construction industry deals with recurrent issues, including unauthorized forklift operation, operator drowsiness, visibility challenges, blind spots, and load placement errors. This paper introduces the "iSafe ForkLift," a comprehensive safety framework powered by computer vision, specifically designed to tackle these multifaceted safety challenges associated with forklift operations. The framework provides an array of integrated solutions, encompassing facial recognition for authorization, anomaly detection for behavior monitoring, stereo cameras for improved visibility, blind spot solutions, and load placement monitoring. Aligned with OSHA safety standards, it offers opportunities for enhanced forklift safety by addressing a broad spectrum of potential risks within a single, efficient framework. Systematically addressing multiple safety risks within this unified framework significantly elevates overall safety. Future studies should prioritize enhancing technology by merging computer vision with IoT to boost precision and safety, especially on challenging terrains, thereby elevating construction industry standards' reliability.

KEYWORDS: *Forklift operations, Computer vision, Safety framework, Operator drowsiness, Visibility challenges, OSHA standards, Regulatory compliance*

1. INTRODUCTION

The construction industry, characterized by its dynamic and complex nature, is a realm where innovation and risk coexist. Here, heavy earth-moving machines, including forklifts, are integral, performing tasks that are pivotal for project progression. Forklifts are indispensable tools in this regard, capable of swiftly transporting heavy loads to various locations within the site. However, the operation of such machinery is filled with risks. Accidents involving heavy earth-moving machines are not uncommon and have led to severe, sometimes fatal, consequences, underscoring the critical need for enhanced safety protocols. Approximately 75 to 100 workers lose their lives in forklift accidents annually, with an average of roughly 87 fatalities per year. This number has seen a nearly 30% increase over the past decade (Forklift Accident Statistics, n.d.). According to the OSHA database, 1117 accidents occurred just because of forklifts (OSHA, 2023a). Operating forklifts on construction sites poses various challenges and risks, from unauthorized personnel attempting to use them to blind spots and improper load placement. Notably, there has been a pressing need to propose a comprehensive solution for these challenges, yet no researcher has put forward an all-encompassing approach to address them concurrently.

iSafe ForkLift, a state-of-the-art monitoring framework powered by computer vision, is meticulously proposed to tackle the multifaceted safety challenges associated with forklift operations. The suggested framework provides a range of solutions: (1) Authorization through Face Recognition: Leveraging a camera installed within the forklift, the system ensures that only authorized personnel can operate the machinery. By utilizing advanced face recognition algorithms, it verifies the identity of the operator in real-time, preventing unauthorized access. (2). Anomaly Detection for Driver Behavior: Beyond just authorization, the system is equipped to monitor the behavior of the operator. Through anomaly detection algorithms, it can identify signs of Drowsiness. Detecting signs such as frequent yawning, heavy eyelids, or nodding off, which can be particularly dangerous when operating heavy machinery, Distraction or Physical Discomfort, or other abnormal behaviors, prompting immediate intervention. (3). Enhanced Visibility with Stereo Cameras: Addressing the perennial issue of sight blocks, stereo cameras are installed to provide drivers with a hidden view. This feature not only enhances visibility but also offers real-time data on the distance between the forklift tip and nearby objects, aiding in precise navigation. (4). Blind Spot Solutions: Blind spots, a significant hazard in forklift operations, are mitigated through strategically placed signalers or mirrors. Computer vision techniques continuously monitor these areas, ensuring that they remain clear and alerting the driver to potential obstructions. (5). Load Placement Monitoring: The proper placement of loads on the forklift's tipover is crucial for stability. Using cameras and computer vision techniques, the system assesses the positioning of loads, ensuring they are securely and correctly placed.

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2. CURRENT MONITORING TECHNIQUES FOR SAFE FORK OPERATIONS

Forklifts encounter several safety challenges, particularly in dynamic construction environments where loading and unloading activities are prevalent. While forklifts find extensive utilization in construction, the risk of accidents in such contexts is significantly elevated compared to other operational settings. Presently, a range of monitoring techniques are employed to mitigate these safety concerns. While there isn't a specific study focused on checking the authorized forklift operators for driving, numerous authors have explored the issue of abnormal driver behavior. Much attention has been devoted to the development of methods for detecting anomalies in this context (Amin et al., 2023; Okan & Rigoll, n.d.). Blind spot problem has been addressed by different researcher, (Shete et al., 2021) The implementation of an ultrasonic sensor to detect nearby obstacles in a forklift is an effective safety measure. However, to address blind spots and obstacles approaching from corners, the integration of convex lenses at these specific locations becomes imperative. These convex lenses serve as additional visual aids, enhancing the forklift operator's field of vision and ensuring a more comprehensive obstacle detection system Moreover, established standards dictate that forklift operation is restricted solely to authorized personnel, representing a fundamental safety measure in this context. This paper investigates factors influencing forklift operator safety and efficiency, including energy usage, training, IoT integration, ergonomic considerations, and worker drowsiness (Mediavilla, 2023). Emphasizing the significance of the matter, previous research did not encompass critical aspects of forklift operations utilizing computer vision technology, such as driver authorization, detecting abnormal behavior, mitigating blind spots, and optimizing load placement. Nevertheless, OSHA has played a vital role in addressing these factors, recognizing that neglecting them can result in severe accidents. These considerations are pivotal in the context of safety rules analysis, a topic to be elaborated on in the following section.

3. SAFETY RULES ANALYSIS

OSHA has established several crucial safety standards for industrial truck operations to mitigate risks and ensure workplace safety (OSHA, 2023b). These standards include prohibiting unauthorized individuals from riding on industrial trucks (1910.178(m)(3) & 1910.178(l)(3)). This measure prevents potential accidents such as falls, entanglements, or collisions that could result from non-operators being on board. Additionally, operators are required to avoid driving industrial trucks toward individuals positioned in front of fixed objects (1910.178(m)(1)). This rule emphasizes the importance of operator awareness and vigilance to prevent collisions that could lead to severe injuries or fatalities. Operators are also expected to maintain a forward-facing orientation while operating industrial trucks (29 CFR 1910.178(n)(4) & 29 CFR 1910.178(n)(6)). This enhances visibility, reducing the risk of accidents, especially in areas with pedestrian traffic or confined spaces. Furthermore, proper load handling is emphasized through the standards that require loads to be secure and correctly positioned (29 CFR 1910.178(o)(1) & 29 CFR 1910.178(o)(2)). Ensuring load stability is vital in preventing accidents such as tip-overs, which can result in injuries, equipment damage, and hazardous material spills. Lastly, while not explicitly stated in the provided standards, it is crucial for drivers to remain attentive (Abnormal Behavior - General Rule). This means avoiding behaviors that could distract them or impair their ability to operate the vehicle safely, as such actions can lead to accidents and must be strictly prohibited. Table 1 outlines OSHA regulations, providing their associated particulars along with proposed solutions.

Table 1 Safety Rules for Forklift

Sr. No	OSHA Standards	Description	Case Scenario	Proposed Solutions
1	1910.178(m)(3) & 1910.178(l)(3)	No unauthorized operator riding on trucks	Unauthorized Person	Face Recognition
2	1910.178(m)(1)	Never drive trucks toward anyone in front of fixed objects	Struck by	Depth Estimation/Object Detection
3	29 CFR 1910.178(n)(4) 29 CFR 1910.178(n)(6)	The driver must face forward path	Blind Spot/Blocked Vision	Signaler/Barriers/Mirrors
4	29 CFR 1910.178(o)(1) 29 CFR 1910.178(o)(2)	Secure and properly positioned loads	Tip over	Measure distance of load placement on fork tip
5	General rule	Driver must be attentive	Abnormal Behavior	Anomaly Detection

4. PROPOSE FRAMEWORK

This paper introduces a safety-oriented computer vision framework comprising five distinct modules: Signaler Detection, Face Recognition, Anomaly Detection, Signaler Detection, Load Monitoring, and Visibility Enhancement. These modules are seamlessly integrated into a central server, responsible for processing and storing information in a database. Additionally, the system is designed to trigger alarms whenever an unsafe event is detected. The setup employs three cameras: Models 1 and 2 are affixed to internal cameras to monitor operators and identify abnormal behaviors, meanwhile Model 3 utilizes a depth camera mounted on the tip of a forklift to improve visibility and Models 4 and 5 are connected to the Signaler Detection and Load Placement Monitoring components, respectively as depicted in Figure 1.

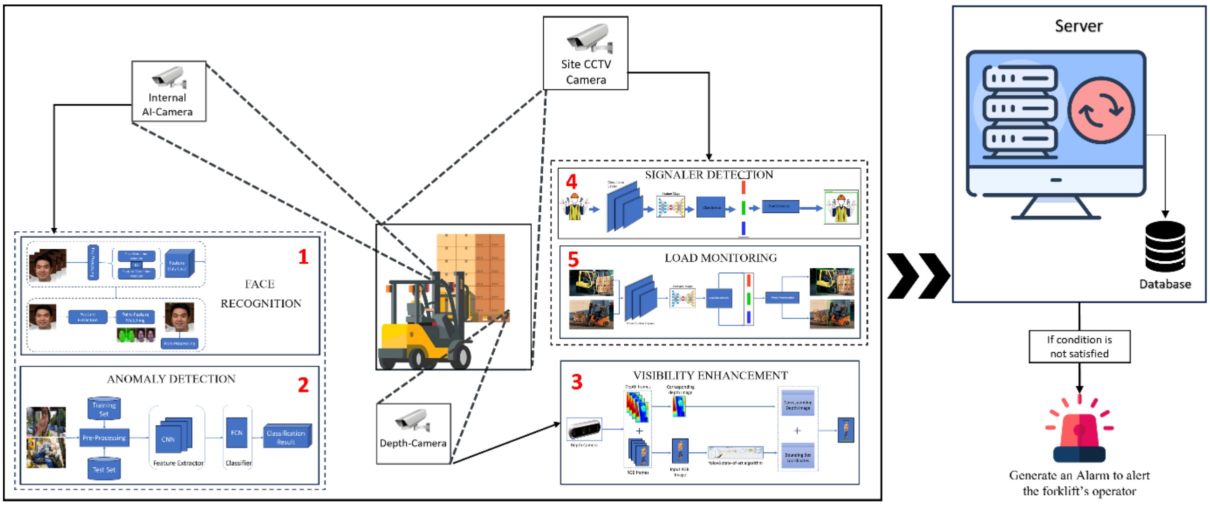

Figure 1: Forklift Operations Framework

4.1 Authorization through face recognition

The proposed framework for authorization employs an advanced facial recognition methodology for identity verification and access control, utilizing cutting-edge algorithms and computational methodologies to scrutinize facial features meticulously as shown in Figure . This comprehensive process initiates with capturing a facial image, subsequently contrasting the unique characteristics of this image against a meticulously curated database of stored facial templates. The seamless integration of state-of-the-art deep learning models, specifically Convolutional Neural Networks (CNNs) (Li et al., 2022), ensures the proficient extraction and meticulous analysis of detailed facial features, granting a high degree of accuracy and security in identity verification. This method emerges as crucial in numerous secure environments, providing swift and efficient determination of access eligibility predicated on the consequential recognition results. The scientific orchestration of our face recognition for authorization unifies the two stages first a facial feature database its elements are pre-processing (Bradski, 2000) to specify faces and feature extraction, attributing a unique ID to each face and storing these features for the second step. The second step involve inferencing for face detection for specific ID in a scenario its components are a deep learning-based feature extractor, a point based matching model (Lindenberger et al., 2023) and a detector for facial feature, while these are for detection part the post processing is crucial step which give authorization.

This amalgamation of techniques ensures the refinement of the recognition results. The subsequent post-processing step manages the comparison results, facilitating the final step of authorization, thereby enhancing the reliability and robustness of the system. In essence, our approach (Figure 2) in blending these advanced technologies and methodologies culminates in the development of a secure, reliable, and efficient system, pivotal in reinforcing security measures and averting unauthorized access. Through the utilization of precise feature comparison and advanced post-processing techniques, our objective is to offer a sophisticated solution that effectively addresses the diverse challenges associated with secure authorization.

4.2 Anomaly detection for driver behavior

In line with the objective of promoting safety and efficiency, the structured framework includes specialized anomaly detection algorithms. These algorithms are tailored to identify signs related to drowsiness, including driver fatigue, physical discomfort, and unusual behaviors requiring immediate attention. This is particularly crucial in scenarios involving heavy machinery operation within the construction industry, where such anomalies can escalate into significant safety risks and losses. The implemented algorithms meticulously observe and analyze various behavioral cues, such as the frequency of yawning, heavy eyelid drooping, moments of nodding off, or any behavior that deviates from the established norm. These cues indicate a potential decline in alertness or an increase in discomfort, both of which can adversely impact machinery operation. The proposed framework aims to identify drowsiness in forklift drivers by analyzing their facial expressions, as depicted in Figure . This system operates in real-time by collecting a dataset of images and labeling them for training purposes. The initial step involves enhancing the image quality and extracting relevant features through image pre-processing. For this purpose, a feature extractor based on the work of (Amir, Gandelsman et al., 2021) is employed. This feature extractor specializes in extracting detailed features from the facial images of drivers.

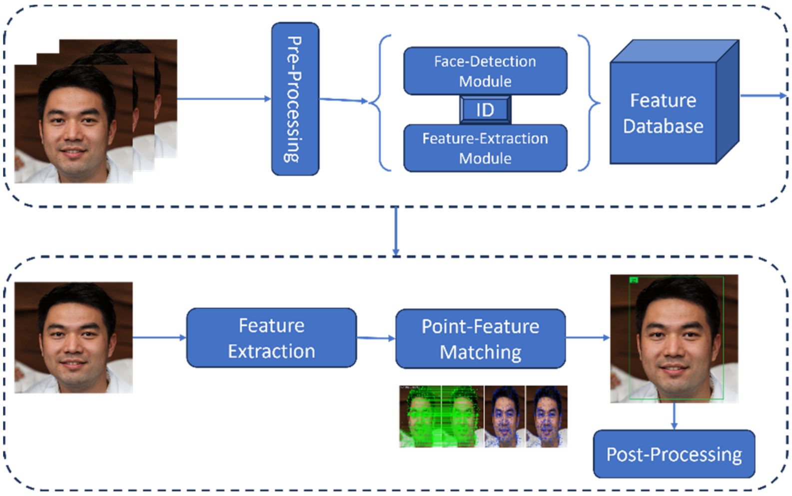

Figure 2: Face-Detection Framework for Authorization

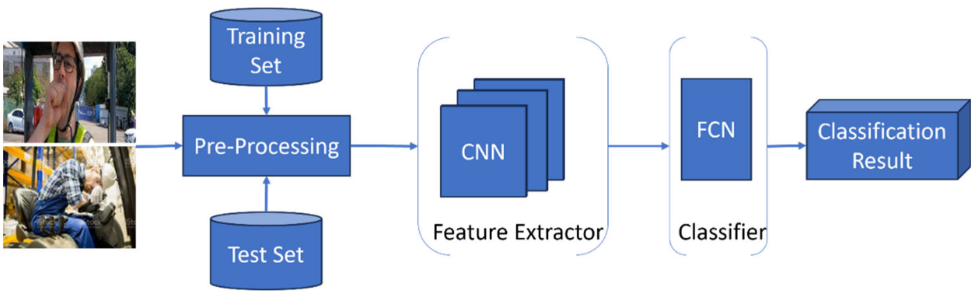

Figure 3: Framework for Forklift drowsiness detection

Once the features are extracted, a state-of-the-art deep learning model is utilized for classification. Specifically, a fully connected network, as described by (Schwing and Urtasun, 2015), is attached to the feature extractor. This network is trained to classify various images based on the driver's condition, distinguishing between normal and drowsy states. By utilizing deep learning, the system can learn intricate patterns and accurately categorize the driver's condition in real-time. After the classification step, a post-processing stage is implemented to activate an alert system based on the identified states. In practical terms, if the system detects drowsiness in the driver, it can promptly issue an alert or trigger a warning mechanism. This rapid response is crucial for preventing potential safety hazards, as it enables corrective actions or interventions to be initiated before accidents or injuries occur.

The application of advanced computational techniques and deep learning models enables the system to achieve a high level of precision in detecting driver states. It can effectively differentiate between normal and unusual behaviors, thereby ensuring the safety and well-being of individuals involved in forklift operations within construction sites. By promptly recognizing and addressing drowsiness, the system contributes to maintaining an overall safe working environment in construction settings.

4.3 Enhanced visibility with stereo cameras

In the scenario depicted in Figure , a challenge arises when the forklift is loaded, blocking the operator's direct line of sight to the area directly in front of the forklift. To tackle this issue, a stereo camera system will be installed at the front of the forklift's fork tip. This setup not only offers an unobstructed view of the concealed area but also employs computer vision-based object detection algorithms, such as yolov8 (ultralytistic, n.d.), to identify objects and determine their distance from the forklift. This comprehensive approach enhances safety by addressing vision obstruction concerns when the forklift is carrying a load.

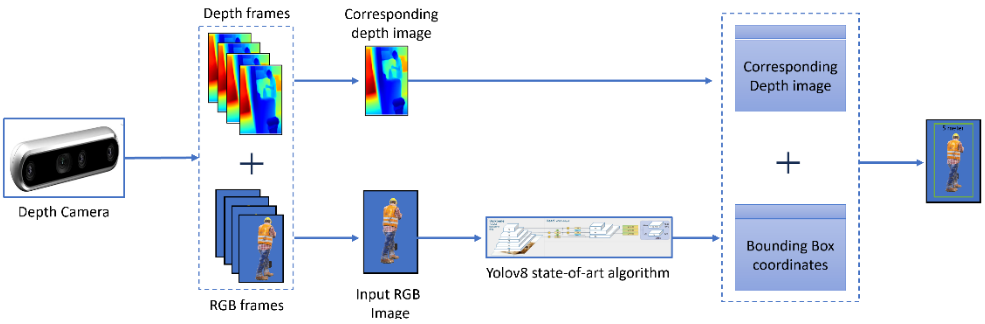

Figure 4: Visibility Framework with stereo camera

4.4 Blind spot solutions

Blind spots that arise when objects approach a forklift from a corner, as illustrated in Figure necessitate specific safety measures. In compliance with [29 CFR 1910.178(n)(4)] and [29 CFR 1910.178(n)(6)] mentioned in (OSHA, 2023b), it is essential to install signalers and convex lens mirrors at every corner within the work area where forklift operations take place. These signalers can be monitored through object detection technology. If a signaler is absent or not in its designated location, an alert message is generated, indicating unsafe conditions.

To ensure comprehensive coverage of the construction site where forklifts operate, multiple cameras need to be strategically installed. These cameras are connected to a server via RTPS (Real-Time Publish-Subscribe) protocol, and an object detection model is deployed on the server to enhance safety and monitor blind spots effectively.

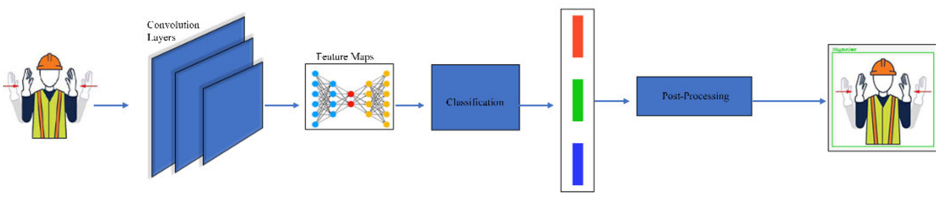

Figure 5: Signaler Detection

4.5 Load placement monitoring

Properly centering the load on a forklift is essential for safety, as highlighted in OSHA's 29 CFR 1910.178(o)(1) and 1910.178(o)(2) regulations. Incorrect load positioning increases the risk of tipping over, potentially causing operator injuries, equipment damage, and harm to nearby structures. Maintaining load stability and preventing tip-over accidents are critical.

Extensive research on forklift safety underscores the significance of load centering. Misalignment of loads elevates the risk of tip-overs, diminishes stability and maneuverability, and can lead to structural damage and injuries.

Adhering to OSHA regulations is imperative. Gavanski's 2022 study identifies safety concerns with forklifts, serving as a valuable reference for safety enhancements (Gavanski, 2022). Furthermore, Xia et al. (2023) introduced a center of gravity estimation algorithm for counterbalanced forklifts, achieving precise position control (Xia et al., 2023).

In this study, we introduce a computer vision-based framework (Figure 6) to oversee forklift operations during material loading and unloading. Utilizing advanced computational techniques and deep learning models, this system accurately identifies objects and reliably estimates the distance between the load's central point and the forklift's front wheel. The proposed framework plays a crucial role in enhancing safety at construction sites, benefiting both forklift operators and the machinery itself. Its primary function is to promptly detect and correct any load positioning issues relative to the forklift's mast, contributing significantly to a safe construction site environment.

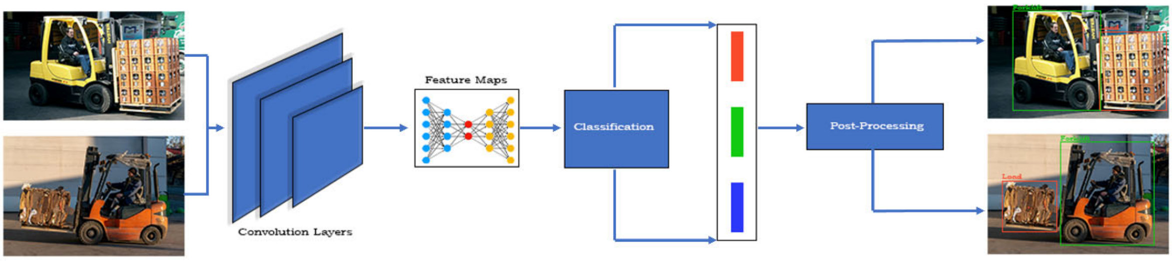

Figure 6: Forklift and Load Detection

5. DISCUSSION & CONCLUSION

The "iSafe ForkLift" framework represents a comprehensive solution aimed at enhancing safety in construction site forklift operations through the integration of advanced computer vision technology. This integrated system encompasses sophisticated features such as facial recognition for driver authentication, anomaly detection to mitigate operator drowsiness, stereo cameras to augment visibility, blind spot solutions, and load placement monitoring to preempt tip-over incidents. This framework stands out due to its holistic approach, a departure from conventional solutions that primarily address safety concerns individually. By systematically addressing multiple safety risks within a singular, efficient framework, it significantly enhances overall safety. However, there are certain limitations that necessitate careful consideration and foster discussions on technology, costs, safety, and compliance, with iSafe ForkLift improving forklift operations and worker well-being. The effectiveness of the framework is contingent upon the dependability of its technology, which may be vulnerable to adverse environmental conditions. Challenges may arise in accurately distinguishing between workers and signalers through computer vision. Acceptance among operators, coupled with concerns regarding data security and privacy management. Pertinent factors such as initial investment costs, ongoing maintenance, and operator training may pose challenges. Furthermore, the framework beckons opportunities for refinement, particularly concerning the reduction of false positives in anomaly detection and scalability. Following OSHA's safety protocols significantly boosts workplace safety. The integration of computer vision and IoT technologies enhances operational precision, while vigilance on uneven or challenging surfaces ensures stability and safety, thereby augmenting overall safety in the dynamic construction industry. In future work, we will delve deeper into these regulations by introducing dedicated computer vision solutions to enhance forklift safety across various industries.

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