Real-Time Safety Analysis at Worksites

Zarmeen Tauseef
Department of AI
FAST NUCES
Islamabad, Pakistan
i210312@nu.edu.pk

Isaam Ansari
Department of AI
FAST NUCES
Islamabad, Pakistan
i210299@nu.edu.pk

***Abstract*—This project focuses on implementing a real-time safety monitoring system using fine-tuned and pretrained YOLO models for object detection. The system leverages dual-model inference to identify safety-critical objects such as safety helmets, reflective jackets, and cell phones, as well as detect human presence in live video streams. A safety scoring mechanism is introduced to assess the compliance of detected persons with safety protocols, integrating factors such as helmet usage and visibility of reflective jackets. The system provides a visual representation of safety scores and scene safety status through bounding boxes and labels with color-coded indicators. The project demonstrates the practical application of computer vision in enhancing workplace safety and monitoring environments in real-time.**

***Index Terms*—Object Detection, YOLO Models, Real-Time Safety Assessment, Dual-Model Inference, Computer Vision, Personal Protective Equipment (PPE), Video Stream Analysis, AI-Driven Safety Solutions, Image Processing**

INTRODUCTION

Workplace safety is vital in industries where non-compliance with Personal Protective Equipment (PPE) standards can lead to accidents and injuries. Traditional safety monitoring methods are often inefficient and lack real-time capabilities. This project addresses these limitations by developing an AI-driven system that uses computer vision to ensure PPE compliance. Leveraging advanced object detection models like YOLO, the system identifies workers and assesses their adherence to safety standards in real-time. By providing instant compliance scores, this solution enhances workplace safety, reduces accident risks, and streamlines monitoring processes, demonstrating the transformative potential of AI in occupational safety.

PROPOSED WORK

The primary objective of this project is to develop an AI-based system that performs real-time safety analysis at worksites, with a focus on ensuring compliance with essential safety protocols. The proposed system will continuously monitor workers and evaluate their adherence to safety standards by detecting the use of Personal Protective Equipment (PPE) such as hard hats, reflective jackets, and the improper usage of mobile phones.

To achieve this, we will implement a computer vision solution using object detection models, specifically the YOLO (You Only Look Once) algorithm, to detect the relevant safety items in real time. The system will assign a safety rating to each worker based on their compliance with these protocols. This rating will be continuously updated throughout the day, providing a dynamic overview of both individual and group safety performance.

The system's real-time feedback will enable site managers to quickly identify and address safety violations, improving overall workplace safety and reducing the risk of accidents. Additionally, the solution will be designed to integrate easily into existing workplace environments without the need for significant infrastructure changes. By automating the safety analysis process, the system will offer an efficient and scalable approach to safety monitoring at worksites.

CONTRIBUTIONS

Our system aims to enhance the accuracy and functionality of safety analysis systems, providing more precise insights into worker safety at construction sites. The primary contributions of this project are as follows:

Real-time Safety Analysis with YOLO

While existing research has explored the use of YOLO for detecting helmets and safety jackets at worksites, these systems lacked the precision needed to determine whether these safety items were being properly worn by individuals. Unlike previous approaches, this project enhances detection by verifying that the helmet and safety jacket are not just present in the scene but are indeed worn by workers, ensuring more accurate assessments of safety compliance.

Detection of Mobile Phone Usage

A unique aspect of this project is the integration of mobile phone detection, specifically monitoring for improper use of mobile phones at construction sites. This addition helps address a critical safety concern that has not been incorporated in previous systems, thereby providing a more comprehensive evaluation of on-site safety behavior.

Safety Scoring System

Unlike existing solutions that only detect safety equipment, this project introduces a safety score system. The system assigns a safety score to each individual and the entire worksite based on real-time detection of helmet, jacket usage, and mobile phone behavior. This rating system provides site managers with a clear, actionable overview of safety compliance, which has not been implemented in prior work.

Methodology

The methodology for this project follows a dual approach using YOLOv11 models to detect safety helmets, reflective jackets, persons, and mobile phones at construction sites. The overall pipeline consists of the following key steps:

Dataset Preparation and Fine-tuning YOLOv11 on Safety Helmets and Reflective Jackets

An annotated dataset *Safety Helmet and Reflective Jacket* of 10,500 images from Kaggle was used for detecting safety helmets and reflective jackets. The dataset was split into training, validation, and test sets in a 70:15:15 ratio. The annotated data was prepared with a data.yaml file to fine-tune YOLOv11. The model was specifically fine-tuned to identify helmets and jackets in various environments and lighting conditions, ensuring robust detection capabilities.

Dual YOLO Approach for Object Detection

- The **fine-tuned YOLOv11** model detects safety helmets and reflective jackets. This model identifies the presence of these objects in the scene.
- A **pretrained YOLOv11** model is used to detect persons and mobile phones. This model is leveraged for general object detection tasks, ensuring robust recognition of workers and mobile phone usage in real-time.

Safety Scoring System

A safety score is calculated for each person based on their compliance with safety protocols:

- Initial score: 0
- If a person is wearing a safety helmet, +50 points are added.
- If a person is wearing a reflective jacket, +50 points are added.
- If a person is using a mobile phone, -30 points are subtracted.

These individual scores are then averaged to generate an overall safety score for the entire scene, reflecting the overall safety compliance on-site.

Bounding Box Alignment and Validation Metrics

To ensure accurate safety scoring, the system performs several checks on the positions of the detected objects. This is done through custom code written using mathematical and computer vision techniques:

- The helmet is only considered valid if it overlaps with the top 70% of the person's bounding box, ensuring it is worn on the head.
- Similarly, the jacket is considered valid only if it overlaps with the appropriate portion of the body (upper body area).
- Additionally, the detection confidence for each person must exceed a threshold of 0.3 to be included in the safety scoring system. This ensures that only reliable detections are considered.

Real-Time Application

The developed system was integrated into a real-time environment where a webcam continuously captures video feed. The YOLO models process the incoming frames, detect the presence of helmets, jackets, persons, and mobile phones, and assign safety scores accordingly. These results are displayed in real-time, providing an up-to-date safety assessment for both individual workers and the overall scene.

This approach ensures that safety compliance is evaluated accurately and in real-time, allowing construction site managers to take immediate action if safety protocols are not being followed.

Flow Diagrams

The diagram illustrates the workflow of the real-time safety analysis system. It starts with capturing a live camera feed, which is processed by YOLO models to detect safety helmets, reflective jackets, people, and mobile phones. Based on this, it calculates a safety score for each person and an overall scene rating to assess compliance with safety protocols.

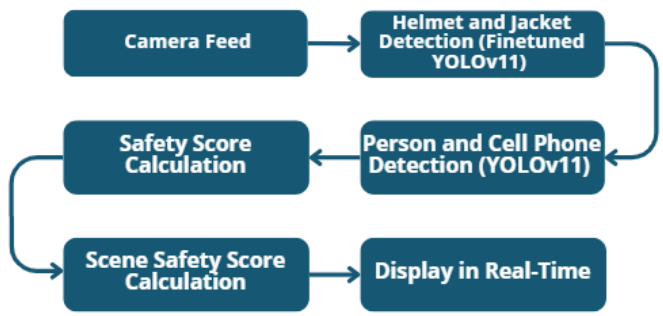

Fig. 1. System Overview

The diagram illustrates the detailed workflow of the real-time safety analysis system. It starts with detecting the 4 objects. The system then checks if the detected objects align correctly with individuals and there is enough confidence. Then it calculates a safety score for each person and an overall scene safety score and displays that in real time with colour coded text and border to show priority. Red indicates high priority or critical, green indicates safe, and yellow indicates moderate priority or warning.

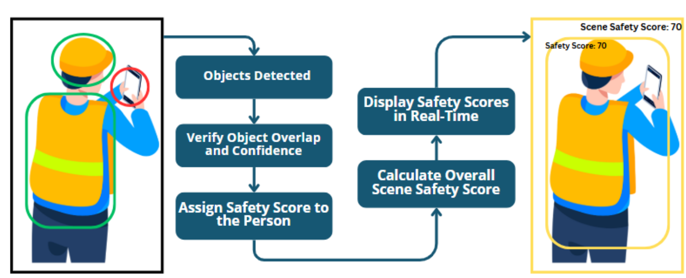

Fig. 2. Detailed Workflow

IMPLEMENTATION

Model Selection

For this project, we selected the **YOLOv11** model for object detection due to its state-of-the-art performance in real-time applications. YOLO (You Only Look Once) is known for its speed and accuracy in detecting objects, which is essential for real-time safety analysis at worksites. YOLOv11 is the latest and fastest version of the YOLO family, offering improved performance and efficiency over previous versions.

To achieve the desired accuracy, we employed a dual approach:

- **Finetuned YOLOv11** for detecting safety helmets and reflective jackets.
- **Pretrained YOLOv11** for detecting persons and cell phones.

This combination allowed for effective detection of both safety gear and mobile phone usage, which are crucial for evaluating safety at construction sites.

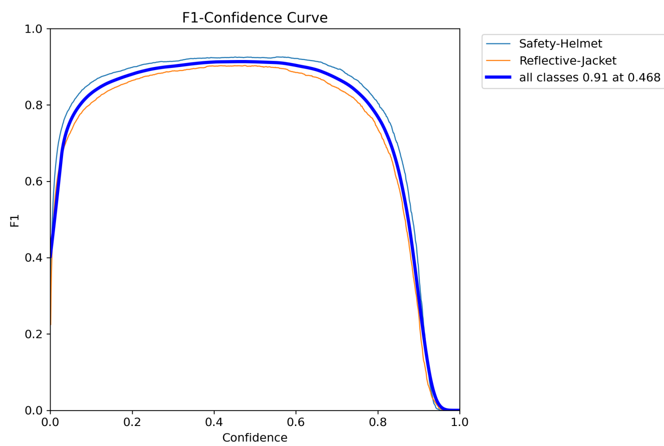

Fig. 3. F1-Confidence Curve of Finetuned YOLOv11

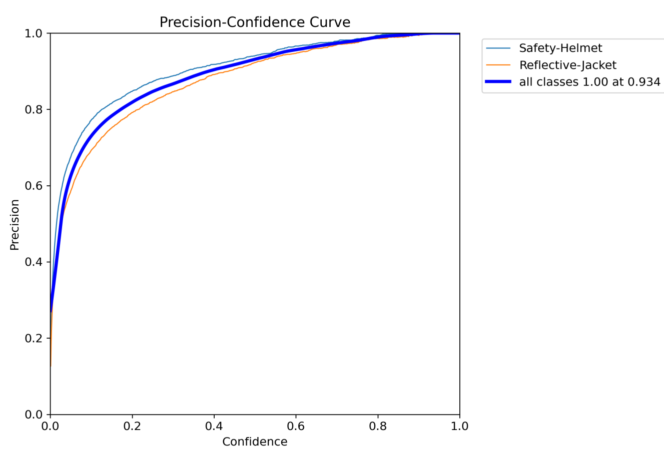

Fig. 4. Precision-Confidence Curve of Finetuned YOLOv11

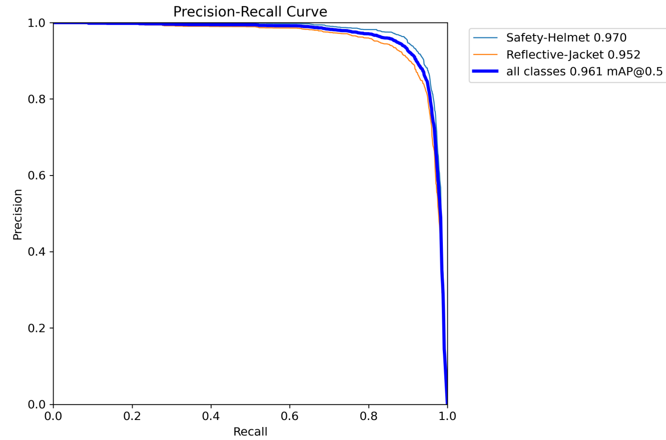

Fig. 5. Precision-Recall Curve of Finetuned YOLOv11

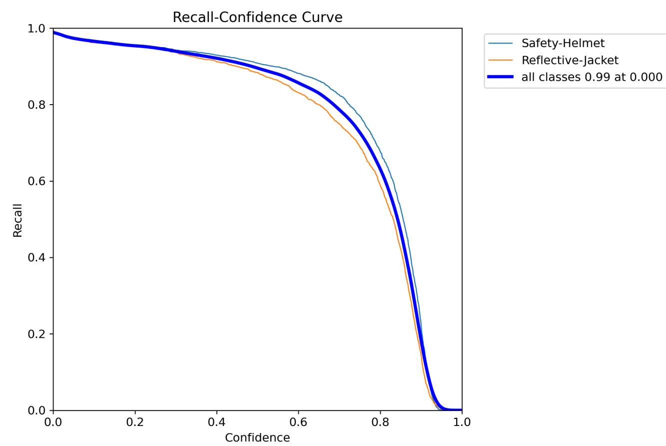

Fig. 6. Recall-Confidence Curve of Finetuned YOLOv11

Analysis

The AI-powered safety analysis system was evaluated in real-time worksite conditions, focusing on the system's accuracy, reliability, and practical effectiveness. The system's ability to detect safety helmets, reflective jackets, and mobile phone usage was central to its performance. We used a dual YOLO approach, where the fine-tuned YOLOv11 model detected helmets and jackets, while a pre-trained YOLOv11 model identified persons and mobile phones.

Detection Accuracy: The detection accuracy was significantly impacted by several factors, including the lighting conditions, image resolution, and the clarity of the objects within the scene. The fine-tuned YOLOv11 model performed well in detecting helmets and jackets, with most detections being correct, although challenges arose in cases of partial occlusion or poor lighting. However, the model was less effective in situations where the helmets or jackets were obscured or out of view.

The detection of mobile phones was also fairly accurate, but misdetections occurred when the phone was held in uncon-

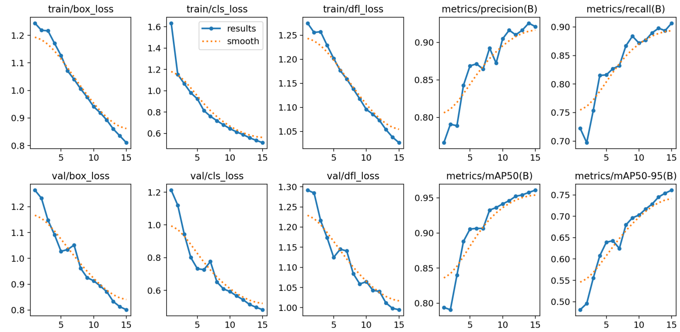

Fig. 7. Results of Finetuned YOLOv11

Fig. 8. Validation Predictions of Batch 2 of Finetuned YOLOv11

ventional positions or obscured by other objects. These edge cases were minimized by adjusting the confidence threshold and refining the bounding box overlap criteria.

Safety Score Calculation: The safety score calculation, based on the presence of safety gear and mobile phone usage, was a key feature of the system. Each person's safety score was computed by considering the detected objects' positions relative to the individual's bounding box. The score assignment mechanism +50 for helmets, +50 for jackets, and -30 for mobile phones—provided a simple yet effective way to quantify safety compliance.

The overall scene safety score was derived by averaging individual safety scores, which allowed for a quick assessment of the site's safety performance. In tests, this approach accurately reflected the overall safety compliance of the site and gave a clear understanding of areas that required attention. The color-coded display of the safety scores in real time (red, yellow, and green) further enhanced the system's usability, enabling site managers to quickly interpret safety conditions.

Performance Evaluation: In terms of real-time performance, the system was able to process video frames at an acceptable speed (approximately 20-30 frames per second on standard laptop hardware). This ensured that the system could provide immediate feedback without significant delays, which is crucial for maintaining safety in dynamic construction environments.

Hyperparameters

For finetuning the YOLOv11 model, we used the following hyperparameters:

- Learning Rate: 0.001 (Optimized for fast convergence without overfitting).
- Batch Size: 16 (A balance between computation efficiency and memory usage).
- Epochs: 15 (To allow sufficient training without overfitting).

To check alignment and detection of objects, we used the following hyperparameters:

- Confidence of Person: 0.3
- Overlap of Safety Helmet with Person: Helmet needs to be at the top 70% of the person's bounding box.
- Overlap of Reflective Jacket with Person: Jacket needs to be at the top 80% of the person's bounding box.
- Overlap of Cell Phone with Person: Needs to exist.

Results

The model was evaluated qualitatively. Visual inspection of the results showed that the system was able to correctly identify safety violations, such as the absence of safety gear or the improper use of mobile phones.

Fig. 9. A Safe Scenario

Fig. 10. An Unsafe Scenario

Strengths

The proposed AI-driven safety analysis system for construction worksites exhibits several key strengths:

Real-time Safety Monitoring

One of the primary strengths of this system is its ability to provide real-time safety monitoring. The model detects critical safety elements such as helmets, reflective jackets, and mobile phone usage, enabling immediate feedback on compliance with safety protocols. This feature ensures that safety violations are identified and addressed promptly, potentially reducing the risk of accidents.

Comprehensive Safety Score System

Unlike previous systems that only detect the presence of safety equipment, our system assigns a safety score to each individual based on their adherence to safety guidelines. This score is derived from a combination of factors, including helmet and jacket detection and mobile phone usage. This quantitative approach provides site managers with an actionable and clear overview of the safety performance of workers, both individually and at the group level.

Accurate Object Detection

The use of YOLOv11, a state-of-the-art object detection model, ensures high accuracy and efficiency in detecting helmets, jackets, persons, and mobile phones. YOLOv11's ability to detect multiple objects in real time, with minimal latency, makes it ideal for safety applications in fast-paced environments such as construction sites.

Customizable Safety Protocols

The system allows for easy customization of safety protocols. The safety score calculation can be adjusted by modifying thresholds for helmet, jacket, and mobile phone detection. This flexibility allows the system to be tailored to specific worksites or safety guidelines, making it adaptable to different industries and regions.

Scalable for Large Sites

The system can be easily scaled to cover large construction sites with multiple workers. The ability to detect and evaluate the safety of several individuals simultaneously, along with its real-time feedback system, makes it a scalable solution for large worksites with complex operations.

User-Friendly Interface

The system's real-time feedback, presented through color-coded safety ratings and visual cues, offers an intuitive interface for construction site managers and workers. The simplicity of the interface ensures that it can be easily used without requiring extensive training, enhancing its practical applicability.

These strengths contribute to the system's potential for improving safety standards, ensuring compliance with safety protocols, and ultimately reducing accidents on construction sites.

Limitations

While the proposed AI-driven safety analysis system offers significant advantages, it also has several limitations that need to be considered:

Dependence on Object Detection Accuracy

The system relies heavily on the accuracy of object detection models (YOLOv11 in this case). If the model fails to correctly detect helmets, jackets, or mobile phones due to poor image quality, obstructions, or incorrect poses, the safety rating may be inaccurate. This limitation may lead to false negatives or false positives, impacting the reliability of the system in certain conditions.

Environmental Factors Affecting Detection

Factors such as lighting conditions, camera angle, or occlusion can affect the accuracy of object detection. In low-light environments or when objects are partially obstructed, the model may not detect safety equipment, leading to erroneous safety scores. Environmental variations across different worksites may affect the system's consistency in performance.

Limited to Visual Detection

The system is based solely on visual detection and does not take into account other important safety factors that are difficult to capture through a camera, such as physical hazards or the behavior of workers. The detection of safety gear does not necessarily guarantee that workers are following all safety procedures, making it a partial measure of overall safety compliance.

Limited Contextual Understanding

The system lacks the ability to understand the context in which safety equipment is worn. For example, a worker may have temporarily removed their helmet for a brief period while in a safe zone, which may be incorrectly flagged as a violation. The system does not account for context-specific variations or worker behavior, which may result in non-compliance being reported inaccurately.

Despite these limitations, the system provides a valuable tool for improving safety on construction sites and can be further enhanced to address these challenges in future versions.

Conclusion

In this project, we developed an AI-driven real-time safety analysis system for construction worksites, leveraging object detection models, specifically YOLOv11, to monitor the use of safety helmets, reflective jackets, and mobile phones. The system assigns a safety score to individuals and the overall scene, providing real-time feedback that can assist site managers in maintaining safety standards.

The proposed solution demonstrates promising results in improving on-site safety by offering an automated, efficient means of monitoring compliance with basic safety protocols. While the system is effective in detecting the presence of safety gear and mobile phone usage, its limitations, such as dependency on environmental factors and the accuracy of the detection models, suggest areas for future improvement.

In conclusion, this AI-powered safety analysis system serves as a useful tool for construction sites, providing both real-time and automated insights into safety compliance. Future developments can enhance its robustness by addressing the current limitations and expanding the scope of safety factors monitored. With further advancements, the system has the potential to play a crucial role in reducing accidents and improving safety awareness on worksites.

References

[1] Nirav Naik, "Safety Helmet and Reflective Jacket Dataset," Kaggle, 2023. Available at: https://www.kaggle.com/datasets/niravnaik/safety-helmet-and-reflective-jacket/data.