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System And Method For Virtual Boundary Detection And Warning Of Safety Zone Violations In Construction And Industrial Environments

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Abstract: Workplace safety, particularly in construction and industrial places, is a critical concern due to the high risks faced by the workers in the hazardous zones. To address these challenges, our study introduces a computer vision based system for virtual border identification and safety monitoring. Using real-time object detection algorithm YOLOv5, the system tracks human movements and monitors proximity to danger zones by overlaying virtual boundaries on live video streams. It instantly detects safety violations, triggering visual and audible alarms while notifying supervisors, and significantly reducing the chance of any accidents.

***Index Terms* -** Virtual Safety Zones, Computer Vision, YOLOv5, Real-Time Monitoring.

I. INTRODUCTION

It is a fact that safety in construction sites or factories is a huge deal. People are surrounded by heavy machinery and dangerous areas throughout the day, which increases the chances of accidents. Although there is safety and rules, things still slip through the cracks [1][2]. Accidents happen, and it's not just about the injuries—it's all the disruptions and the costs that pile up for the company too.

The problem with the outdated safety methods—like having someone manually watching everything or relying on just warning signs—is they don't really work well anymore [3][4]. They can't adapt to all the different situations that come up, and they also can't cover huge workspaces.

The primary objective of this project is to develop a system that uses computer vision to monitor everything in real time. It works by looking at live video feeds from cameras and using YOLOv5 to track where workers are and how close they are to danger zones [7].

So, when the system sees someone getting too close to one of these boundaries, it sends an alert right away. It can be anything from a loud alarm to a visual warning on the monitor or even a message to the supervisor [9]. The best part is it's customizable—so no matter how the site is laid out, we can set up safety zones to match the area.

II. RELATED WORKS

Recently, there has been much talk about the application of computer vision with AI in the enhancement of safety at workplaces, especially on construction sites and industrial setups. Some studies have focused specifically on real-time monitoring using object detection models such as YOLO and SSD. For example, Kim et al. (2020) worked on a system based on YOLOv4 to track workers in dangerous areas. It worked well, with pretty good accuracy and no delays [3].

Ahmed et al. (2021) took a different approach by combining video analytics with IoT devices to monitor safety. Their system used geofencing to create virtual safety zones that would alert workers if they got too close to a hazard [4]. Zhao et al. (2022) also worked on using computer vision to detect whether workers were wearing the right safety gear, like helmets, to make sure they followed safety regulations [5].

There are still a few challenges, like when the lighting's bad or when the camera is set up in a blind spot, which is more likely to happen on bigger sites [6][7]. Our system handles this by using object detection with adjustable safety zones and fast alerts, so it can still respond quickly, even when things aren't perfect [8][9].

What we're suggesting in this paper is a safety monitoring system that combines the best aspects of existing solutions while tackling some of their limitations. By using YOLOv5 for real-time object detection, our system provides a more flexible and proactive way to monitor safety.

III. PROPOSED METHODOLOGY

Our proposed system ensures safety on job sites using computer vision and real-time video processing. It has four key components:

1. Camera Setup

Multiple cameras are strategically placed to cover high-risk zones and capture video footage under different conditions. The video which is recorded is used as input for processing.

2. YOLOv5 is used for Real-Time Detection

This system uses **YOLOv5**, it is an advanced object detection model, which processes each video frame by frame. YOLOv5 is known for its speed and accuracy, hence it is ideal for real-time monitoring[2].

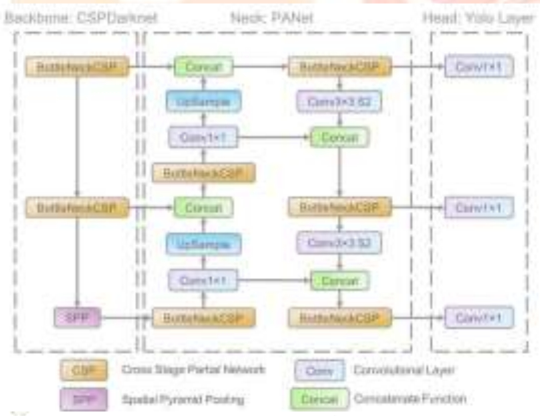


Fig. 1: YOLOV5 Architecture

3. Virtual Safety Zones

The user selects the Region of interest on the video feed to mark the Virtual safety boundaries or to identify restricted areas. ROI can be defined as a binary mask image, where pixels inside the ROI are set to 1 and pixels outside the ROI are set to 0. ROI can be customized by the user to include a specific number of pixel rows and columns.

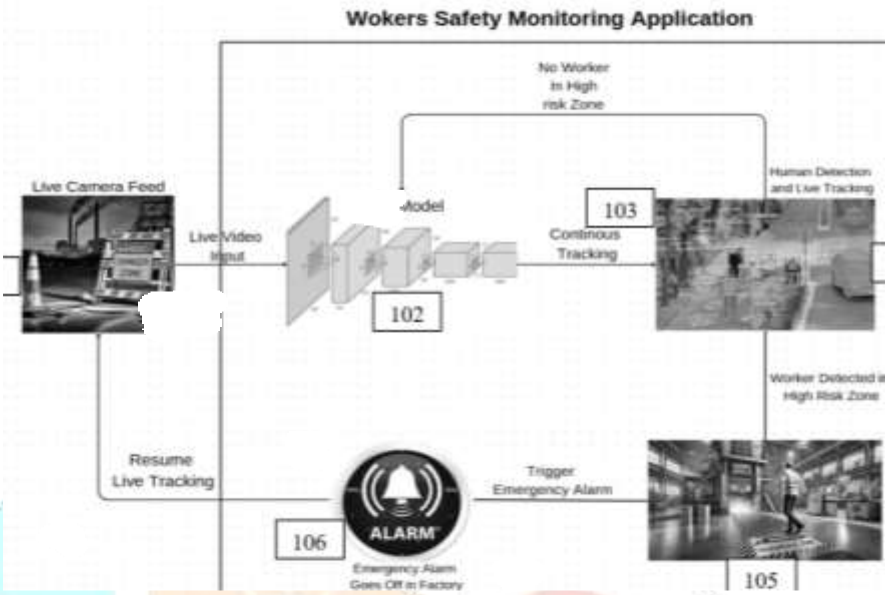
4. Alerting System

Predefined parameters are set to determine when an event is significant enough to trigger an alert. When the trigger condition is met, which is when a worker is in a danger zone, then the system generates an alert , which can be delivered through a message like notification displaying a pop-up on a monitor with relevant video footage.

This approach ensures real-time intervention and maintains a high level of safety on the job site.

IV. OPERATIONAL SYSTEMS

The system operates through the following steps, as shown in **Figure 2**:



.Fig. 2: Project Architecture

1. Setup and Installation:
Setup all the high-resolution cameras at strategic locations across the worksite. The cameras are connected to the system's processing unit, once the setup is done, run the object detection algorithm.

2. Video Capture:
Capture video input from the camera, which is then used for boundary detection.

3. Preprocessing and Object Detection:
YOLOv5 processes the video feed frame by frame. This model identifies humans in the scene ensuring precise tracking of worker movements.

4. Defining the Region of Interest (ROI):
Before monitoring, the system allows the user to define the specific Region of interest. Roi are those areas that need to be monitored. These are customisable and can be adjusted.

5.Virtual Boundary Detection:
Virtual lines are drawn on the video feed to mark hazardous zones. These boundaries can be tailored to different site layouts.

6. Violation Detection:
The system tracks the positions of detected people and checks if any of them cross the hazardous zones defined.

7. Alarm Triggering:
The system will activate an alarm when it detects a boundary violation. It will alert workers and supervisors, and the alarm may include sirens, visual signs or notifications sent to connected devices.

8. Enhancement and refinements:
Updates can include refining the object detection model for higher accuracy, integrating additional sensors, or expanding the system to cover larger or more complex worksites.

9. Continuous Monitoring:
The system ensures ongoing surveillance and reverts to a safe state if no violations are detected.

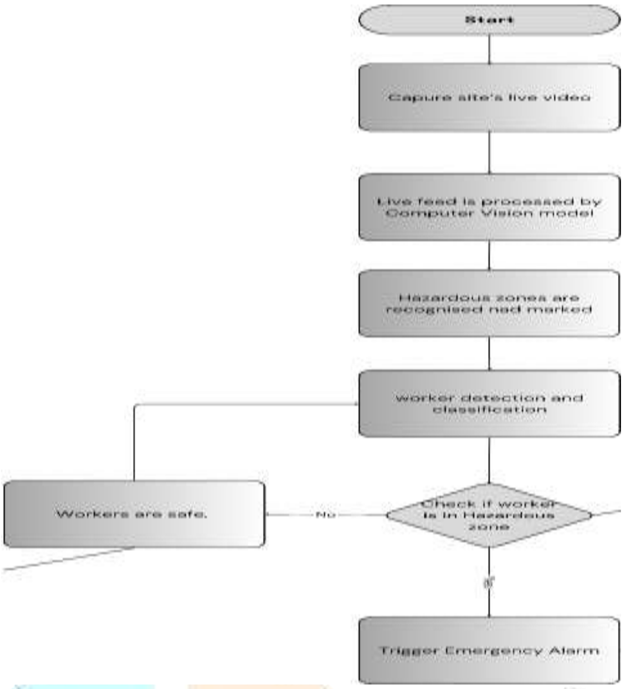


Fig. 3: Work-Flow Diagram

V. RESULTS

Case 1: Human not in Hazardous Zone

Fig. 4: Case 1

Human Outside the Hazardous Zone:
When the workers are outside the hazardous zone(Region of Interest), the system detects them clearly but it doesn't trigger any warning message This reduces false alerts, ensuring workers do their jobs without any interruptions.

Case 2: Human in Hazardous zone

Fig. 5: Case 2

Human Inside the Hazardous Zone :

When a worker accidentally steps into the hazardous zone, the system immediately detects the worker and raises an alarm or a message. This quick response helps in preventing any accidents before they happen. It is designed to work even in places with bad lighting and it works reliably in real time.

The YOLOv5 model is highly accurate at spotting people, even in cluttered or complex environments. The virtual safety zones are easy to understand, with clear visual markers that help supervisors quickly assess the situation.

VI. CONCLUSION AND FUTURE ENHANCEMENTS

5.1 Conclusion

In this paper, we have introduced a system that is designed to make construction and industrial workplaces safer through virtual boundary detection and real-time safety monitoring. By using computer vision and the YOLOv5 algorithm, this system can instantly detect when workers enter hazardous zones, triggering alarms and notifications to prevent accidents before they even happen. This system is modular and has a scalable design, which makes it adaptable to worksites and safety needs. By acknowledging the limitations and working to address them, the system can continue to evolve into a more robust and reliable safety solution.

5.2 Future Enhancements

While this study presents a comprehensive approach to virtual boundary detection and safety monitoring, there are certain limitations like time constraint and limited access to diverse industrial environments that we would like to investigate further. While the current system detects safety zone violations, we still need to refine its accuracy in highly dynamic environments, such as construction sites with frequent layout changes. Exploring multi-sensor fusion, including LiDAR and thermal imaging, could significantly enhance its robustness and address the limitations making the system better [7].

Research efforts should also focus on scalable and cost-effective hardware solutions to ensure accessibility for smaller organizations. Further we would also plan on enhancing the alert system, making it generate audio warnings in multiple languages, which would make it useful for diverse teams working in different workplaces.

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