Chapter 7
Multi-Class Personal Protective Equipment Detection for Construction Safety Using YOLOv11

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ABSTRACT

Construction sites remain hazardous environments where inadequate personal protective equipment (PPE) compliance contributes significantly to injuries and fatalities. This study presents a YOLOv11-based system for automated multi-class PPE detection at construction site entry points. The system detects six categories: safety helmets, vests, shoes, and their non-compliant alternatives. We trained YOLOv11n on 352 annotated images using 7:2:1 split with COCO pretrained weights. The system achieves overall mAP50 of 0.602, with performance variation across

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classes—safety vests reach 0.834 mAP50 while footwear proves most challenging at 0.487 mAP50. The integrated system provides real-time detection at 25-30 FPS, visualization dashboards, and automated alerts. Results demonstrate proof-of-concept viability, with dataset scale identified as the primary constraint. This work contributes to proactive construction safety through continuous, automated PPE compliance verification.

1. INTRODUCTION

Head injuries at industrial sites often occur because workers don't wear safety helmets. Manual supervision is error-prone, inconsistent, and lacks continuous feedback, which hampers timely intervention. To address this, a Smart Safety Helmet Compliance Monitoring System leverages computer vision, IoT, and real-time visualization. The system employs an MQTT client that periodically requests helmet detection data from a remote AI service, which returns results along with labeled images. A Python application processes these responses, tracking helmet-wearing behavior over time, and visualizes compliance trends via dynamic graphs and live camera feeds. Results demonstrate that the system can accurately measure helmet compliance rates, distinguish compliant from non-compliant events, and significantly enhance situational awareness. This modular framework exemplifies how AI and IoT can be integrated into safety management, leading to more effective training tools and safety protocols.

The global construction industry faces a critical paradox: while serving as a primary driver of economic growth and urbanization, it remains one of the most hazardous work environments. The International Labour Organization reports that approximately 2.93 million workers die annually from work-related causes (International Labour Organization, 2024). Although construction employs only 6-10% of the workforce in industrialized nations, it accounts for a disproportionate 25-40% of workrelated fatalities (International Labour Organization, 2023). This disparity underscores the inherent dangers of construction environments characterized by heavy machinery, work at heights, and constant material movement.

In Hong Kong specifically, 1,153 industrial accidents occurred in the construction industry in 2025 (Construction Industry Council, 2024). The four main categories;slips, trips or falls from the same height; struck-by moving objects; injuries from lifting or carrying; and falls from height;consistently represent approximately 65.7% of all construction accidents (Occupational Safety and Health Council, 2022). The economic implications are equally profound, with the ILO estimating that improved safety measures could save the global economy 361 billion annually (International Labour Organization, 2024).

Pedestrian Detection and Tracking

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