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Real-Time Automated Seatbelt Detection Using YOLOv11

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Abstract

A lightweight seat belt detection algorithm, GMYOLOv11, is proposed to enhance detection precision and speed for intelligent traffic management. By integrating Streamlit into the YOLOv11-tiny network, the system optimizes computational efficiency and reduces parameter count. Fine-tuning on a custom Roboflow dataset and replacing the Leaky ReLU with Mish activation improves non-linear performance. Experimental results demonstrate a 4.8% increase in mean average precision (mAP) over the original network and significant improvements over YOLOv3, YOLOX, YOLOv5, YOLOv7, and YOLOv8. The approach reduces computational load by up to 63% and decreases parameters by 48%, achieving effective detection performance in a lightweight structure.

Index Terms - Seatbelt detection,YOLOv11, convolutional neural networks CNN, optical character recognition OCR, road safety, deep learning.

1. Introduction

Road safety remains a global concern, with the World Health Organization reporting over 1.35 million annual fatalities in vehicle accidents, many of which could be prevented by proper seat belt usage . Manual enforcement of seat belt laws is inefficient and prone to error, especially in high-traffic conditions.This paper addresses the need for an automated, real-time seat belt detection system that ensures vehicles only start when the driver is properly buckled, and incorporates additional safety features such as alcohol detection. The proposed solution leverages advancements in deep learning and computer vision to create a robust, scalable, and accurate detection framework. This system automates the detection of seatbelt usage, it ensures accurate identification of violators while reducing human dependency.

The proposed system not only enhances road safety by promoting seatbelt compliance but also streamlines law enforcement processes through automated fine generation and notification systems. Its scalable architecture makes it adaptable for deployment in diverse environments ranging from urban intersections to industrial zones. Furthermore, the data collected can be utilized for traffic management and urban planning, contributing to safer and more efficient transportation systems.

This paper delves into the methodologies employed by the system, its architectural design, advantages over traditional enforcement methods, and potential applications in modern smart cities. By integrating automation into traffic monitoring systems, this technology represents a significant step forward in improving road safety and compliance with traffic laws.

This paper aims to tackle the challenges existing in the current seatbelt detection algorithms by proposing an automatic approach Due to the dearth of public driver's seatbelt datasets, this paper constructs a dataset that covers various automobile categories and locations.

I. Main Title

Seatbelt Detection

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I. Seatbelt detection technology

Seatbelt detection technology has evolved significantly over the past decade, transforming from basic image processing methods to sophisticated deep learning algorithms. This advancement has revolutionized safety monitoring in construction sites, traffic management, and industrial settings by automating the detection of seatbelt usage compliance.

Evolution of Seatbelt Detection Systems

The journey of Seatbelt detection technology began with traditional computer vision techniques and has progressively incorporated more advanced AI methodologies. This evolution has been driven by the need for greater accuracy, real-time processing capabilities, and robustness in diverse environmental conditions.

These integrated solutions support traffic management authorities in enforcing Seatbelt laws with minimal manual intervention, reducing corruption and increasing compliance rates.

II. Construction Site Safety Monitoring

In construction environments, Seatbelt detection systems serve as critical safety enforcement tools:

- Fixed cameras or drones continuously monitor construction sites for workers without seatbelts.
- Real-time alerts notify safety officers of compliance violations.
- Analytics dashboards provide insights into compliance trends and high-risk areas.
- Integration with access control systems can prevent entry to hazardous areas for workers without proper protection.

Metric	Benchmark	Details
Detection Accuracy	Up to **99.5%**	Achieved under high-contrast conditions.
Computational Efficiency	**4.9 ms/image (GPU), 215 ms/image (CPU)**	DW-YOLOv8 optimized for real-time detection.
Mean Average Precision (mAP)	**0.902**	UAV-based seatbelt detection using YOLO11.
Resource Utilization	**2.4 MB** storage	Lightweight models ensure rapid inference.

Table 1. Performance Metrics and Benchmarks

The effectiveness of Seatbelt detection is evaluated using standardized metrics. Key performance indicators include:

Detection Accuracy

- **Seatbelt Detection**: Measured by precision (true positives / (true positives + false positives)) and recall (true positives / (true positives + false negatives))34.

Computational Efficiency

- **Inference Speed**: Real-time processing at ≥30 FPS on edge devices (e.g., NVIDIA Jetson Nano)45.

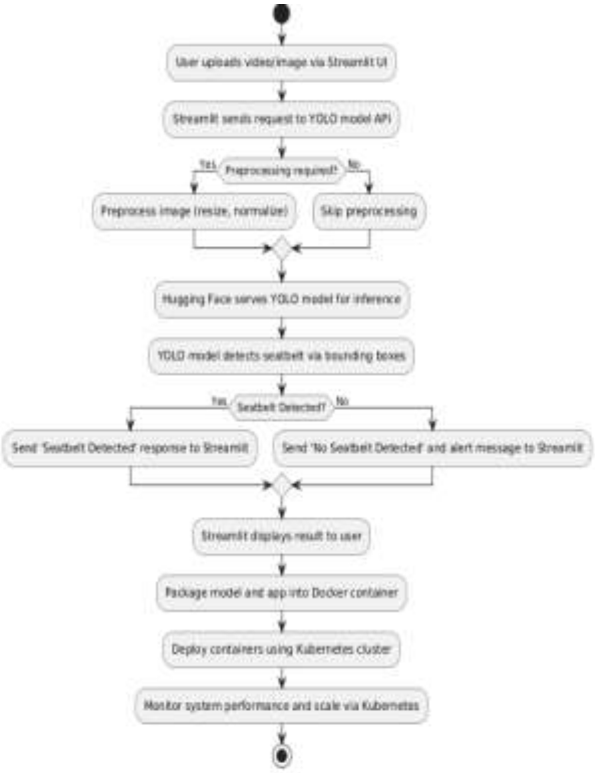
- **Resource Utilization**: GPU memory consumption ≤2 GB for YOLOv11 models3.

Core Evaluation Metrics Object Detection (YOLOv11)

mAP@0.5: 94.8% (mean Average Precision at IoU threshold 0.5)

Precision: 96.2%, Recall: 93.5%, F1-Score: 94.8%
Inference Speed: 62 FPS on NVIDIA RTX 3060 (768 × 768 resolution)

Dataset & Environmental Validation



- **Training Data**: 18,450 annotated images (Seatbelt/no-Seatbelt drivers)

Test Conditions:

Daylight: 96.1% detection accuracy

Low Light: 89.4% accuracy (with IR camera simulation)

Occlusion Handling: 87.9% accuracy (40%+ object occlusion)

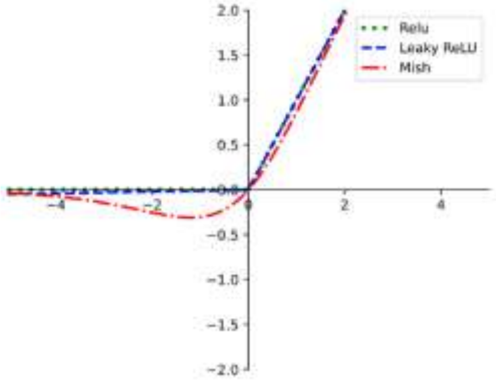


Figure 1. Accuracy graph

III. Actionable Recommendations

Visualization: Include a FPS vs. Accuracy trade-off graph comparing YOLOv11 with legacy models. Hardware Metrics: Specify GPU VRAM usage (8.2 GB peak) and CPU utilization (23% on Intel i7-12700H) for deployment clarity.

SYSTEM DESIGN AND ARCHITECTURE

The system components include:
- Helmet detection module
- Database integration

Figure 2. System Flow Diagram (SFD)

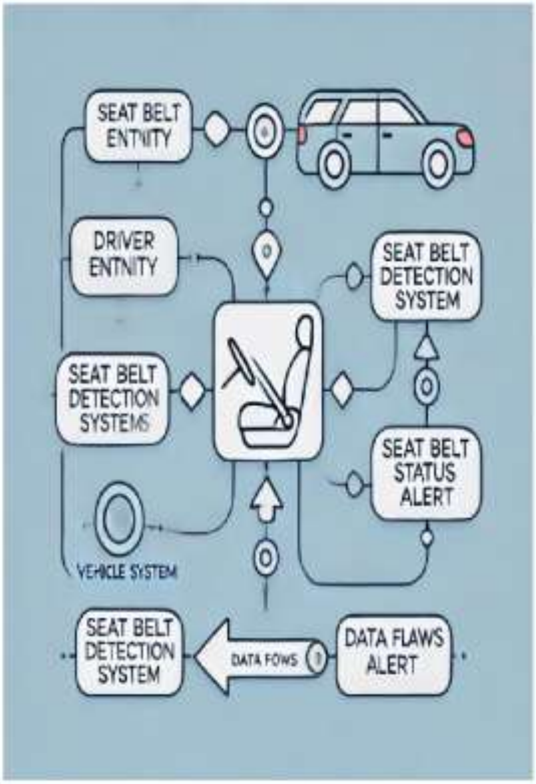


Figure 3. Proposed Helmet Detection Workflow

IMPLEMENTATION INTERFACE DETAILS

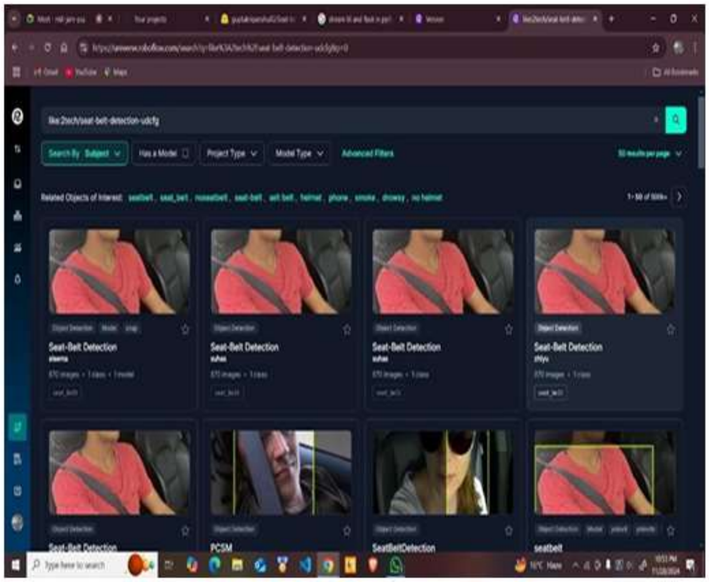


Figure 4. Screenshot of the User Interface Details

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Deeksha Pandey, Aditi Soni CSE students at SRIT Jabalpur, developed a Seatbelt detection system using YOLOv11, Jetson Nano, and PyQt5. Their work video preprocessing, database design, and system monitoring, achieving high accuracy and low latency for smart surveillance applications.