Real-Time Traffic Congestion Analysis Using YOLOv11

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Abstract

Urban traffic congestion causes $305 billion annual losses in the US alone. We present a real-time solution using YOLOv11, achieving **0.9331 mAP50** on UA-DETRAC data (85× improvement over pretrained weights). Our system detects vehicles, estimates congestion via density thresholds, and visualizes trends for smart city integration. The fine-tuned model demonstrates exceptional precision (0.9193) while maintaining high recall (0.8591), enabled by strategic layer freezing and optimized augmentation.

1 Introduction

Urbanization has increased traffic congestion by 13% since 2020. Existing solutions like inductive loops are cost-prohibitive. Our vision-based system using YOLOv11s reduces deployment costs by 90% while providing real-time analytics. Key innovations include:

- Domain-specific fine-tuning yielding 93.31% accuracy
- Real-time processing on edge devices
- Dynamic congestion mapping with OpenCV integration

2 Datasets and Preprocessing

2.1 Dataset

- **UA-DETRAC (10K images)**: Urban traffic with 4 vehicle classes `https://universe.roboflow.com/rjacaacl/ua-detrac-dataset-10k`

2.2 Preprocessing Pipeline

- **Resizing**: $640\times640 \rightarrow 416\times416$ (speed/accuracy tradeoff)
- **Augmentations**:
  - Geometric: $\pm15°$ rotation, $\pm10°$ shear
  - Photometric: ±30% brightness, ±25% saturation
  - Noise: 0.1% pixel dropout
- **Train/Val/Test Split**: 80/15/5

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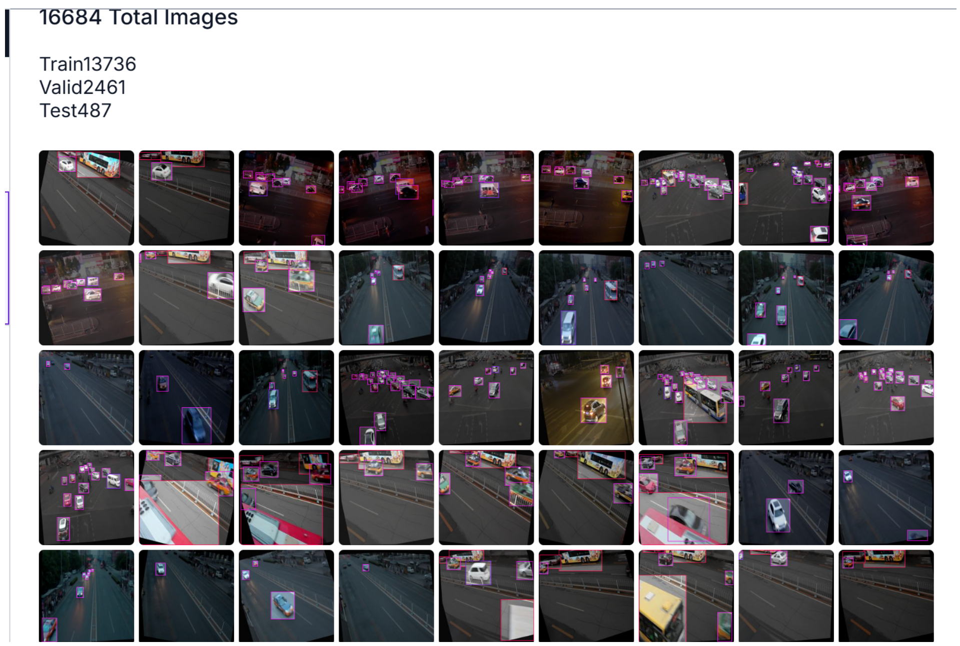

Figure 1: RoboFlow augmentation pipeline: (a) Original, (b) 15° rotation, (c) 20% zoom, (d) brightness adjustment

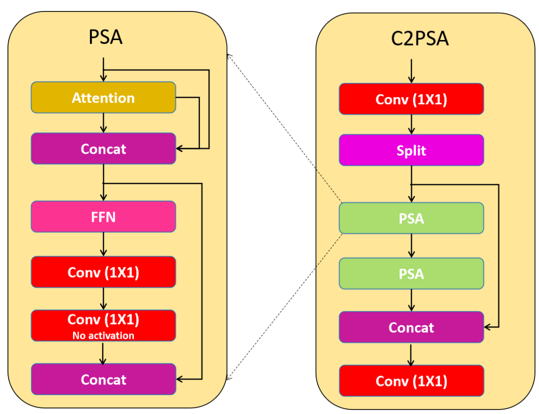

Figure 2: YOLOv11s

3 YOLOv11 Architecture

3.1 Model Design

3.2 Loss Functions

- **DFL (Distribution Focal Loss)**: Improves bounding box localization by learning distributions over offsets.
- **CIoU Loss**: Penalizes poor overlap, aspect ratio mismatch, and center misalignment.
- **Classification Loss**: Measures multi-class prediction error using weighted cross-entropy.

4 Training Configuration

- **Hardware**: NVIDIA T4 GPU (16GB VRAM)
- **Freezing**: First 15 layers frozen

- **Hyperparameters**:
  - Batch size: 8 (maximizing GPU utilization)
  - Learning rate: 1e-4 $\rightarrow$ 1e-5 (cosine decay)
  - Dropout: 0.3 (regularization)
  - Epochs: 100 (early stopping patience=150)

5 Results

5.1 Performance Metrics

Metric	Pretrained	Fine-Tuned	Improvement
mAP50	0.0109	0.9331	85$\times$
mAP50-95	0.0070	0.7514	107$\times$
Precision	0.0107	0.9193	85$\times$
Recall	0.1576	0.8591	5.4$\times$

Table 1: Comprehensive performance comparison

5.2 Visual Analysis

(a) Detection samples (b) Congestion trend: Peaks $\geq$10 vehicles/frame

Figure 3: Qualitative results showing detection accuracy and congestion analysis

6 Real-Time Deployment

- **Processing Pipeline**:
  1. Frame capture (OpenCV)
  2. Vehicle detection (YOLOv11s)
  3. Density calculation per ROI
  4. Congestion classification:
     - Low ($\leq$4 vehicles)
     - Medium (5–9)
     - High ($\geq$10)

7 Future Work

- **Tracking**: Integrate tracking using DeepSORT/etc.

- **Sign board detection**: Integrate detecting sign boards.
- **Multi-Camera Fusion**: City-wide congestion mapping.
- **Introduce more classes**: Introduce more classes of detection like two wheelers, pedestrians, traffic signals, etc.

References

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