Impact of Raindrops on Camera-Based Detection in Software-Defined Vehicles

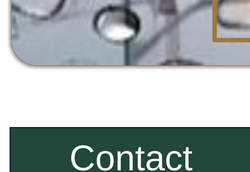
Yichen Luo, Daoxuan Xu, Gang Zhou, Yifan Sun, Sidi Lu
William & Mary

Background & Introduction

- **Software-defined vehicles (SDV)**
  - Multiple algorithms (over 150 million lines of code)
  - Camera-based algorism

TESLA — Full Self-driving (FSD) Vision-based

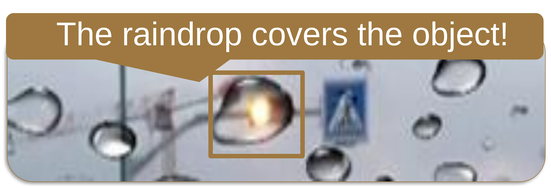
- **Unique challenges**
  - Mechanical solutions (e.g., wipers) do not work
  - Raindrops impact visibility & leave traces

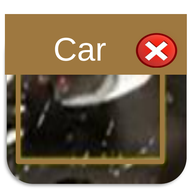


- **Research gap**
  - Principal component analysis (PCA)
    - Con: only detect raindrop
  - Super-resolution via repeated refinement (SR3)
    - Con: lack real-world development / testing
    - Con: limited on human face-dominated dataset

Challenges on AI-driven Methods

- **The impact of the incremental weather (e.g., rain)**
  - Impairing visibility
    - Incorrect detection
      - Car tail light not traffic light
      - Raindrop instead a car
    - Missing detection





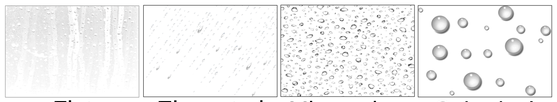
Contact

Email:
yluo11@wm.edu

Paper | Vehicle Computing Lab | Contact Details

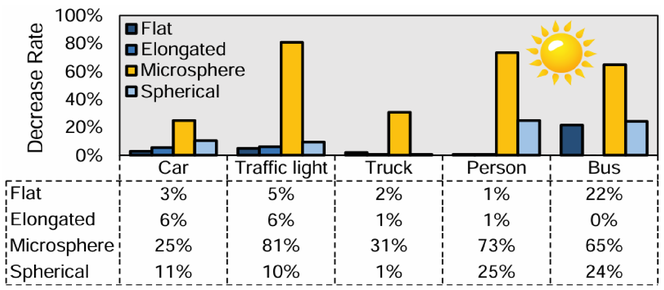
Qualitative Analysis (RQ1)

- RQ1: Which raindrop type most affects camera-based detection in daytime and nighttime?



Raindrop Impact on Object Detection

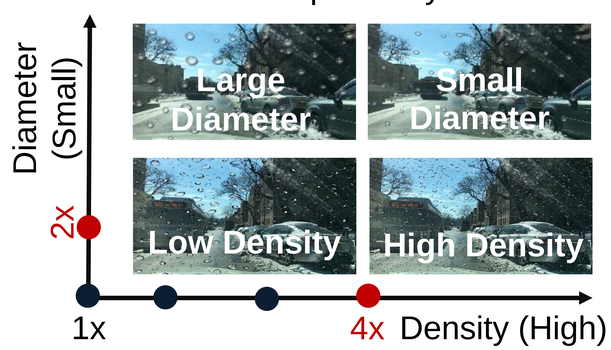
- **Microsphere** and spherical >> flat and elongated
- **Flat** raindrops impact results more at night



	Car	Traffic light	Truck	Person	Bus
Flat	3%	5%	2%	1%	22%
Elongated	6%	6%	1%	1%	0%
Microsphere	25%	81%	31%	73%	65%
Spherical	11%	10%	1%	25%	24%

Quantitative Analysis (RQ2)

- RQ2: Which has a greater impact on camera-based detection: raindrop density or diameter?



Results

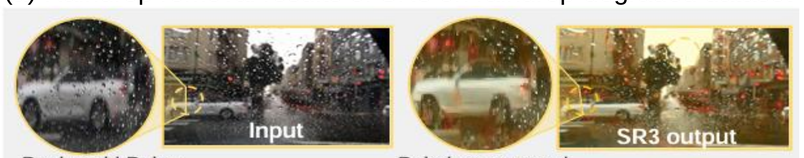
- Lower Density > Higher Density (gap: 13.7%)
- Large Diameter > Small Diameter (gap: 6.7%)
- Lower Density > Large Diameter (gap: 6.2%)
- Our YOLO-RA consistently outperforms YOLOv7

Effective Solutions (RQ3)

Raindrop Removal (SR3)

- Raindrop-removed images: **PSNR = 18.75dB**

(a) Raindrop removal results of SR3 on raindrop-degraded dataset

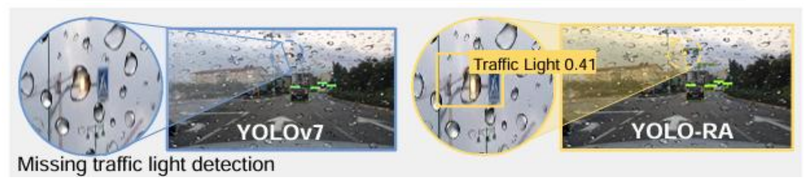


(b) Raindrop removal results of SR3 on real-world dataset

Proposed Model (YOLO-RA)

- YOLO-RA: detect small-size objects → learn more features in backbone → **ELAN-CBAM**

Raindrop Removal + YOLO-RA



(a) Detection examples on raindrop-degraded dataset

(b) Detection examples on real-world rainy dataset

Evaluation metrics of software **accuracy**

Model	YOLOv7	Mosaic	CBAM	Precision	mAP	F1
YOLOv7	✓			0.78	0.82	0.81
YOLO-Mosaic	✓	✓		0.71	0.67	0.65
YOLO-CBAM	✓		✓	0.85	0.83	0.78
YOLO-RA (Ours)	✓	✓	✓	**0.89**	**0.85**	**0.82**

Comparative software **speed** (processing time)

Models	T_{inf} (ms)	T_{NMS} (ms)	T_{total} (ms)	FPS
YOLOv7	8.1	3.4	11.5	86.96
YOLO-RA (Ours)	6.1	2.4	8.5	**117.65**
SR3 + YOLOv7	8.2	3.6	11.8	84.75
SR3 + YOLO-RA (Ours)	6.4	4.2	10.6	**94.34**