Advancing Environmental and Infrastructure Resilience Through Scalable Mobile Sensing and Data Acquisition

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Collaborators: Adriaan Van Berkel – DAQ recording program; Chloe Bogaert – Digital twin development; Long Li – Laboratory methodology; Magna – Laboratory sensor project; ACE – Wind tunnel rain simulation

From Wind Tunnel Controlled Testing to Real-World Field Research Under Dynamic Environmental Conditions

2020 – 2023 Controlled Wind Tunnel Testing

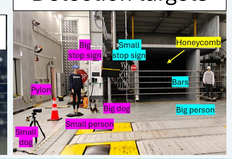
- **Environmental characterization:** Developed a rain simulation system and quantified relationships between environmental conditions and sensor performance.

Controlled wind tunnel testing

Hydrophilic Lens | Hydrophobic Lens



Detection targets

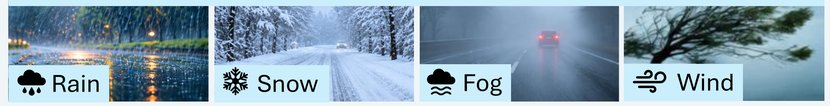


Rain system



Potential Applications

Mobile weather station





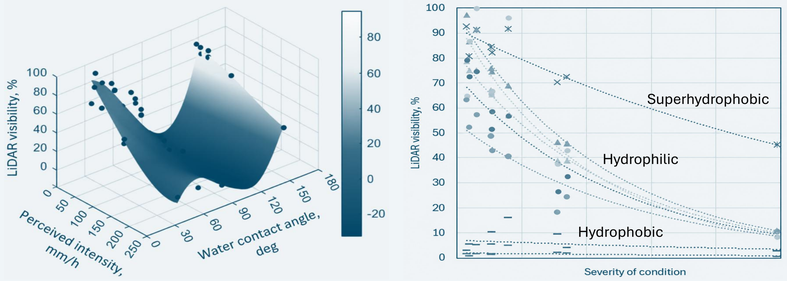
Plant inspection | Traffic monitoring | Autonomous nav. | Weather response

Novelty & Innovation

- **Intelligent automation:** Streamline synchronized multi-sensor recording, data management, and processing with minimal manual intervention.
- **Smart data integration:** Enable efficient data querying, correlation, reusable datasets for multidisciplinary research.
- **Scalable & modular architecture:** Support flexible sensor integration, cross-platform deployment, including vehicles, robots, drones, and remote monitoring systems.

2023 – 2025 Physics-Informed Modeling

- **Predictive mathematical modeling:** Developed semi-empirical models linking controlled environmental conditions, sensor characteristics, and performance degradation.



- **LiDAR performance prediction model**

$$f(x,\lambda,d) = a(\lambda)e^{-b(\lambda)x+c(d)} \qquad a = P_1(\lambda^3) + P_2(\lambda^2) + P_3(\lambda) + P_4$$

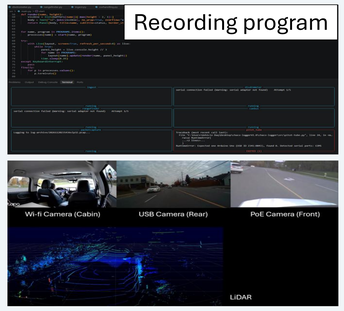
$$b = \begin{cases} P_5^{(1)}(\lambda) + P_6^{(1)}, \lambda < 80° \\ P_5^{(2)}(\lambda) + P_6^{(2)}, \lambda \geq 80° \end{cases}$$

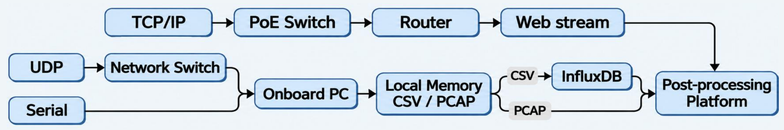
x = rain intensity (mm/h)
λ = material water contact angle (deg)
d = droplet size distribution descriptor

Custom data acquisition platform

- **Integrated multi-sensor acquisition:** Onboard computing, synchronized sensor recording, multi-protocol connectivity, and uninterrupted power supply.

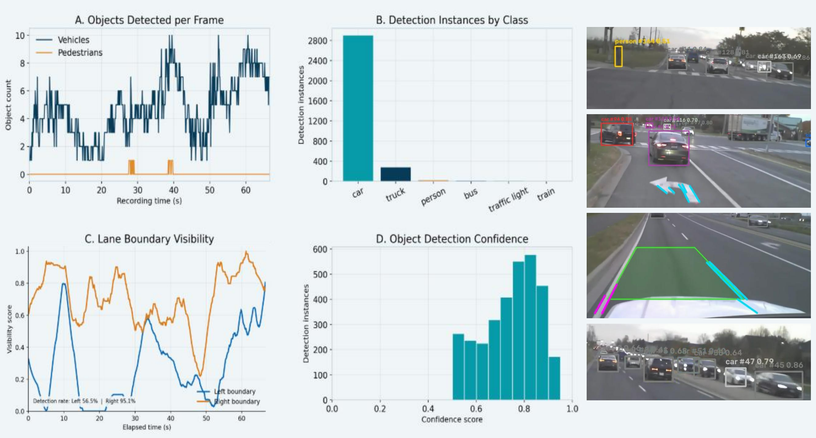






Research Outcomes & Demonstration

- **Object detection analytics:** Identify object classes, traffic signs, vehicle colors, lane boundaries, time series and confidence level.
- **Weather monitoring**: Quantify location, precipitation, wind speed.



2025-2027 Field Validation

- **Real-world validation:** Demonstrated synchronized environmental and multi-sensor data acquisition and visualization under dynamic, naturally varying conditions.



Custom developed data processing tools

- **Integrated data analytics:** All-in-one Python-based visualization, synchronized multi-sensor data processing, and automated quantitative performance evaluation.

Dashboard viewer | Disdrometer processor



LiDAR processor | Object detection processor

Conclusions & Future Work

- **Platform development:** Completed the build and integrated multi-sensor DAQ platform, with a research paper submitted to the Society of Automotive Engineers (SAE).
- **Data processing & analytics:** Developed customized tools for visualization, management, and processing, with ongoing improvements toward data-driven and research-oriented analytics.
- **Intelligent field testing:** Integrate IoT-based environmental monitoring to identify optical field=-testing opportunities.
- **Automated data intelligence:** Advance automated object classification, data labeling, and dataset management for machine learning applications.
- **Broader applications:** Demonstrate platform adaptability across environmental monitoring, infrastructure resilience, autonomous systems, and emergency or weather responses.