Quantifying Environmental Influences on Lidar Sensors for Simulation

Dr.-Ing. Clemens Linnhoff & Dr.-Ing. Philipp Rosenberger

Persival at a Glance

Perception Sensor Simulation & Model Validation

Project highlights

- Sensor model customization and performance evaluation for the ASAM OSI interface
  https://github.com/OpenSimulationInterface
- Automated perception sensor model testing for Open-Source Sensor Models for BMW in the GAIA-X4PLC-AAD project
  https://github.com/GAIA-X4PLC-AAD

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Founders

Dr.-Ing. Philipp Rosenberger, CEO

Responsible for business development

Founding member of the change-control-board (CCB) for the ASAM Open Simulation Interface

Expertise: *Metrics for Specification, Validation, and Uncertainty Prediction for Credibility in Simulation of Active Perception Sensor Systems*

Dr.-Ing. Clemens Linnhoff, CTO

Responsible for technical development

Founding member of the maintainer for perception sensor models at asc(s e.V. - ENVITED Open Source Model & Simulation Library

Expertise: *Analysis of Environmental Influences for Simulation of Active Perception Sensors*

Customers

BMW GROUP

MINI

Active Member of

ASAM
CCB of ASAM Open Simulation Interface

asc(s
Automotive Solution Center for Simulation

Spin-off from

TECHNISCHE UNIVERSITÄT DARMSTADT

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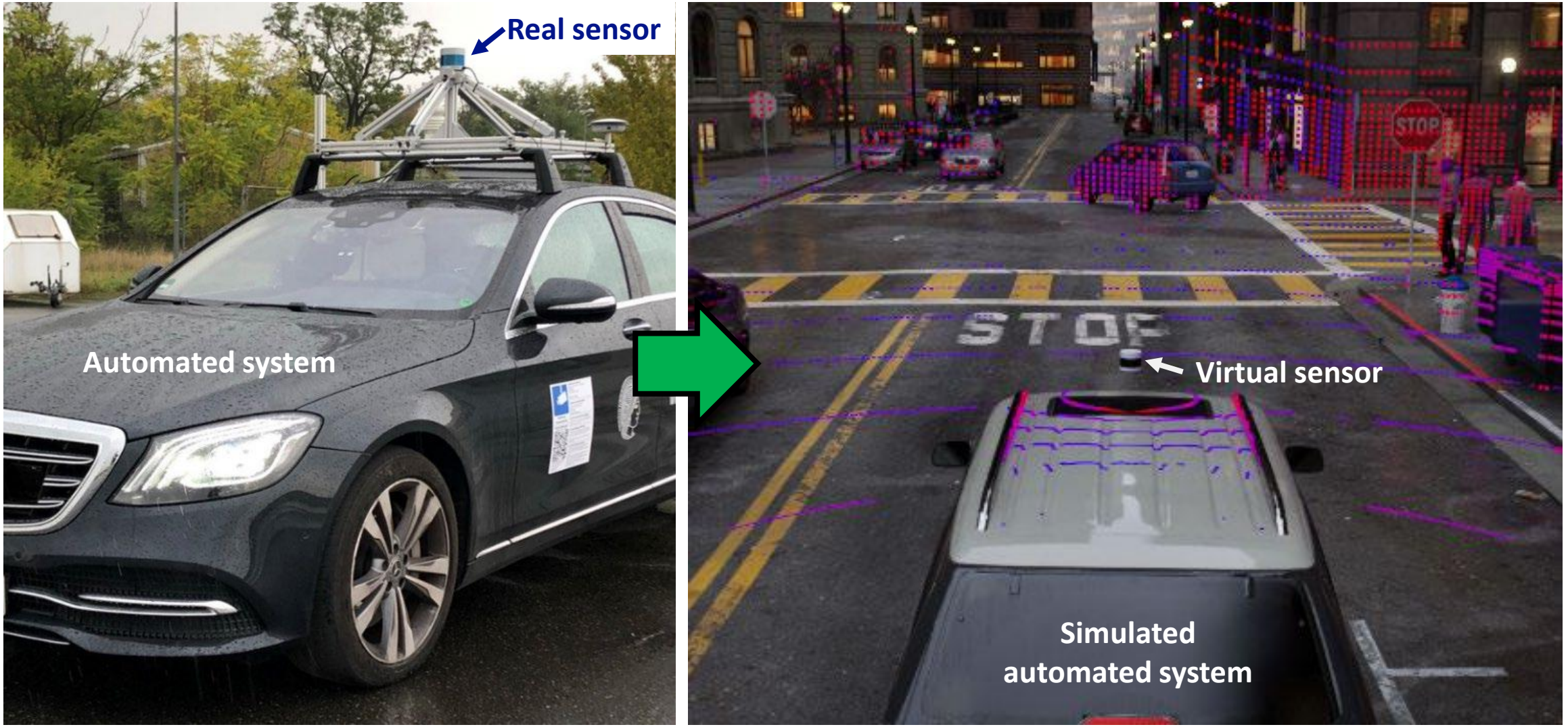
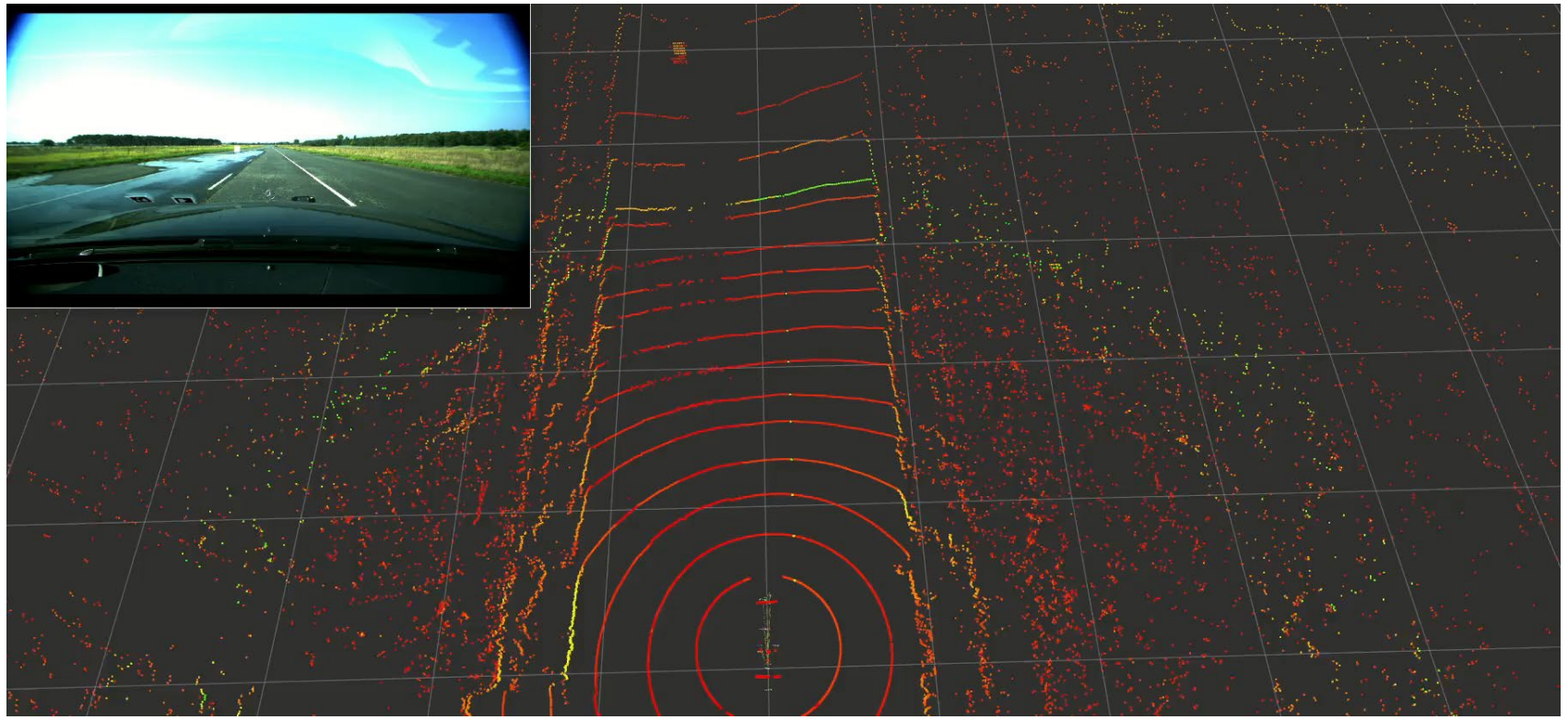
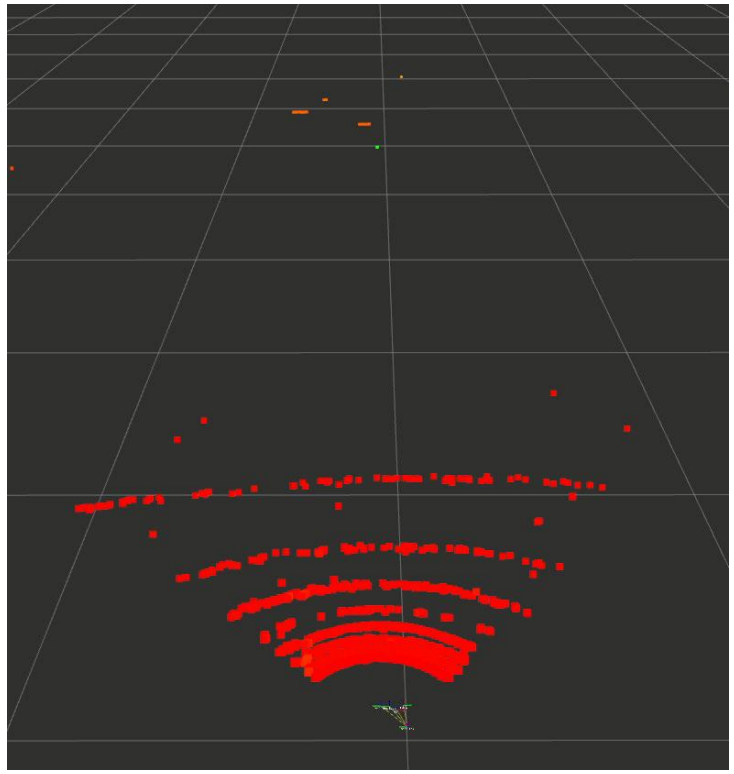
Target: Testing of Automated Systems in Simulation



Problem: Environmental Influences





Environmental influences on lidar such as road spray or rain can be critical for autonomous systems.
Therefore, they need to be included in simulation models for virtual testing.

Three Questions to be Answered

What environmental conditions exist in road traffic?

How do these conditions affect lidar?

How can the influences be quantified and simulated?

What are Environmental Conditions ?

Definition: *An environmental condition is every entity that is added to an idealized object-based surrounding to describe a real-world environment.*

Leaves
Wind
Smoke
Exhaust Gas
Adverse Temperature
Rain
Headlights
Broken Water Hydrant
Hail
Wet Pavement
Fog
Dust
Wet Road
Snow
Blinding Sun
Road Spray
Humidity
Windshield Washer
Sound

What are Environmental Conditions ?

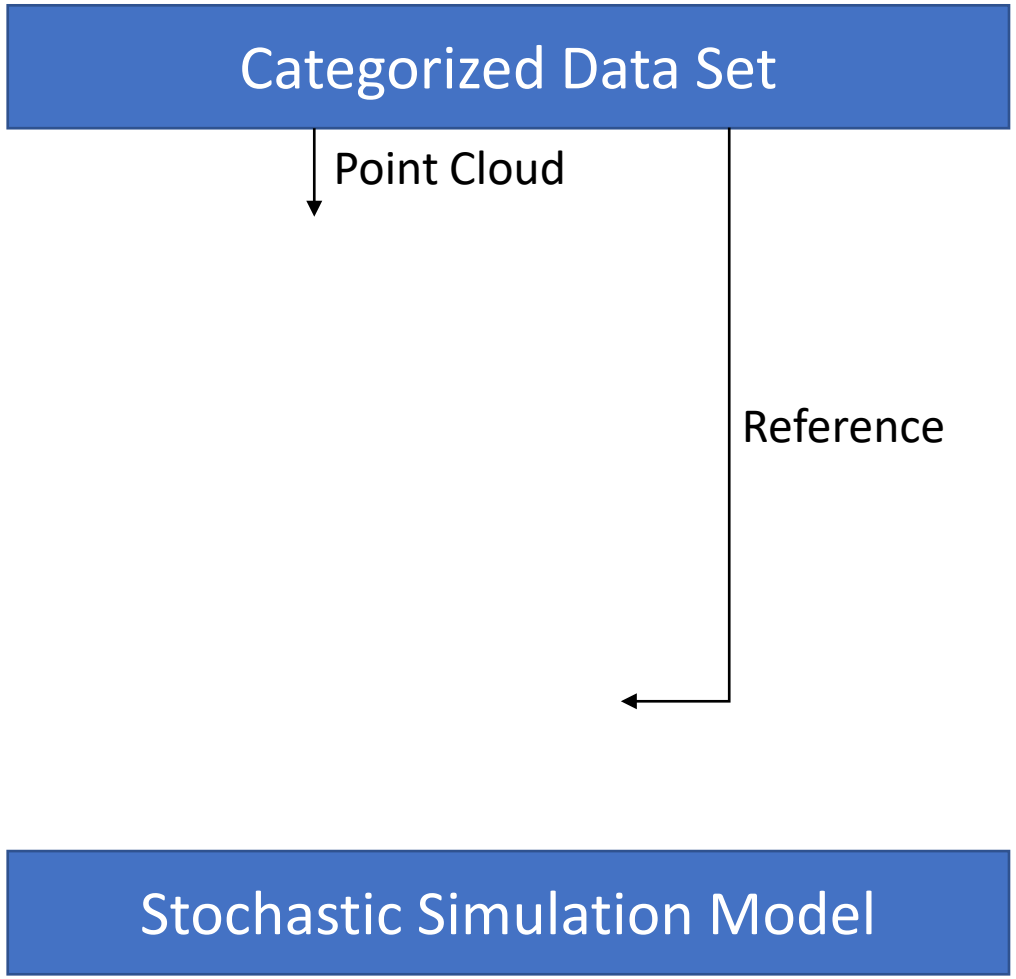
Object Independent Conditions

- Rain
- Blinding Sun
- Fog
- Snow
- Hail
- Humidity
- Adverse Temperature
- Wind

Object Dependent Conditions

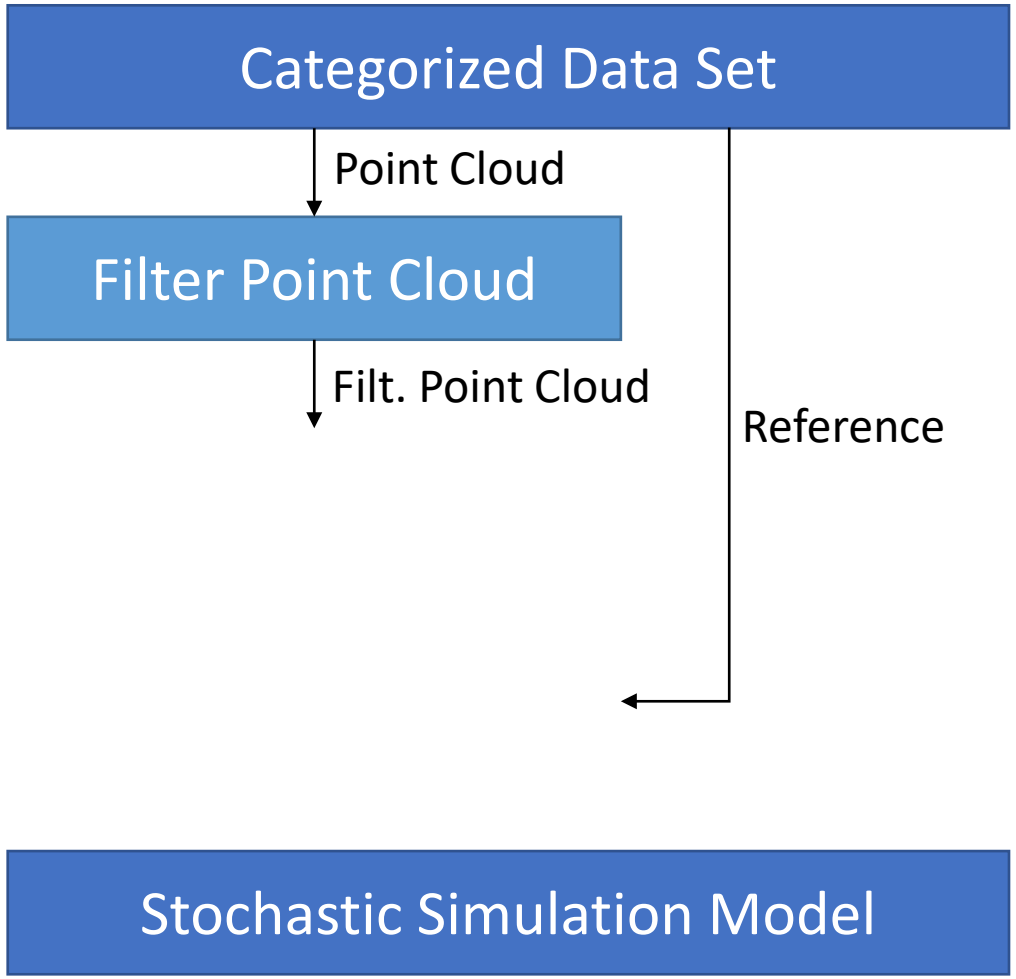
- Road Spray
- Windshield Washer
- Wet Pavement
- Exhaust Gas
- Broken Water Hydrant
- Dust
- Smoke
- Leaves
- Headlights
- Wet Road
- Sound

Method



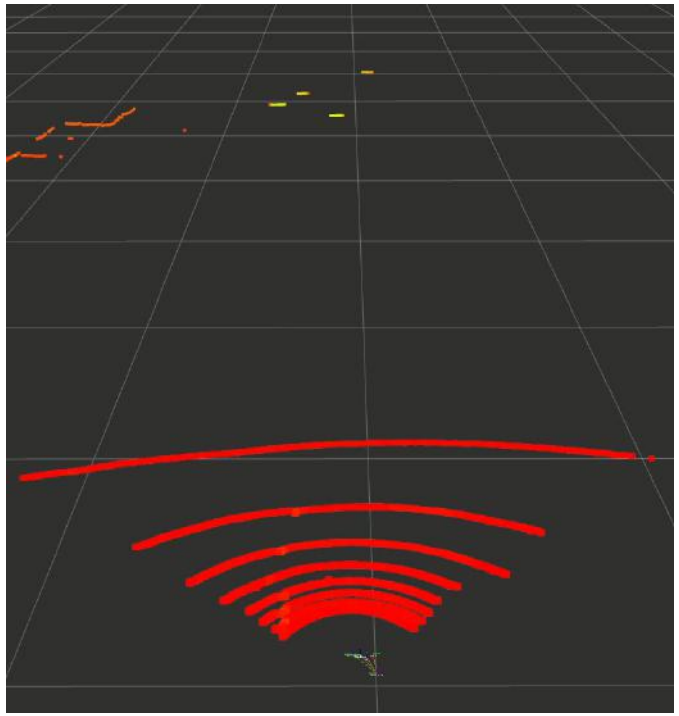
- Real-world measurements
- Reference sensors
- Change only one parameter at a time
- Systematic setup to allow semi-automatic analysis

Method

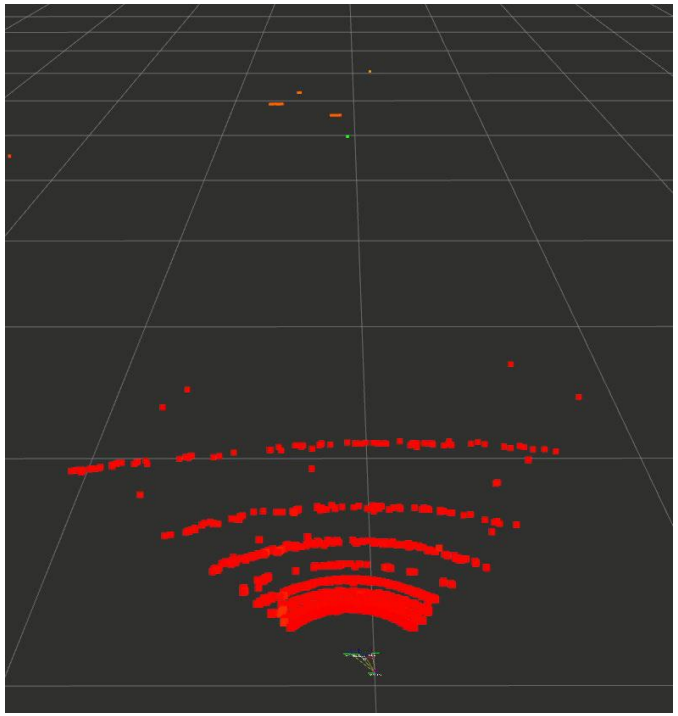


- False-positive detections
- Atmospheric attenuation

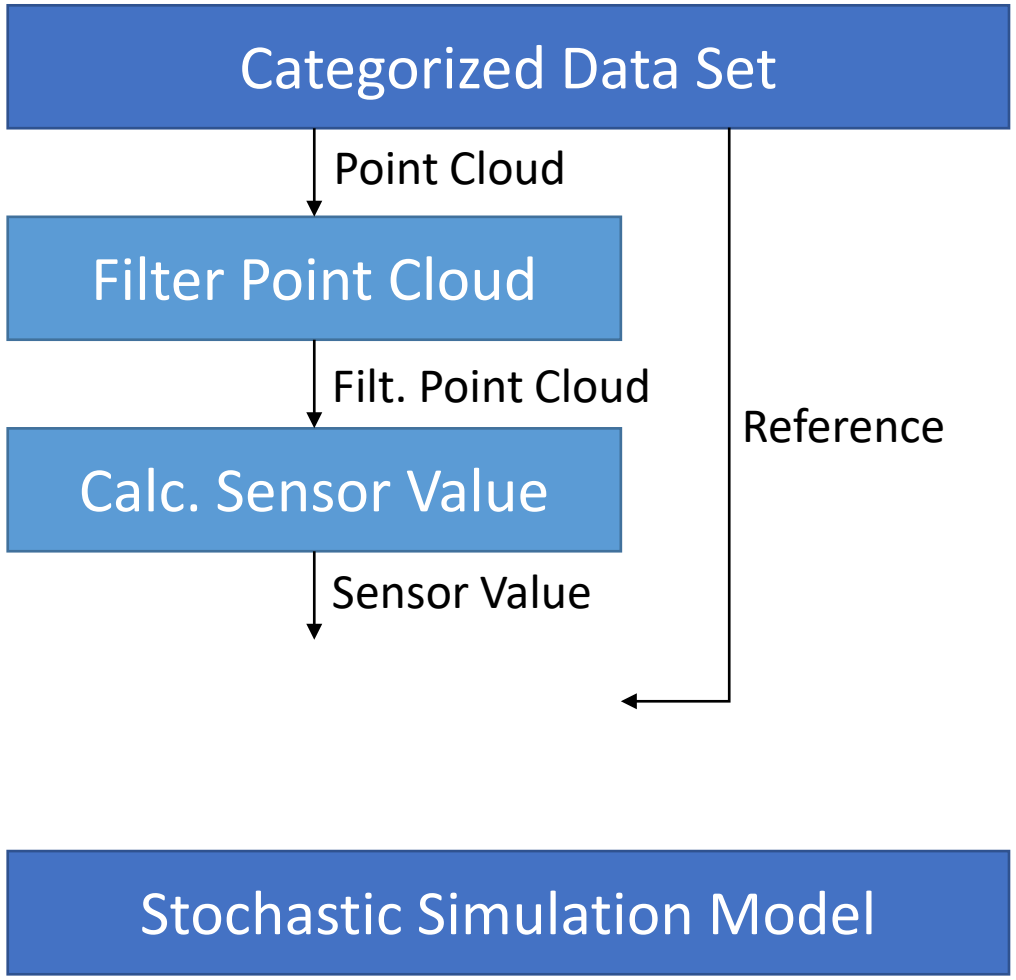
No Rain



Rain

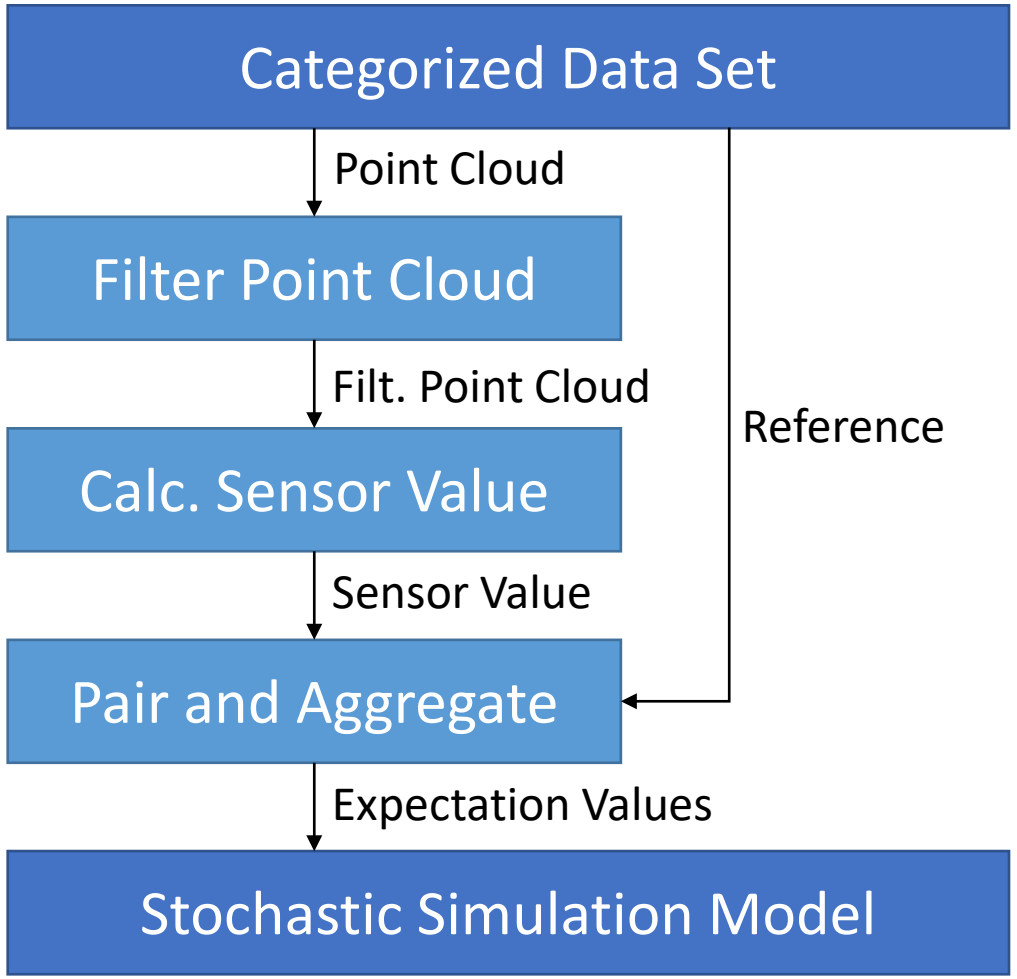


Method

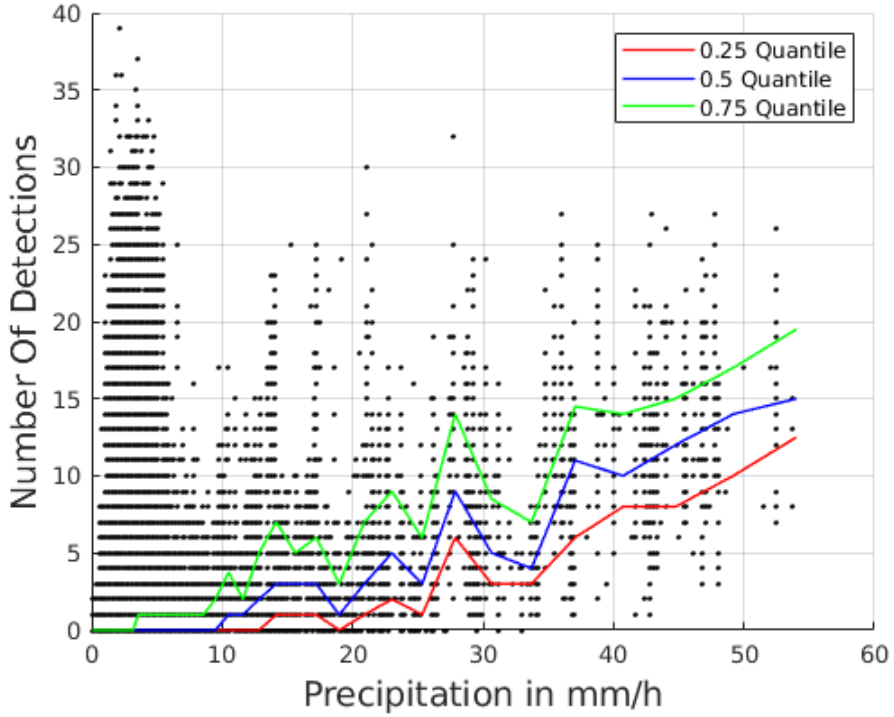


- False-positive detection in atmosphere
  - Number of detections
  - Position distribution
  - Intensity distribution
- Atmospheric attenuation
  - Detection loss in certain distances

Method

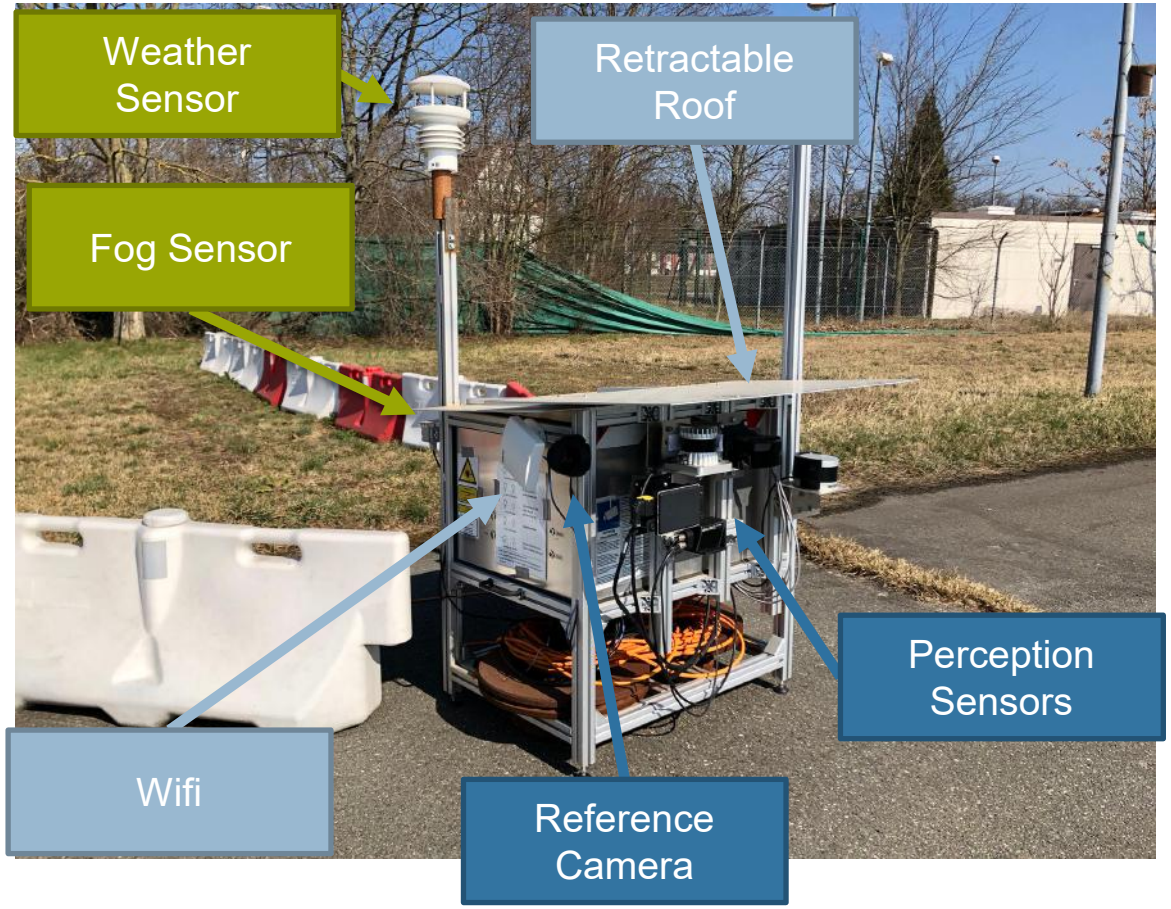


- Use all data available
- Get median values over several measurements

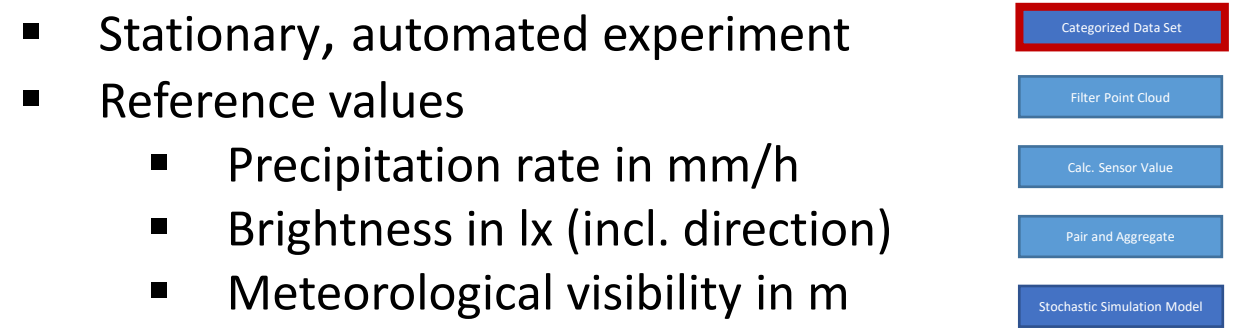


Object Independent Influences

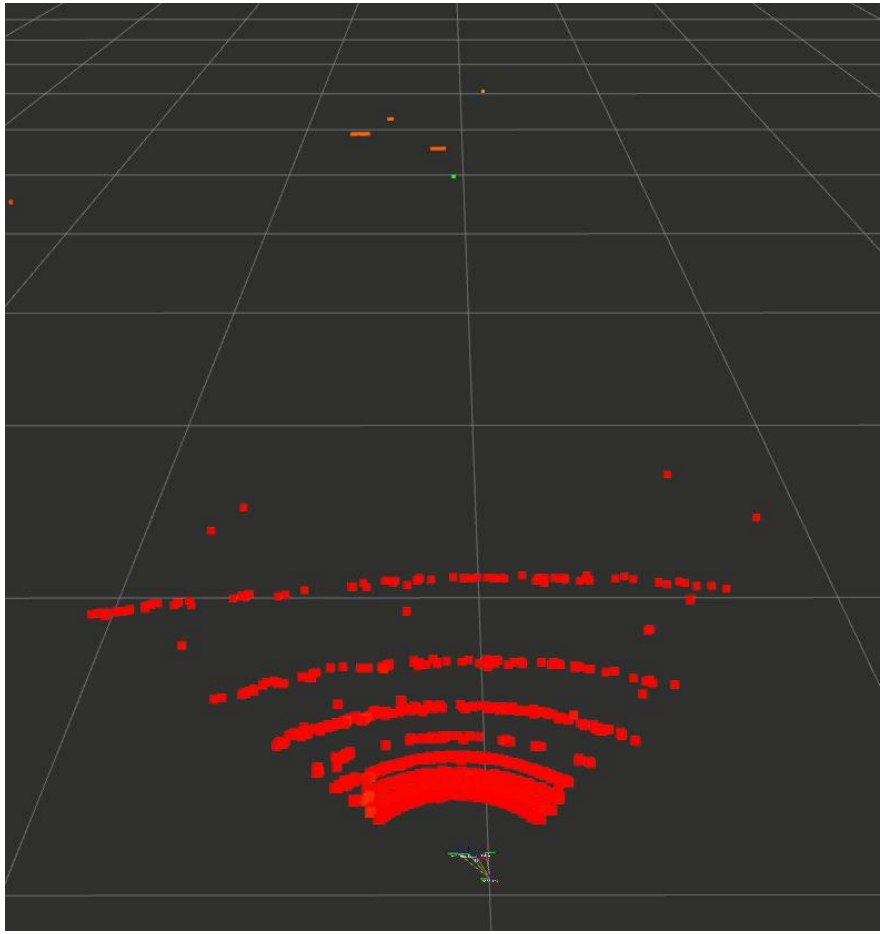
Data Set

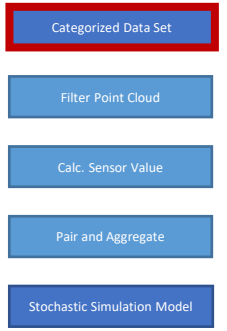


- Stationary, automated experiment
- Reference values
  - Precipitation rate in mm/h
  - Brightness in lx (incl. direction)
  - Meteorological visibility in m
  - Synop present weather code



Object Independent Influences
Data Set

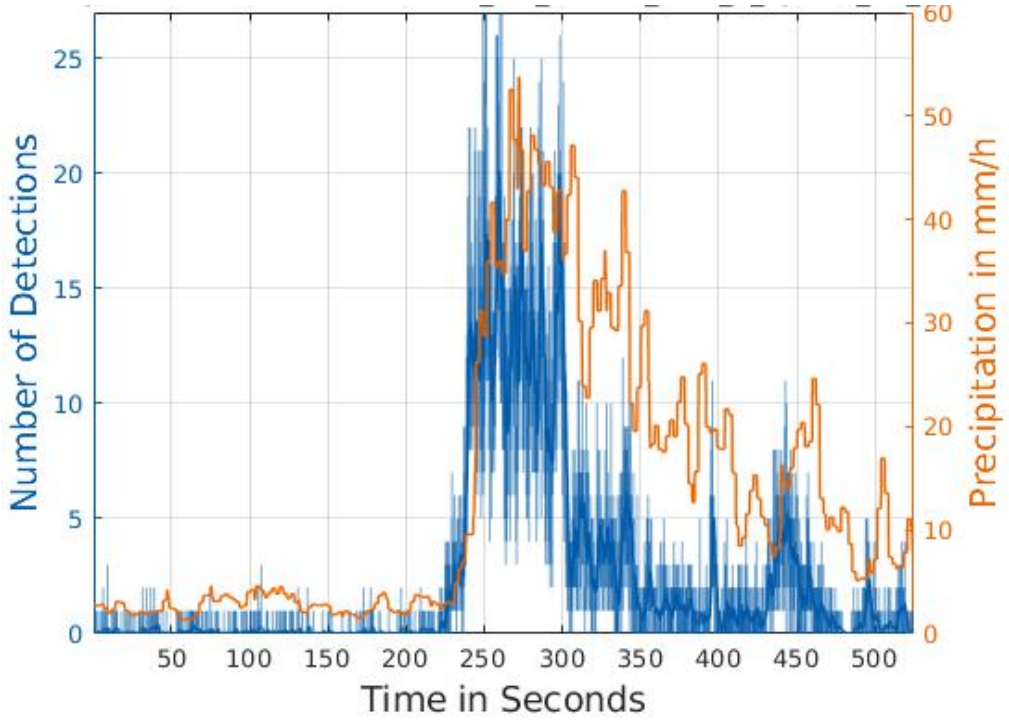




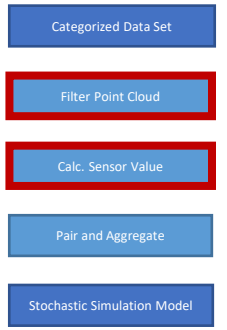
Object Independent Influences

Filter Point Cloud / Sensor Values

Detections in the atmosphere



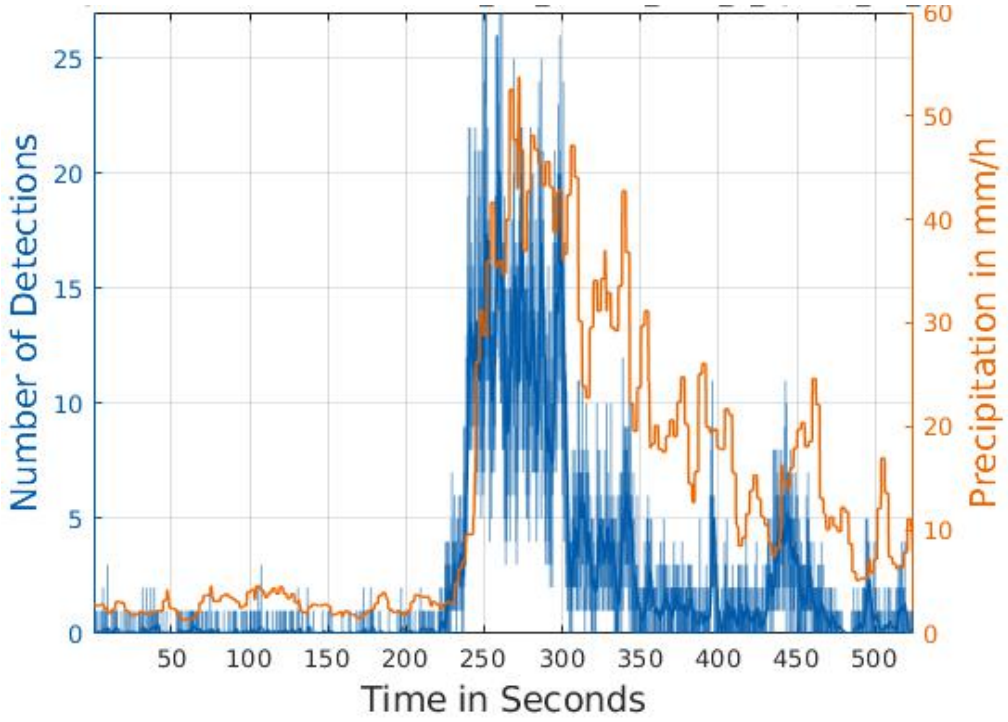
- Targets
  - Detection probability per distance
- Atmosphere
  - Detection probability per beam
  - Range to atmospheric detections
  - Intensities



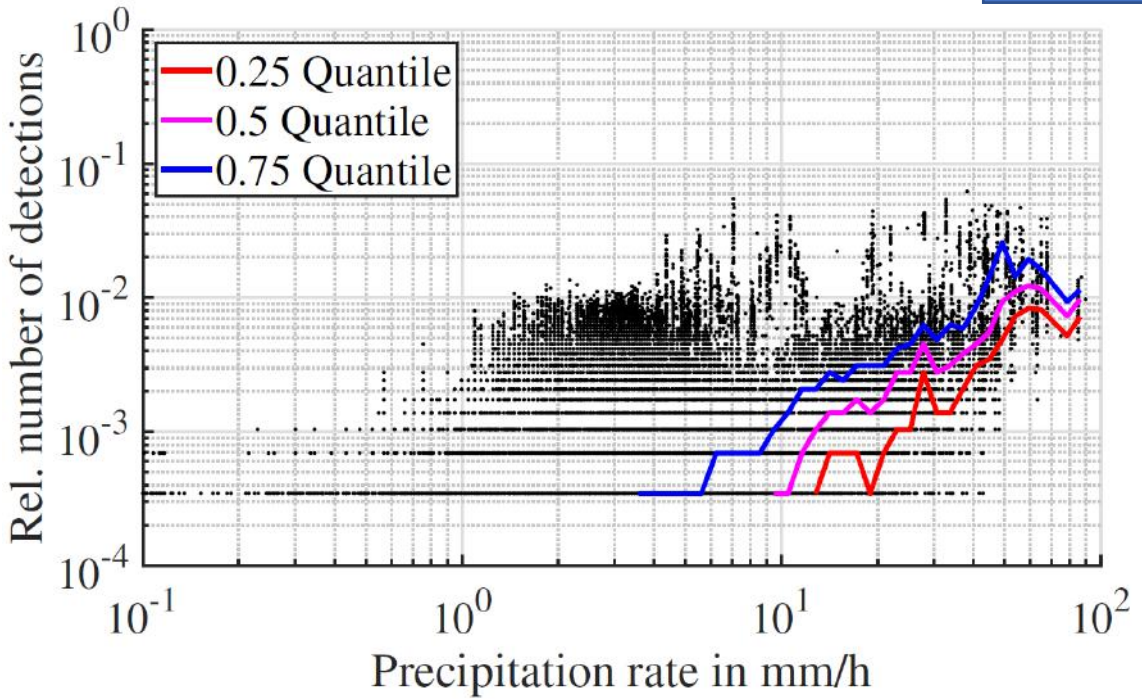
Object Independent Influences

Pair and Aggregate

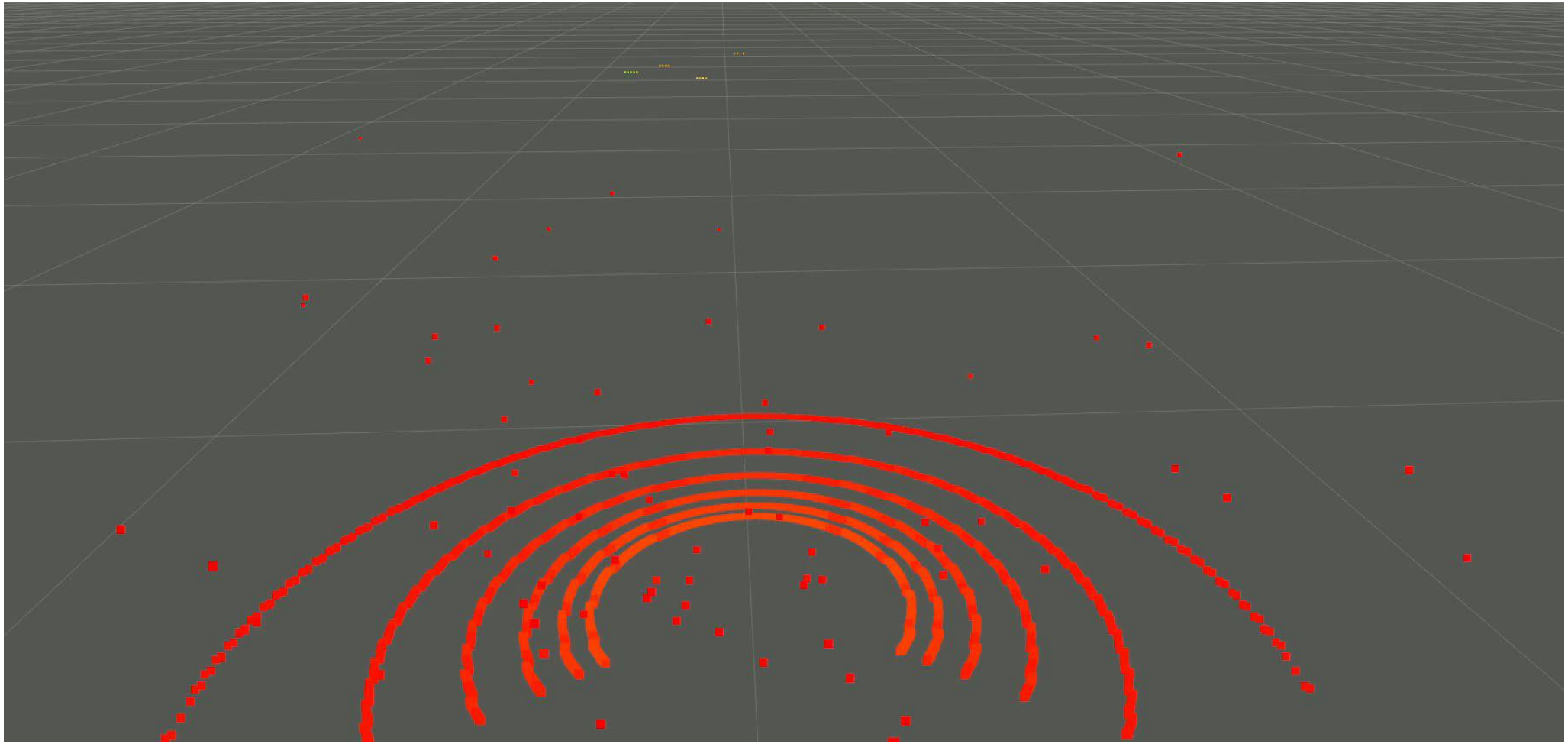
Detections in the atmosphere



Aggregate, Sort



Object Independent Influences
Simulation



Categorized Data Set

Filter Point Cloud

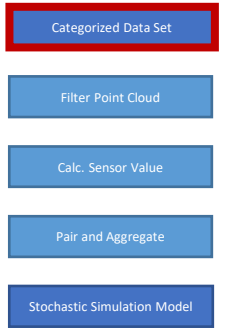
Calc. Sensor Value

Pair and Aggregate

Stochastic Simulation Model

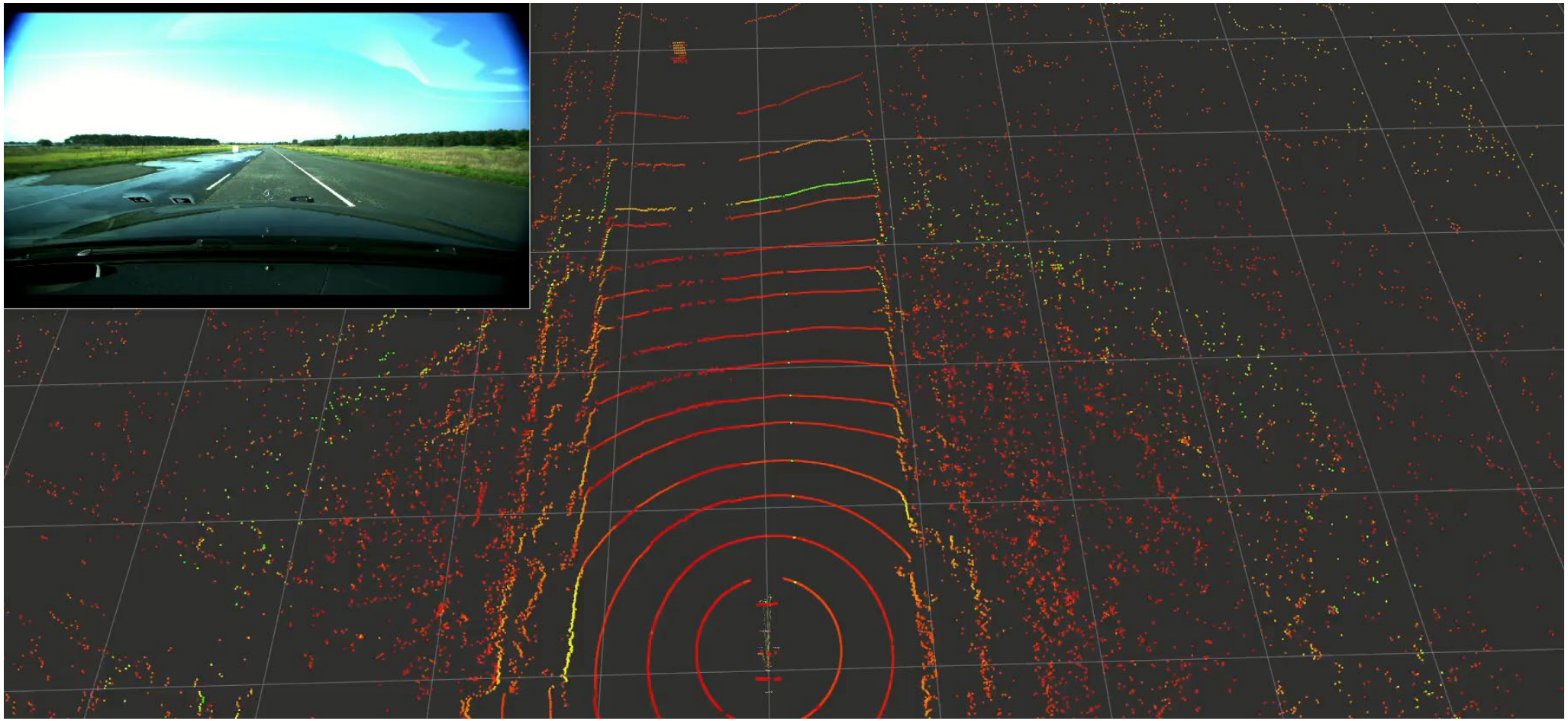
Object Dependent Influences
Data Set

Experiments with varying objects, speeds and water levels



Object Dependent Influences

Data Set



Categorized Data Set

Filter Point Cloud

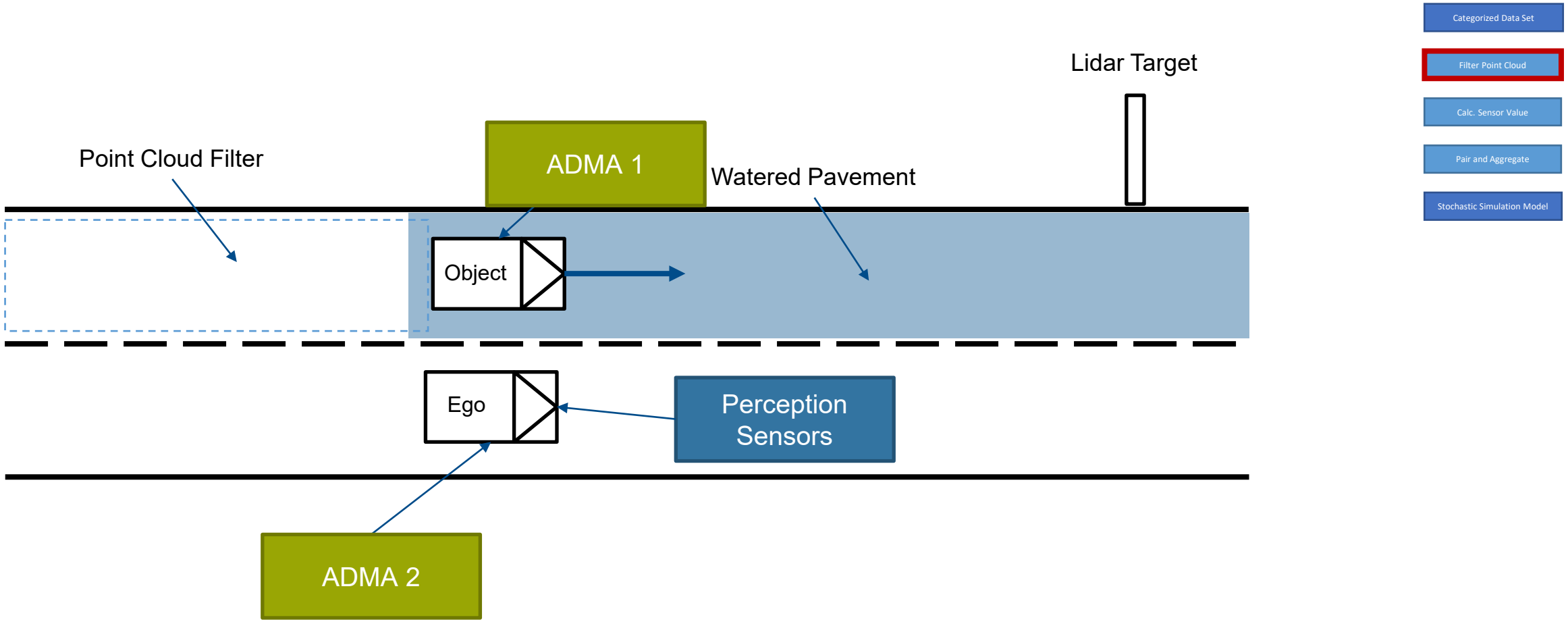
Calc. Sensor Value

Pair and Aggregate

Stochastic Simulation Model

Object Dependent Influences

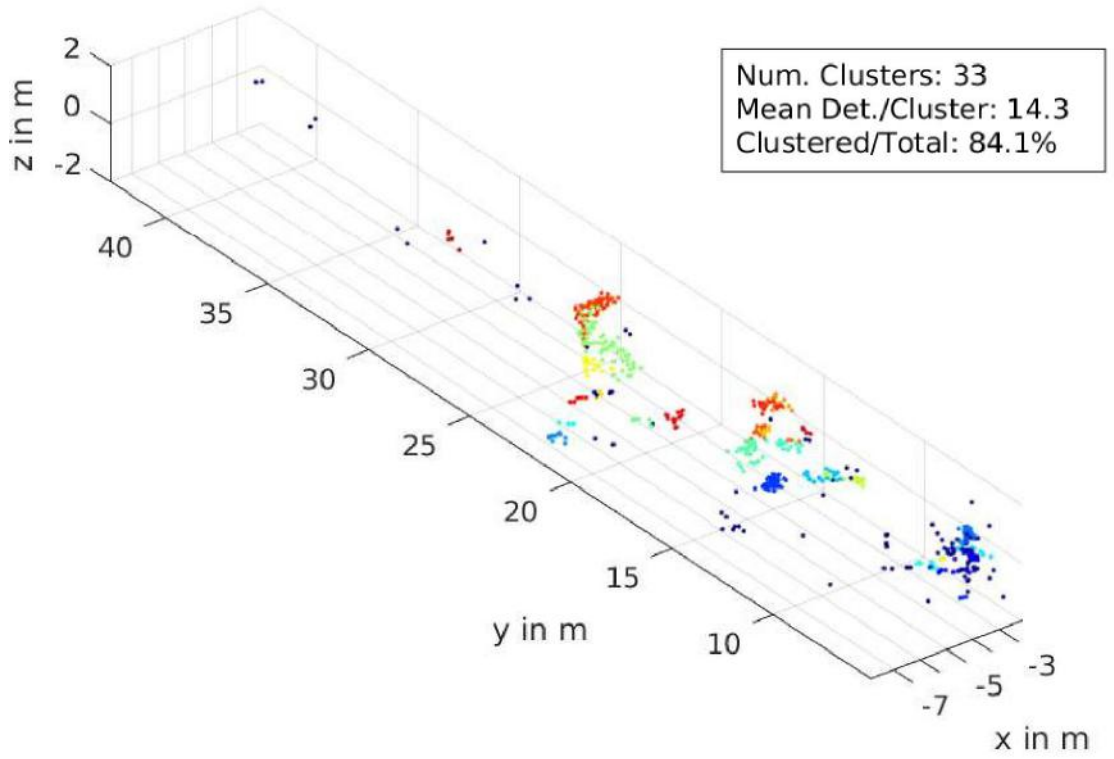
Filter Point Cloud

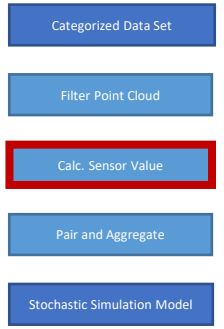


Object Dependent Influences

Calc. Sensor Value

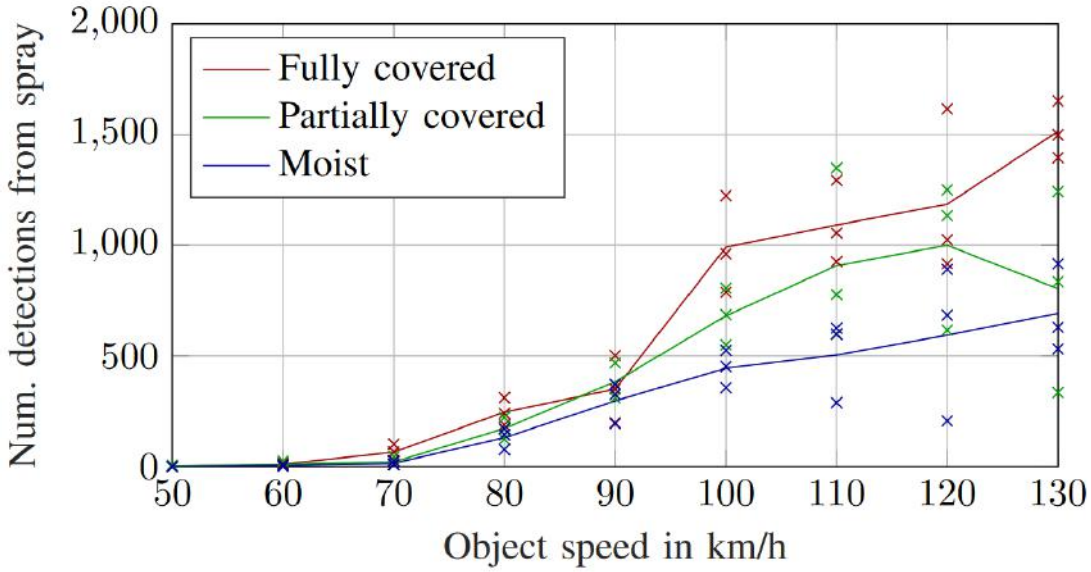
- Number of clusters per scan
- Cluster radius
- Detection probability in cluster
- Dissipation time constant
- Cluster movement (incl. wind influence)
- (Attenuation)

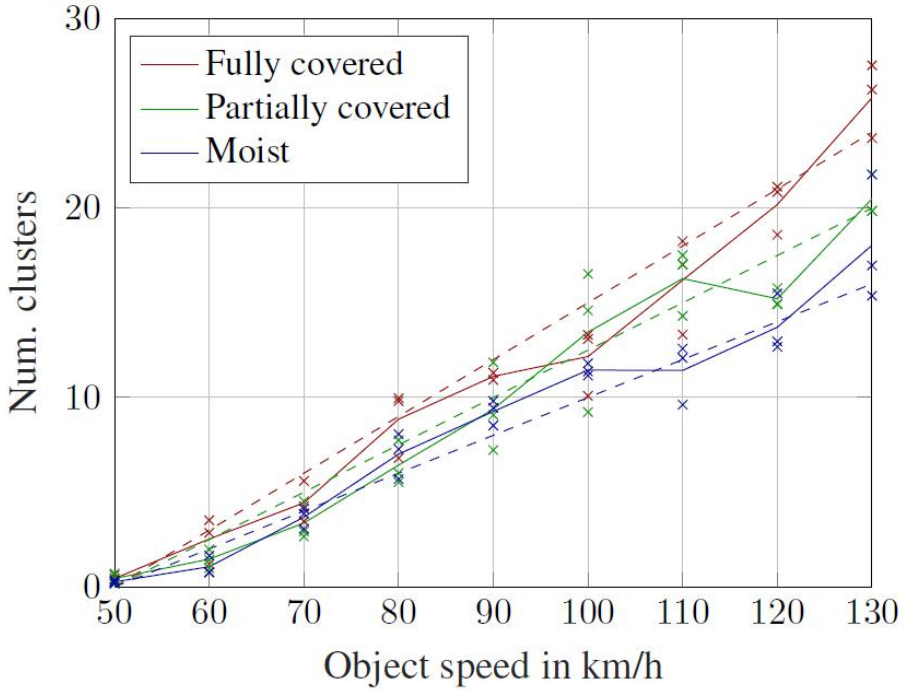




Object Dependent Influences

Pair and Aggregate





Categorized Data Set

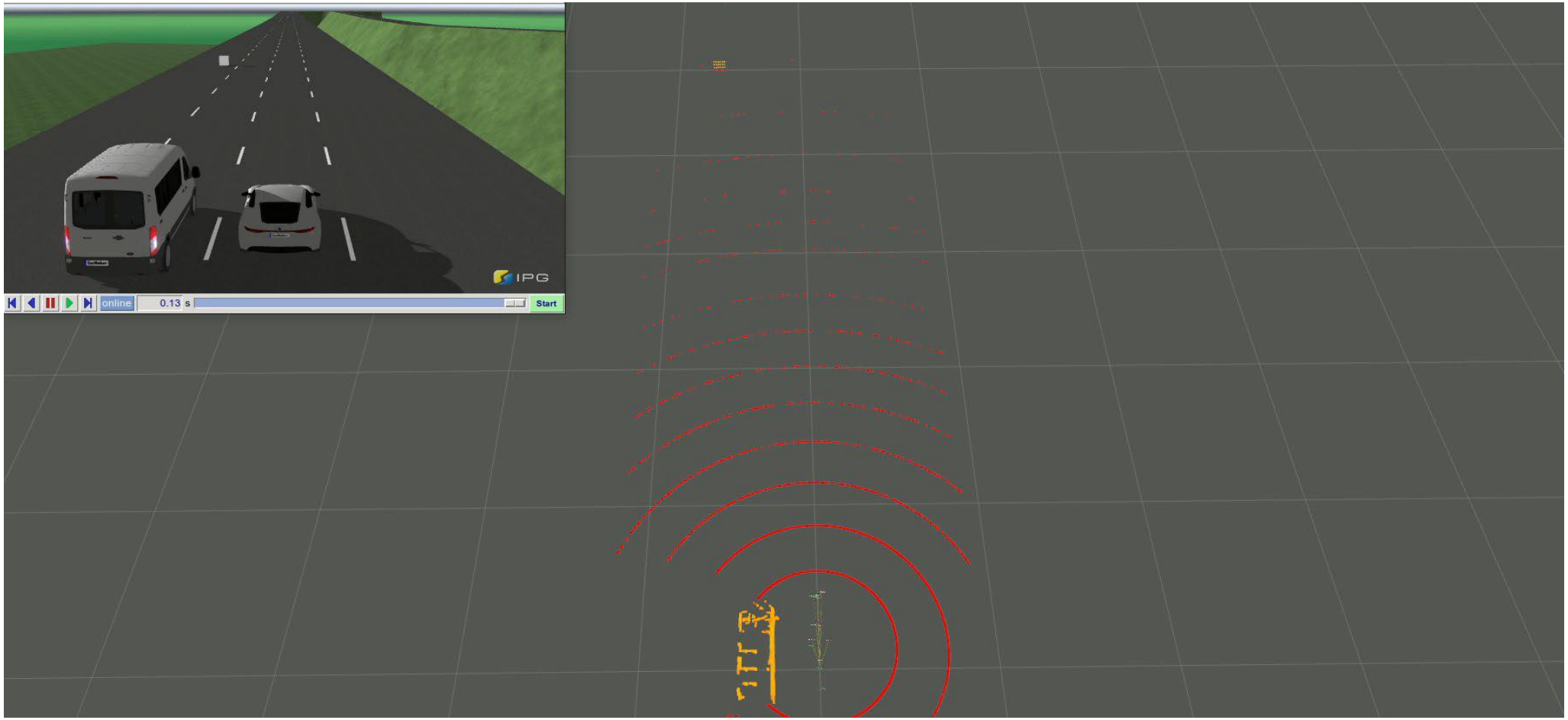
Filter Point Cloud

Calc. Sensor Value

Pair and Aggregate

Stochastic Simulation Model

Object Dependent Influences
Simulation



Categorized Data Set

Filter Point Cloud

Calc. Sensor Value

Pair and Aggregate

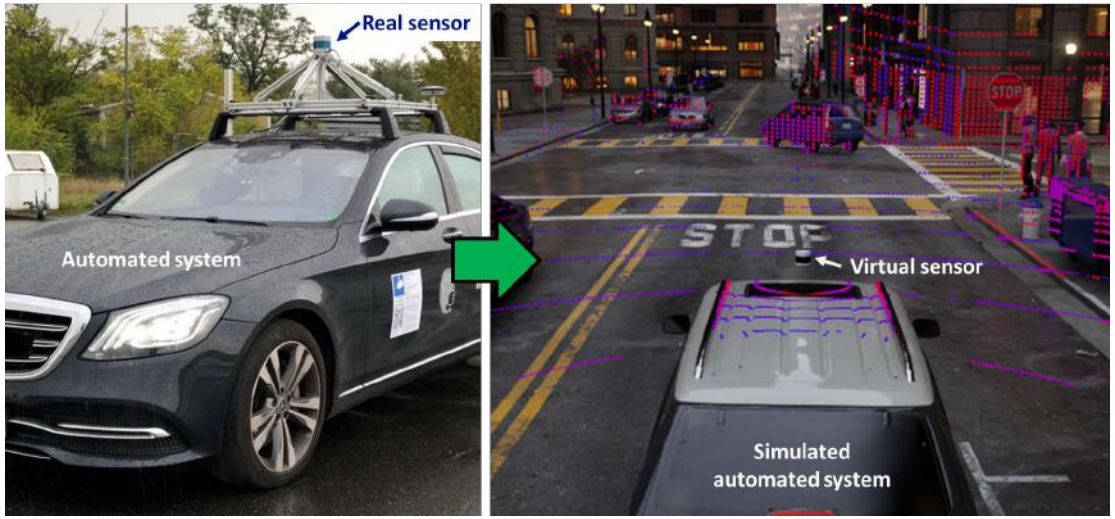
Stochastic Simulation Model

Perception Sensor Simulation & Model Validation

The Full Package for Perception Sensor Modeling

Requirement Analysis
PerCollECT, CEPRA, ODD / parameter space

github.com/PerCollECT



Sensor Model Customization
Basis e.g.: OpenMSL Open Source Perception Sensor Models with object and/or detection in-/output

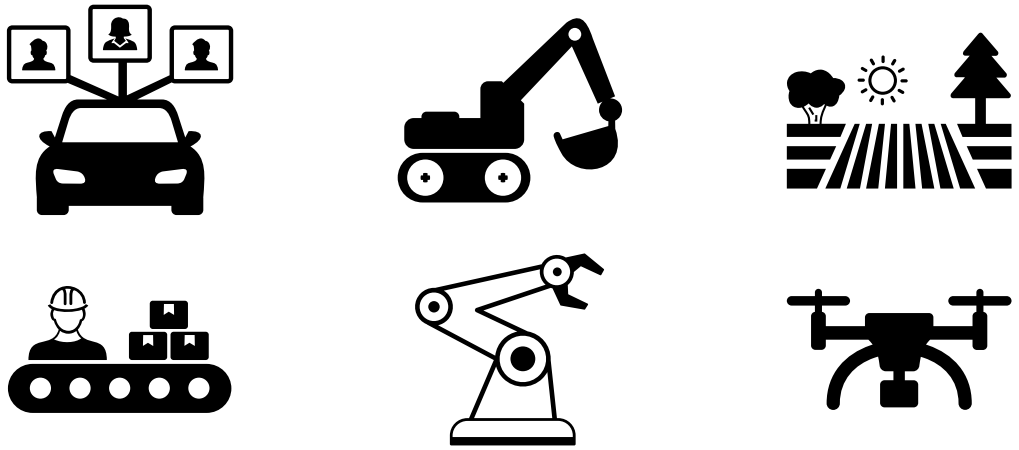
github.com/OpenMSL

Sensor Model Integration
Incl. usage and further development of ASAM OpenX standards like Open Simulation Interface (OSI)

Sensor Model Validation
Sample validation measurements with reference sensors on test track
Uncertainty quantification of models for their application

Targeted Markets

One Solution – Multiple Domains



Further information

- FZD Datasets: https://www.fzd-datasets.de/overview/
- Perception Sensor Collaborative Effect and Cause Tree (PerCollECT) for Lidar: https://github.com/PerCollECT/LidarLimbs
- asc(s e.V. - ENVITED Open Source Model & Simulation Library: https://github.com/openMSL
- Linnhoff et al.: *Measuring the Influence of Environmental Conditions on Automotive Lidar Sensors*, https://www.mdpi.com/1424-8220/22/14/5266
- Linnhoff et al.: *Simulating Road Spray Effects in Automotive Lidar Sensor Models*, http://arxiv.org/abs/2212.08558
- PhD thesis Linnhoff: *Analysis of Environmental Influences for Simulation of Active Perception Sensors*, https://tuprints.ulb.tu-darmstadt.de/23116/
- PhD thesis Rosenberger: *Metrics for Specification, Validation, and Uncertainty Prediction for Credibility in Simulation of Active Perception Sensor Systems,* https://tuprints.ulb.tu-darmstadt.de/23034/
- ASAM e.V. OpenODD: https://www.asam.net/standards/detail/openodd/

Questions to the Audience

- How will the shown influences possibly affect downstream signal processing algorithms?
  (object detection, SLAM etc.)
- Is it possible to have a generic simulation model with environmental conditions that can be parameterized to different lidar sensors?
- What part does the ODD play when considering environmental conditions?
  (There is no rain in parking structures, but there is a lot of dust on a corn field)

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