



# CHALLENGES OF AUTOMOTIVE PERCEPTION UNDER ADVERSE VISIBILITY CONDITIONS FOR AUTOMATIC DRIVING SYSTEMS (ADS)

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DVN 8th Conference Lidar / AD – 19-20 Nov. 2025, Wiesbaden

## CURRENT STATUS AUTOMATIC DRIVING

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- China (Pony AI) and USA (Waymo): Level 4 Robotaxis in urban areas (Wuhan and San Francisco)
- Europa: Level 3 "Conditional Driving Automation" first serial products on the road Focus on highways)
  - Mercedes DRIVE PILOT, allows conditionally automated driving at up to 95 km/h on German highways under specific conditions.
  - BMW Personal Pilot L3 enables drivers to hand over control of the vehicle completely to the system at speeds of up to 60 km/h on separate lanes of motorways in Germany.

**One main difference is the max. speed: Robotaxis mostly  $\leq 40$  km/h, European L3 application up to 130km/h and thus the observation distance**

**46 m**

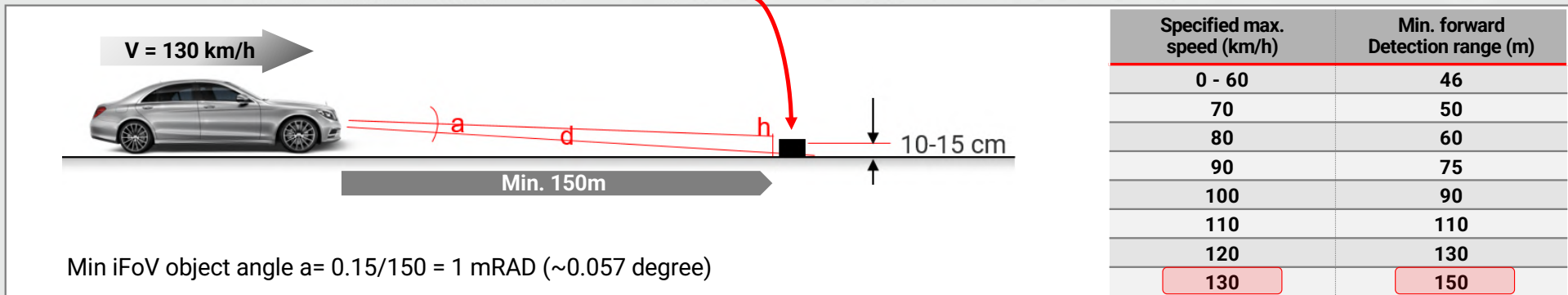
**150 m**

# UN REGULATION ALLOWS AUTOMATED DRIVING UP TO 130 KM/H



## January 1<sup>st</sup>, 2023: Revised UNECE regulation R157 for ALKS comes into effect for all contracting countries (42)

- Allows OEMs to legally provide customers with ALKS (SAE Level 3 up to 130 km/h for “Minimum forward detection range”)
- “A passable object is such an object, **that may be driven over without causing an unreasonable risk** to the vehicle occupants or other road users regardless of whether the tyre of the ALKS vehicle encounters the object or not.”
- ALKS can *only* operate in conditions that allow bigger than “**passable object**” to be detected



- ▶ **Min iFoV sampling angle 0,01 degree!!** Min Resolution due to sampling theorem **x2** | traversability **x2** | safety margin **x2**
- ▶ Means vertical resolution of **2000** lines with a required 30x20 degree FoV
- ▶ **Challenging with current LiDAR!**

# NEW UN REGULATION: ALKS MUST TAKE WEATHER INTO ACCOUNT



United Nations  
ECE/TRANS/WP.29/2022/59/Rev.1

**Economic and Social Council**  
Distr.: General  
30 May 2022  
Original: English

**SINCE JANUARY 1ST 2023**

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**Economic Commission for Europe**  
Inland Transport Committee  
**World Forum for Harmonization of Vehicle Regulations**  
187th session  
Geneva, 21-24 June 2022  
Item 4.8.2 of the provisional agenda  
**1958 Agreement:**  
Consideration of draft amendments to existing  
UN Regulations submitted by GRVA

**Proposal for the 01 series of amendments to UN Regulation No. 157 (Automated Lane Keeping Systems)**

Submitted by the Working Party on Automated/Autonomous and Connected Vehicles'

Revision 1

The text reproduced below was adopted by the Working Party on Automated/Autonomous and Connected Vehicles (GRVA) at its thirteenth session. It is based on ECE/TRANS/WP.29/2022/59, as amended by GRVA-13-48/Rev.1. It is submitted to the World Forum for Harmonization of Vehicle Regulations (WP.29) and to the Administrative Committee (AC.1) for consideration at their June 2022 sessions.

## 5.2.3.2. The activated system shall adapt the vehicle speed to infrastructural and environmental conditions (e.G. Narrow curve radii, inclement weather)

"Automated lane keeping system (ALKS)" is a system which is activated by the driver and which keeps the vehicle within its lane for travelling speed of 130 km/h or less by controlling the lateral and longitudinal movements of the vehicle for extended periods without the need for further driver input.

- 2.1. "Operational design domain (ODD)" of the automated lane keeping system defines the specific operating conditions (e.G. Environmental, geographic, time-of-day, traffic, infrastructure, speed range, **weather** and other conditions) within the boundaries fixed by this regulation under which the automated lane keeping system is designed to operate without any intervention by the driver.
- 2.8. "operational design domain (ODD)" of the automated lane keeping system defines the specific operating conditions (e.G. Environmental, geographic, time-of-day, traffic, infrastructure, speed range, **weather** and other conditions)
- 2.9. "Operational design domain (ODD)" of the automated lane keeping system defines the specific operating conditions (e.G. Environmental, geographic, time-of-day, traffic, infrastructure, speed range, **weather** and other conditions) within the boundaries fixed by this regulation under which the automated lane keeping system is designed to operate without any intervention by the driver.
- 2.11. "Control strategy" means a strategy to ensure robust and safe operation of the function(s) of "the system" in response to a specific set of ambient and/or operating conditions (such as road surface condition, traffic intensity and other road users, **adverse weather conditions**, etc.). This may include the automatic deactivation of a function or temporary performance restrictions (e.G. A reduction in the maximum operating speed, etc.).



# THE CHALLENGE

**Mandatory:** For safety reason as a minimum, the L3 system must be able to detect and delegate the driving task back to the driver on time if inoperability is foreseeable:

**SAE J3016™ LEVELS OF DRIVING AUTOMATION™**  
 Learn more here: [sae.org/standards/content/J3016\\_202104](https://www.sae.org/standards/content/J3016_202104)

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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are <b>not</b> driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	<b>These are driver support features</b> These features are limited to providing warnings and momentary assistance These features provide steering OR brake/acceleration support to the driver These features provide steering AND brake/acceleration support to the driver			<b>These are automated driving features</b> These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met This feature can drive the vehicle under all conditions		
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering OR</li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering AND</li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>
	Current systems			Next generation systems - ADS		
	Driver is responsible for driving task			ADS is responsible for driving task		

For broad market acceptance: The system should also function in adverse weather conditions (up to a defined degree). ... means to be able to detect the „lost cargos“

Lost Cargo Detection Capability In Adverse Weather

**ODD Monitoring (Visibility Estimation):** The system must independently detect its inoperability in e.g. adverse weather! and inform the driver to take over in good time

Visibility Estimation Capability

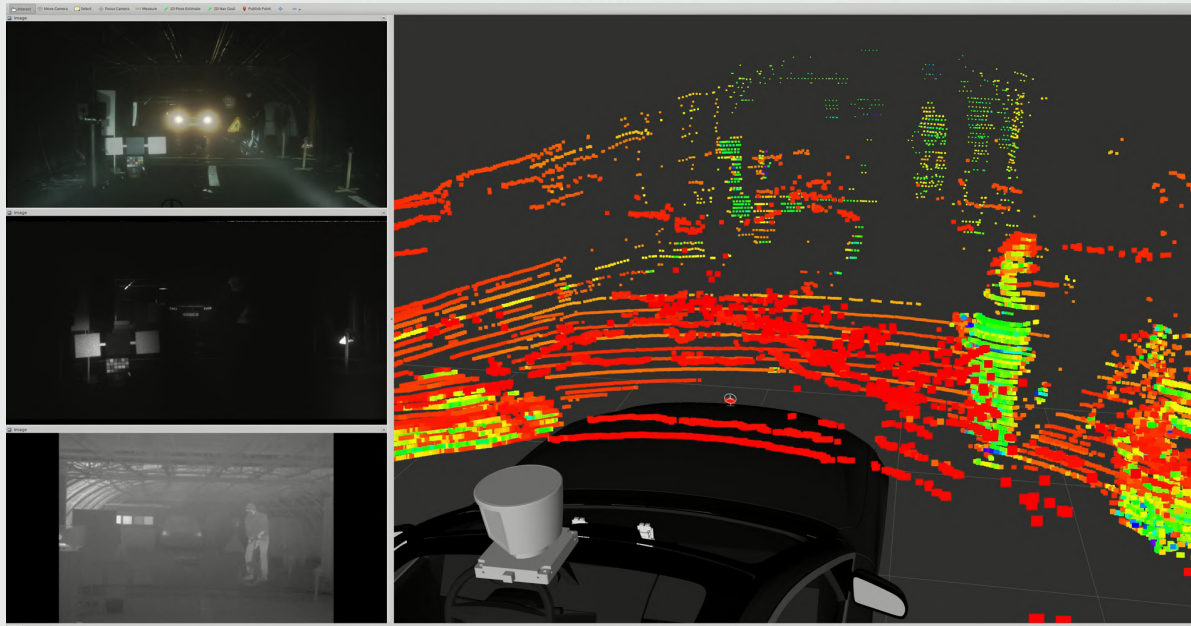
The background is a solid red color with various faint, light-red geometric patterns and symbols scattered across it. These include circles, squares, lines, and 'X' marks, some of which are larger and more prominent than others. The overall aesthetic is modern and technical.

# LOST CARGO DETECTION IN ADVERSE WEATHER

# ADVERSE WEATHER CHALLENGES



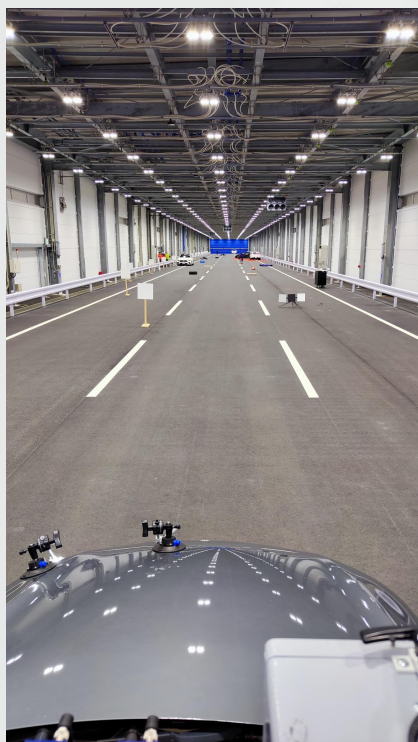
**AW-Test in 2016:** Installed sensors performance degrades strongly in bad weather, e.g. Fog with 50m-60m visibility range



- **Stereo Camera**  
Short visibility, invisible pedestrians next to a blinding car headlight
- **Gated Camera** (an AI-SEE development)  
larger visibility and less problems with backscattering/airlight
- **LiDAR**  
lots of reflections directly in front
  - ▶ Pedestrians at approx. 30m from vehicle can not be detected (not visible) with either the LiDAR or conventional camera.
  - ▶ Only “visible” with thermal imaging or a gated camera

**AW-Test in 2024:** Conventional sensors still degrade strongly in adverse weather conditions !

# LOST CARGO MEASUREMENT CAMPAIGN IN THE JARI WEATHER CHAMBER IN DEC 2024



Test scenario for lost cargo distributed over 200 m weather chamber length.

Quiz: Where is the motorcyclist?



# LOST CARGO MEASUREMENT CAMPAIGN IN THE JARI WEATHER CHAMBER



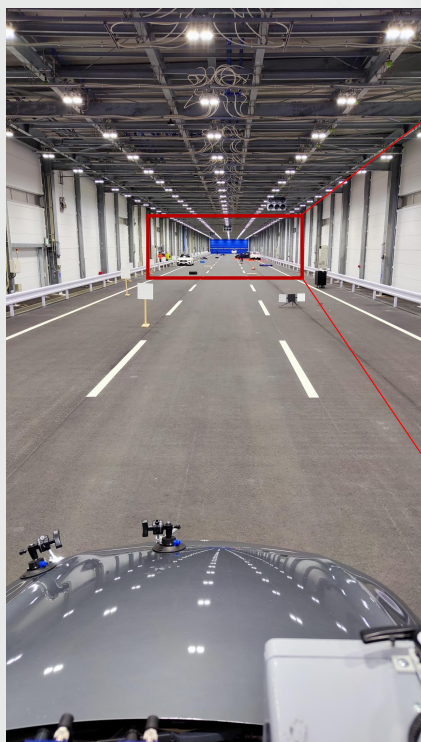
Motorcyclist  
160m

100,25 SQS white from the back	
110,00 S-Klasse blue from the side	
110,00 Bumper	
120,00 tire	
160,00 motorcyclist	
170,00 wooden bar	
Pedestrian Standing dark	
180,00 blue	
190,25 car Mistubishi	

49,00 Palette				
50,50 Tire				
60,00 Bricks				
70,00 Light Blue Doll laying perpendicular to car				
70,00 Mercedes C-Klasse T				
80,00 Exhaust				
85,00 Plastic Box blue				
87,50 Dark Blue Doll Standing looking in front to the car				



# A BIT HARDER: LOST CARGO > 75 M DISTANCE WITH FOG 80M VISIBILITY



Fog 80 m visibility range,



# MB & JARI - CONTROLLED FOG CHAMBER SETTINGS - LOST CARGO TEST SCENARIO



## Fog Chamber Characteristics (JARI)

- ▶ Rain: Two different sprinklers with particle size of  $640\mu\text{m}$  and  $1400\mu\text{m}$ , and 3 precipitation levels: strong (30 mm/h), intense (50 mm/h), and very intense (80 mm/h)
- ▶ Strong light: Controlled mobile 6 kW xenon light source with maximum luminous intensity of 350Mcd, and adjustable position, yaw and pitch angles
- ▶ Reproducible adverse weather effects ranging from rain to strong oncoming sunlight and fog
- ▶ 200m long and 15m wide fog chamber
- ▶ Fog:  $7.5\mu\text{m}$  particle size and controllable visibility of 10m up to 80m

## Ground Truth Depth Acquisition

- ▶ Ground Truth Depth Acquisition for static scenarios with a Leica ScanStation P30 laser scanner
- ▶ Accumulation of multiple point clouds, captured at different overlapping positions to mitigate occlusions and increase resolution

## Scenario Setup

- ▶ Highway scenarios with lost cargo and constructions site
- ▶ Lost cargo objects, pedestrians (mannequins), and cars are placed at different distances in the fog chamber
- ▶ Each scenario is captured in clear, rain, and fog conditions

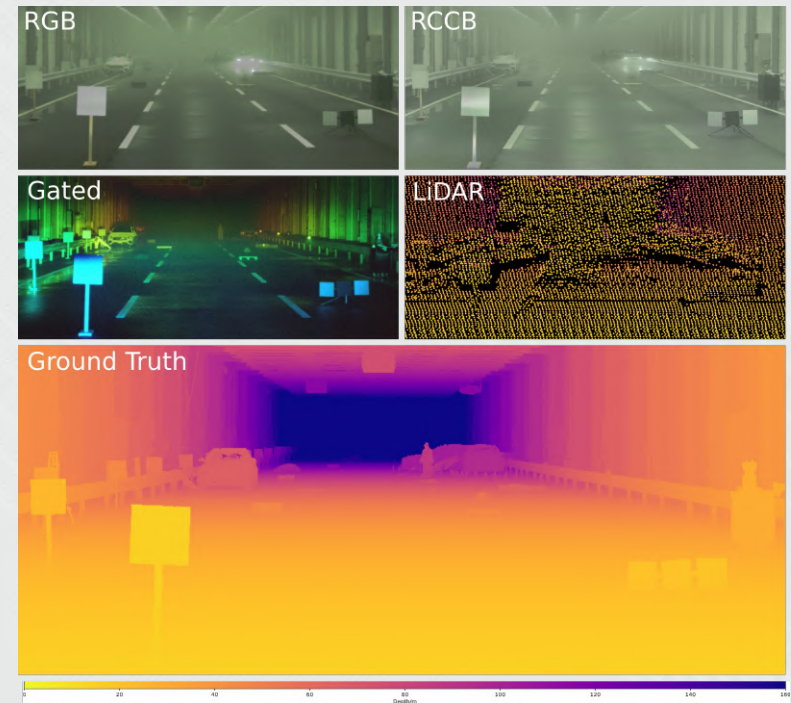


Fig. 1: Sensor Measurements and Ground Truth Depth.



# MB & JARI - QUANTITATIVE DEPTH ESTIMATION RESULTS FOR LOST CARGO EVALUATION



	METHOD	clear					rain					fog				
		RMSE	MAE	$\delta_1$	$\delta_2$	$\delta_3$	RMSE	MAE	$\delta_1$	$\delta_2$	$\delta_3$	RMSE	MAE	$\delta_1$	$\delta_2$	$\delta_3$
DAY	RGB	16.81	5.50	92.22	95.84	<b>99.83</b>	16.85	5.85	92.49	96.02	<b>99.89</b>	27.14	12.50	78.27	85.42	91.60
	Stereo-RGB	6.81	5.11	<u>98.43</u>	<u>99.53</u>	<u>99.82</u>	10.39	6.49	91.29	97.42	98.68	29.03	16.02	71.86	80.80	86.14
	LiDAR-RGB	6.84	2.75	<u>97.53</u>	<u>99.30</u>	<u>99.75</u>	14.86	5.86	89.99	95.18	96.95	55.62	36.05	32.02	36.72	41.33
	RCCB	17.21	7.39	91.66	97.82	99.02	28.58	14.62	65.94	90.22	95.26	<u>15.87</u>	<u>7.80</u>	<u>88.37</u>	<u>95.77</u>	<u>98.18</u>
	Stereo-RCCB	7.41	4.62	97.63	99.10	99.59	8.20	5.62	87.41	96.91	99.35	27.29	15.15	71.72	80.52	86.96
	LiDAR-RCCB	7.20	2.97	96.82	98.97	99.76	16.29	6.56	87.48	93.74	96.37	56.78	37.47	29.90	34.63	39.56
	Stereo-Gated	<u>5.95</u>	<u>2.42</u>	98.27	99.52	99.70	<u>7.56</u>	<u>3.21</u>	<b>97.83</b>	<u>99.35</u>	99.56	<b>11.30</b>	<b>5.41</b>	<b>92.73</b>	<b>98.28</b>	<b>99.43</b>
	Stereo-Gated-RCCB	<b>5.22</b>	<b>1.68</b>	<b>98.84</b>	<b>99.58</b>	99.75	<b>6.81</b>	<b>2.53</b>	<u>97.75</u>	<b>99.36</b>	<u>99.60</u>	28.07	14.08	75.16	82.02	87.67
NIGHT	RGB	17.07	6.13	91.45	95.90	<b>99.90</b>	48.60	27.43	44.58	60.28	73.08	46.53	24.79	55.99	67.97	75.02
	Stereo-RGB	7.00	5.14	96.93	<b>99.58</b>	<u>99.83</u>	10.27	7.43	82.03	94.25	99.27	34.91	19.54	59.82	74.23	82.04
	LiDAR-RGB	6.74	2.70	97.86	99.42	<u>99.75</u>	16.98	6.81	87.67	93.48	95.64	55.37	35.81	32.21	37.22	42.12
	RCCB	24.16	10.93	82.88	93.66	97.51	39.19	21.73	49.94	72.37	86.19	<u>23.60</u>	<u>11.06</u>	<u>80.50</u>	<u>92.29</u>	<u>96.64</u>
	Stereo-RCCB	7.64	4.74	97.10	99.12	99.69	<u>7.87</u>	4.71	96.93	99.13	<b>99.66</b>	33.46	19.55	58.45	69.40	78.04
	LiDAR-RCCB	6.84	2.83	97.09	99.09	99.77	17.25	6.86	86.83	93.29	95.94	56.16	36.80	30.76	35.65	40.64
	Stereo-Gated	<u>6.06</u>	<u>2.49</u>	<u>98.36</u>	99.51	99.70	7.99	<u>3.82</u>	<u>97.87</u>	<u>99.38</u>	99.61	<b>10.56</b>	<b>4.90</b>	<b>93.90</b>	<b>98.44</b>	<b>99.47</b>
	Stereo-Gated-RCCB	<b>5.33</b>	<b>1.64</b>	<b>98.78</b>	<u>99.56</u>	99.73	<b>6.46</b>	<b>2.15</b>	<b>98.16</b>	<b>99.39</b>	<u>99.63</u>	29.84	14.12	75.99	82.79	88.26

### RGB/RCCB based methods:

- ▶ Good performance in daytime
- ▶ Limited performance in nighttime due to reduced visibility

### LiDAR based methods:

- ▶ Good performance in clear conditions
- ▶ Limited performance in adverse weather due to clutter within the point clouds

### Gated based methods:

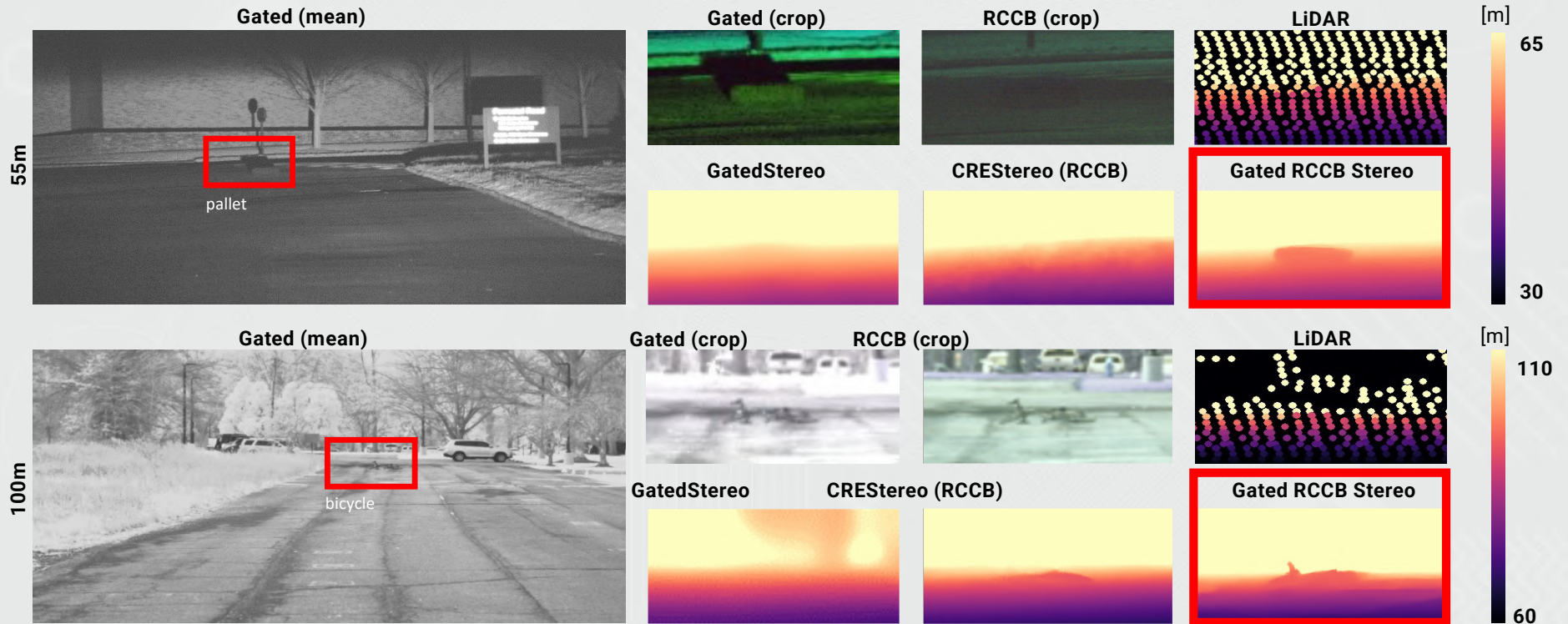
- ▶ Strong performance at day and night
- ▶ Good performance in adverse weather due to the gating principle, reducing backscatter significantly

▶ For more details see Paper "A Multi-Modal Benchmark for Long-Range Depth Evaluation in Adverse Weather Conditions, IROS 2025"

**Lost Cargo Detection Benchmark!**



# GATED RCCB STEREO FOR LOST CARGO DEPTH ESTIMATION



**So that ... Gated RCCB Stereo is Currently THE Best solution Worldwide for Lost Cargo Depth Estimation!**

► For more information see Paper CVPR 2024 "Cross-spectral Gated-RGB Stereo Depth Estimation"



# VISIBILITY ESTIMATION

The background is a solid red color with a complex, abstract geometric pattern. The pattern consists of various shapes and lines in a lighter red shade, including circles, squares, triangles, and zig-zag lines. Some of these shapes are filled with fine, parallel lines, creating a textured effect. The overall composition is symmetrical and modern.

# VISIBILITY ESTIMATION



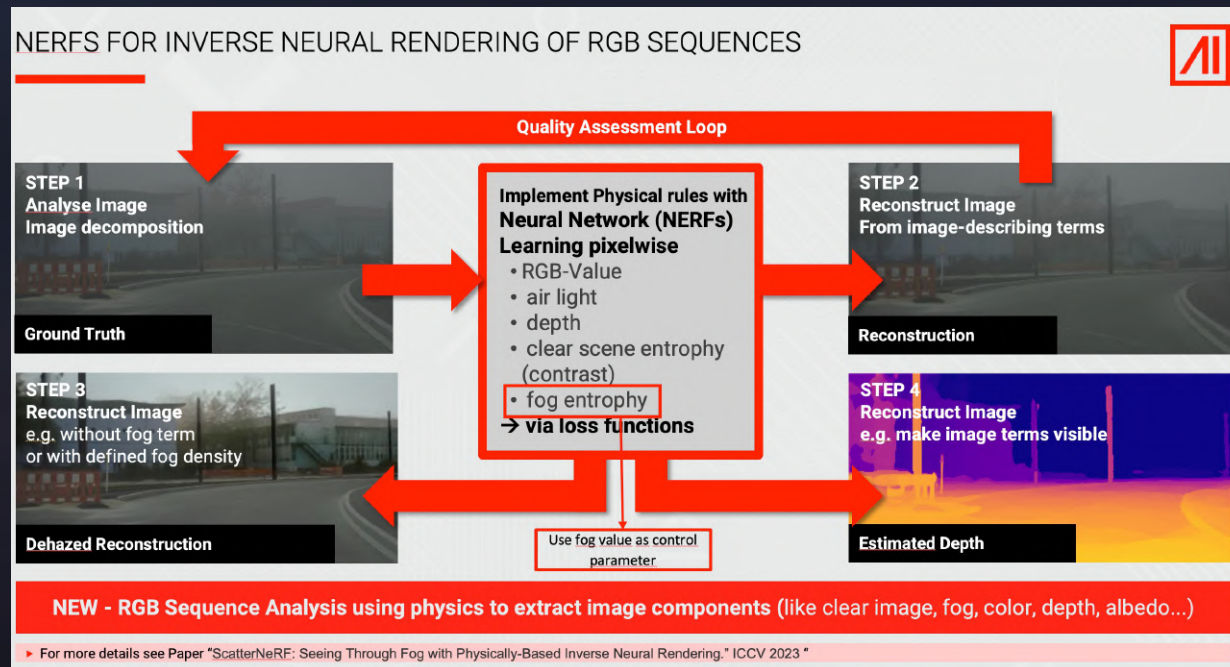
## Question to be answered:

- Can I still detect lost cargo in time at my current speed ... even under the current visibility conditions?
- A physics-based solution proposal was developed in AI-SEE.


## HOW (What Method) ?:

### Imponderables:

- Day and night and/or AW particles in the air
- Object/Background Reflectivity per se unknown (from traffic participants and also from )
- Light sources unknowns (air light, lamps, reflected light from objects, etc.)
- 3D-Geometrie of the scene unknown
- When you "see" fog clutter with LiDAR than you are to late to switch off the system
- In presence of spray (additional strong clutter)



► Extended Approach with Gated Cam see CVPR 2024 "Gated Fields: Learning Scene Reconstruction from Gated Videos"



BACK UP GATED CAMERA  
RESILIENT AGAINST ADVERSE WEATHER  
CLEAR IMAGE + HIGH RESOLUTION 3D DEPTH MAP  
INHERENT WEATHER (VISIBILITY) MONITORING

# ADVANTAGES OF A GATED CAMERA (COMPARED TO A STANDARD CAMERA)



RGB-Standardcamera

Gated Camera

Fog chamber scenario,  
50m visibility.



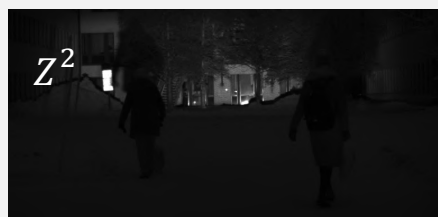
snow scenario



**The Gated Image is almost undisturbed by adverse weather due to gating effect!**

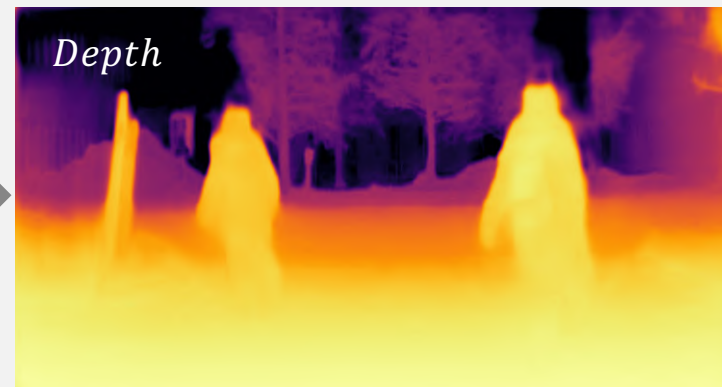


# GATED DEPTH ESTIMATION – INHERENT DEPTH ESTIMATION FROM 3 GATED DEPTH SLICES



Gated Images

Neural Network  
based  
Approach

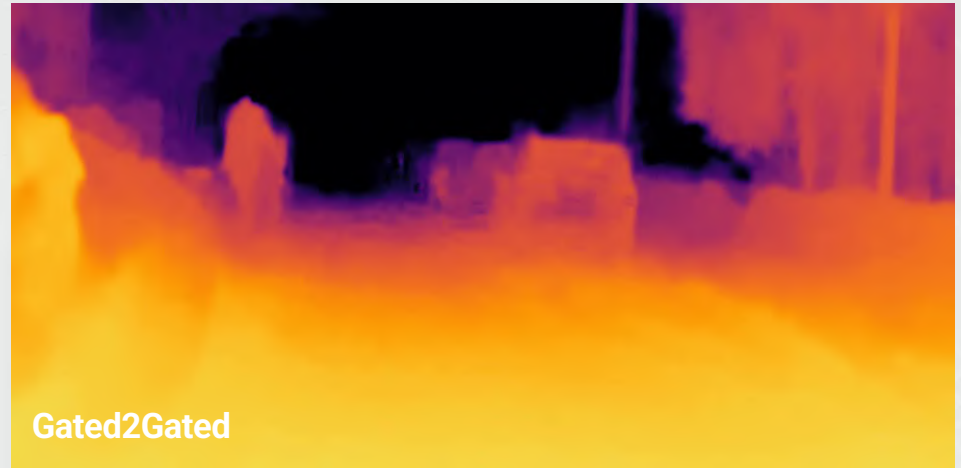
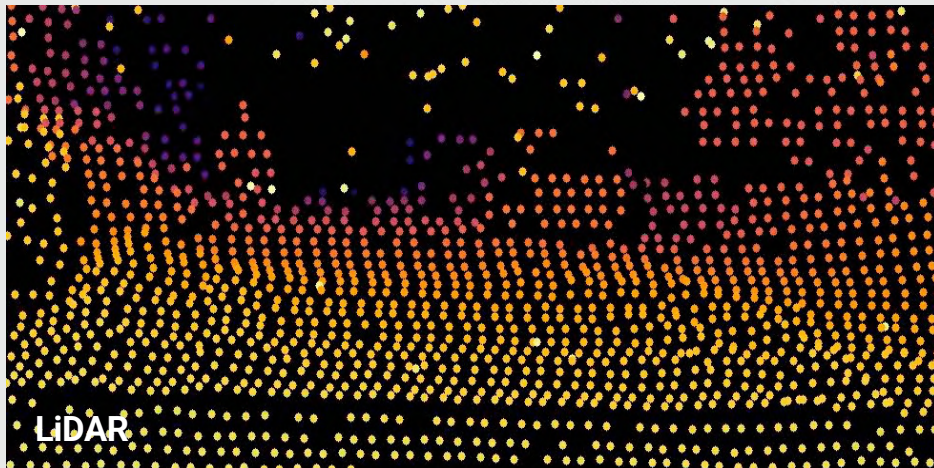
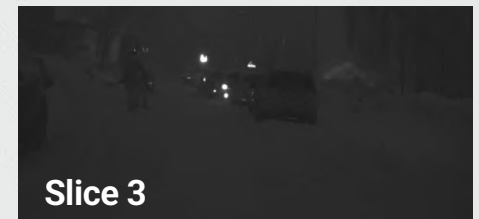
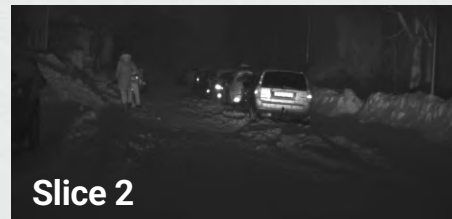


Depth Map Resolution 1280x720

**Additionally to clear images, the gated camera can be also used to inherently generate high-resolution depth maps!**



# QUALITATIVE RESULT IN SNOW – STATUS FROM 2021



Status 2021 - Depth Map Resolution of 1280x720 (better than any LiDAR), Accuracy better than 5%\*distance

The background is a solid red color with various faint, semi-transparent geometric patterns and symbols scattered across it. These include circles, squares, lines, and crosses. A large, faint circle is centered on the left side, and another is in the top right. There are also several crosses and lines of varying sizes and orientations. The overall aesthetic is modern and abstract.

TAKE AWAY

## TAKE AWAY

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- For a broad market acceptance of automatic driving an extension of the availability to adverse visibility conditions is a must!
- This requires a least two AD system capabilities:
  - Lost cargo detection capability in adverse weather/visibility conditions (with improved or novel sensors)
  - A good working visibility estimation algorithm based on improved or novel sensors
- Gated Camera proved to be the benchmark solution for lost cargo detection in all (good and adverse) weather conditions. Adaption to prevailing visibility conditions with inherent visibility estimation based on physical laws could be demonstrated.



# THANK YOU FOR YOUR ATTENTION

For more information about the project AI-SEE contact

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