Impact of LiDAR Performance Degradation Caused by Outer Factors on Headlight Lens

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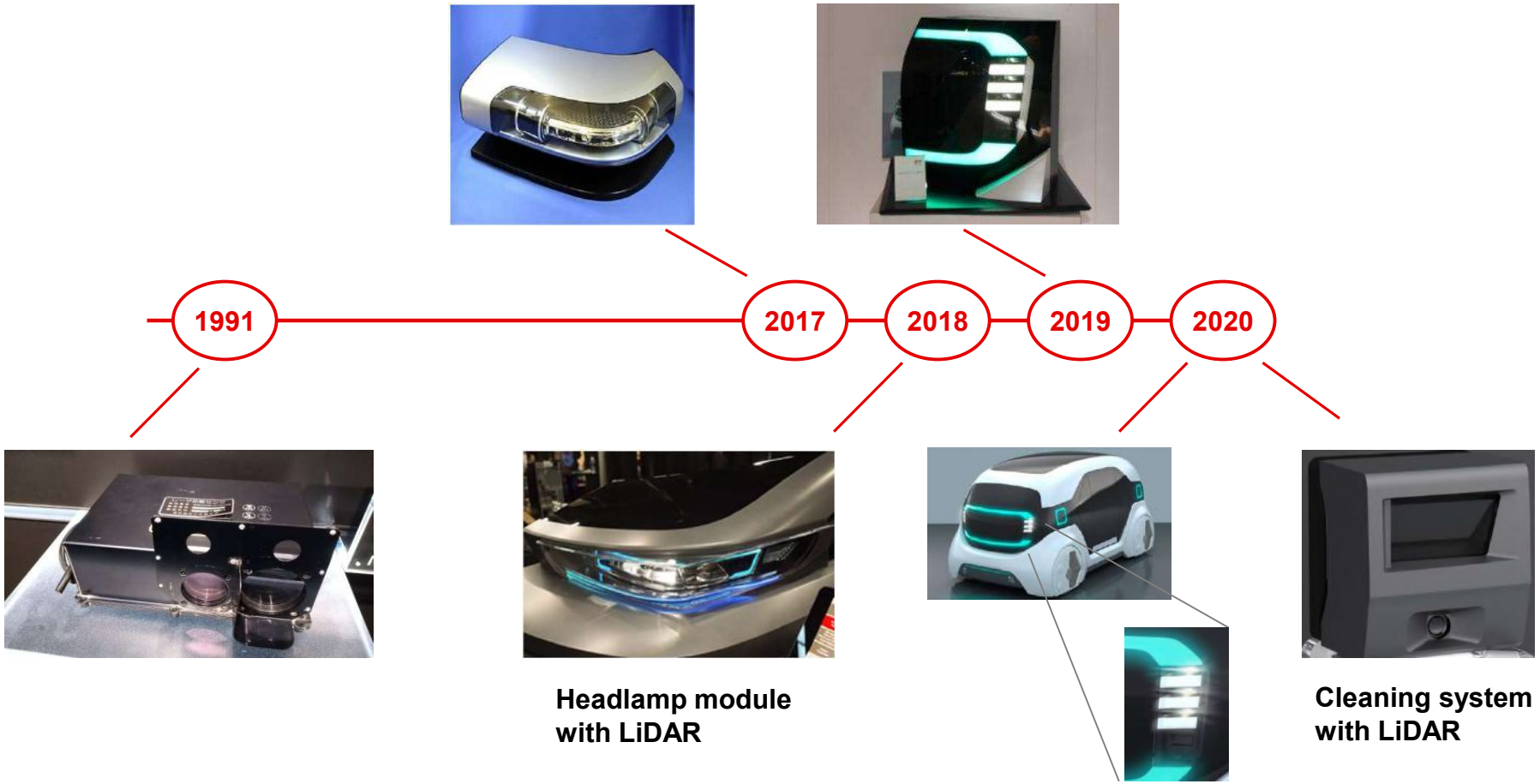
- Introduction (about Koito)
- The Issue: Impact of outer lens degradation on sensor performance
- Experimental method and verification procedure
- Experimental results and discussion
- Suggested solutions (Cleaner)
- Conclusion

Introduction: Koito LiDAR History

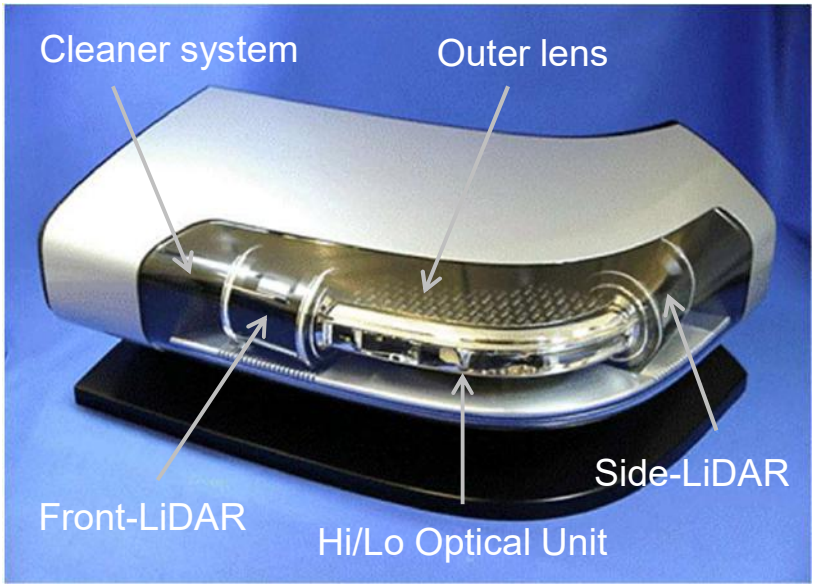
- Developing Laser Range Finder in 1991.
- Suggesting headlamp and cleaning system with sensor (CES 2020).
  - Headlamp module built-in LiDAR
  - Compact integrated module of LiDAR/Camera with cleaning system



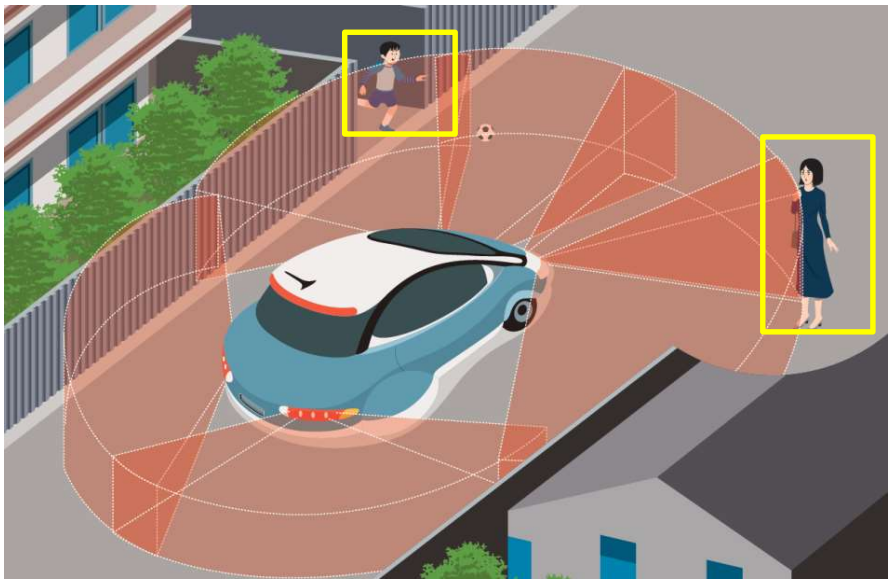
Introduction: Purpose of Sensor Built-in Headlamp

1. Sensor built-in headlamp / rear lamp at four corners of vehicle detect pedestrians and vehicles at 360˚ around the vehicle.
2. Outer lens protects sensor from pebbles and dirt.
3. Headlamp cleaner removes dirt to maintain sensor performance.

Expected features

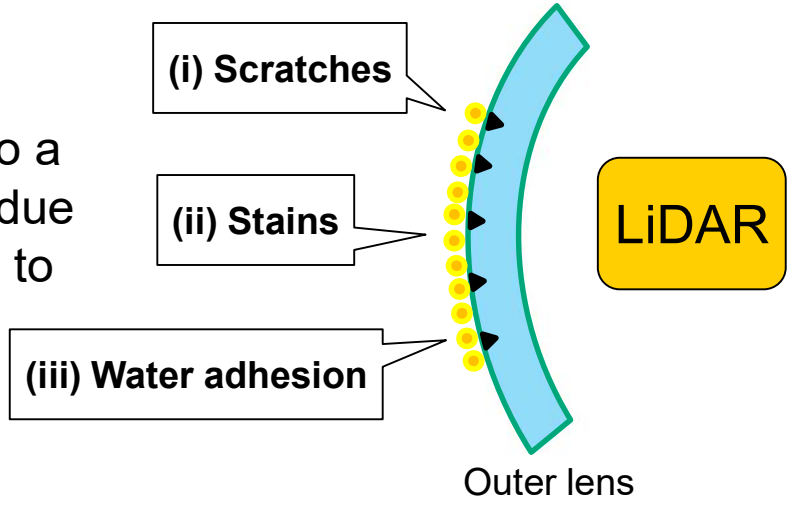


Conceptual diagram



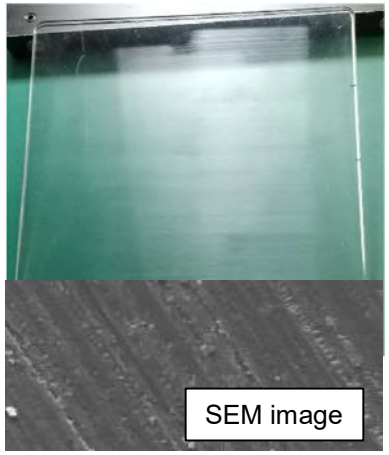
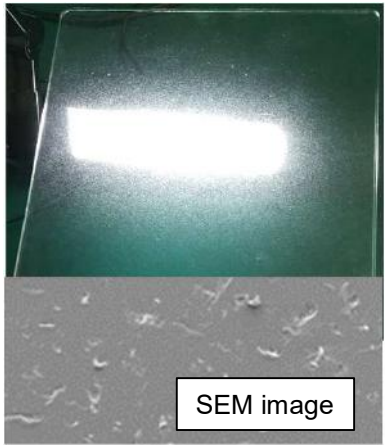
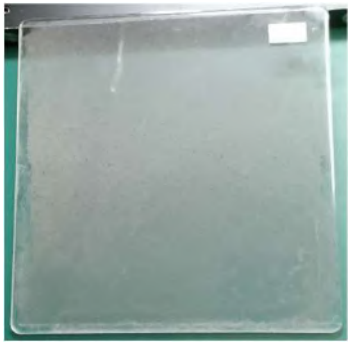
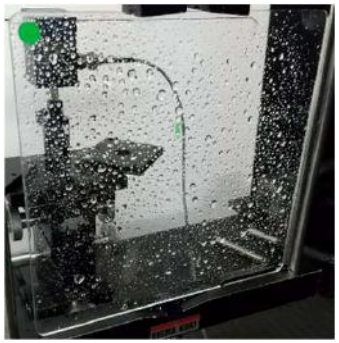
Influence on LiDAR Performance Due to Outer Lens Degradation

A serious concern when sensors are built into a lamp is the influence of LiDAR performance due to scratches and adhesion of mud and water to the lens.



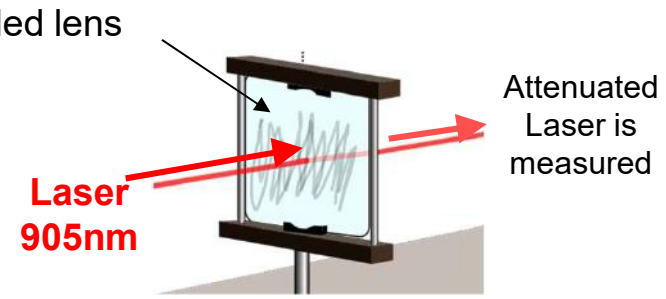
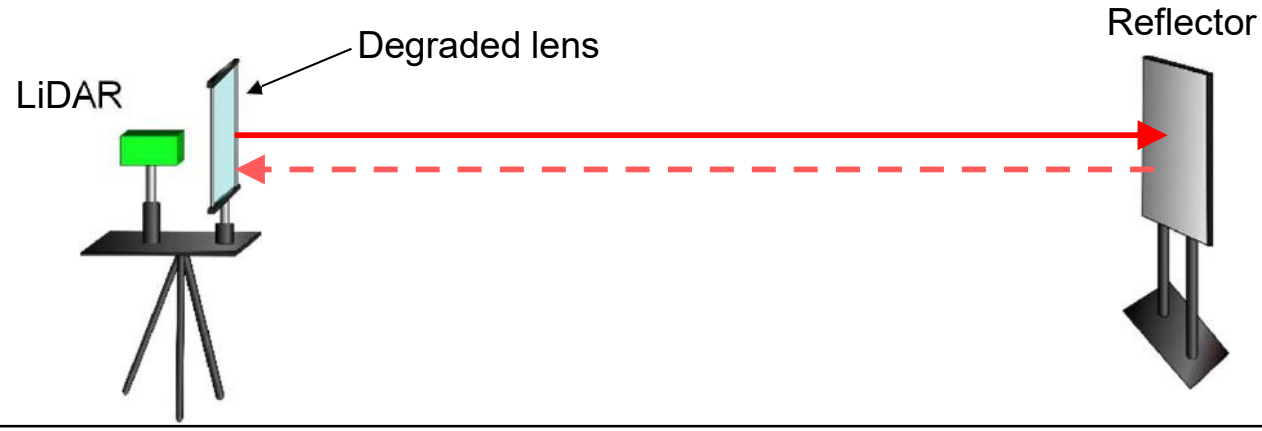
(i) Scratches	(ii) Stains	(iii) Water adhesion
Car wash, scratches, pebbles, flying rocks	Mud, sand, dust	Rain, fog
		

Reproduction of Deteriorated Lens

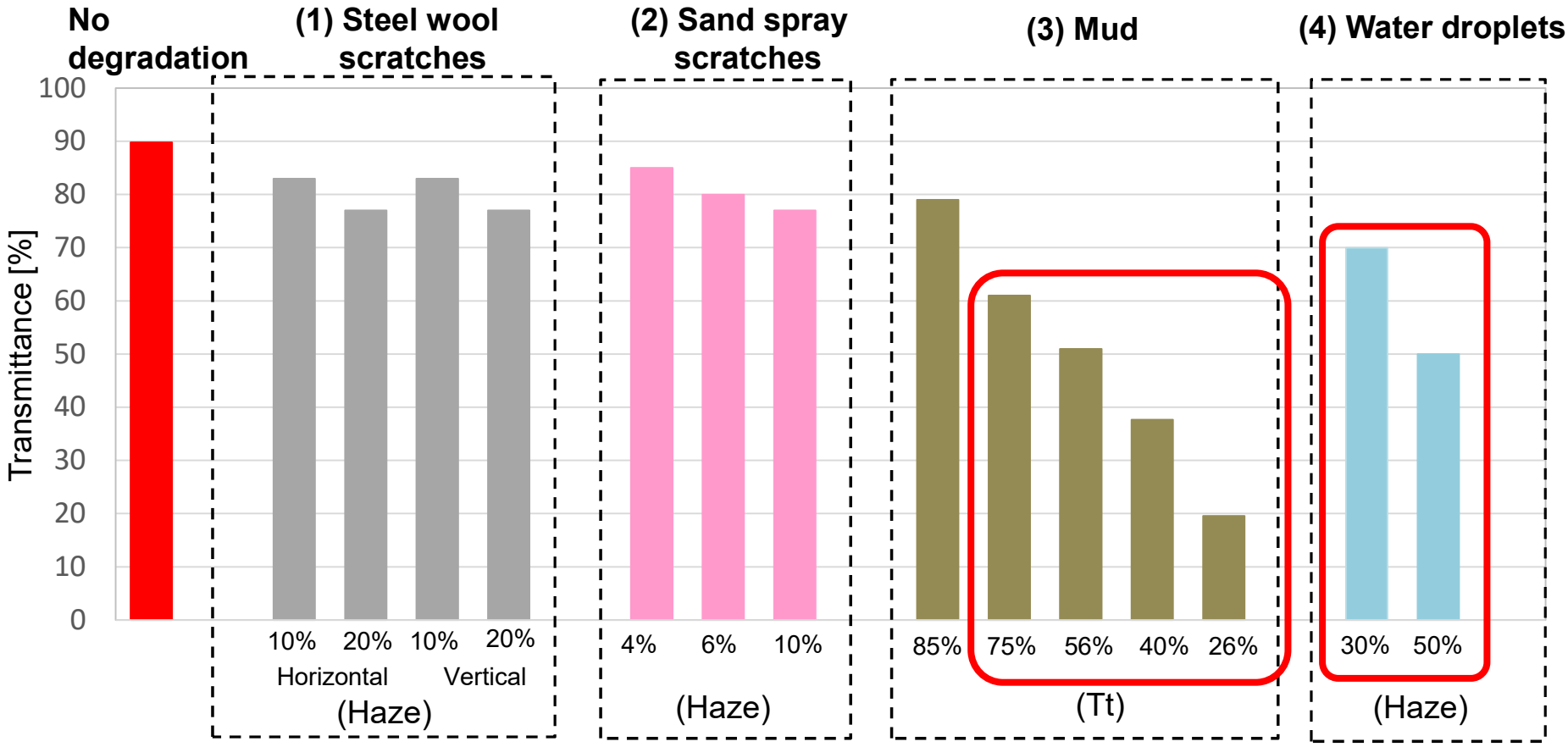
(i) Scratches		(ii) Stains	(iii) Water adhesion
(1) Steel wool scratches (anisotropic)	(2) Sand spray (microscopic dents)	(3) Standardized mud for cleaner test	(4) Spray gun
Haze(*1): 10%/20%	Haze: 4%/6%/10%	Tt(*2): 85%/75%/56%/40%/26%	Haze: up to 50%
			

(*1) Haze: ratio of light diffusion at the material
(*2) Tt: ratio of visible light transmittance through the material

Effect of Lens Degradation: Steps of Verification

Step 1	**Measure the transmittance of a 905 nm wavelength laser** 
Step 2	**Evaluate detection performance using LiDAR by:** **(1) Measuring the maximum detection distance** **(2) Measuring the detection position** 

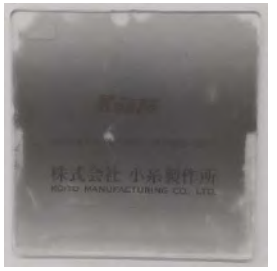
Step 1: Result: Laser Transmittance of Degraded Lens



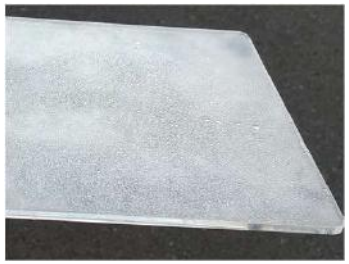
- Transmittance of mud samples decreases as mud becomes thicker from transmittance 75%
- Water adhesion is a major factor to attenuate laser.

Step 1: Appearance of Degraded Lens

(3) Mud

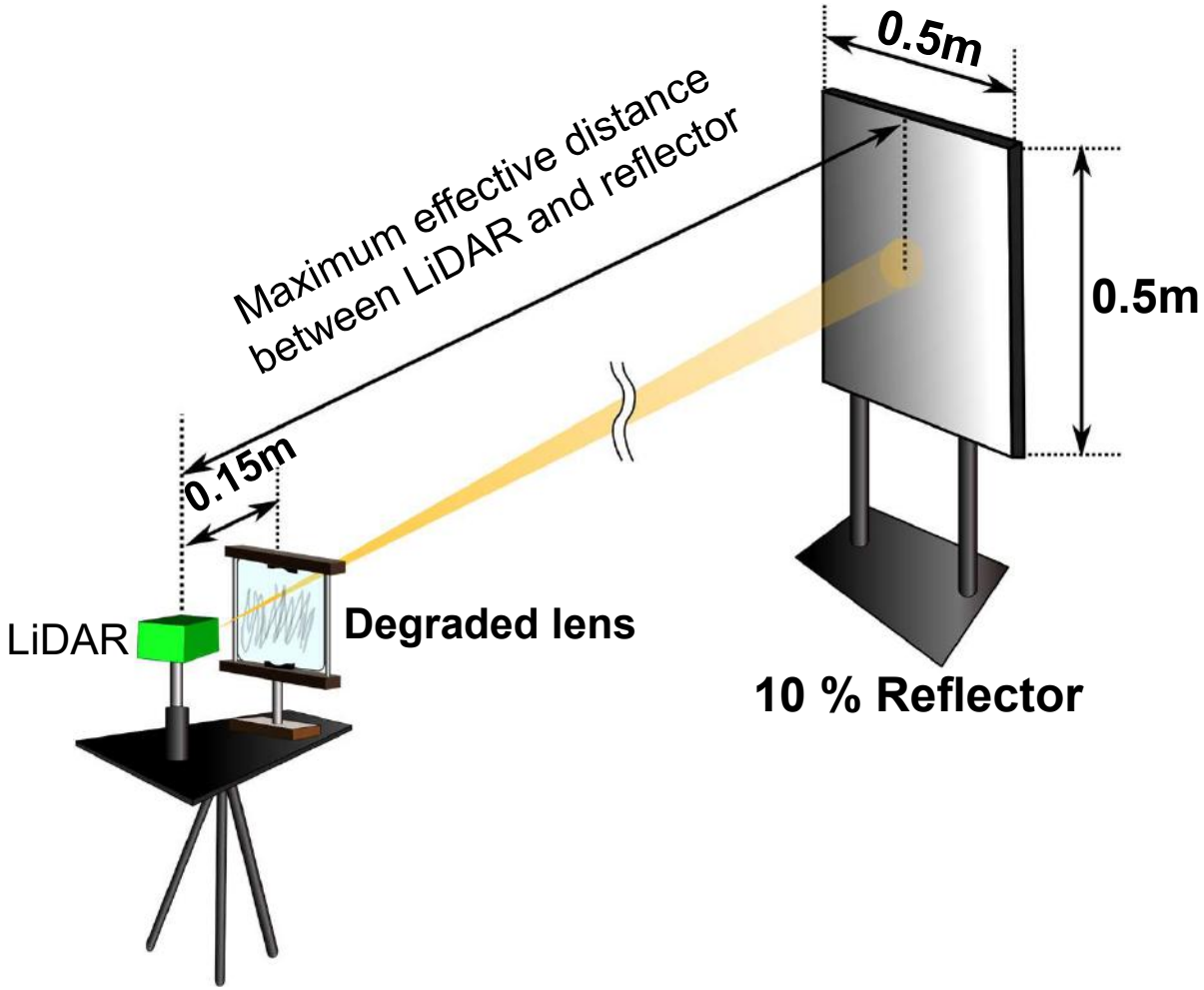
Appearance					
Transmittance	**85%**	**75%**	**56%**	**40%**	**26%**

(4) Water droplets

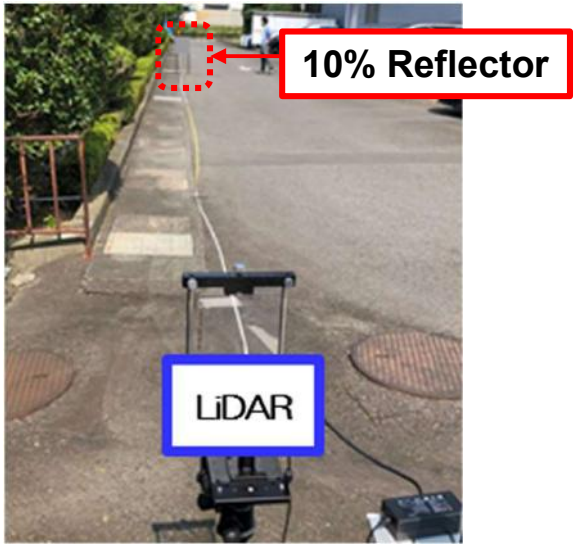
Appearance		
Transmittance	**70%**	**50%**

- Influence of water droplets depends on how they adheres.
- Tiny and congested droplets blocks laser most.

Step 2: (1) Evaluation of LiDAR's Maximum Effective Distance

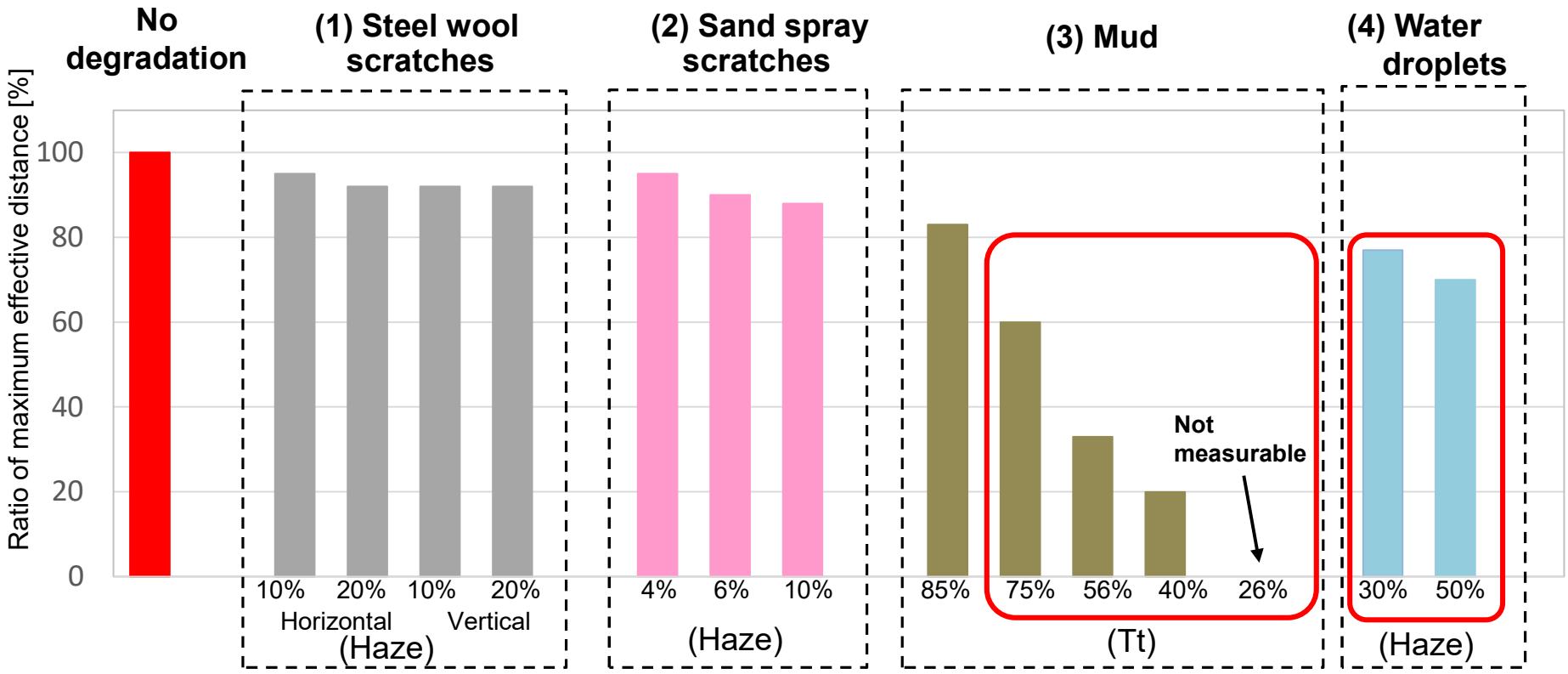


Overview of the experiment



（＊）LiDAR: MEMS and ToF

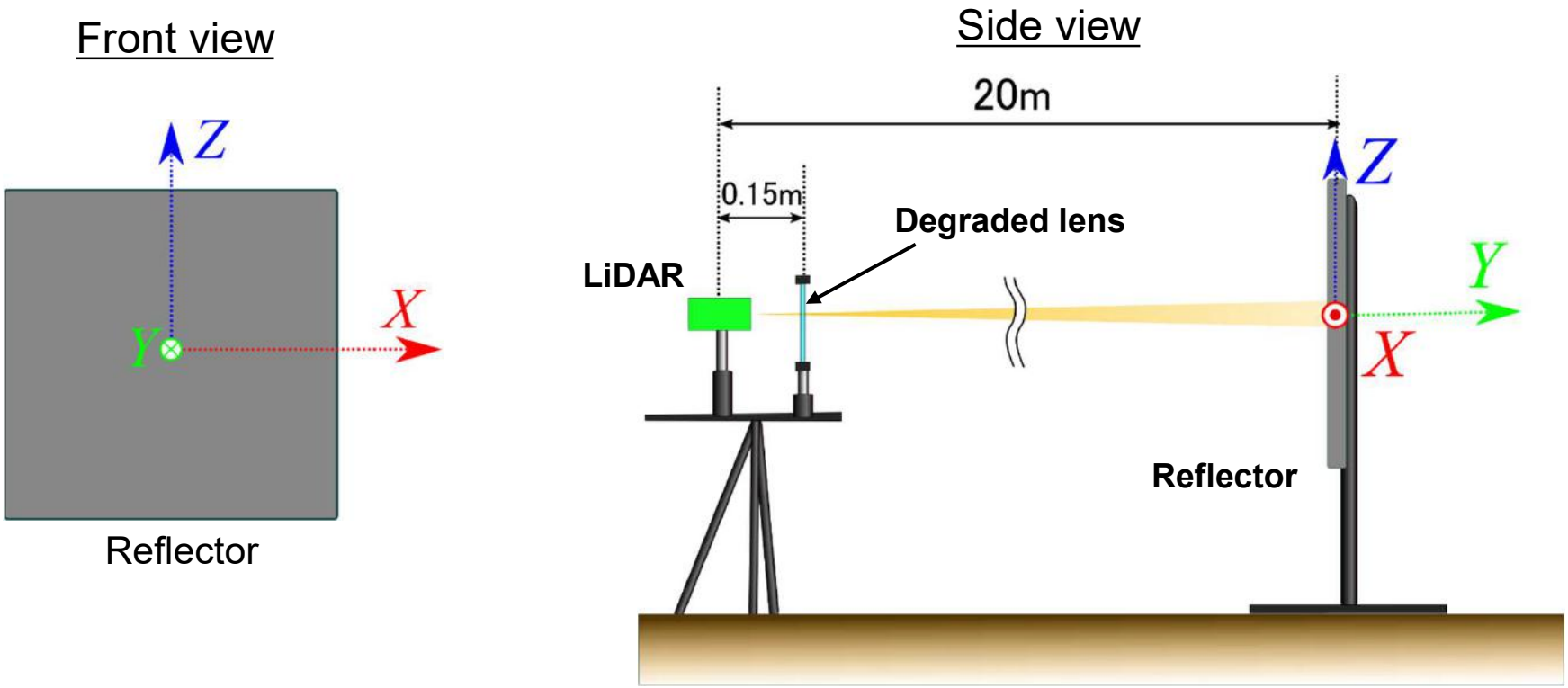
Step 2: (1) Evaluation of LiDAR's Maximum Effective Distance



- Scratches are rather tolerable, but mud and water droplets may cause significant degradation of LiDAR performance depending on the degree of adhesion.

- The result is similar and almost predictable from Step 1 (laser transmittance).

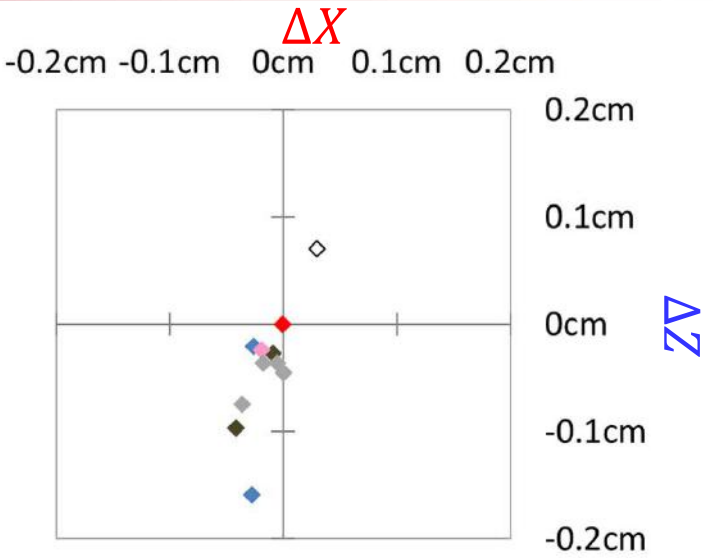
Step 2: (2) Verifying the Deviation of the Detection Position

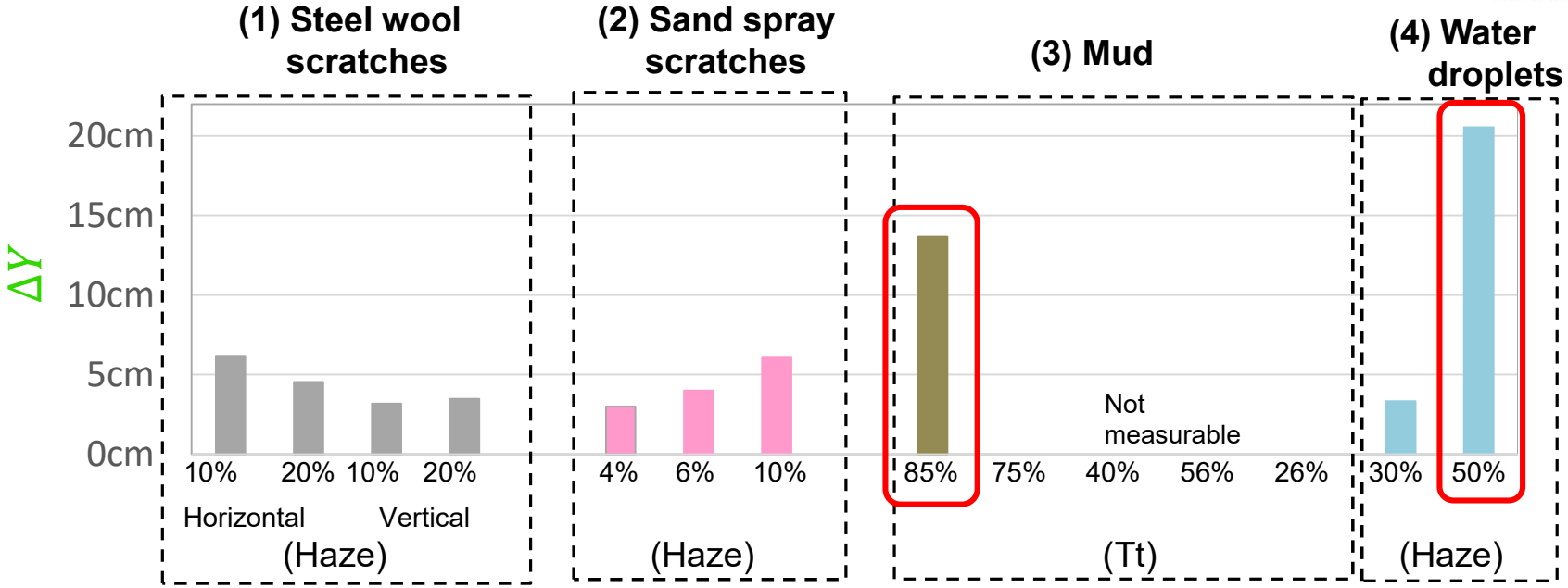


- Each type of degraded lens is set 0.15m in front of a LiDAR.
- Accuracy (average position) in X-, Y-, and Z-direction is measured.

Step 2: (2) Verifying the Deviation of the Detection Position

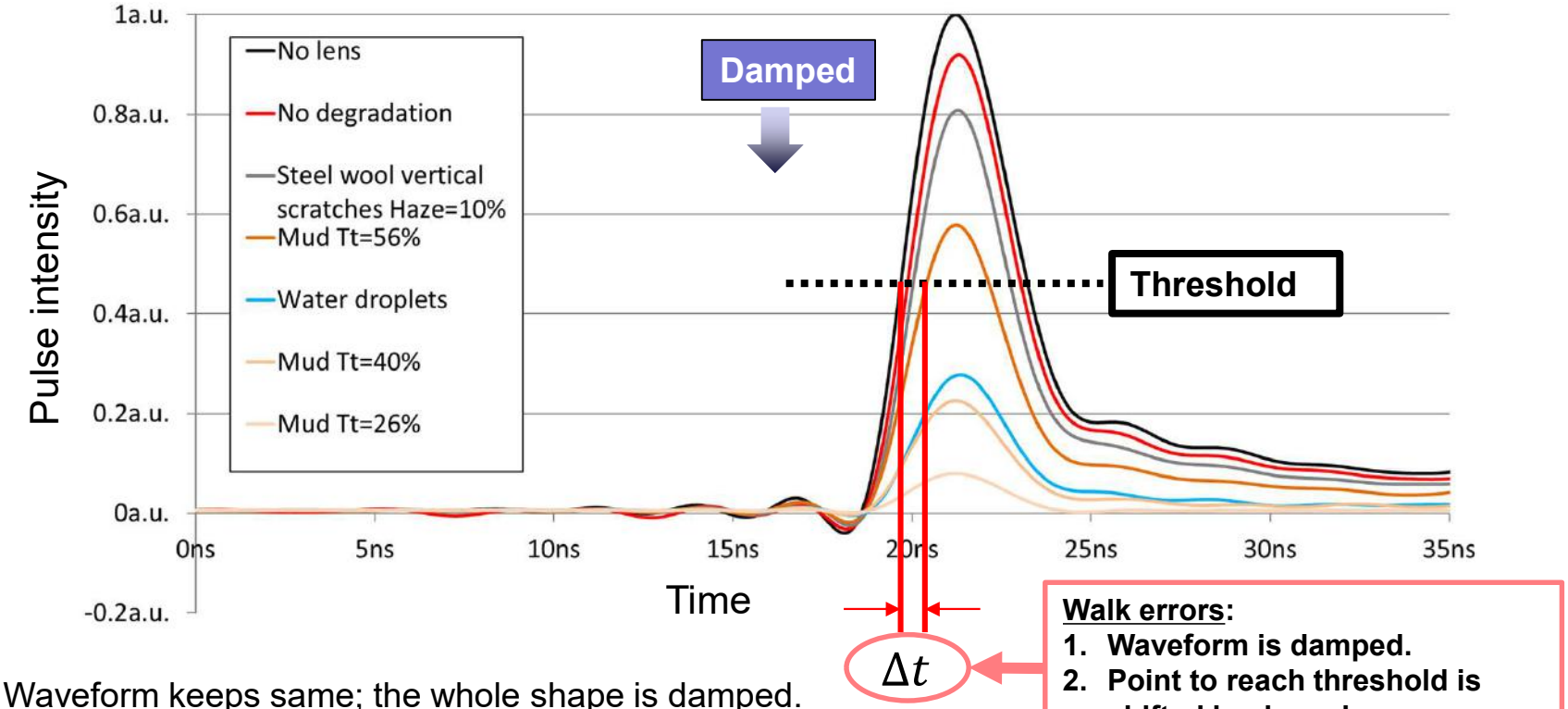
- ΔX and ΔZ is less than 0.2cm.
- ΔY is up to 21 cm.
- Influential factors on distance measurement:
  Water droplets > Mud > Scratches





Cause Analysis of Increased Distance through Degraded Lenses

Quantitative analysis of pulse waveforms after passing through degraded lenses is conducted.



- Waveform keeps same; the whole shape is damped.
- Walk errors are suspected due to damping.

For ToF LiDAR's post-processing, countermeasure of walk errors is recommended in order to keep high accuracy and precision even in adverse environments.

Summary of the Results of Verification Experiments

Type of degradation		Degradation factor in the market	Impact level
Scratches	(1) By steel wool	Scratches	★
	(2) By sand spray	Flying rocks, sandstorms	★
(3) Mud		Mud, sand or dust stains	★★★
(4) Water adhesion		Rain	★★★

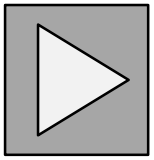
- The impact on LiDAR performance was significant for adhesion of mud, water, etc. to the lens.

- This requires lenses that are resistant to rain and dirt.

Koito's Sensor cleaning system

- Using air blow and liquid injection, Koito's cleaning system deals with both mud and water droplets.

  - Air blows away water droplets and prevents them from sticking by continuing to blow.
  - For mud stains difficultly removable by spraying alone, the cleaner liquid is used.



Video Demonstration

Summary

As a result of our experiment with deteriorated lens samples, the influential factors that deteriorate performance of LiDAR are dirt and waterdrops.

Factors	Impact level
Scratches	★
Microscopic dents	★
Mud (dirt)	★★★
Water adhesion	★★★

→ Sensor cleaning system

We recommend an integrated module with LiDAR and cleaning system.

Future plan

Development of more effective cleaner, lens material,
and surface treatment to maintain LiDAR performance.

Thank you so much for your attention.

Lighting for Your Safety

KOITO MANUFACTURING CO., LTD.