

Development of an artificial weather chamber that reproduces a dynamic weather environment for autonomous driving sensors(4th report)

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To evaluate the recognition performance of various sensors used in autonomous driving systems, we developed an all-weather artificial weather chamber capable of reproducing various weather environments. Using this chamber, experiments were conducted to evaluate the effects of fog, specifically particle size and visibility.

To control the fog particle size, two fog-generation methods were employed in this study. One method uses an ultrasonic humidifier(here after UH) to generate fine water droplets. The other method atomizes water by mixing water and compressed air through a nozzle.

For the visible-light camera, the apparent recognizability of the targets was quantified and compared using the No fog condition as the reference. The red, green, and blue panels and the red cone were evaluated, and their recognizability was expressed as a Visibility Score.

In a fog environment, fog particles interfere with the propagation of LiDAR laser light. Consequently, an arc-shaped point cloud centered around the LiDAR is generated for the 2D LiDAR, whereas a spherical-shell-shaped point cloud is generated for the 3D LiDAR. Previous studies on 2D LiDAR under fog conditions have clarified the relationship between visibility and both the mean radius and coefficient of variation of the arc-shaped point cloud. Therefore, this study also focused on the mean radius of the measured point-cloud data. For the 3D LiDAR, attention was also given to the numbers of valid points and invalid points, where invalid points were defined as points for which distance information could not be successfully obtained.

For the thermal camera, the apparent recognizability of the human target and hand warmer was quantified and compared using the No fog condition as the reference, and the results were expressed as a Visibility Score.

When the fog particle size is much smaller than the wavelength used by the sensor, Rayleigh scattering is dominant, whereas Mie scattering becomes dominant when the particle size is comparable to or larger than the sensor wavelength. In Rayleigh scattering, scattered light is distributed approximately in all directions, and shorter wavelengths are scattered more strongly. In Mie scattering, forward scattering becomes dominant, with a larger proportion of light being scattered in the direction of propagation. This scattering behavior can reduce effective light transmission and consequently affect sensor recognition performance.

Using an all-weather artificial climate chamber, the recognition performance of a visible-light camera, LiDAR, and a thermal camera was evaluated under fog conditions in which both particle size and visibility were controlled. The following findings were obtained.

- 1) The wavelength range of the visible-light camera is 0.38–0.78 μm , which is smaller than the fog particle size. Therefore, controlling the fog particle size was found to have only a limited effect on the recognition performance of the visible-light camera.
- 2) A significant difference in the recognition characteristics was observed depending on the presence or absence of fog particles larger than 5 μm .
- 3) The wavelength measured by the thermal camera is approximately 9.6 μm at 30 $^{\circ}\text{C}$, suggesting that fog particles larger than 10 μm may affect its recognition performance(see Fig.1, Fig.2, Fig.3).
- 4) It was confirmed that natural fog conditions could be reproduced in the all-weather artificial climate chamber and that the fog particle size could be controlled at a visibility of 5 m.



Fig. 1 No Fog



Fig. 2 Visibility 5 m_UH



Fig. 3 Visibility 5 m_Nozzel