Study of Roadway Visibility as a Function of Lighting Direction

Davide Cassanelli [a], *Stefano Cattini* [a], *Luigi Rovati* [a]

[a]Università degli studi di Modena e Reggio Emilia, Modena, Italy
*Corresponding author: davide.cassanelli@unimore.it

Abstract : This study investigates how the geometry of illumination affects the visibility of a target as seen by a camera in a foggy environment. The visibility is expressed in MOR (Meteorological Optical System). An experimental setup was developed using a transparent Fog Chamber (FC) that allows fog generation, enabling visibility variation along the optical path without the need for large-scale fog environments. A moving light source provides the lighting. We compare the MOR calculated with the camera captured image contrast with a reference MOR estimated with an illumination-independent system. The results show the MOR perceived by the camera varies with the lighting angle for angles higher than 15°.

Keywords: Fog, Contrast, ADAS, Illumination, Imaging System

1. INTRODUCTION

Reliable perception in adverse weather remains a key challenge for Advanced Driver Assistance System (ADAS) and autonomous vehicles. Fog is a complex scenario due to its strong scattering and absorbing properties, which strongly affect the driver visibility and ADAS systems such as cameras or LiDAR [1-4]. Considering a human driver or cameras, a relevant influence on the capability to distinguish targets in a foggy environment is given by the light sources enlightening the target. The primary illumination of a scene may come from the vehicle headlights, streetlights, or the headlights of other vehicles. Each lighting configuration introduces a different geometric placement of the light source, the object (or target), and the imaging sensor/eye.

This geometric variation can significantly influence the apparent contrast of objects and, so, their detectability. In foggy conditions, it is crucial to know the visibility to prevent risks. Visibility in foggy conditions is commonly characterized by the Meteorological Optical Range (MOR) [5], defined as the distance at which a human observer can distinguish a target of known properties [5-6]. The MOR can be computed by estimating the light attenuation due to an amount of fog along an optical path. Studies have been made accounting for the use of cameras and contrast for estimating visibility. For example, Chen et al. [7] proposed a method for evaluating visibility with cameras in different environmental light conditions. Hautière et al. [8] proposed a probabilistic model for estimating the visibility starting from the distribution of the contrast of an image.

In this work, we developed a measurement procedure to evaluate how the fog and lighting geometry affects the contrast of an image captured by a camera and which is the impact on the visibility estimated with the contrast itself. We aim to study how camera perceived visibility varies by varying the fog density and how the illumination angle influences such perceived visibility.

2. METHODS AND PROCEDURES

The proposed procedure is based on a setup consisting of a transparent cube Fog Chamber (FC) (1x1x1) m. The FC can be filled with fog to vary the visibility inside. The fog is generated in a chamber above the FC by an ultrasonic fog generator and pushed into the FC by a fan. Figure 1 schematically stands for the measurement setup.
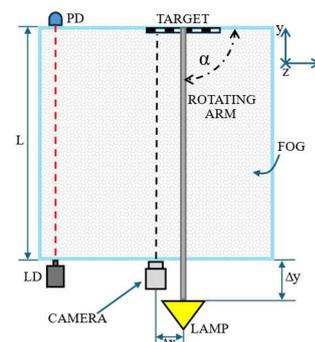

Figure 1 Schematic representation of the measurement setup.

The FC is interposed between a CMOS camera (UI324XML-M by IDS, Obersulm, Germany) with a 12.5 mm objective (HF12.5SA-1 by Fujinon. Odawara, Japan) and the target, a black and white chessboard. The distance between the camera and the target is $L = 1$ m. The light source is an LED lamp (MR16 50 by Osram, Munich, Germany, with an illumination angle of $\Omega = 36°$), which is attached to the FC with a rotating aluminium arm, allowing for varying the illumination angle α to the camera optical axis. α ranges from 0° to 80° by increments of $\Delta\alpha = 5°$. The lamp is aligned with the target, and its rotational point is in correspondence with the target center. Thus, the distance between the target and the lamp during the rotation is kept fixed. The lamp and the camera positions differ by an offset $\Delta x = 4.5$ cm on the x direction and $\Delta y = 37.5$ cm. A Laser Diode - Photodiode couple (LD-PD) is placed on the same z-plane of the camera and lamp to check the light attenuation due to the fog, which is unaffected by the lighting setup.

A single measurement consists of the acquisition of $N = 1500$ samples at frequency $f = 0.5$ Hz. Such procedure was repeated for $M = 14$ lighting angular positions ranging from $\alpha = 0°$ to $\alpha = 80°$. The measurement procedure involves four steps: i) the acquisition of the reference target image in the best case condition, $\alpha = 0°$, to compute the reference contrast C_{ref}; ii) the j-th reference acquisition of light attenuation $I_{ref}(j)$, used for the $MOR_{ref}(j)$ estimation; iii) the fog pumping in the FC and, iv) the N acquisitions at variable visibility. After the FC is filled, the fog generation is stopped and the acquisition of the target images $F(j,i)$ and light attenuation $I(j,i)$ starts, fog level gradually decreases as it naturally dissipates through a small vent. The collected data were analysed by first computing the reference visibility,

$MOR_{ref}(j,i)$ derived from light attenuation measurements obtained using the LD-PD system. Subsequently, the contrast $C(j,i)$ of each captured target image was calculated.

For this preliminary work we consider two different definitions of contrast [9] among the possible definitions: RMS and Mitchelson. The RMS contrast C_{rms} is defined as the standard deviation of pixel intensities normalized in the range [0,1]. This definition provides an information about the variability of the pixel intensity. The Mitchelson contrast measures the difference in intensity between the light and dark areas of an image of the image F, and it is defined as:

$$C_m = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}, \tag{3}$$

Where I_{max} and I_{min} are the maximum and minimum intensity of $F(j,i)$ respectively. However, equation (3) is not directly applicable since C_m reaches its maximum value 1 each time $I_{min} = 0$. In our case, even under poor visibility conditions the contrast may still equal 1 simply because $I_{min} = 0$. Thus, we change the definition to overcome such issue, by normalizing it by the mean intensity of the image. The modified Mitchelson constant is defined as in (3) but replacing I_{max} and I_{min} with the following values:

$$I^*_{max} = I_{white} + 128 - \bar{I}, \tag{4}$$
$$I^*_{min} = I_{black} + 128 - \bar{I},$$

where I_{black} and I_{white} are respectively the mean intensity of the black and white square of the target and $\bar{I}$ is the mean intensity of $F(j,i)$ and 128 is the half of the camera bit depth. According to (3), when the $I_{max} = 255$ and $I_{min} = 0$ and the mean value is $\bar{I} = 128$, the difference between the squared intensities is maximized, and so the contrast.

We aim to evaluate the effect of lighting geometry on camera-perceived visibility MOR_C, which is assessed based on image contrast. The MOR is computed as defined in [6]:

$$MOR(i,j) = \frac{1}{\sigma(i)} \ln\left(\frac{1}{0.05}\right), \tag{1}$$

$$\sigma(i,j) = \frac{1}{L} \ln\left[\frac{E_{ref}(j)}{E(i,j)}\right], \tag{2}$$

where $\sigma(i,j)$ is the absorption coefficient related to the i-th acquisition of the j-th lighting angle and E_{ref} and E stay for the photogenerated current $I_{ref}(j)$ and $I(j,i)$ of the PD for MOR_{ref} or the contrast C_{ref} and $C(j,i)$. Note that $C(j,i)$ is computed by adopting always the best-case contrast C_{ref}, to consider also the drop of visibility due to the changes in lighting geometry. Both $MOR_{C-m}(j,i)$, and $MOR_{C-rms}(j,i)$ have been computed for each contrast definition.

3. RESULTS AND DISCUSSION

The result of this analysis shows a dependence on the contrast to the MOR_{ref}, i.e. the fog density. This dependence is accentuated by increasing the lighting angle. Figure 2 shows the results of the analysis. Figures (a) and (b) show respectively the behaviour of C_m and C_{rms} in percentage respect with the MOR_{ref}. Figure (c) and (d) show MOR_{C-m} and MOR_{C-rms}. The contrast perceived by the camera increases as well as MOR. The highest contrast is for the $\alpha = 0°$ (coaxial) and it decreases by increasing the illumination angle. Both the contrast definitions show the same behaviour with a difference in absolute values. Figures (c) and (d) show MOR_C follows the ideal bisector, showing a good correlation

for $\alpha < 15°$. For wider angles, MOR_C is proportionally lower than MOR_{ref}.
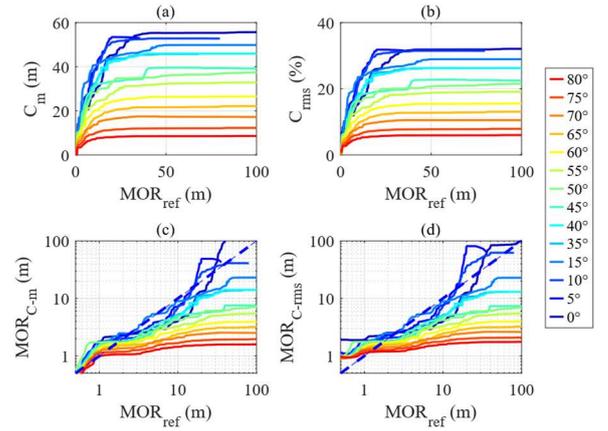

Figure 2 Results of the contrast-visibility analysis. The blue dashed line (--) is the bisector of the plot.

4. CONCLUSIONS

This study evaluates the impact of illumination angle on the visibility of objects in foggy conditions as perceived by a camera. The MOR perceived by the camera follow the reference MOR only for $\alpha < 15°$. For wider angle it is no more possible to evaluate the visibility using the contrast of the camera, highlighting a huge sensitivity of MOR_C to the lighting geometry. Future studies could extend this work by introducing an optics simulation to offer a more detailed view of the system and the use of different lighting sources.

REFERENCES

[1] M. Dreissig, D. Scheuble, F. Piewak, J. Boedecker, **Survey on lidar perception in adverse weather conditions**, 2023 IEEE Intelligent Vehicles Symposium (IV), 2023, pp. 1–8.
[2] M. Kutila, P. Pyykönen, H. Holzhüter, M. Colomb, P. Duthon, **Automotive lidar performance verification in fog and rain**, 2018 21st International Conference on Intelligent Transportation Systems (ITSC), 2018, pp. 1695–1701.
[3] D. Cassanelli, S. Cattini, G. Di Loro, L. Di Cecilia, L. Ferrari, D. Goldoni, L. Rovati, **A simple method for the preliminary analysis and benchmarking of automotive LiDARs in fog**, 2022 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), 2022, pp. 1–6.
[4] Cassanelli, Davide, et al. "**A simple experimental method to estimate and benchmark automotive LIDARs performance in fog.**" *Acta IMEKO* 13.4 (2024): 1-8.
[5] W. M. Organization, **Guide to Instruments and Methods of Observation**, World Meteorological Organization, 2018, vol. 1.
[6] I. 289021:2012, **Air quality - environmental meteorology part 1: Ground-based remote sensing of visual range by lidar**, ISO — International Organization for Standardization, Geneva, Switzerland, Tech. Rep., 2012.
[7] Chen, L., Yu, Z., Wang, H., Wang, S., Liu, X., Mei, L., ... & Zuo, P. (2023). **Error Analysis and Visibility Classification of Camera-Based Visiometer Using SVM under Nonstandard Conditions**. *Atmosphere*, *14*(7), 1105.
[8] Hautiére, N., Babari, R., Dumont, É., Brémond, R., & Paparoditis, N. (2010, November). **Estimating meteorological visibility using cameras: A probabilistic model-driven approach.** In *Asian Conference on Computer Vision* (pp. 243-254). Berlin, Heidelberg: Springer Berlin Heidelberg.
[9] Peli E. **Contrast in complex images**. J Opt Soc Am A. 1990 Oct;7(10):2032-40.