Instructions on Implementing the Radial Contrast Measurement Method

I. Concentric Ring Patterns

As illustrated in Fig. A1. The concentric ring patterns consist of alternating black and white rings with the same pitch ($p_W = p_K$). The diameter of the center white circle also equals to the pitch of the rings.

Figure A1. Circular concentric ring patterns with low (left), medium (center), and high spatial frequencies.

II. Experimental Setup

This method uses a high-resolution array LMD with photopic response mounted on a three-axis stage that provides a wide-view spatial luminance measurement. As shown in Fig. A2, the optical axes of the LMD and HMD (left or right eyepiece) shall align with each other. The entrance pupil location of the LMD should be placed at the eye-point of the HMD. The LMD should be calibrated such that the digital output is linear to the luminance.

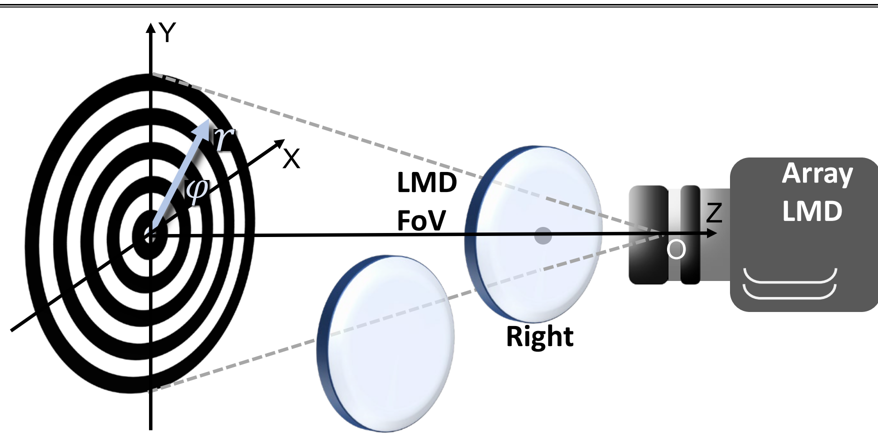

Figure A2. Experimental setup for Michelson contrast measurement using the concentric ring method.

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III. Image Acquisition

As illustrated in Fig. A2, the measurement takes a wide-view image of the concentric ring pattern and computes the Michelson contrast (C_M) as a function of the angular radius (r) and rotation in the virtual plane (φ).

The following procedure describes the experimental setup and image acquisition steps:

1) Set up the array LMD and align the entrance pupil location of the LMD to the optical axis of the HMD using methods described in Sec. 19.3 of the Information Display Measurement Standard (IDMS) [1].
2) Render the concentric ring pattern on the HMD with the center of the pattern aligned with the optical axes of the HMD and LMD.
3) Adjust the focus of the LMD to the virtual image plane of the test pattern.
4) Acquire an image of the test pattern using the LMD.
5) Repeat the measurements using concentric ring patterns with different spatial frequencies (for example, low, medium, and high spatial frequencies as shown in Fig. A1).

IV. Analysis

The following procedure describes the image processing and analysis methods following image acquisition.

6) On a captured concentric ring image, find the center position of the pattern (center of the central circle).
7) As illustrated in Fig. A3 (a) and (b), starting from $\varphi_j = 0$ (horizontal), obtain a luminance profile across the center as a function of angular radius r in degrees.
8) Perform a running average (moving-window average filter) or a Gaussian filtering on the luminance profile where the averaging window width or the standard deviation of the Gaussian filter are comparable to the pixel pitch shown on the LMD.
9) From the smoothed luminance profile $S(r, \varphi_j)$, as illustrated in Fig. A3(b), find the boundaries between white and black rings r_i ($r_i = \frac{p_W}{2} + ip_W$, where i is an integer).
10) Compute the local Michelson contrast $C_M\left(r_i, \varphi_j\right)$ measured at the boundaries between the white and black rings from the local maximum and minimum luminance (highlighted as red circles in Fig. A3(b)) of the neighboring white and black rings located at $r_i \pm \frac{p_W}{2}$. The Michelson contrast is expressed as
$$C_M\left(r_i, \varphi_j\right) = \frac{\left|S\left(r_i + \frac{p_W}{2}, \varphi_j\right) - S(r_i - \frac{p_W}{2}, \varphi_j)\right|}{S\left(r_i + \frac{p_W}{2}, \varphi_j\right) + S(r_i - \frac{p_W}{2}, \varphi_j)}.$$
11) Repeat steps 7 to 10 for $\varphi_j \in [0, 360°]$ with a step of 10° or smaller.
12) Apply a 2D interpolation on $C_M\left(r_i, \varphi_j\right)$ to obtain a spatial distribution of $C_M(r, \varphi)$ as shown in Fig. A3(c) and/or a polar expression in Fig. A3(d).
13) Repeat steps 6 to 12 for each concentric ring pattern image with different spatial frequencies.

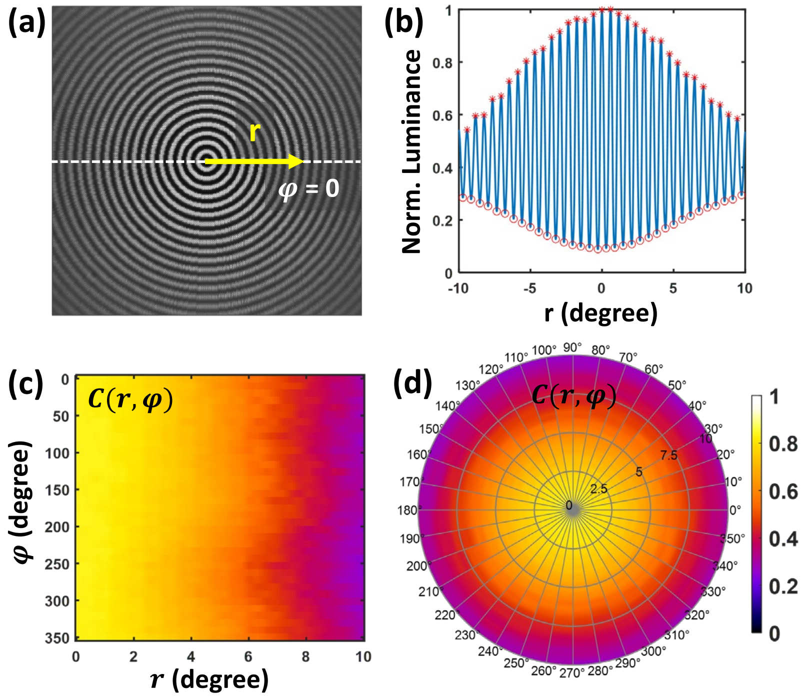

Figure A3. Example illustrations of image processing steps to obtain the contrast maps: (a) Measured camera image of a high-spatial-frequency concentric ring pattern. (b) Luminance profile across the center of the pattern. (c) A radial-angular (r, φ) contrast map obtained by repeating the contrast calculation for each φ. (d) is the same as (c), but in a polar plot.

V. Reporting

Report discrete Michelson contrast measurements of $C_M(r_i, \varphi_j)$ covering the LMD FOV, and/or an interpolated 2D contrast map of $C_M(r, \varphi)$ (see Fig. A3(c) and (d) as an example) for better visualization of the spatial contrast distribution.

References:

[1] Information Display Measurements Standard, SID, 2023

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