INTRA-LENS-SPECTROMETER FOR A NEAR-EYE DISPLAY MEASUREMENT APPLICATION

Schramm, S., et al.

DOI 10.25039/x051.2025/q9tjg8

Proceedings of the CIE 2025 Midterm Meeting Vienna, Austria, July 4-11, 2025:
Scientific Conference (July 7-9, 2025)

DOI 10.25039/x051.2025

in

Proceedings of the CIE (International Commission on Illumination)

ISSN no. 3061-015X (print), 3061-0168 (online)

The paper has undergone double-blind peer review and its final version has been presented at the CIE 2025 Midterm Meeting, Vienna, Austria, July 4–11, 2025.

CIE Central Bureau
Babenbergerstrasse 9/9A
A-1010 Vienna, Austria
Tel.: +43 1 714 31 87
e-mail: ciecb@cie.co.at — www.cie.co.at

INTRA-LENS-SPECTROMETER FOR A NEAR-EYE DISPLAY MEASUREMENT APPLICATION

Schramm, S. [1]; **Krüger, U.[1]**, Görlich, S. [2]; Mende, J.[2]

[1] TechnoTeam Bildverarbeitung GmbH, Ilmenau, GERMANY, [2] JETI Technische Instrumente GmbH, Jena, GERMANY

email: Stefan.Schramm@technoteam.de

Abstract

A spectroscopic measurement should reference color measurement parameters for high-precision color measurements using an imaging color measuring device (ICMD). Within an augmented and virtual reality (AR/VR, in general, called near-eye displays - NED) measurement application, the spectral distribution of the device under test (DUT) should be measured within a 2° field of view according to the standard observer. The measuring spot should be on the optical axis of the imaging device. Integrating the spectrometer coupling in an AR/VR measuring lens can guarantee those fundamental criteria by optical design and adjustment. We present a lens design that meets these requirements and thus combines other various advantages of the elemental lens design.

Keywords: Photometry, Colorimetry, Spectrometer, Near Eye Display NED, ILMD, ICMD

1 Introduction

Typical requirements for a lens for augmented and virtual reality (AR/VR, in general, called near-eye displays - NED) device characterization are the necessity of a front stop from 2-4 mm, which has to fit the virtual pupil position of the device under test (DUT) in position and size. A physical front stop has the advantage that the operator can easily determine the position of the aperture.

The measurement optics must have a maximum diameter of 60 mm to fit the optical axis of the DUT and measure the properties of the AR/VR device in a completely assembled condition (in an end-of-line measurement application). Typical imaging luminance and color measurement devices (ILMD, ICMD) (CIE244:2021, 2021) are too large to fit between the temple arms of the DUT. For this purpose, the lens requires a certain minimum length and, in some cases, a deflecting mirror to position the imager outside the DUT space.

For the spectrometer, an array spectrometer for the visible (VIS) range will be used to be integrated into the system. Its optical resolution depends on the spectrum of the AR/VR device. Here, a version with a full width at half maximum (FWHM) of 3,5 nm is used, but up to 2 nm is possible in the case of narrow band-shaped spectra.

Low stray light is necessary for precise color measurement; a high dynamic range is also desirable for a wide luminance range.

2 Fundamentals

AR/VR systems must be evaluated in the entire image field or at least in a large part of it. Uniformities in luminance, color, and imaging properties — like the modulation transfer function (MTF) — play an important role here.

The photometric and colorimetric measurements with an ILMD/ICMD, which usually works according to the tristimulus measurement method, are to be corrected despite excellent spectral adaptation (CIE179:2007, 2007) to the color-matching functions of CIE 1931 standard colorimetric observer using spectral data.

Based on the individual measured spectral responsivities of the measurement device and the spectral measurements of the spectrometer used, a spectral mismatch correction factor (SMCF) can be evaluated and used.

In general applications, it is often simpler to conduct the spectrometer measurement directly rather than through the beam path of the ILMD. In this case, the spectrometer can be calibrated as standard and set up independently of the camera. Only for AR/VR applications where measurements are to be taken simultaneously or without mechanical setup changes must the spectrometer measure using the same optics as the camera. This places high demands on integrating the spectrometer into the recording optics and its calibration, which are explained in more detail below.

3 Optics and Spectrometer

In this section, the optics and the spectrometer design will be described.

3.1 Optics

The measurement device described here is based on a conoscopic design principal schematically shown in Figure 1. Its basic parameters are listed in

Table 1. The system can be focused using a liquid lens, a first optical element behind the front stop, followed by the conoscopic lens tip that focuses the light into an intermediate image plane. With a long focal length, the base lens images the intermediate image plane onto the sensor. The principle of this design follows the patent application DE102023113210B3 (Schramm *et al.*, 2024).

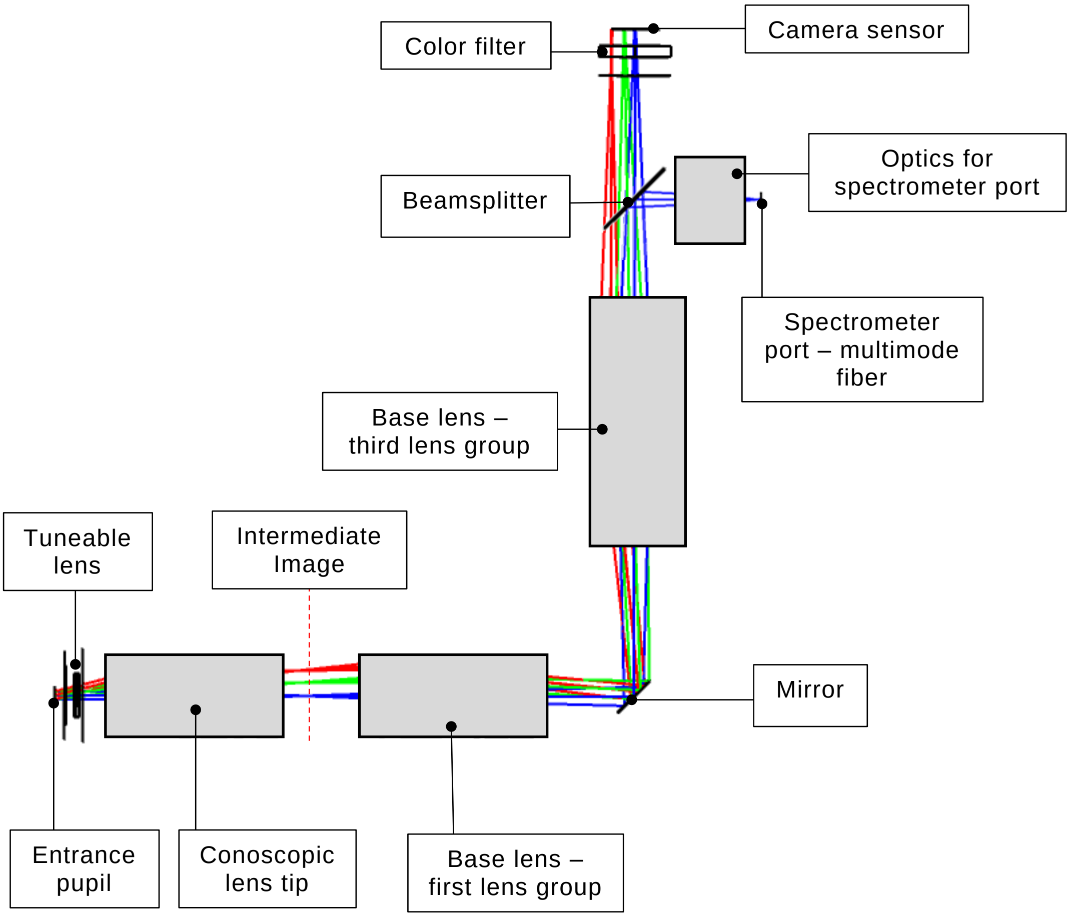

Figure 1 – Schematic optic path of the NED-measurement lens with spectrometer port.

Table 1 – Lens parameters

Parameter	Value
Overall focal length	-37,5 mm
Total Track	400,6 mm
Front spot diameter	2-6 mm (here 2,5 mm)
Focus range	-5 to +10 dpt.
Field of view	±15°

Using a conoscope design (also called Fourier optics (Moreau, Curt and Leroux, 2000)) offers the possibility of integrating a mirror and a beam splitter into the base lens due to the relatively large spaces between the optical elements. The assembled system is shown in Figure 2.

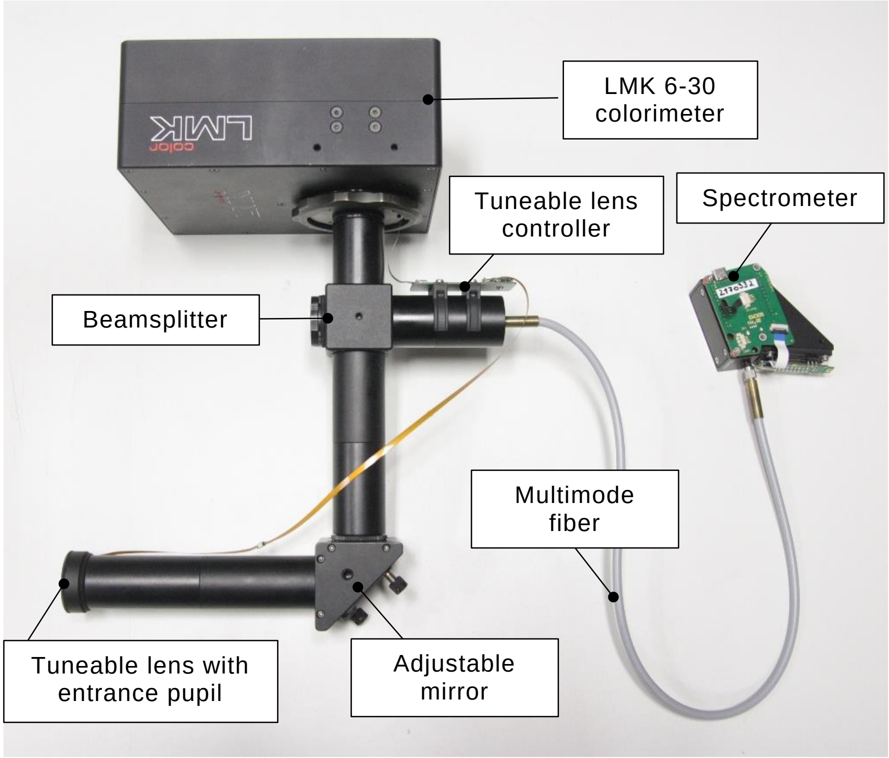

Figure 2 – NED light measurement system with a spectrometer.

The tuneable lens is positioned near the entrance pupil (EP) to maximize the tuneable range while minimizing the gravitational aberrations of the lens since only part of the lens aperture is used (Blum *et al.*, 2011). This ensures that both the camera and the spectrometer are in focus.

3.2 Spectrometer

The spectrometer is based on an imaging grating (see Figure 3). This makes it possible to use only one optical element and thus achieve a high level of effectiveness. A low scattered light level of < 0,1% is achieved by outstanding grating quality, optimized beam traps, and a very oblique angle of incidence on the array detector.
The above-mentioned resolution of 3,5 nm (FWHM) is achieved using a 50 µm wide input slit in front of the input fiber.

Additionally, the spectrometer is equipped with a mechanical shutter. Repeated dark scans during the measuring series allow for precise baseline correction.

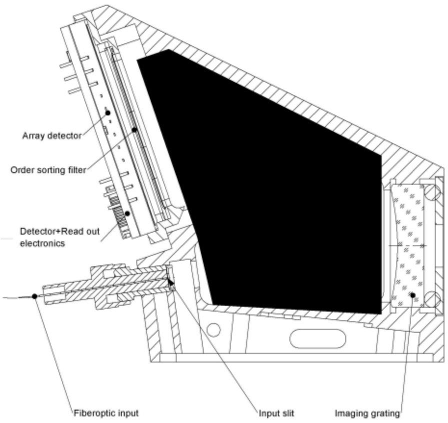

Figure 3 – Scheme of spectrometer

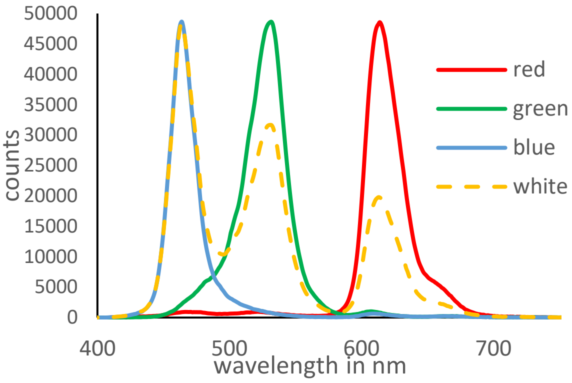

Figure 4 – Spectra of the displayed flat field images.

4 Application

A test measurement was performed with an EPSON Moverio BT-40 AR device, as shown in Figure 5. The device was controlled as an extended display. Flat field test images with color values 255 red, 255 green, and 255 blue as single colors and in combination with white were displayed in a darkened room. The corresponding spectrum (Figure 4) and a luminance image were recorded.

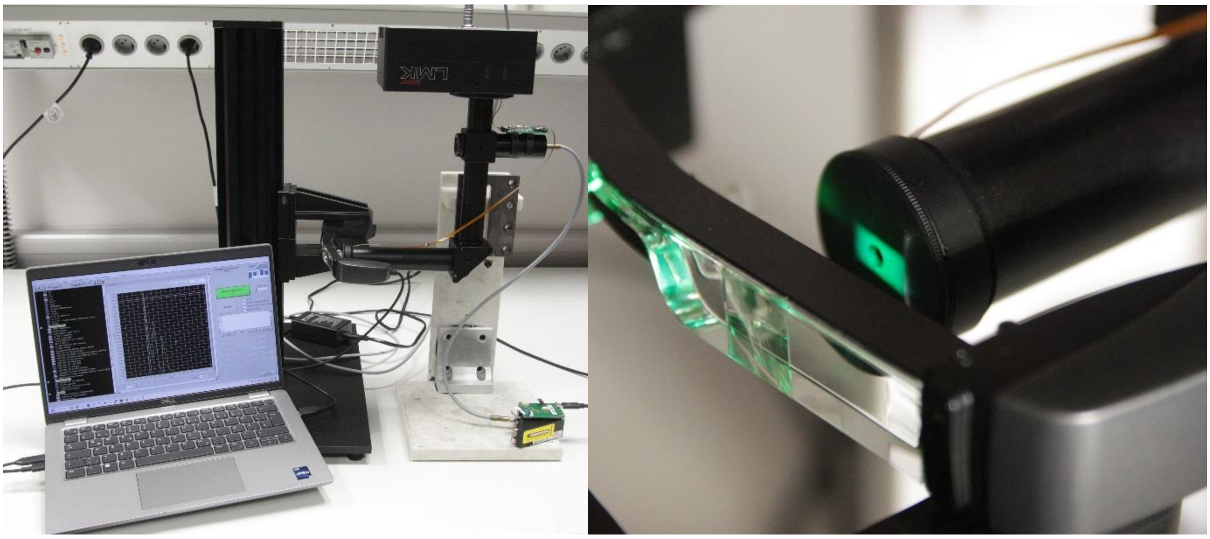

Figure 5 – Left: Measurement setup with an EPSON Moverio BT- 40. Right: Detail of the illumination of the entrance pupil with a green flat field test image.

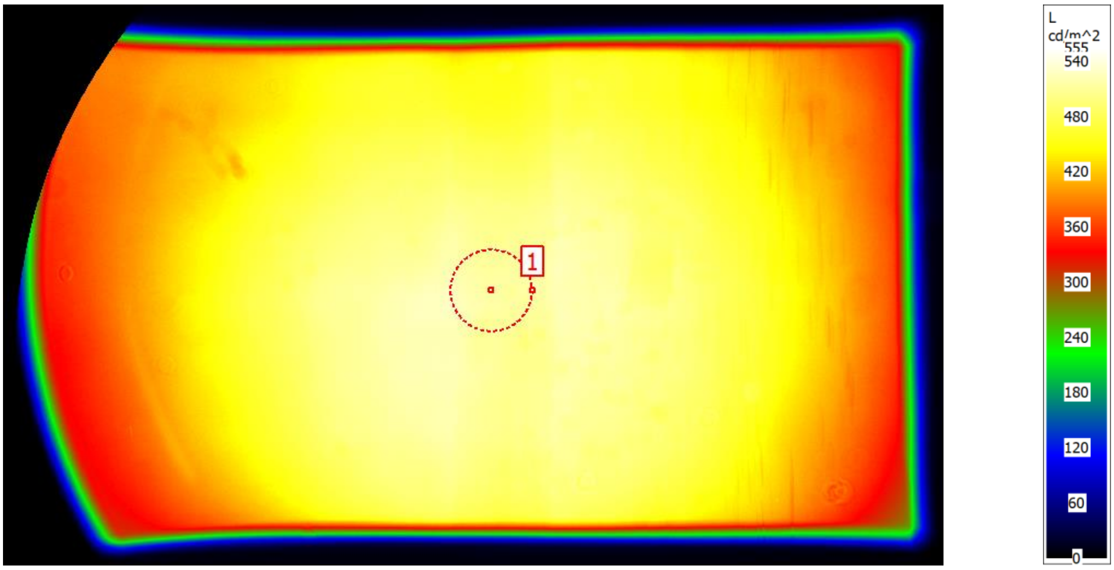

Figure 6 – Luminance image of the white state with the spectral measurement region.

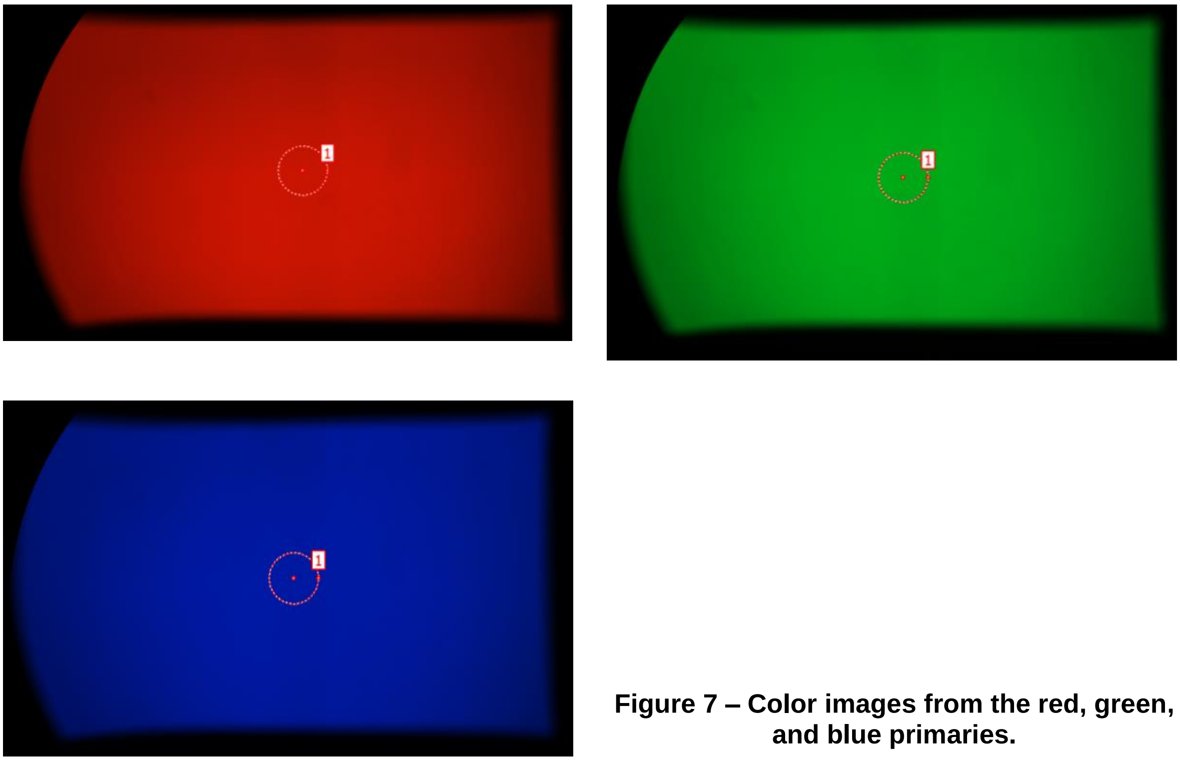

Figure 7 – Color images from the red, green, and blue primaries.

Based on the spectral responsivity of the ICMD used (f_1' values of 2,5 ... 3,5% for the individual color channels) and the spectral distributions of the primaries and white measured with the spectrometer; the following spectral mismatch correction factors were calculated.

Table 2 – Spectral mismatch correction factors

Channel	White	Red	Green	Blue
X	1,012	0,991	1,015	1,050
Y	**0,992**	**0,988**	**0,995**	**0,983**
Z	1,003	1,078	0,995	1,004

Table 3 – Resulting Corrections of the chromaticity values (x,y) in the CIE1931 Color Space

	W	R	G	B
dx	-0,0025	0,0007	-0,0030	-0,0056
dy	0,0032	0,0014	0,0025	0,0019

5 Conclusion

The conoscopic design presented here, with a liquid lens, tilted beam path, and spectrometer decoupling, can further improve the measurement value of the ILMD/ICMD despite good previous spectral matching, which can be very helpful in the critical luminance ranges of NEDs.

Table 2 shows that the excellent spectral matching of the system results in only minimal spectral correction factors. Only the corrections for the primary color blue and the X channel, as well as for the primary color red and the Z channel, are significant. However, the latter is irrelevant, as the values for Z do not contribute significantly to the chromaticity values when measuring the primary color red. Even the corrections regarding chromaticity values are minor, as shown in Table 3. Depending on the application and the measurement uncertainty of the spectrometer calibration, the user should decide whether such a correction is required.

6 References

Blum, M. *et al.* (2011) ‘Compact optical design solutions using focus tunable lenses’, in *Optical Design and Engineering IV. Vol. 8167*. SPIE, p. 81670W. Available at: https://doi.org/10.1117/12.897608.

CIE179:2007 (2007) *CIE 179:2007 METHODS FOR CHARACTERIZING TRISTIMULUS COLORIMETERS FOR MEASURING THE COLOUR OF LIGHT*. Vienna. Available at: https://cie.co.at/publications/methods-characterising-tristimulus-colorimeters-measuring-colour-light.

CIE244:2021 (2021) *CIE 244:2021 Characterization of Imaging Luminance Measurement Devices (ILMDs)*. Vienna. Available at: https://doi.org/10.25039/TR.244.2021.

Moreau, O., Curt, J.-N. and Leroux, T.R. (2000) ‘Contrast and colorimetry measurements versus viewing angle for microdisplays’, in C.B. Chinnock (ed.) *Proceedings of SPIE - The International Society for Optical Engineering*, p. 20. Available at: https://doi.org/10.1117/12.411767.

Schramm, S. *et al.* (2024) ‘Objektivanordnung, Messvorrichtung und Verfahren zur Vermessung eines Near Eye Displays’. DE: TECHNOTEAM HOLDING GMBH. Available at: https://lens.org/099-081-866-262-220.