The effect of glass neutral density filter on illuminance measurement error

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Abstract. We present an analysis of the illuminance measurement results when a glass neutral density filter (ND Filter) inserted between light source and photometer. ND filters are widely used as an alternative solution in illuminance calibration systems to perform lower illuminance level which caused by inadequate length of the photometric bench. However, there are some variables that must be considered when inserting ND filters in illuminance measurement, one of which is the perceived color temperature of the light source which is influenced by the non-flatness profile of the filter’s spectral. This research was conducted by calculating correction factor for each ND filters, which contribute to illuminance error. Six different ND filters in the range of 1% to 49% are used in this experiment. Scanning the spectral distribution of filter are done to analyzing the change of color temperature of the light source as it passes through an ND filter, due to the lamp must correspond to Illuminant A. This research shows the illuminance measurement error can be up to 20% proportionality to the transmittance as the effect of using ND filters. The results of this study are expected to provide recommendations for the calibration laboratory, especially in illuminance meter calibration.

1. Introduction

In accordance to Invers Square Law [1–4], regarding the relationship between illuminance and lamp-to-photometer distance, to carry out illuminance level below 50 lux, a photometric bench with a length of more than 6 m is needed. This will certainly be an obstacle, especially for calibration laboratories or industries with small space capacity in Indonesia. Thus, various methods are available to perform lower illuminance level, for instance by providing different power levels of lamps [1], using integrating sphere source or inserting neutral density filter (ND Filter) in the calibration system [5]. Glass ND filter is recommended [6] to use in wavelength range above 400 nm as it does not has interreflections [7] and preferred by laboratories as it is easier to use, low risk and almost zero maintenance.

Based on experiments conducted in SNSU-BSN, the use of ND filter change the perceived color temperature of the light source. Since use in illuminance calibration system, the filter should only reduce the amount of light source [8,9] not change the perceived color temperature of lamp as well [10]. Light source must referred to Illuminant type-A at around 2856 K [4,11–18] and it is determined by adjusting
current of DC power source. When these color temperature conditions were not meet, the error of illuminance value will be counted inaccurately. Therefore, the aim of this research is to analyze how much ND filter affect in illuminance measurement process.

2. Methods

The light source used in this study is a 1000 W Halogen lamp, operated at 3.89 A of DC power to produce 2856 K of color temperature. In this experiment, the change of color temperature due to ND filters influence was measured using calibrated spectroradiometer at distance of 1 m from light source. The measurement configuration shown in Figure 1, where the filters are put between the light source, and the spectroradiometer.

The main experiments are done using the same configuration as Figure 1 to quantify the influence of ND filter in the Illuminance measurement by change the spectroradiometer by a calibrated reference photometer. Different with the first experiment, the illuminance measurements are carried out at two distances of 1 m and 1.29 m. To examine the ND filters’ effect related with its transmittance level, several tests were carried out using 6 different glass filters which are 1%, 10%, 15.85%, 25.12%, 39.81% and 49%.

![Figure 1. Instruments configuration for illuminance measurement.](image)

Ideally, when the filter spectral profiles are flat in its nominal transmittance value \((T\%)\), then the measured illuminance \((I_{T\%})\) by the photometer can be estimated by simply multiply the measured illuminance without filter \((I_0)\) with the nominal transmittance value of the filter used as shown in Equation (1). However due to the non-flatness profile of the filter spectral, then the measurement results can be deviate from the calculation result. To analyze how much this deviation can occur and how to do correction for this deviation then each filter is scanned to determine its spectral profile using double monochromator which is set at 380 nm to 780 nm of wavelength with a 10 nm step. The light source used in this spectral measurement is a 250 W Halogen lamp.

\[ I_{T\%} = I_0 \times T\% \]  

3. Results and Discussion

Table 1 describes the measurement results of color temperature that appears when ND filter inserted in the light path as well as the measured illuminance in both distance. The measured color temperatures of the lamp are increase as the transmittance of filter decrease. The change in color temperature occurred when spectral profile of the ND filters are not flat in visible wavelength region, as shown in Figure 2 after normalize to unity. ND filters were scanned using double monochromator on spectral bandwidth (SBW) more than 2 nm to produce a better signal to noise ratio (SNR). However, the smaller the SBW will contribute to produce to produce a clearer graphic on a sharp spectrum form (peak/valley)[19].
Table 1. Color temperature measurement using ND filter.

| ND Filter (%) | Color Temperature (K) | Illuminance 1 m (lux) | Illuminance 1.29 m (lux) |
|---------------|-----------------------|------------------------|--------------------------|
| 100           | 2854                  | 1695.8                 | 1000.0                   |
| 49            | 2875                  | 825.6                  | 489.0                    |
| 39.81         | 3040                  | 664.1                  | 389.7                    |
| 25.12         | 3049                  | 413.4                  | 243.6                    |
| 15.85         | 3173                  | 246.1                  | 145.7                    |
| 10            | 3261                  | 144.3                  | 86.8                     |
| 1             | 3239                  | 15,280                 | 9,009                    |

In term of illuminance measurement, this non-flatness profile of the filter spectral will also make the measured illuminance contain an error. This error can be estimated approximately by subtracting the measured illuminance by calculated illuminance \( I_{T\%} \) as expected value for each expected filter. However, this method is just approximately because not based on the real profile of the ND filter spectral. Therefore, we calculate the correction factor based on the measured profile of the filter spectral using Equation (2). Where \( S_{\text{measured}} \) is the filter spectral, \( S_{\text{true value}} \) is the profile at expected nominal value of the filters, and the \( V(\lambda) \) is the photometer head responsivity.

\[
f_{c} = \frac{\int_{\lambda} S_{\text{measured}}(\lambda) V(\lambda) d\lambda}{\int_{\lambda} S_{\text{true value}}(\lambda) V(\lambda) d\lambda} \tag{2}
\]

The estimated error from measurement in percentage of the measured illuminance are shown in Figure 3, where the value range are can be up to about 15%. Same with the effect of color temperature change the error is also increase as the transmittance of filter decrease. This error trend is similar for both range of measurement of 1 m and 1.29 m, which is verified that the error is coming from the filters not the distance. By applying the correction factor calculated from Equation (2), the errors are decrease for almost all the filters used down to below 4%, as shown in Figure 3 with circle marker. Except for the filter with 0.01% transmission, which the corrected values are still far to about 15%. This big error at 0.01% filter maybe due too little signal measured by the photometer, which is improve the noise ratio.
4. Conclusion
ND filter can be used to attenuate or cut the intensity of light source, so that only requires a short photometric bench to perform illuminance calibration. For calibration laboratory, it reduces the investment cost of equipment. It is important to note that in using a filter for illuminance measurement, initially, the filter’s profile must be characterized to ensure the light transmitted properly. A correction factor was needed to overcome the error caused by non-flatness of the filter’s spectral. The error was proportional to transmittance value of ND filter, where the smaller the filter transmittance value, the higher of error generated. Low transmitted ND filter, for instance 1%, contribute to the large error of measurement, which up to 15 %. Therefore, when running lower level of illuminance, the use of higher transmission filter would be recommended.

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References
[1] Ohno Y 1996 OSA Handbook of applied photometry, ed C DeCusatis (IBM Corporation: New York)
[2] Shibuya T, Kitaguchi K and Iwanaga T 2019 Light. Res. Technol. 52 407
[3] Voudoukis N and Oikonomidis S 2017 Eur. J. Eng. Res. Sci. 2 23
[4] Petrina S, Ivanov D and Yaneva N 2018 Conf. Light. 6 1
[5] Boivin L P 2005 Optical radiometry, ed Parr A., Datla R., Gardner J vol 41 (Amsterdam: Elsevier) p 339
[6] NATA 2018 Specific Accreditation Criteria Calibration ISO / IEC 17025 Annex Optical metrology
[7] National Physical Laboatoyr 2006 A National Measurement Good Practice Guide : Regular Transmission Measurements (Middlesex, UK: NPL) p 14.
[8] Bermingham A 2003 Colour temperature/ND filters Location Lighting for Television (Amsterdam: Elsevier) p 63
[9] Membrey L, Kogure S, Fitzke F 1998 Perimetry Updat. 8 75
[10] Czajkowski KM, Schmid M 2017 IEEE Photonics J. 9 6
[11] ISO/CIE 19476:2014 2014 Characterization of the performance of illuminance meters and luminance meters (Vienna : CIE Central Berau)
[12] Schanda J 2015 CIE Standard Illuminants and Sources Encyclopedia of Color Science and Technology (New York : Springer)
[13] Zong Y, Tsai BK, Miller CC, Miller CC 2018 NIST Measurement Services Photometric Calibrations (USA : NIST) p 17.
[14] PTB. PTB Mitteilung Das Jahr des Lichtes 2015. p 8.
[15] Sametoglu F 2007 Opt. Eng. 46 093607.
[16] Lippens P, Muehlfeld U 2016 Indium tin oxide (ITO): Sputter deposition processes. p 324
[17] Godo K, Tamura Y, Watari O 2020 Source. Light. Res. Technol. 52 1009
[18] Westland S 2020 Encyclopedia of Color Science and Technology.
[19] Valencia G 2006 Fifth Symp. Opt. Ind. 8 1