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Improvement Uncertainty of Total luminous Flux Measurements by Determining Some Correction Factors

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KEYWORDS

Uncertainty, Sphere Calibration Factor, Total luminous Flux, spatial non-uniformity, Spectral Quality Factor, Spectral Responsivity of Sphere.

ABSTRACT

In this research, the improvement uncertainty of total luminous flux measurements has been done by determining some important correction factors at National Institute of standards (NIS) in Egypt. Such as sphere photometer calibration factor (SPCF), the spectral efficiency of the integrating sphere and the Photometer Spectral Quality Factor f_1'. A set up based on 2.5meter NIS integrating sphere and NIS photometer with a group of NIS luminous flux standard lamps calibrated at National Physical Laboratory in England (NPL) with uncertainty 0.8% are used to determine SPCF. The combined uncertainty of the final SPCF used is 0.15%. Another set up based on NIS Spectroradiometer with uncertainty 4.7% and 2.5 meter NIS integrating sphere system for measuring the sphere-photometer spectral responsivity and spectral quality factor f_1' 'has been determined for the sphere-photometer with value 6.25% . This percentage value has been classified NIS photometer as medium quality.

Introduction

The total luminous flux quantity is an important quantity for applied laboratories in the form of standard lamps and detectors as well as calibrated instruments. These standards are used in a calibration laboratory to calibrate secondary standard lamps and detectors as well as instruments to be used in the practical photometric laboratory.

The total luminous flux of a light source is usually measured with a goniophotometer or with an integrating sphere [1, 2].

Traditionally, the total luminous flux unit is realized by using goniophotometers [3]. It is often difficult, however, to build and maintain high accuracy goniophotometers require a large dark room and costly, high-precision positioning equipment. It also takes long hours for a goniophotometer to take data at many points and, yet the photometer head scans only a small portion of the total spherical area (typically less than 3 % with a point-by-point measurement and less than 20 % with a continuous integration measurement) [4]. As the burning time of the lamps should be kept to a minimum, the scanning intervals (thus measurement accuracy) and the measurement time are always compromised. Integrating spheres, on the other hand, provide instantaneous and continuous spatial integration (almost 100 % coverage) over the entire spherical area, which is a great benefit over goniophotometers. Goniophotometers need less characterization measurements than integrating spheres. However, they are mechanically demanding facilities, and the measurements are time consuming.

To overcome these difficulties, the standard substitution method is used by integrating sphere photometer system. Measurements are accomplished faster, resulting in shorter burning times for the lamps. Integrating sphere photometers allow fast measurements and are widely utilized. There are several challenges in measuring the luminous flux of light sources. This include the mismatch between the relative spectral responsivity of the sphere photometer and the spectral luminous efficiency $V(\lambda)$ of the human eye, the near-field absorption of the backward emission of low-power light sources, the measurement of high-power light sources that require large heatsinks for thermal management [5].

Laboratories with photometric calibration facilities often have integrating spheres available for measurements lamps [3]. The diameters of these spheres are typically in the range of 1 – 4 m. A typical integrating sphere designed for measurement of light source has ports photometer head, and for an auxiliary lamp that is needed for the self-absorption measurement. The sphere surface is typically coated with barium sulfate BaSO4 [6]. The integrating sphere is a device for measuring total luminous flux for any light source and its function is to spatially integrate radiant flux. Light incident on a diffuse surface creates a virtual light source by reflection [7]. Items located inside the sphere, including baffles, lamps, and lamp sockets absorb some of the energy of the radiant source and decrease the throughput of the sphere. This decrease in throughput is best avoided by coating all possible surfaces with a highly reflective.

As any part of the sphere surface sees all other parts of the sphere surface equally; the detector at any point on the surface can measure the total power in the entire sphere [8]. In addition, the reflections from the coating added to the power of the lamp, lead to the fact that there is always more power inside a sphere than the lamp generates [9].

Photometers are designed to have spectral responsivity close to the International Commission on Illumination (CIE) $V(\lambda)$-function that describes the luminous sensitivity of a human eye in photopic conditions [10]. In a typical illuminance measurement with a photometer, spectral mismatch error is due to the difference between the $V(\lambda)$ and the real spectral responsivity of the photometer. The mismatch can be corrected for, if the spectral responsivity of the photometer and the spectral power distributions of the light sources being measured are known [10]. CIE quality factors are often used for reporting the performance of photometers in general lighting conditions. The quality factors are typically reported as percentage values. Although they cannot be used for applying corrections for measured values, they are important because a photometer with better characteristics typically leads to lower measurement uncertainties due to smaller correction factors needed. One of the CIE quality factors is the spectral quality factor f_1' [10]. That is gives information on the possible errors introduced when measuring broadband light sources without spectral mismatch correction. The deviation of the spectral sensitivity of the photometer from the $V(\lambda)$ function may lead to error values of the luminous flux which is measured by that photometer. An exact match to the CIE luminous efficiency function is not entirely possible. The CIE recommend a good-of-fit value $f_1{}'$ as a universal method of specifying the quality of a photopic (the $V(\lambda)$ function) response photometer [10].

In this paper, a set up based on 2.5 m sphere photometer system of National Institute of Standards (NIS) and photometer with a group of luminous flux standard lamps calibrated at National Physical Laboratory (NPL) are used to [11] to determine the Sphere Photometer Calibration Factor (SPCF) and also estimated the uncertainty due to it.. Another set up based on NIS Spectroradiometer and integrating sphere system for measuring the sphere-photometer spectral responsivity and spectral quality factor $f_1{}'$ 'has been determined for the NIS sphere-photometer.

Methods

Measurements Set-up of Determining the Sphere Photometer Calibration Factor (SPCF)

The NIS photometer used is LMT U1000 and the integrating sphere [11] used has a diameter of 2.5 meter and is coated internally with a uniform layer of barium sulfate ($BaSO_4$). The flux lamps are mounted in a base-up configuration at the center of this sphere into a lamp socket supported from the top of the sphere. Figure 1., shows the 2.5 meter diameter integrating sphere photometer at NIS, Egypt. The baffle is coated with a uniform layer of barium sulfate ($BaSO_4$), and suspended on wire supports from the wall of the sphere and was situated approximately halfway between the lamp and the photometer port. Figure 2. shows the lamp baffle, the photometer port, and the lamp holder and the lamp socket.

The direct exposure of the photometer head is blocked using a small baffle between the lamp and the detector head. When using standard lamps, the test lamp is calibrated against a standard lamp of the same color temperature and the same size. Otherwise, spectral and spatial corrections are needed.

It has been chosen to consider that the standard lamps calibrate the sphere photometer to give Sphere-Photometer Calibration Factor (SPCF) [12] that may vary over time. We use the NIS 2.5 m integrating sphere photometer for the measurement, the set up as shows in the Figure 3.

Measurement Set-up of the integrating sphere photometer spectral responsivity

The sphere-photometer spectral responsivity was determined as the product of the relative spectral throughput of the sphere and the relative spectral responsivity of the photometer head. The spectral responsivity of the integrating sphere is determined by rationing the spectral distribution measured at the photometer port of one of the total flux working standard lamps to that measured directly of the working standard lamp using the photometric bench and the Spectroradiometer ocean optics HR 2000 at NIS with uncertainty 4.7% [13,14]. A set up of measuring used to determine the sphere photometer spectral responsivity as shown in Figure. 4 and Figure. 5**.**

Results and Analysis

Results of the Sphere Photometer Calibration Factor (SPCF)

On the first and second days of measurements, the fourteen measurements of the standard lamps give the ability to have seven measurements of the sphere responsivity over the course of the day. It has been found that there was a drift in this value during the day and were able to mathematically fit the sphere photometer responsivity to a linear drift behavior.

The equations of the fitted line in Fig 6. and Fig 7. represent the Sphere-Photometer Calibration Factor (SPCF) of the integrating sphere. The equation in each figure contains two values: SPCF and t, where SPCF is the Sphere-Photometer Calibration Factor and t is the calibration time for this reading. SPCF is a function of the slope (the rate of changing of lamp SPCF per unit time) and the SPCF intercept (SPCF value at t=0). These curves are very useful to determine a slight modification to the usual calibration calculations.

$$\mathbf{SPCF} = 0.0133\mathbf{t} + 0.9951 \qquad (1)$$

The results of first day, the equations of the fitted lines in Fig 4. and Fig 5. represent the Sphere-Photometer Calibration Factor (SPCF). The equation in each figure contains two values SPCF and t, where SPCF is the Sphere-Photometer Calibration Factor, and t is the calibration time for this measurement. The SPCF is a function of the slope (the rate of change of the SPCF per unit time) and the SPCF intercept (SPCF value at t=0).

$$\mathbf{SPCF} = 0.0051\mathbf{t} + 0.9962 \qquad (2)$$

The relative spectral responsivities [15] of photometers change depending on the temperature of their optical components. Unless the photometer is a temperature-controlled type, measurement errors may occur if a photometer is used at an ambient temperature different from that at which it was calibrated. When a lamp is turned on in the integrating sphere, the photometer head on the sphere is heated up due to the heat from the lamp and the responsivity of the photometer can drift.

Figure. 8. and Figure. 9. show the sphere photometer temperature variation for the two days of the measurements. We see in these two curves that the variation in the first day is within 0.15 degree and the variation in the second day is within 0.2 degree.

Results of the integrating sphere photometer responsivity

The relative spectral responsivity of the integrating sphere photometer was determined by measuring separately the relative spectral responsivity of the photometer and the relative spectral throughput of the sphere.

The ratio of these two values was used to give the relative spectral responsivity of the integrating sphere. The spectral throughput of the integrating sphere was measured, Fig 10. .

The relative spectral responsivity of NIS Sphere-Photometer is shown in Fig 11. It obtained from the product of the relative spectral responsivity of the sphere shown in Fig 9. and the relative spectral responsivity of the photometer obtained the spectral efficiency of the total luminous flux integrating sphere as shown in Fig 10.

Table.1 The Electrical Control Results of NIS standard Lamps

NIS Standard Lamps	***SET Current***	***Voltage***	***Colour temperature***	***Total luminous flux***
	(amperes)	***(Volts)***	***(Kelvin)***	***(lumen)***
NIS-E21	1.7869	102.1	2750	2587
NIS-E22	1.7991	101.6	2750	2597
NIS-E31	0.20482	91.9	2400	131.5
NIS-E32	0.20315	92.0	2400	130.8
NIS-E33	0.20382	92.4	2400	132.4

Figure.1 The NIS Integrating Sphere Photometer system (2.5 meter diameter)

Figure.2 The Lamp baffle, the photometer port, and the lamp holder of the 2.5 integrating sphere system

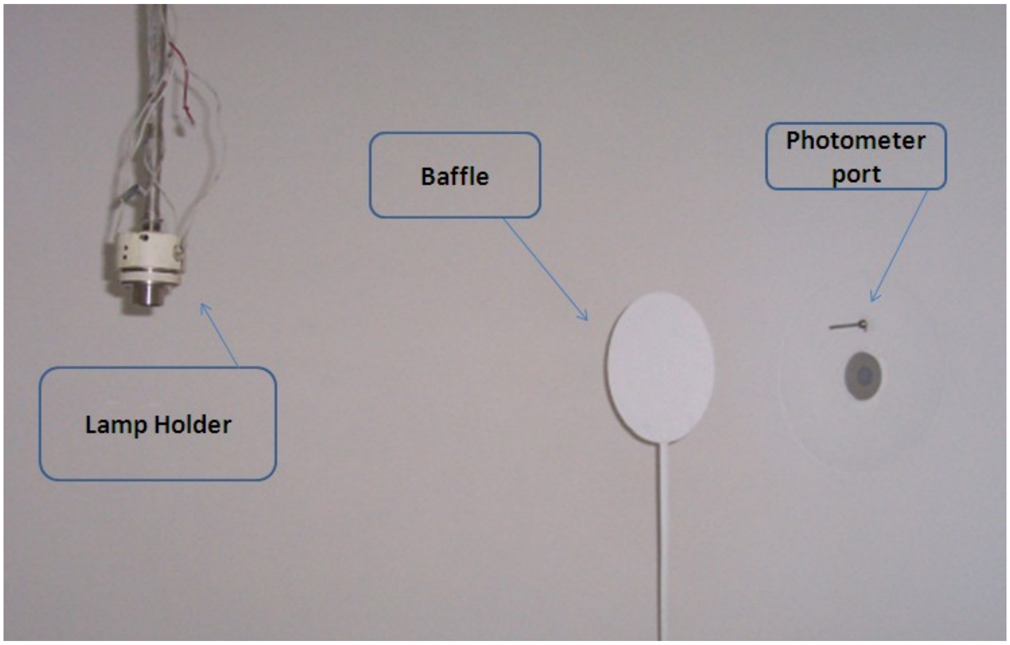


Figure.3 The 2.5 m NIS integrating sphere photometer system set up for the luminous flux measurement

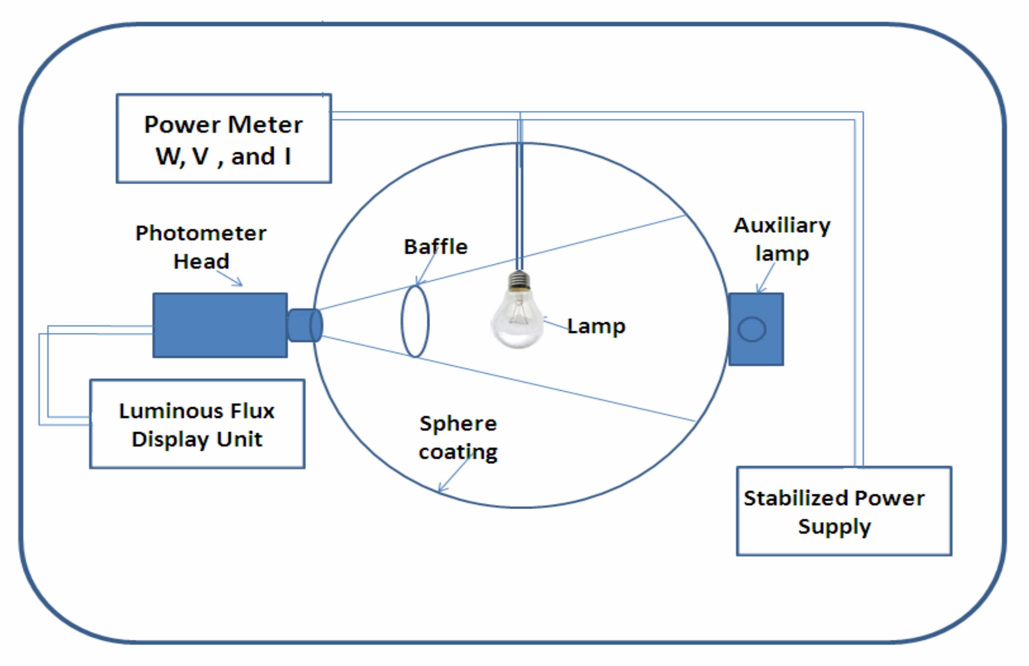


Figure.4 Set up of measuring the spectral power distribution of NIS total luminous flux working standard lamps

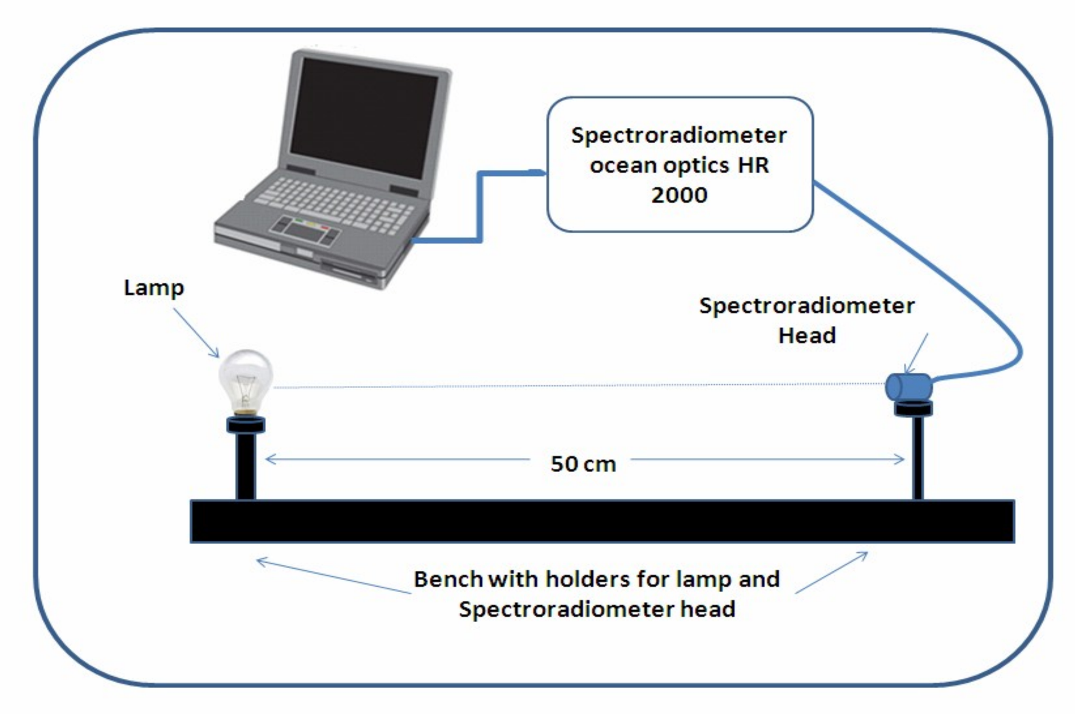


Figure.5 Set up of measurements the spectral responsivity of NIS Integrating Sphere Photometer system with NIS total luminous flux standard lamps

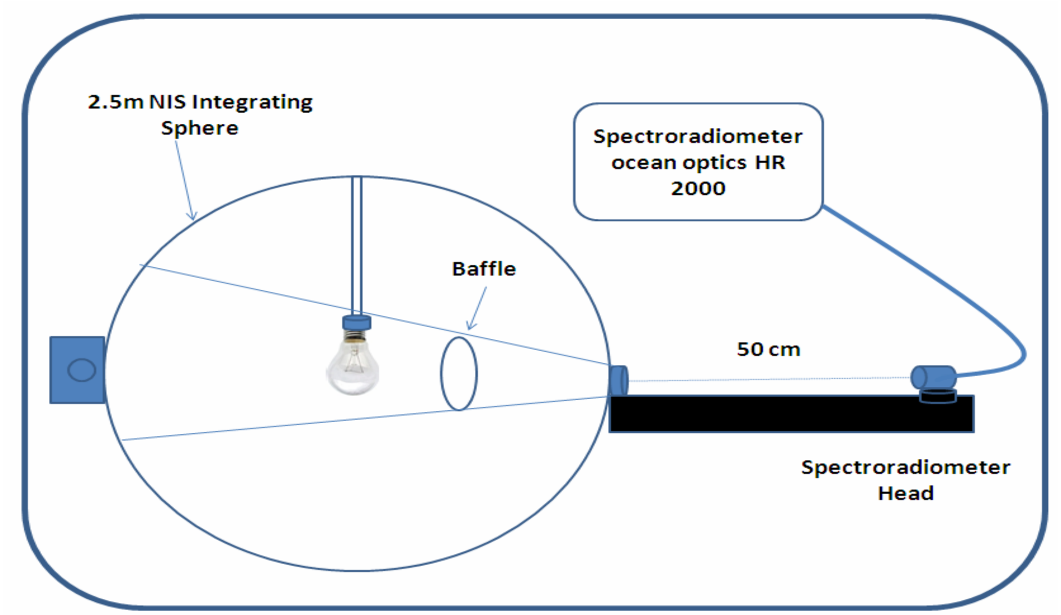


Figure.6 Sphere –Photometer Calibration Factor (SPCF) for the standard lamps in the first day

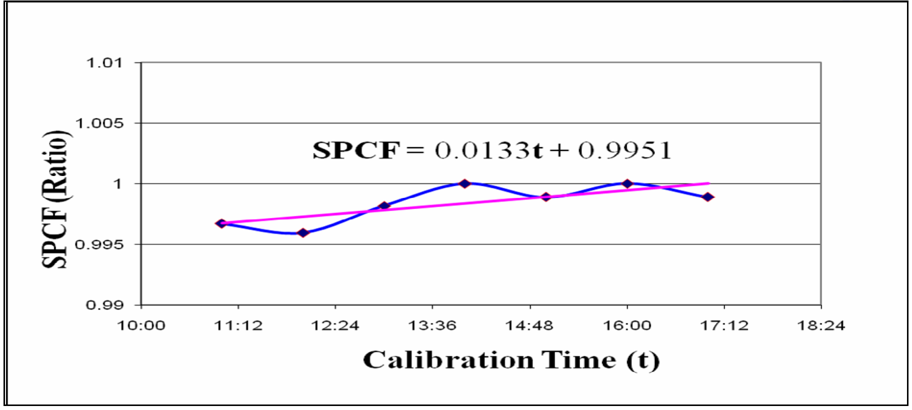


Figure.7 Sphere –Photometer Calibration Factor (SPCF) for the standard lamps in the second day

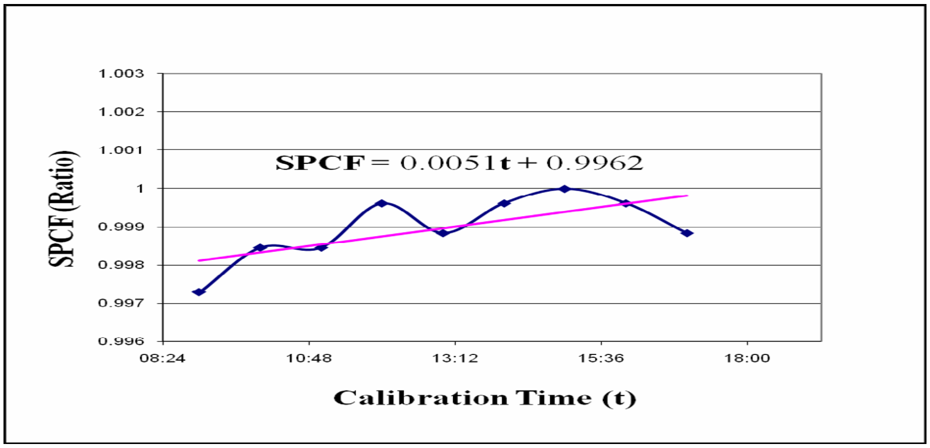


Figure.8 Temperature Variation of Sphere –Photometer of Day1 Measurements

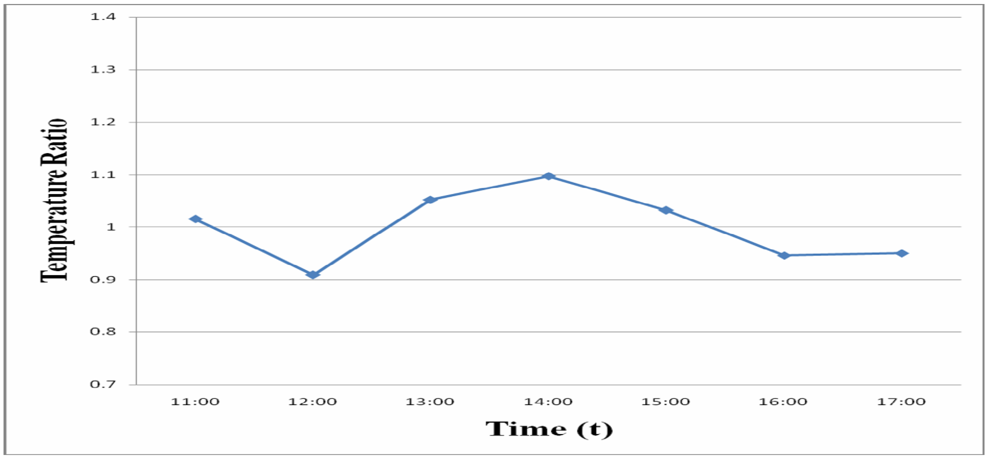


Figure.9 Temperature Variation of Sphere –Photometer of Day2 Measurements

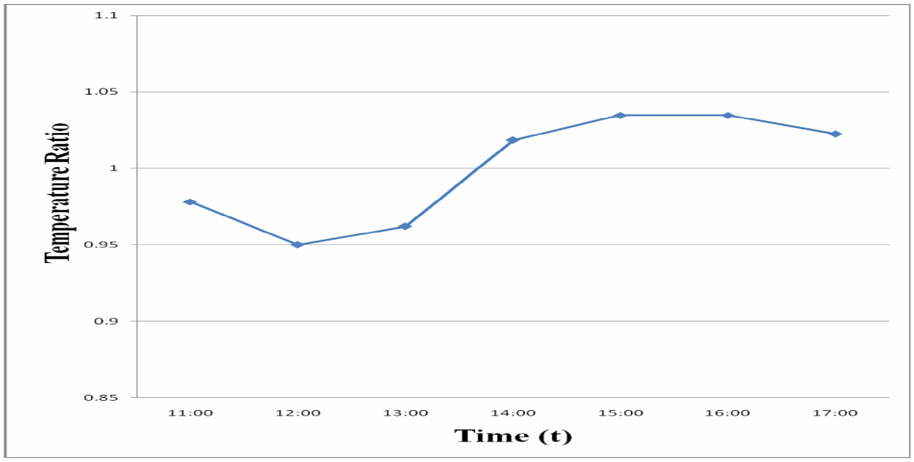


Figure.10 The spectral Responsivity of the NIS-Integrating Sphere

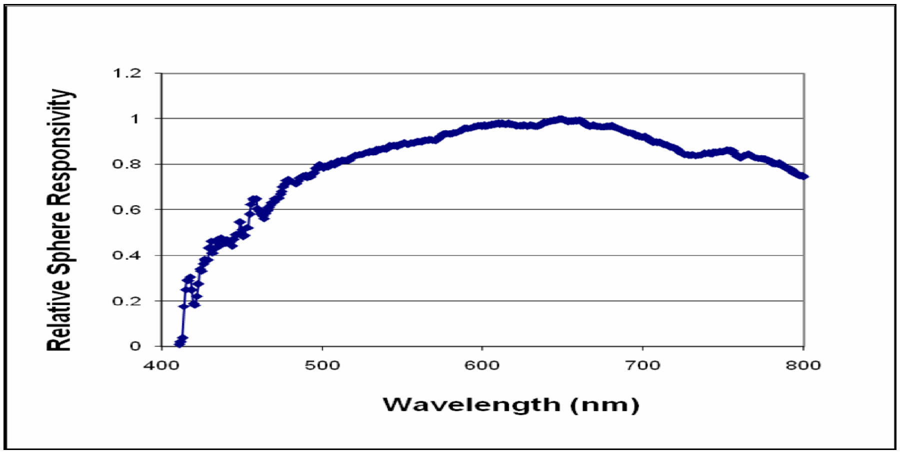


Figure.11 The spectral Responsivity of the NIS-Integrating Sphere Photometer System

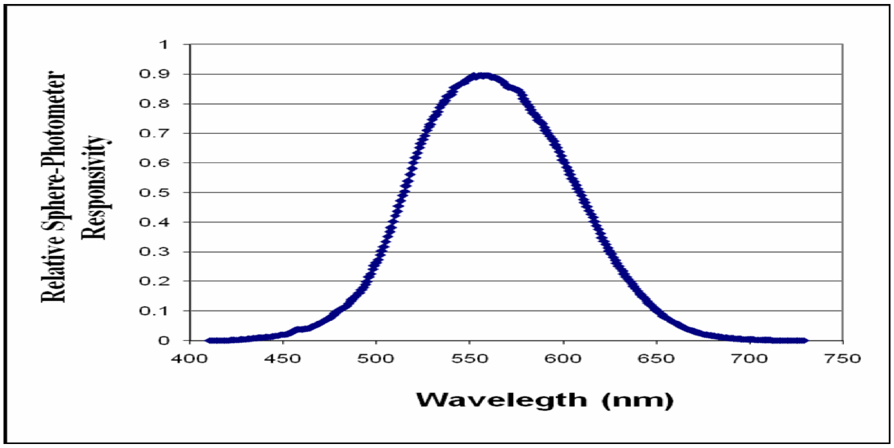
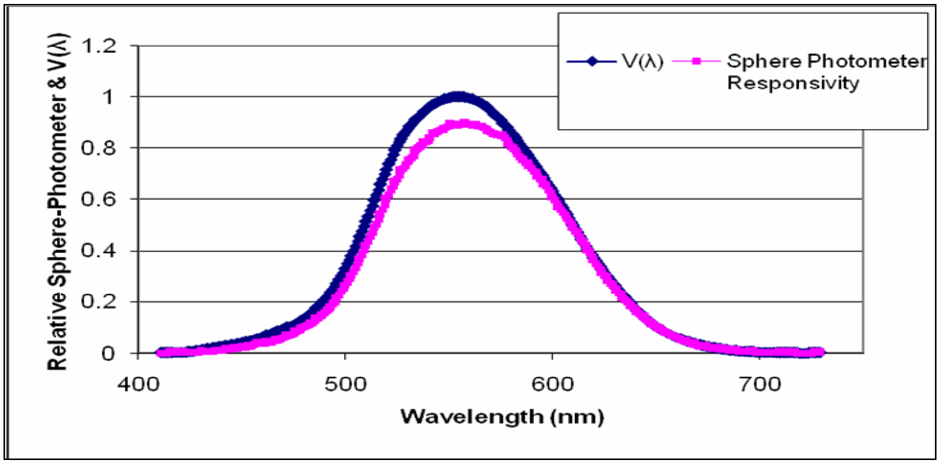


Figure.12 The Sphere-Photometer Responsivity at NIS with the function



Results of the NIS Sphere Photometer Quality Factor (f_1')

The relative spectral responsivity of a photometer can be evaluated using f_1' value as recommended by CIE [10]. The f_1' value is an evaluating index which is calculated from the relative spectral responsivity $S_{rel}(\lambda)$ of the sphere-photometer system according to Yoshi Ohno[15]: The spectral matching of a photometer is high quality if (f_1'〈3％), medium quality if (3〈 f_1'〈8％) and poor quality if (f_1'〉8％).

$$f_1' = \frac{\int_\lambda \left| S^8_{rel}(\lambda) - V(\lambda) \right| d\lambda}{\int_\lambda V(\lambda) d\lambda} \times 100\% \qquad (3)$$

$$S^8_{rel}(\lambda) = \frac{\int P_A(\lambda) V(\lambda) d\lambda}{\int P_A(\lambda) S_{rel}(\lambda) d\lambda} \times S_{rel}(\lambda) \qquad (4)$$

Where:

$S_{rel}(\lambda)$: the relative spectral responsivity of the photometer.

$V(\lambda)$: the spectral efficiency of the human eye for photopic vision.

$P_A(\lambda)$: the spectral power distribution of illuminant A.

From the experimental work, the f_1' value for the responsivity of the sphere-photometer is found to be 6.25 %.

Uncertainty

The ideal method for evaluating and expressing the uncertainty of the result of a measurement should be applicable to all kinds of measurements and to all types of input data used in measurements. Also, the actual quantity used to express uncertainty should be directly derivable from the components that contribute to it. According to Guide to the Expression of Uncertainty in Measurement (GUM) [16], it is assumed that the result of a measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effect.

The determination of a Sphere Photometer Calibration Factor (SPCF) give the ability to incorporate and average the effects of several measurement factors which include [12]:

1- The repeatability of our NIS Lamps, since there were repeated measurements of the Transfer Standard Lamps.
2- Effects caused by sphere spatial non-uniformity and lamp output distribution.
3- Near-field absorption by lamp socket and holders. The same socket and holders were used for all lamps used in this comparison. Any effects due to differences in near-field absorption are expected to be accounted for in the uncertainty of the SPCF.
4- The effects of temperature changes on the sphere coating reflectance and the detector during the course of the measurements.

The linear-least-squares analysis gives the ability to estimate the uncertainty due to the above four factors as 0.15%. The NIS Spectroradiometer ocean optics HR 2000 with uncertainty 4.7% .

Conclusions

The current research work gives the ability to calibrate the integrating sphere system during the total luminous flux measurements and to evaluate the uncertainty of it. The final SPCF used the result of a linear-least-squares fit of the calibration factors as a function of time during the course of the measurements for each day. The estimated uncertainty of the final SPCF is found to be 0.15%. The determination of a Sphere Photometer Calibration Factor (SPCF) enabled us to incorporate and average the effects of several measurement factors which include the repeatability of our NIS Incandescent standard lamps, since there were repeated measurements of the standard lamps. Also, effects caused by sphere spatial non-uniformity and lamp output distribution. Any effects due to differences in near-field absorption by lamp socket and holders are expected to be accounted for in the uncertainty of the SPCF.

2- During the measurements of SPCF, it was observed a drift with time. This because the photometer is not temperature controlled and the burning of lamps during the measurements course may affect on the measurements. The temperature variation during the measurements course has been determined. The variation in the first day is within 0.15 degree and the variation in the second day is within 0.2 degree.

3- The sphere-photometer spectral responsivity has been determined for the integrating sphere system to be considered in the measurements and the estimated uncertainty in the future work.

4-The spectral quality factor f_1' value for the responsivity of the sphere-photometer is found to be **6.25 %.** This percentage value tells that the NIS photometer has medium quality.

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