

Measure Uncertainty in Ultraviolet Index Standard

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Abstract This paper follows International Standards Organization (ISO) by “Guide to the Expression of Uncertainty in Measurement, GUM”. In order to measure Ultraviolet Index (UVI) standard, it is necessary in calibration or test laboratory field norm on the authentication. By distance Inverse-Square Law of the Optical Radiation, We constructed measurement equation, to consider the error source when you are measuring, to evaluate the uncertainty of system. Evaluate the uncertainty of this system: The measurement distance is 75mm, ultraviolet index of the standard source is $y = 11.7$ UVI, effective degrees of freedom is $V_{eff} = 67$, coverage factor is $k = 2.0$, confidence level is 95%, the standard uncertainty is $u_c = 0.13$ UVI, expanded uncertainty is $U = 0.3$ UVI, the result is $Y = y \pm U = 11.7 \pm 0.3$ UVI.

Keywords Ultraviolet Index, Uncertainty, Calibration

1. Introduction

Measurement of light is an ancient science. Generally, it can be divided into optical radiation measurement [1], photometric measurement, and color measurement. Colorimetry [2] is clearly part of optical measurement related to color. Optical radiation and photometric measurements are measurements of optical parameters, and the main difference is that the latter includes the human visual response. The main purpose of this research is to construct a laboratory for testing standard. It refers to the spirit of ISO/IEC 17025 Standard, and follows “Guide to the Expression of Uncertainty in Measurement” (ISO GUM) made by ISO organization. The content includes UV test system construction, UVI transmittance measurement uncertainty, and the plan of measurement quality assurance that assures the stable operation of the laboratory system. Construct the equations of measurement uncertainty by the system methods that apply to the UVI transmittance measurement by UV spectroradiometer. The standard uncertainty is $u_c = 0.13$ UVI, expanded uncertainty is $U = 0.3$ UVI, the result is $Y = y \pm U = 11.7 \pm 0.3$ UVI.

2. Objectives

2.1. Definition of Measurement Uncertainty

Measurement uncertainty is an estimate of the interval [3] used to represent the degree of dispersion of the measured values, so it is an evaluation of measurement quality. The

more concentrated the measurement results are, the higher the measurement quality is, that is, the measurement uncertainty is smaller. On the contrary, the more dispersed the measurement results are, the lower the measurement quality is, and the measurement uncertainty is larger relatively.

2.2. Process to Measure Uncertainty

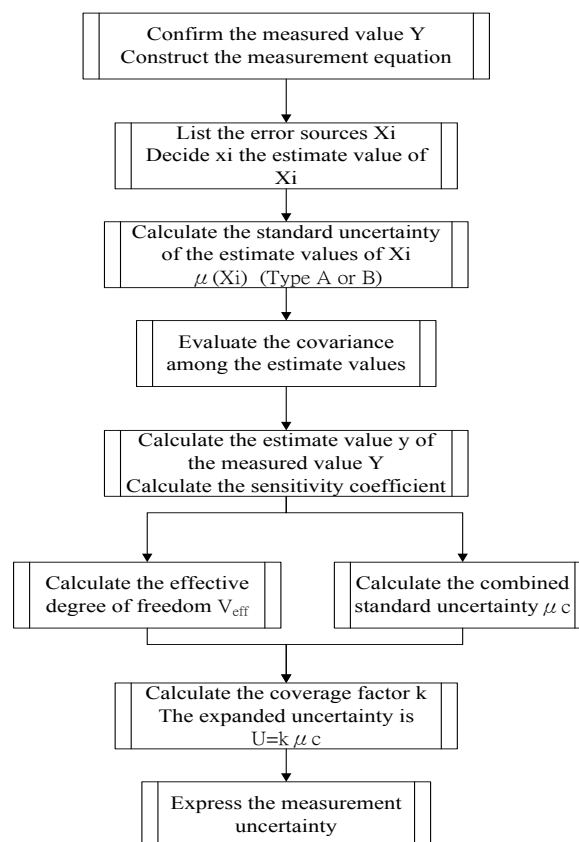


Figure 1. Flow Chart of Process to Measure Uncertainty

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Published online at <http://journal.sapub.org/eee>

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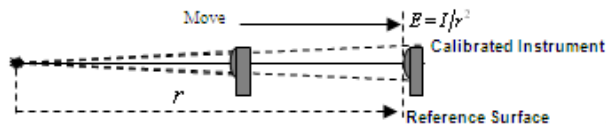


Figure 2. Calibration Based on the Light Source

According to “Guide to the Expression of Uncertainty in Measurement, GUM”[4] published by International Standards Organization (ISO) in 2008, the eight steps of the process to measure uncertainty are illustrated in Fig. 1.[5]-[10]

3. Methods

3.1. Calibration Based on the Light Source

There are two methods for calibration; one is based on the light source, and the other is based on the instrument. The method based on the light source is shown in Fig. 2.[11]

The intensity of the light source is I , and the illuminance[12] at r can be derived by inverse square law $E = I / r^2$. Then, compare the derived illuminance with that measured by the calibrated instrument. It can be calibrated with different illuminance values by changing the distance between the light source and the calibrated instrument. The following items should be considered in this method: 1) distance accuracy, 2) stability of the light source, 3) uniformity of the light source, 4) cosine correction of the instrument.

3.2. Calibration Based on the Light Source

The other calibration method is based on the instrument. The instrument is calibrated by exchanging the position of the standard instrument with the calibrated one. The system structure is shown in Fig. 3.

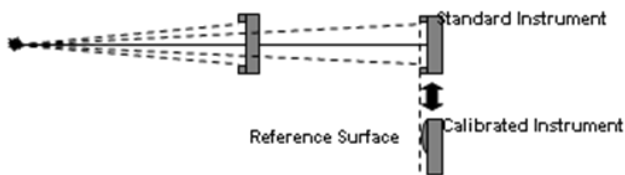


Figure 3. Calibration Based on the Instrument

First, adjust the distance between the standard instrument and the light source to measure the standard ultraviolet index UVI_{std} . Then, use the same distance to measure the ultraviolet index of the calibrated instrument UVI_{test} . The UVI instrument can be calibrated by comparing the standard value with the test one. The following items also need to be considered in the method based on the instrument: 1) consistency of the reference surface, 2) uniformity of the light source, 3) cosine correction of the instrument or the distance between the instrument and the light source. The data in this paper are measured by UVI instrument, but are calculated with the unit of irradiance W/m^2 . The measured

values should be transferred by $1UVI = 0.025 W/m^2$ [13] before being calculated.

4. Results

4.1. Structure of Measurement System

According to the calibration methods mentioned in 3.2, the structure of the system in this thesis is shown in Fig. 4.

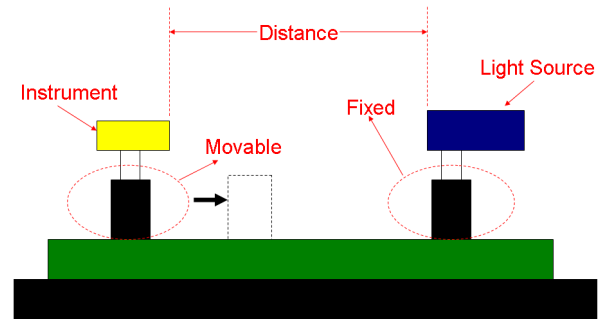


Figure 4. Structure of Measurement System

4.2. Experiment Procedures

Measurement procedures of the experiment: Set up the equipments as Fig. 5.

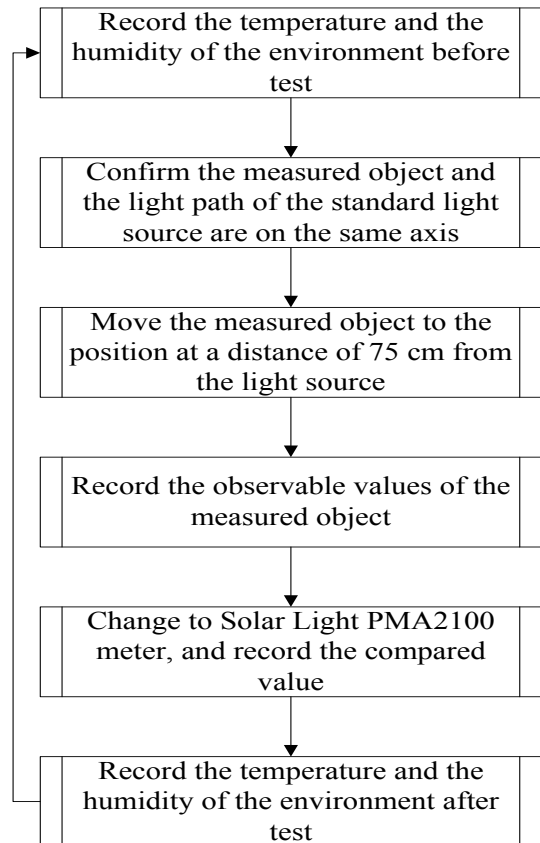


Figure 5. Measurement Procedures of the Experiment

Align the end surface of the instrument and the standard light source with the platforms respectively, and consider them as the starting and the end points for distance

calculation.

Procedures:

Use TES-1367 thermo-hygrometer to record the humidity and temperature of the environment before measurement, and record them again after measurement. Check the level and the collimation of the instrument and the standard light source: Confirm if the emitting light of the light source and the instrument are at the same level, and if the light has a collimated incident. The method of confirmation: First, take the instrument to the position that the light source emits from, and observe if the detector of the instrument collimates with that position. If not, adjust the level of the supporting bar and the direction of the platform, shown as Fig. 6. Turn on the power of the instrument and the light source for 40 minutes before measurement [14][15]. When the system is steady, the measured values without the light source should be recorded.



Figure 6. Align the Instrument and the Standard Light Source with the Platform

The displacement platform should be aligned with the slide scale to reduce the error. Every time after measurement, the light source should be changed to Solar Light PMA2100. Then, measure and record the data at the starting, middle and end point with erythemal spectral detector to ensure the stability of the standard light source.

4.3. Error Sources and Calculate Uncertainty

Actually, the error sources include the measurement methods, the equipments, the people, the environment, and the measured objects. Because of the time issue, only the measurement equipments and the environment are discussed in the thesis. Other factors are ignored. The error sources in our research are shown in Fig. 7. The four main impact factors are lamp current, UV radiation intensity, range, and meter reading.

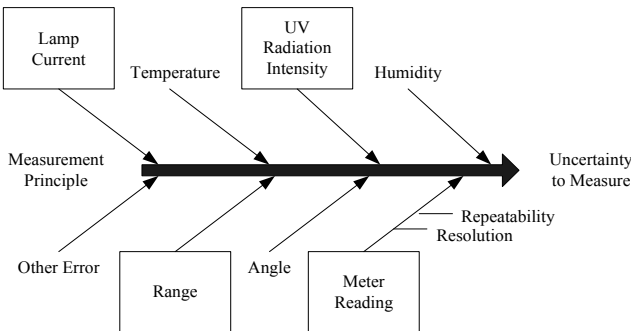


Figure 7. Error Sources

• **Distance:** Due to the inverse square law of irradiance,

the error of distance is necessary to be considered.

• **Temperature and Humidity:** Find the correlation coefficient r by the measured values of ultraviolet index, “Using (1), temperature, and humidity. The correlation r between temperature and UVI is -0.228, and that between humidity and UVI is 0.215. The correlations are both below 0.3. Temperature and humidity are low correlation, and aren’t included in error factors.

• The average temperature and humidity in this experiment are 26°C and 64 %RH.

• **Angle:** The angle is always set to zero about light source before measurement every time, so the error of angle is not considered.

• **Other Errors:** Other errors are interferences of other light sources, the calibration differences of thermo-hygrometer, thermal expansion coefficient of other measurement equipments, etc. These can be extended for advanced research direction.

$$r(x_i, x_j) = \frac{\sum_{k=1}^n (x_{i,k} - \bar{x}_i)(x_{j,k} - \bar{x}_j)}{\sqrt{\sum_{k=1}^n (x_{i,k} - \bar{x}_i)^2 \sum_{k=1}^n (x_{j,k} - \bar{x}_j)^2}} \quad (1)$$

r : Correlation between any two input x_i
 $-1 \leq r(x_i, x_j) \leq +1$

The measurement equation of this research is shown below:

$$E = \frac{I \times i}{L^2} \quad (2)$$

Which:

I: Radiation Intensity Unit: Watt/Steradian (W/Sr)

E: Irradiance Unit: Watt/meter² (W/m²)

L: Measurement Distance Unit: meter (M)

i: Lamp Current Unit: Ampere (A)

Definitions :

e : UVI Reading

e_1 : Resolution of UVI instrument

e_2 : Repeatability UVI instrument

I : Radiation Intensity of Standard Lamp

i : Current of Standard Lamp

L : Distance

The measurement equation is represented by a function:

$$\Delta E = e - E = e - \frac{I \times i}{L^2} = f(e, I, i, L) \quad (3)$$

Combined Standard Uncertainty:

$$U_c(\Delta E) =$$

$$\sqrt{\left[\frac{\partial f}{\partial e}\right]^2 u^2(e) + \left[\frac{\partial f}{\partial I}\right]^2 u^2(I) + \left[\frac{\partial f}{\partial i}\right]^2 u^2(i) + \left[\frac{\partial f}{\partial L}\right]^2 u^2(L)} \quad (4)$$

Each sensitivity coefficient $\frac{\partial f}{\partial X_i}$ can be calculated

below:

$$\frac{\partial f}{\partial e} = 1 \quad (5)$$

Table 1. The Uncertainty Analysis of UVI Detector Calibration

Uncertainty Source x_i	Variation Range of Uncertainty Source	Probability Distribution	Standard Uncertainty $u(x_i)$	Sensitivity Coefficient $\left(\frac{\partial f}{\partial x_i}\right)$	Component of Uncertainty $\left \frac{\partial f}{\partial x_i}\right u(x_i)$	Degree of Freedom $\nu(x_i)$	Evaluation Type
e	--	--	0.044 UVI	1	0.045 UVI	69	-
e ₁	0.1	t	0.033 UVI	1	0.033 UVI	30	A
e ₂	0.188	Rectangular	0.029 UVI	1	0.029 UVI	50	B
I	0.01	-	5.4×10^{-6} W/Sr	177.8 m^2	0.00096 W/m^2 = 0.038 UVI	50	B
i	1.5×10^{-4}	Rectangular	1.4×10^{-7} W/Sr	177.8 m^2	$2.6 \times 10^{-5} \text{ W/m}^2$ = 0.001 UVI	∞	B
L	1	Normal Distribution	0.00033 m	14.2 W/m^3	0.0032 W/m^2 = 0.12 UVI	50	B
1) Measurement Distance: 75mm ; 2) $u_c(\Delta E) = 0.13 \text{ UVI}$; 3) $\nu_{\text{eff}} = 67$; 4) $U(\Delta E)_{95} = 0.3 \text{ UVI}$ (Coverage Factor $k = 2.00$)							

$$\frac{\partial f}{\partial i} = \frac{-I}{L^2} \quad (6)$$

$$\frac{\partial f}{\partial L} = \frac{-2I}{L^3} \quad (7)$$

$$\frac{\partial f}{\partial I} = \frac{-i}{L^2} \quad (8)$$

ν_{eff} : Effective Degree of Freedom

$$\nu(\Delta E) = \frac{u^4(\Delta E)}{\frac{u^4(e)}{\nu(e)} + \frac{u^4(I)}{\nu(I)} + \frac{u^4(i)}{\nu(i)} + \frac{u^4(L)}{\nu(L)}} \quad (9)$$

Calculation of each standard uncertainty:

• UVI Reading (e):

$$U_c(e) = \sqrt{U_c^2(e_1) + U_c^2(e_2)}$$

- Resolution (e₁):

The resolution of the instrument is: 0.1 UVI. It belongs to type B uncertainty evaluation. According to the references, the shape of the probability distribution is rectangular.

The degree of freedom is $\nu_1 = 50$

The standard uncertainty is $U_c(e_1) : 0.029(\text{UVI})$

- Repeatability (e₂) :

It belongs to type A uncertainty evaluation.

The degree of freedom is $\nu_2 = 31 - 1 = 30$

The standard uncertainty is $U_c(e_2) : 0.033(\text{UVI})$

• **Radiation Intensity** of Standard Lamp (I) :

Radiation intensity of the light source is 0.00165 W/Sr

The measurement distance is $75 \text{ mm} \Rightarrow 0.075 \text{ m}$

The standard uncertainty is $U_c(I) : 0.038(\text{UVI})$

• Current of Standard Lamp $U_c(i) : 0.001(\text{UVI})$

• Distance (L):

During measurement, the possible variation of L is less than

$\pm 1 \text{ mm}$. The data have more probability of appearing in the center of

the interval than at both ends. The data of distances are

estimated to form a normal distribution, and the degree of freedom $\rightarrow 50$. The

standard uncertainty is $U_c(L) : 0.12(\text{UVI})$

Substitute each value into equation (2)~(9) respectively for calculation. The results of uncertainty analysis are shown in Table (1).

The combined standard uncertainty is $U_c(\Delta E) = 0.13(\text{UVI})$. The effective degree of freedom is $\nu_{\text{eff}} = 67$. The expanded uncertainty: Set the confidence level 95%. By searching from the table, the coverage factor is $k=2.0$, $U(\Delta E)_{95} = 2.0 \times 0.13 \approx 0.3(\text{UVI})$.

5. Discussion and Conclusions

This paper refers to "Guide to the Expression of Uncertainty in Measurement" of ISO GUM to complete the uncertainty evaluation of UVI measurement. It is expected to get the ISO 17025 certification from international laboratory. It is calibrated by the UVI instrument and the UVB biologic lamp sold in the market. The error values can be known, and the reliability of the product is got by the users. Besides, the standard light source used in this thesis hasn't been calibrated by the advanced laboratory. If the light source is calibrated in the future, this paper will become more credible. Finally, in our laboratory we built this measurement distance is 75mm, ultraviolet index of the standard source is $y = 11.7 \text{ UVI}$, effective degrees of freedom is $\nu_{\text{eff}} = 67$, coverage factor is $k = 2.0$, confidence level is 95%, the standard uncertainty is $u_c = 0.13 \text{ UVI}$, expanded uncertainty is $U = 0.3 \text{ UVI}$, the result is $Y = y \pm U = 11.7 \pm 0.3 \text{ UVI}$.

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