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Development of Mesopic Photometers based on CIE 191

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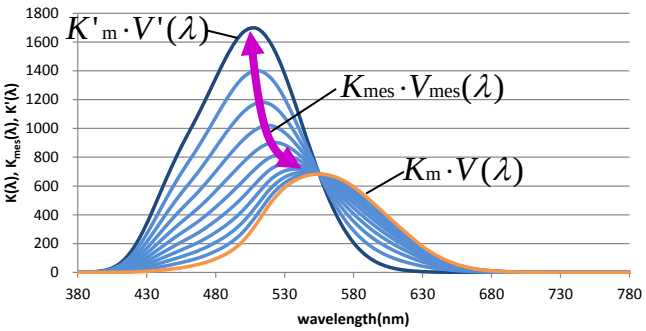
Panasonic

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Introduction

$V_{mes}(\lambda)$ defined in CIE 191 could make outdoor lighting more energy efficient and/or visually effective – but issues remain

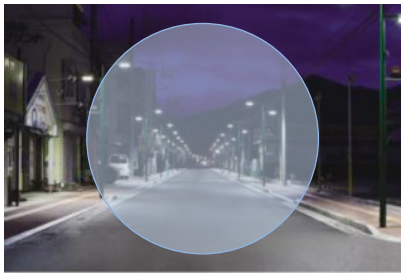
- Take into account Purkinje effect – $V_{mes}(\lambda)$ peak shifts to short wavelength



- SSLs have more blue-rich spectrum than HPS – CIE 191 evaluate potential advantages of SSLs over HPS for outdoor lighting

Remaining Issues

Adaptation field definition



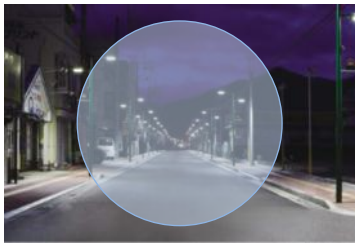
Instruments to measure mesopic quantities

Uniqueness of mesopic luminance measurement

Two steps, two channels, various geometrical conditions

- **Two steps – adaptation field and test target measurement**

Photopic/Scotopic Adaptation Luminance

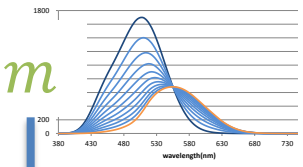


$L_{p,a}$

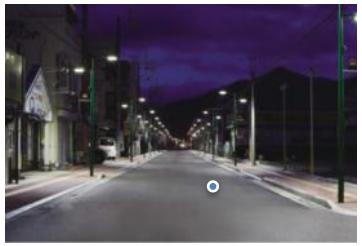
$L_{s,a}$

Adaptation Parameter

m



Photopic/Scotopic Luminance of the test target



$L_{p,t}$

$L_{s,t}$

$L_{mes,t}$

- **Two channels – photopic and scotopic channel**

- **Various geometrical conditions – adaptation field depends on application**

Two types of mesopic luminance meter

To avoid use of too many optical attachments, two types of instruments can be employed

Imaging luminance meter

- Measure luminance image by one shot
- Realize adaptation fields by image processing (mask pattern)

- Small geometrical error
- Large spectral mismatch
  - glass filters are necessary

Spot luminance meter

- Measure luminances at point-by-point
- Realize an adaptation field by definition of a measurement points set

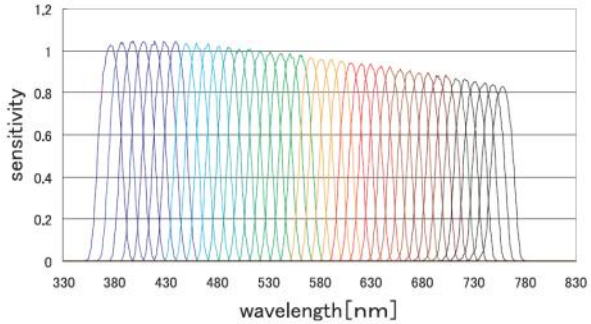
- Large geometrical error
- Very small spectral mismatch when employ spectrometer

Spot Mesopic Luminance Meter (SMLM)

Modify coefficients of channels on a SiPD array colorimeter

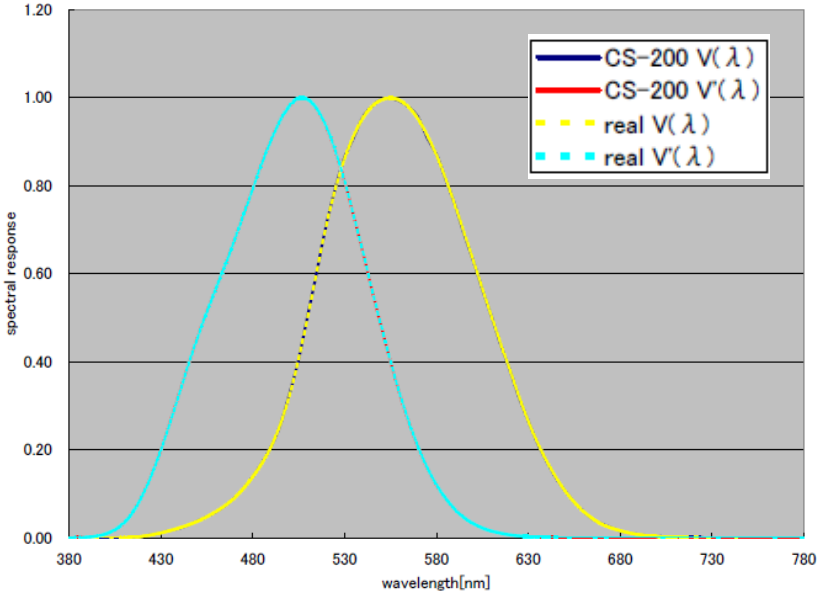
Base photometer

Colorimeter based on
40 channels SiPD array



(Shimizu et al. KONICA MINOLTA Technology Report vol.2, 2006)

Spectral sensitivities (model)



Field of view (FOV): 1 degree

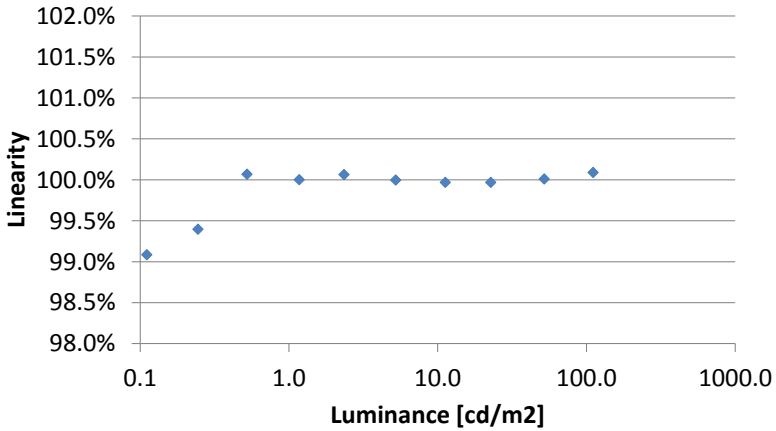
Measurement time: 1 – 60 sec.

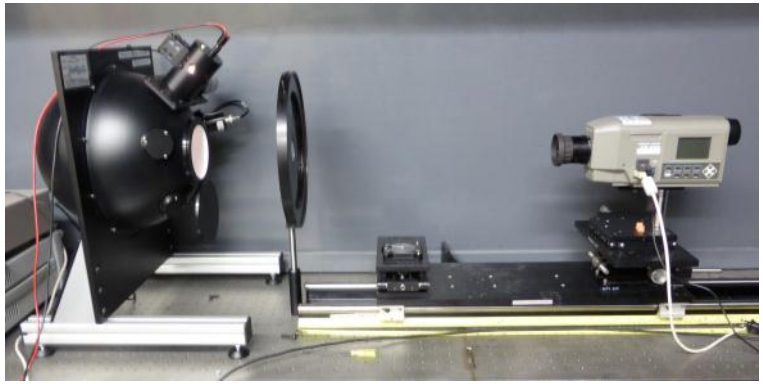
(Including dark measurement)

SMLM: Linearity & Repeatability

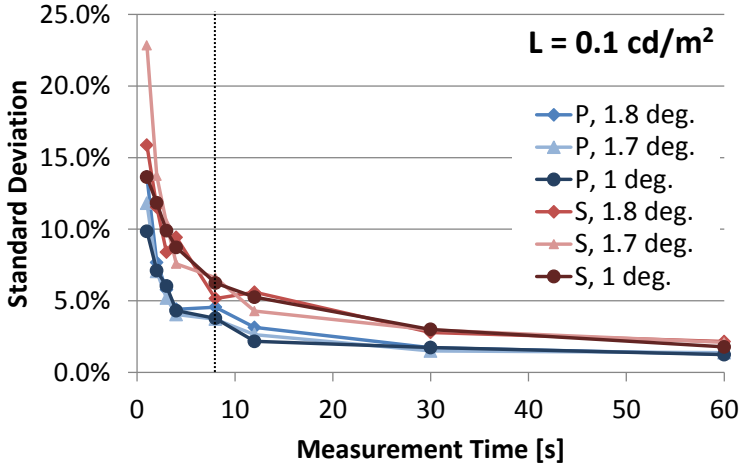
Linearity & Repeatability were evaluated with a stable sphere source and a monitor detector (SiPD)

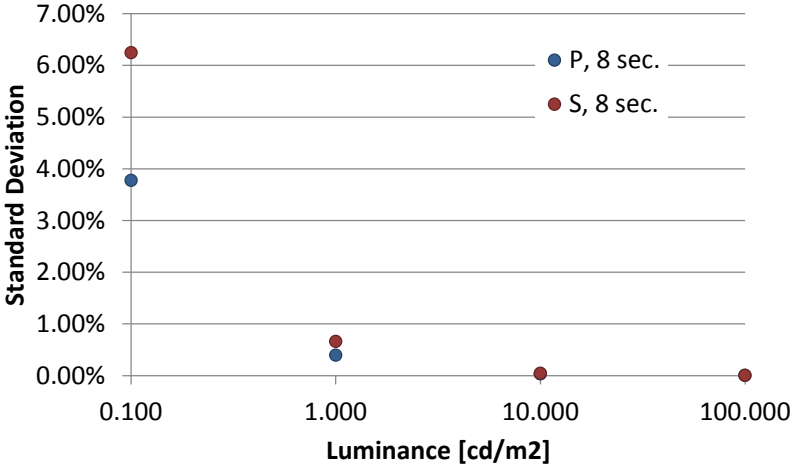
Linearity





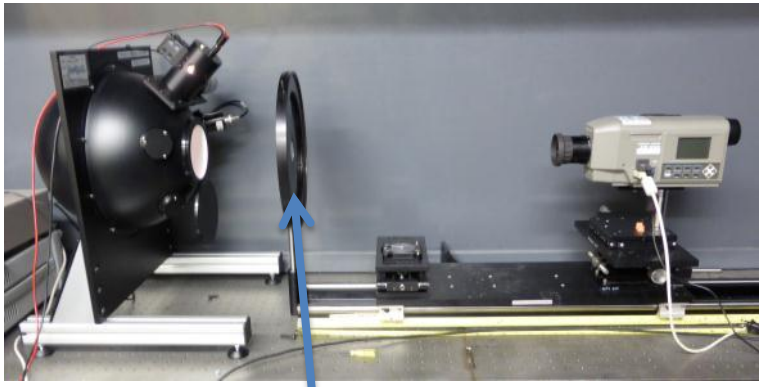
Repeatability



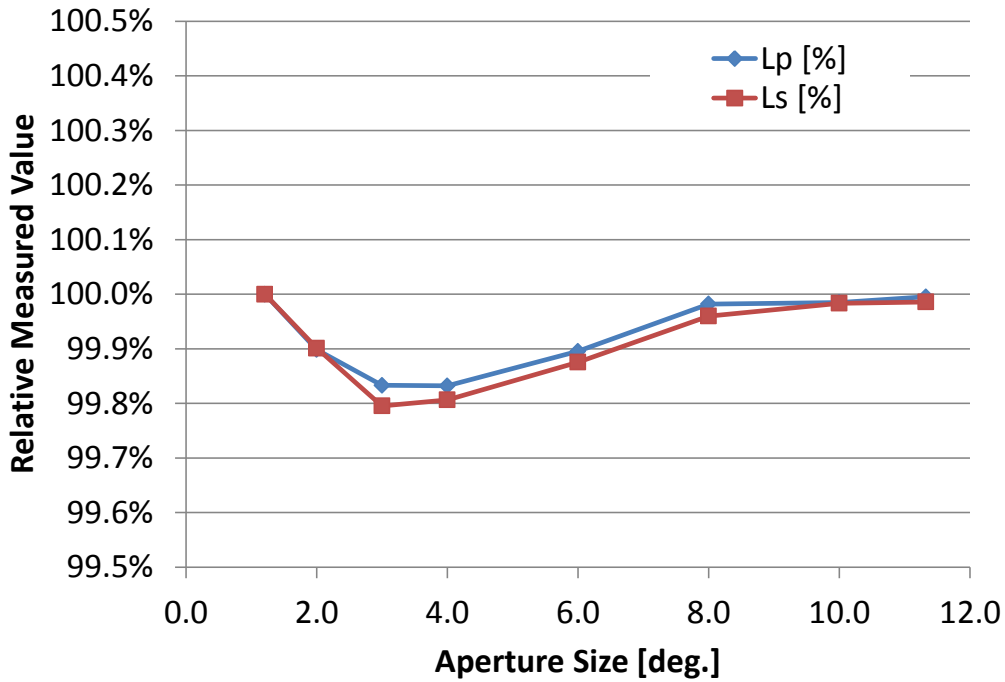


SMLM: Spatial stray light (Surrounding luminance effect)

Only small error is caused by spatial stray light



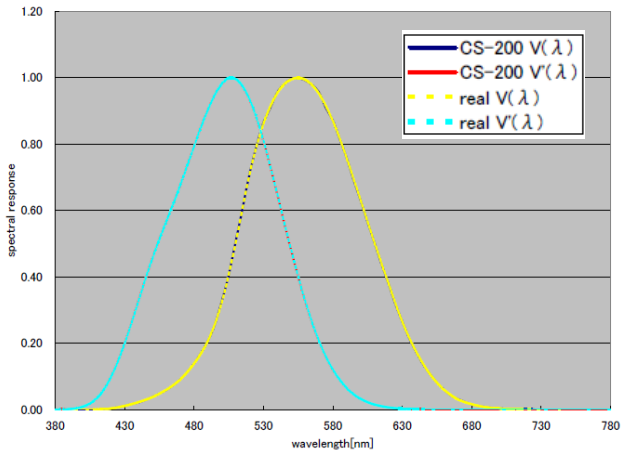
Change aperture size



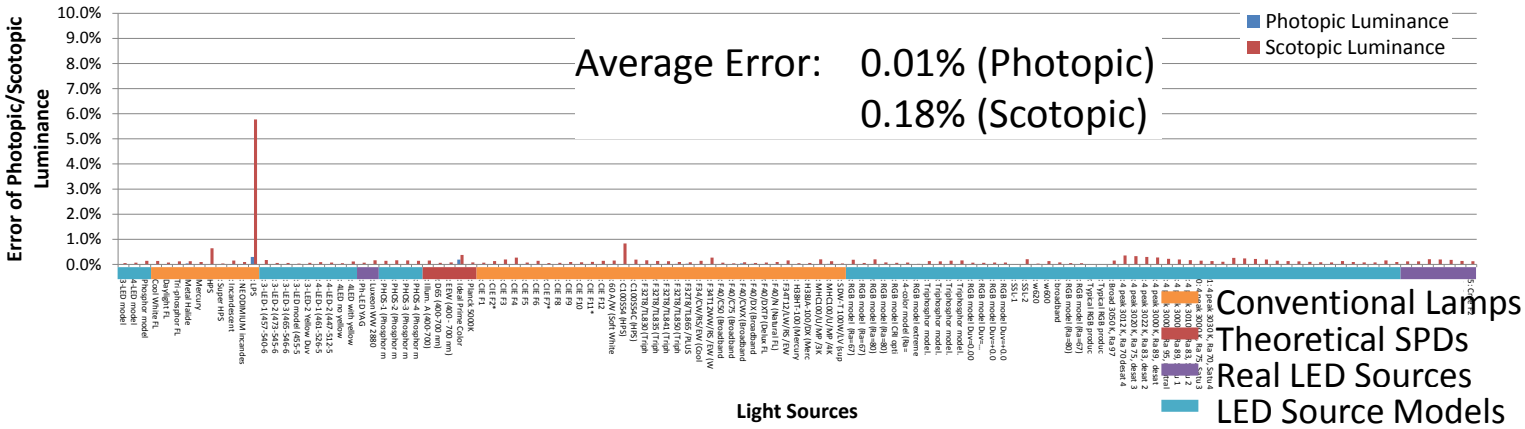
SMLM: Spectral mismatch error (1)

Calculated spectral responsivity seems very accurate…

- **Spectral responsivity calculated from all channel responsivities**



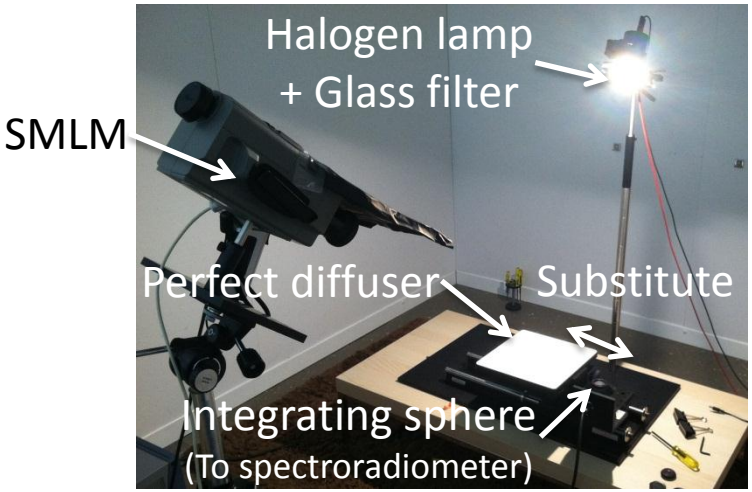
- **Spectral mismatch error (simulated with the model)**



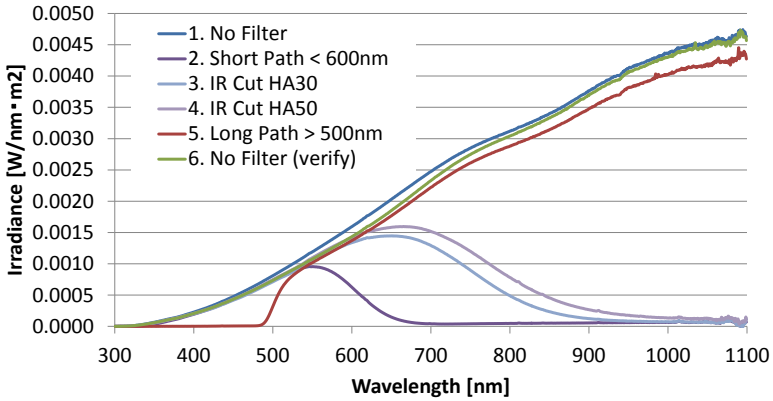
SMLM: Spectral mismatch error (2)

Systematic error was observed by comparison with a stray-light-corrected array spectroradiometer

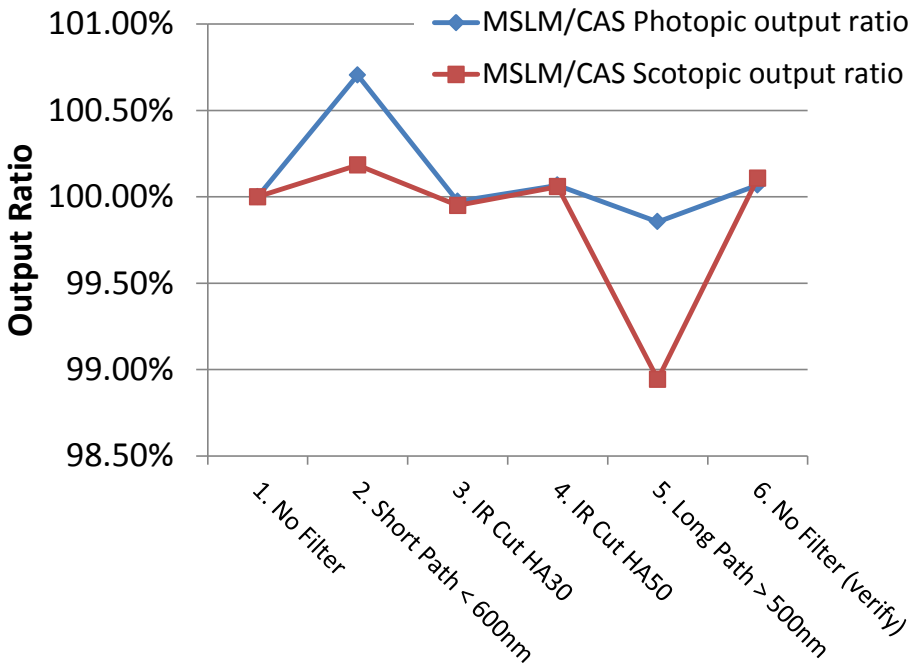
Set-up



Source SPDs



Output ratio: SMLM vs. CAS



The error may be caused by spectral responsivity calibration

SMLM: Uncertainty budget

Repeatability is the largest uncertainty for mesopic test target

MUs were combined by assuming no correlation (But it is not true)

Uncertainty for photopic/scotopic channel

Uncertainty Factor	Unit	8 s, Photopic Channel				8 s, Scotopic Channel			
(Photopic luminance level)	cd/m^2	0.1	1	10	100	0.1	1	10	100
Calibration	%	1.25	1.25	1.25	1.25	2.00	2.00	2.00	2.00
Linearity	%	0.53	0.00	0.02	0.05	0.53	0.00	0.02	0.05
Repeatability	%	3.77	0.39	0.03	0.00	6.24	0.66	0.05	0.01
Spectral mismatch	%	0.44	0.44	0.44	0.44	0.61	0.61	0.61	0.61
Spatial Stray light	%	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Long term drift	%	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Combined Standard Uncertainty	%	4.07	1.47	1.42	1.42	6.63	2.25	2.15	2.15
Expanded Uncertainty (k = 2)	%	8.14	2.95	2.84	2.84	13.25	4.51	4.31	4.31

Uncertainty for mesopic luminance of a test target

Uncertainty Factor	Unit	Standard Uncertainty (in mesopic luminance)			
(Photopic luminance level)	cd/m^2	0.1	1	10	100
Photopic Measurement for m	%	0.12	0.04	0.00	0.00
Scotopic Measurement for m	%	0.14	0.01	0.00	0.00
Photopic Measurement for test	%	2.37	1.26	1.42	1.42
Scotopic Measurement for test	%	2.76	0.33	0.00	0.00
Combined Standard Uncertainty	%	3.64	1.30	1.42	1.42
Expanded Uncertainty (k = 2)	%	7.29	2.60	2.84	2.84

Sensitivities were calculated numerically

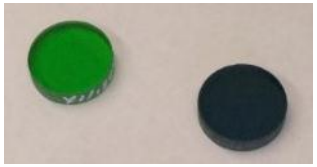
A method to combine partially correlated uncertainties is needed

Imaging Mesopic Luminance Meter (IMLM)

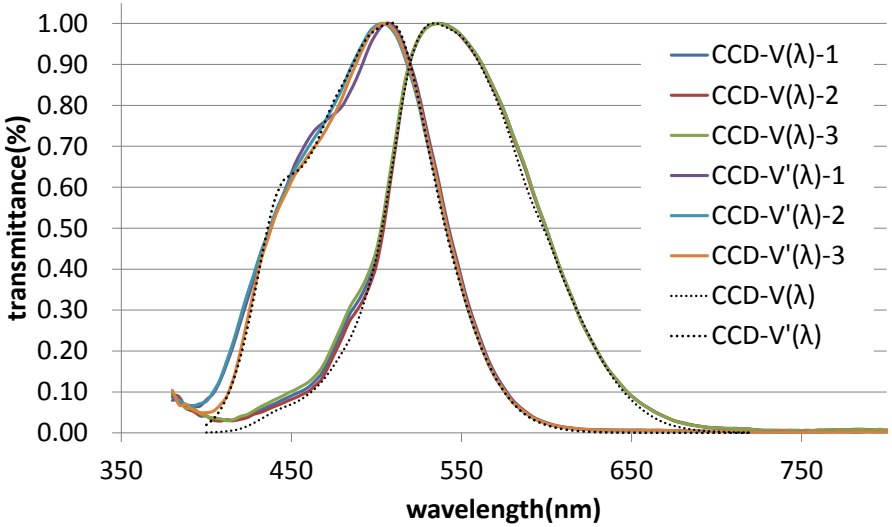
Glass filters for $V(\lambda)$ & $V'(\lambda)$ were installed inside of an ILM

Base photometer and modification

Install $V(\lambda)$ &$V'(\lambda)$ filters on a wheel inside



Filter transmittances



Field of View

- Whole image: 41 x 31 deg.
- 1 x 1 pixel: 0.027 x 0.031 deg.
- 3 x 3 pixels: 0.080 x 0.092 deg.

(with 20 mm lens)

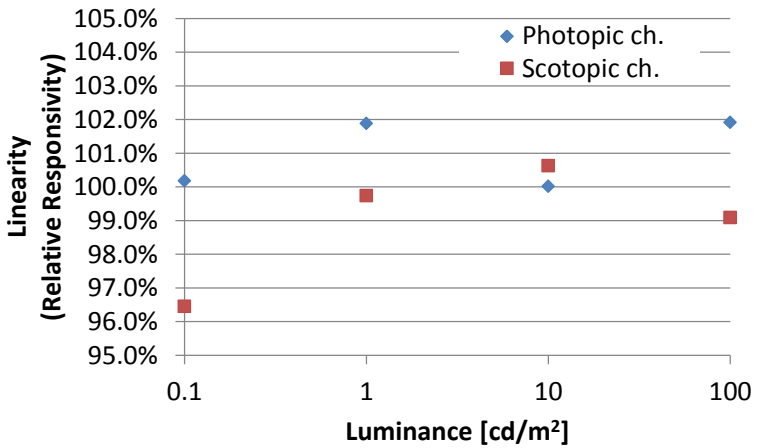
Exposure time

- 0.1 – 10 cd/m^2: 60 sec.
- 100 cd/m^2: 6 sec.

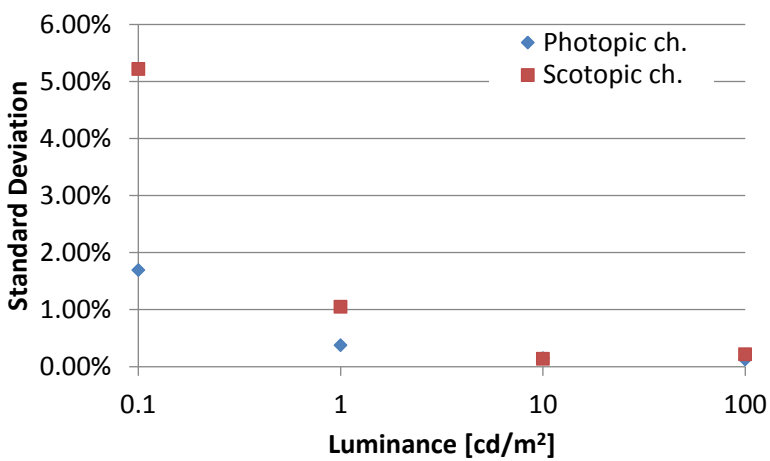
IMLM: Linearity & Repeatability

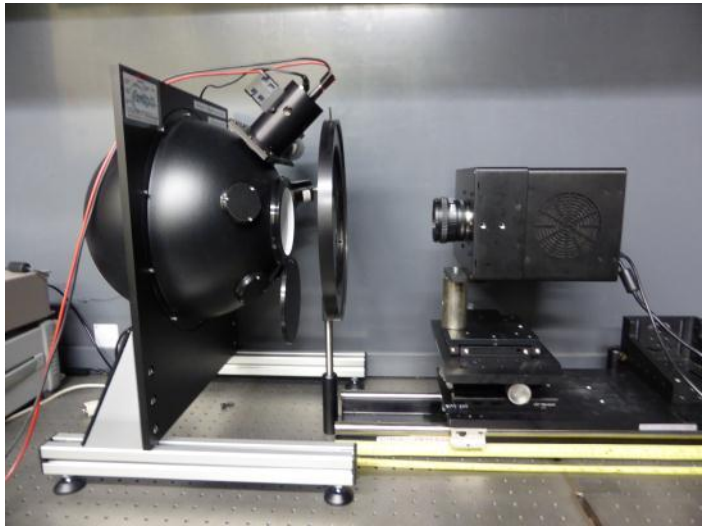
Linearity & Repeatability were evaluated with a stable sphere source and a monitor detector (SiPD)

Linearity (3 x 3 pixels)



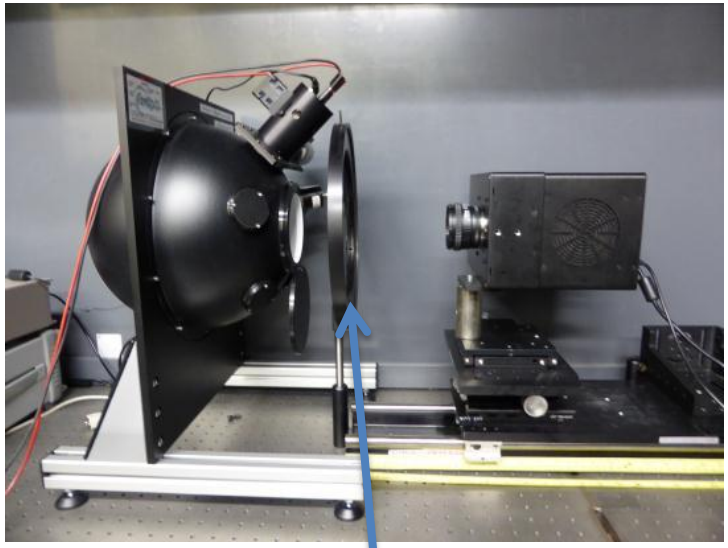
Repeatability (3 x 3 pixels)



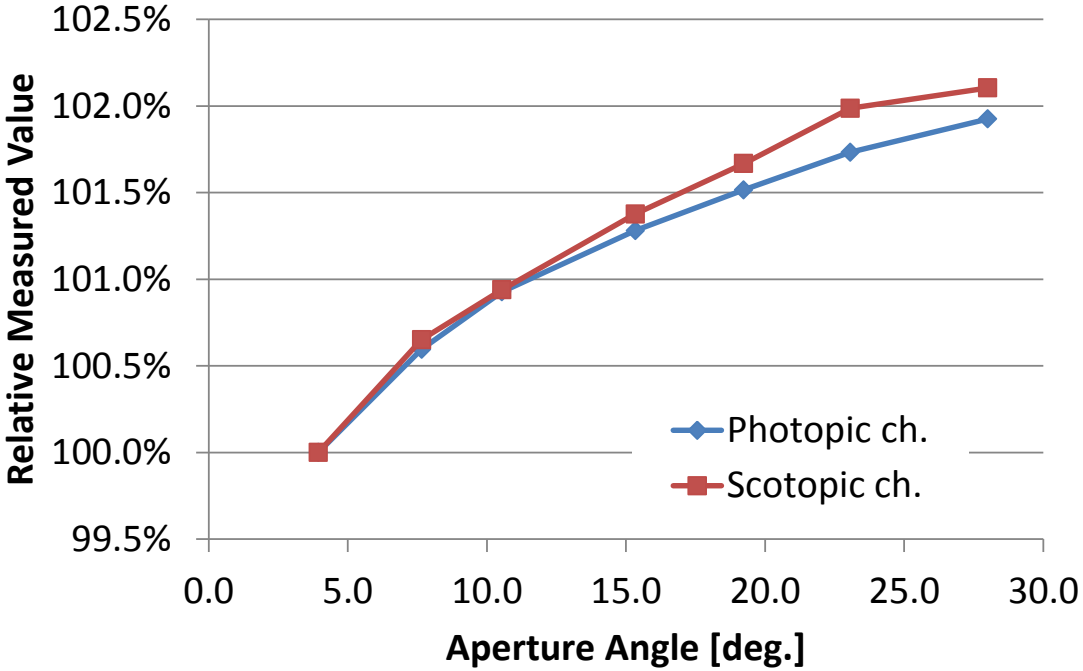


IMLM: Spatial stray light (Surrounding luminance effect)

Error by spatial stray light is much larger than SMLM

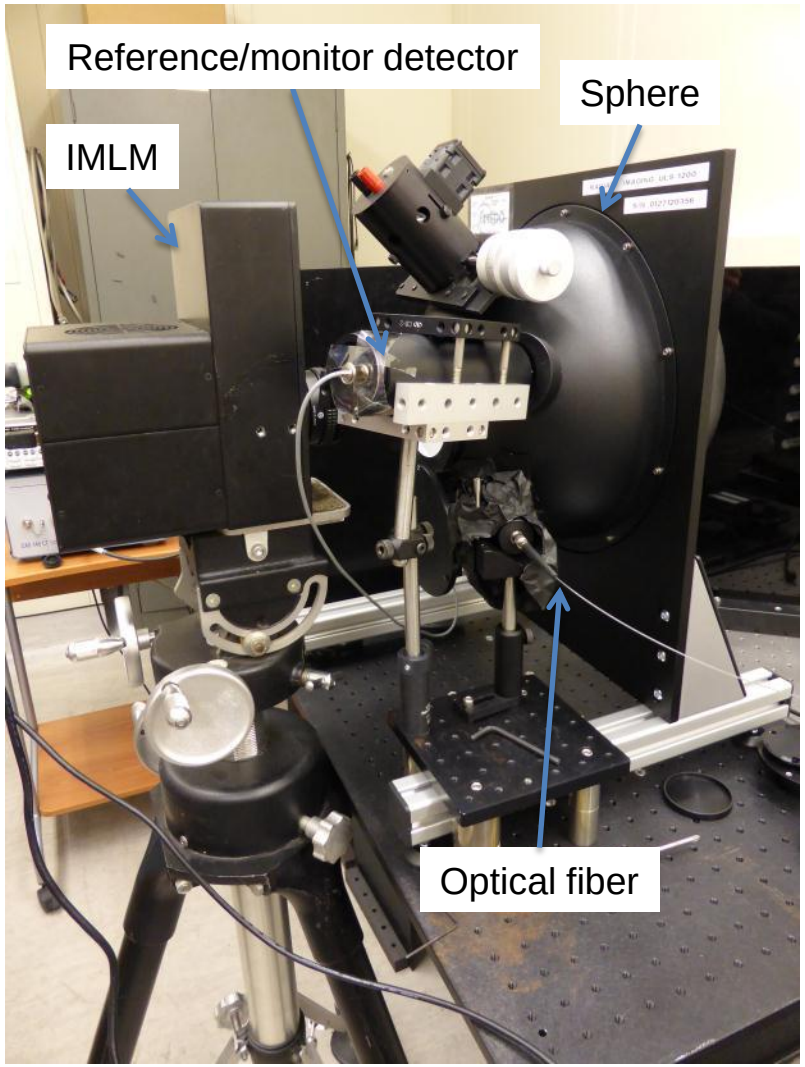


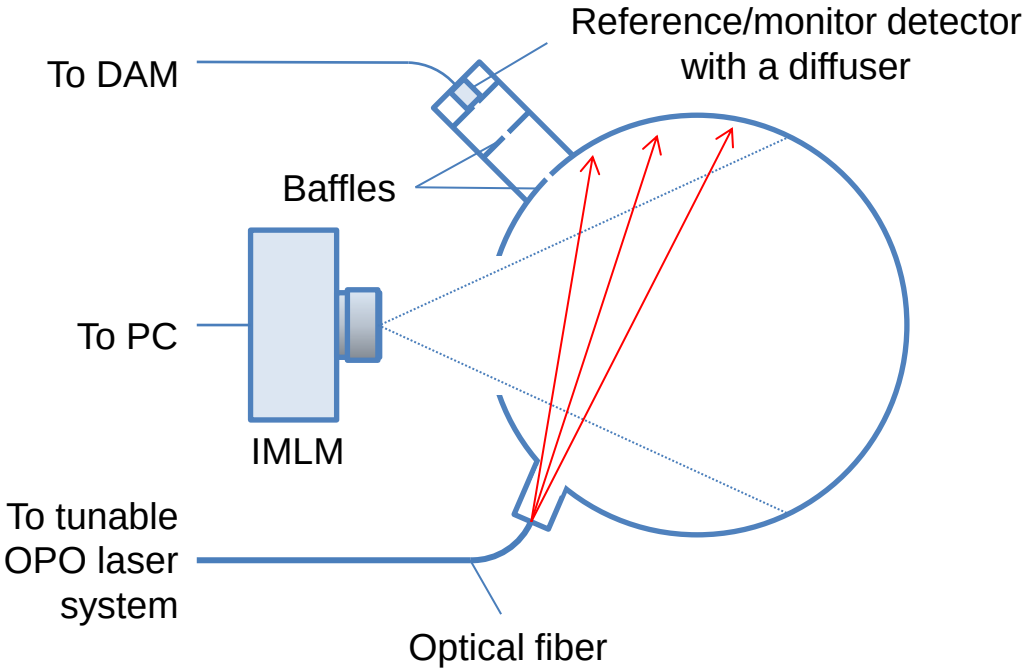
Change aperture size



IMLM: Spectral mismatch error (1)

Tunable OPO laser system was used to measure IMLM spectral responsivity



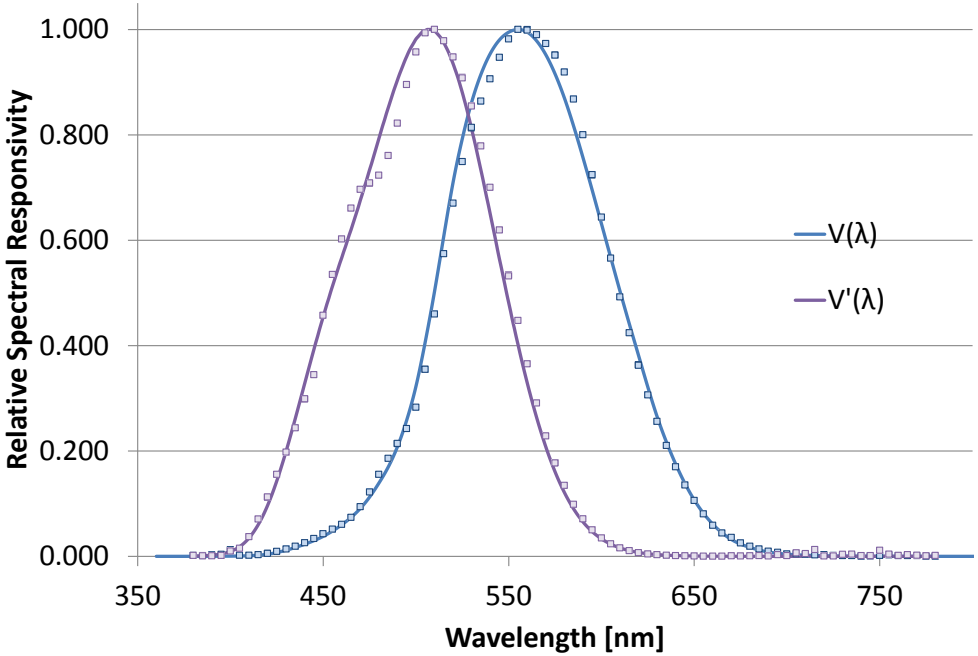


High-power spectrally tunable sphere source

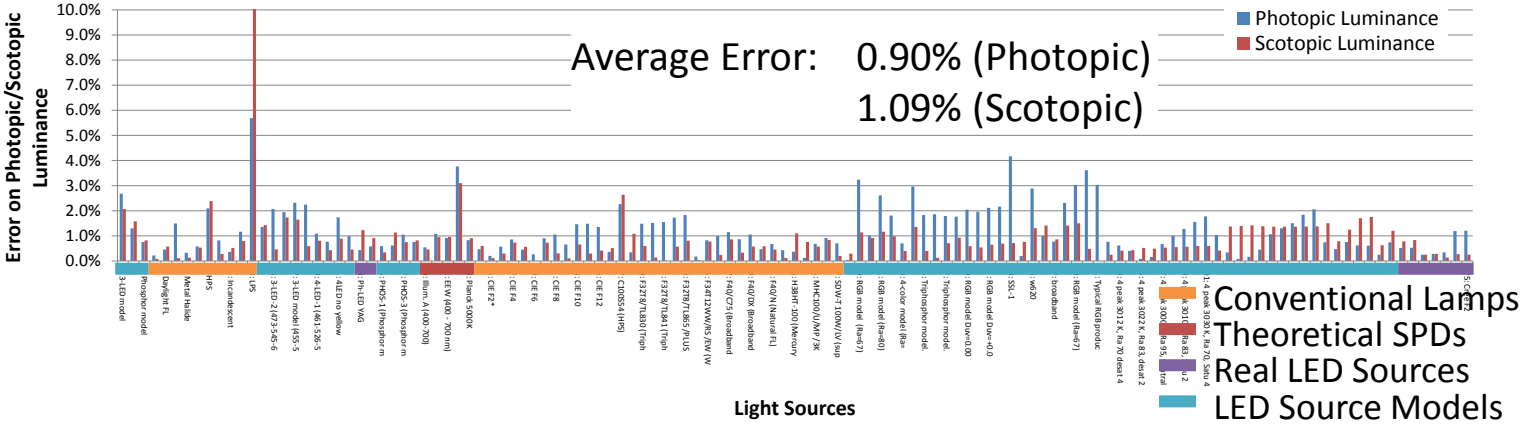
IMLM: Spectral mismatch error (2)

Average spectral mismatch error for various sources is around 1%

- **Spectral responsivity**



- **Spectral mismatch error**



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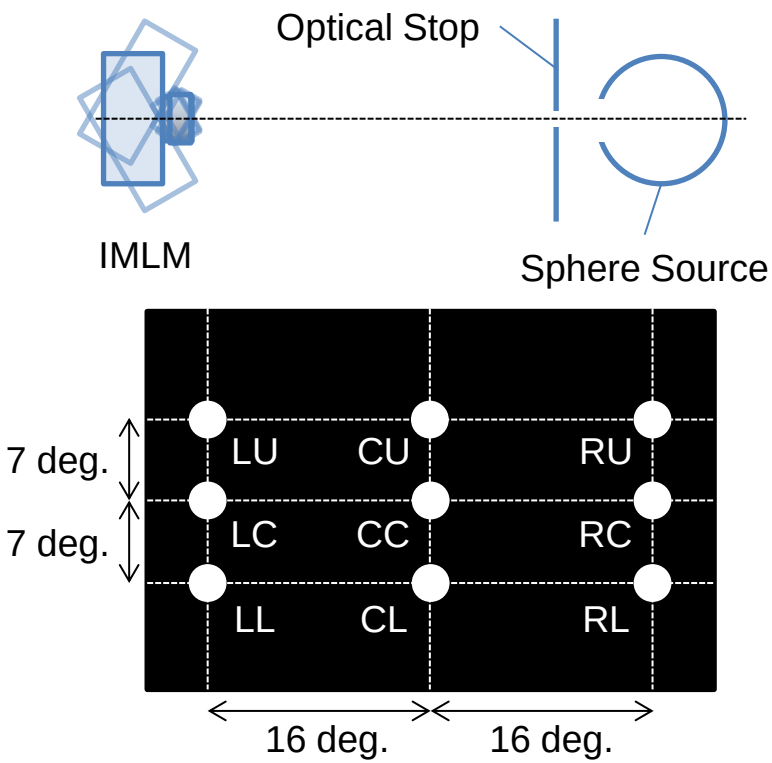
IMLM: Spatial uniformity

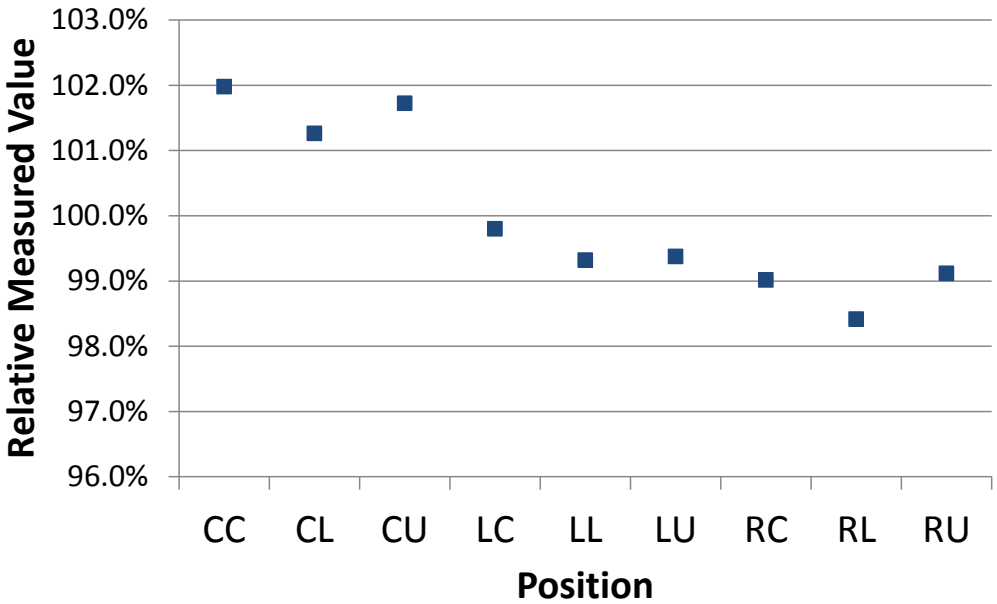
Maximum discrepancy of the measured value is 3.6 %

Set-up

A sphere source was measured at nine positions in FOV



Relative measured value at each point



IMLM: Uncertainty budget

For relatively uniform luminance distribution, IMLM can measure the mesopic luminance with lower uncertainty than SMLM

Uncertainty for photopic/scotopic channel for B-Y LED source

Uncertainty Factor	Unit	60 s or 6 s, Photopic Channel				60 s or 6 s, Scotopic Channel			
(Photopic luminance level)	cd/m^2	0.1	1	10	100	0.1	1	10	100
Calibration	%	1.25	1.25	1.25	1.25	2.00	2.00	2.00	2.00
Linearity	%	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
Repeatability	%	1.69	0.38	0.15	0.12	2.59	0.51	0.30	0.28
Spectral mismatch	%	0.07	0.07	0.07	0.07	2.22	2.22	2.22	2.22
Spatial Stray light	%	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Spatial Uniformity	%	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
Long term drift	%	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Combined Standard Uncertainty	%	3.08	2.60	2.58	2.57	4.55	3.77	3.75	3.75
Expanded Uncertainty (k = 2)	%	6.16	5.20	5.15	5.15	9.10	7.55	7.50	7.50

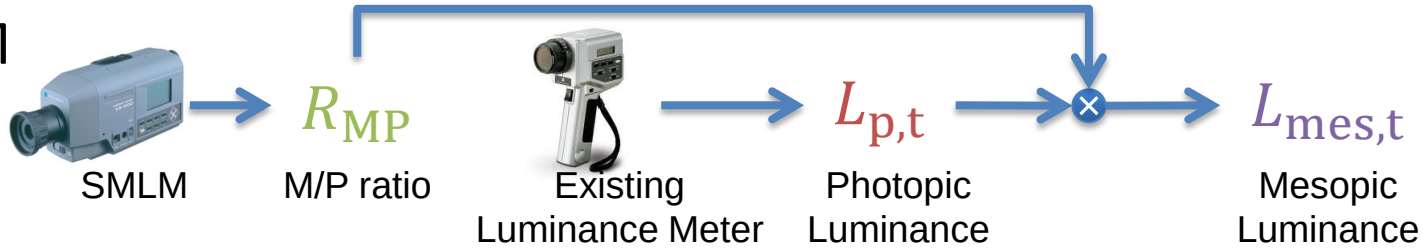
Uncertainty for mesopic luminance of a test target

Uncertainty Factor	Unit	Standard Uncertainty (in mesopic luminance)			
(Photopic luminance level)	cd/m^2	0.1	1	10	100
Photopic Measurement for m	%	0.15	0.15	0.00	0.00
Scotopic Measurement for m	%	0.21	0.05	0.00	0.00
Photopic Measurement for target	%	1.58	2.10	2.58	2.57
Scotopic Measurement for target	%	2.21	0.73	0.00	0.00
Combined Standard Uncertainty	%	2.73	2.23	2.58	2.57
Expanded Uncertainty (k = 2)	%	5.46	4.45	5.15	5.15

Further issues

For Spot Mesopic Luminance Meter…

- Geometrical error of the adaptation luminances
- 1 deg. FOV is still too large to measure road lighting installations
- Multiple point measurement for the adaptation luminance reduces the repeatability error – M/P ratio method can work with SMLM



For Imaging Mesopic Luminance Meter…

- Spatial stray light is much larger than SMLM – Error by glare sources (luminaires, headlamps) needs to be evaluate

For both types…

- Calibration procedures should be established
- Temperature dependency of the instruments

Conclusions

- Prototypes of Spot Mesopic Luminance Meter (SMLM) and Imaging Mesopic Luminance Meter were made and evaluated
- Measurement uncertainties (k = 2) for 0.1 cd/m^2 test target are:
  - 7.29 % with SMLM
  - 5.46 % with IMLM (for relatively uniform luminance distribution)
- For SMLM, sensitivity is too law to measure the mesopic luminance of a test – but it can be used to measure the adaptation luminance and can work with M/P ratio method
- For IMLM, error caused by glare sources needs to be evaluate

Thank you for your attention

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