ALLICE
Automotive Lighting LED-IT Convergence Education
자동차조명융합 전문인력양성 사업단

VISIBILITY UNDER ADVERSE WEATHER CONDITION IN AUTOMOTIVE LIGHTING

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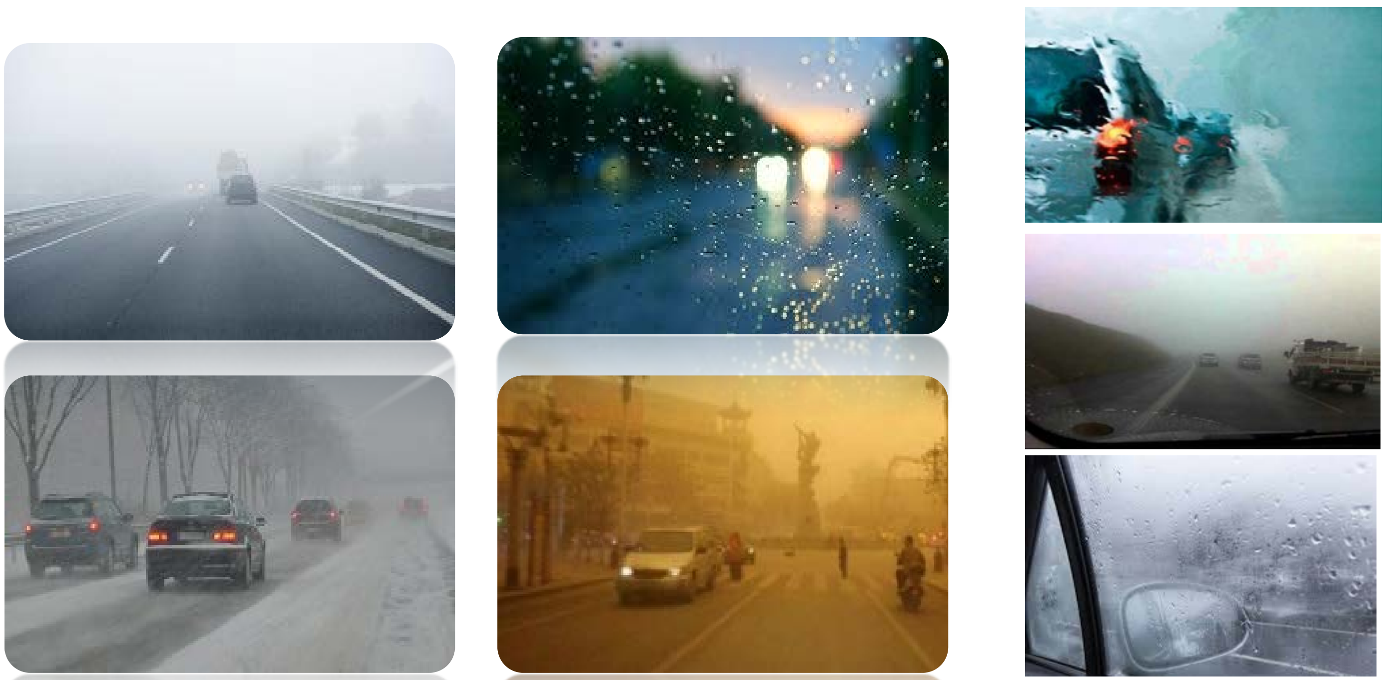
Introduction

- Adverse weather condition or atmosphere like fog, rain, snow and yellow is a threat to the driver's visibility on the road and can be one of the main reasons of traffic accidents. (Zaini et al., 2009)



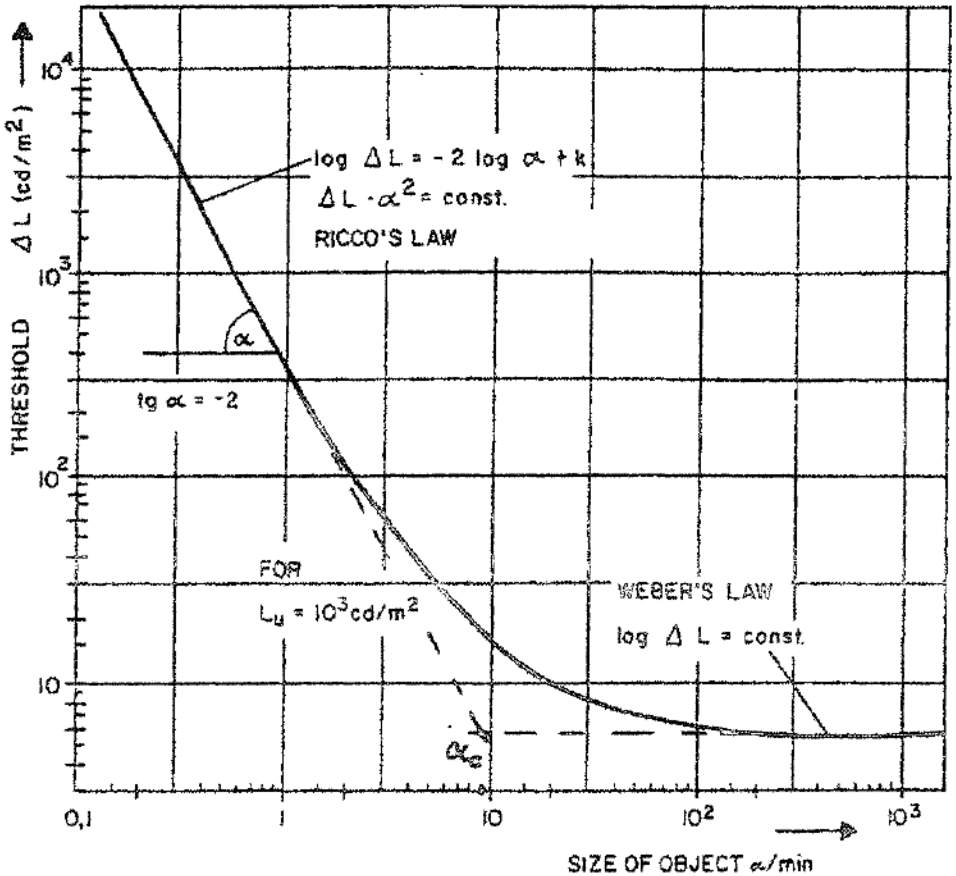
- Important for automotive vehicle as well to run autonomus driving all the time

Introduction

- Yellow dust occurs more frequently and seriously in these days among some Asian countries.
  - Therefore, people as well as governments are trying to reduce its occurrence and to take systematic measures against the problem.
- It also deteriorates the visibility of drivers and induces the traffic accidents.
  - Scientific research and data on the yellow dust is not enough.
  - Need to collect more empirical data and to understand the characteristics of yellow dust.

Introduction

- **Visibility** : Adrian Model development



$$\log \Delta L = -2\log \alpha + k|_{\alpha\to\infty}$$
$$\to \Delta L = K\alpha^{-2}$$
$$\to \Delta L_{\alpha\to 0} = \Phi(L_b)\alpha^{-2}$$

Ricco's law: summation of receptive field, the size of which is indicated by Ricco's critical angle

$$\log \Delta L = \text{const}|_{\alpha\to 0}$$
$$\to \Delta L/\Delta L_b = \text{const}$$
$$\to \Delta L_{\alpha\to\infty} = L(L_b)$$

Weber's law: for larger objects, the threshold is dependent only on background luminance

Introduction

- **Visibility** : Adrian Model Extension
- Influence of observation time, contrast polarity, and age

$$\Delta L = 2.6\left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2}\right)^2 F_{CP}\frac{a(\alpha, L_b) + t}{t} AF$$

$F_{CP} = 1$, for positive target, $AF = 1$, for a young observer group

- Influence of disability glare
  - The presence of glare sources in the visual field impair vision and results in a necessary increase in ΔL to keep targets visible
  - Holladay suggested expressing the effect of the straylight on the target visibility in terms of a uniform luminance that adds to the background luminance

$$L_{seq} = k\sum_{i=1}^{n}\frac{E_{Gl_i}}{{\theta_i}^2}$$

Introduction

- **Visibility** :Extension for Adverse Weather Condition
- Add additional factor like fog density(FD), spectral distribution(SP) and so on

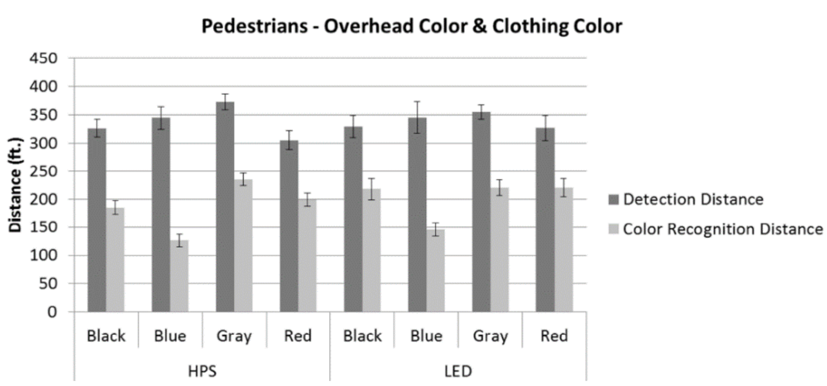
$$\Delta L = 2.6\left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2}\right)^2 F_{CP}\frac{a(\alpha, L_b)+t}{t} AF\ \mathbf{FD}\ \mathbf{SP}$$

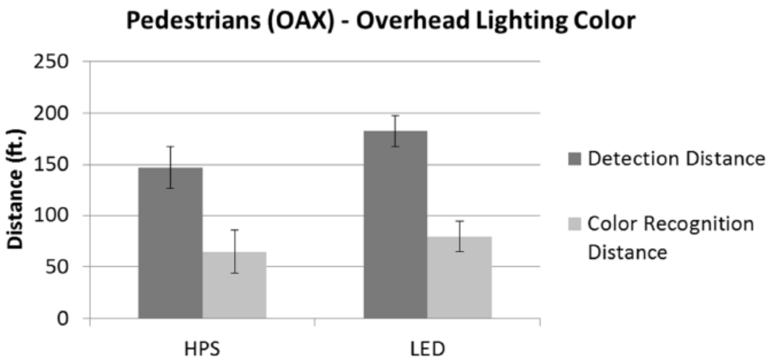
$F_{CP} = 1$, for positive target, $AF = 1$, for a young observer group
FD = 1, for clear weather condition, SP= 1, for D65 white light source

We need to develop how threshold ΔL changes according to fog density (FD), spectral frequency(SP)

Introduction

- **Spectral distribution vs Visibility**:
  - Adrian model: White or near white light
    - Luminance difference between target and background
    - In levels of mesopic vision, color has minor influence
  - Impact of correlated colour temperature of headlamps on visibility





Gibbons, R.B., Meyer, J., Rau, P.S., Price, M.L.:"Impact of Correlated Color Temperature of Headlamps on Visibility," ESV, NHTSA, 2013

Introduction

- **Subjective glare evaluation**

de Boer rating	Schmidt (1974)	Lehnert (2001)	Bullough et al.(2002)	Theeuwes et al.(2002)	Akashi et al.(2005)	Illuminance range (lx)
1 (Unbearable)	10	6	–	–	–	Above 6
2	5	–	2.6	20	–	2.6~20
3 (Disturbing)	1.26~2	2	1.3	10	4	1.26~10
4	0.4~0.7	–	–	5	–	0.4~5
5 (Just admissible)	0.12~0.27	0.8	–	2.5	2	0.12~2.5
6	–	–	–	1.26	1	1~1.26
7 (Acceptable)	–	0.2	–	0.63	–	0.2~0.63
8	–	–	0.04	0.32	–	0.04~0.32
9 (Noticeable)	–	0.1	–	0.16	–	0.1~0.16

- **Glare evaluation based on psycho-physiological response such as pupil size?**

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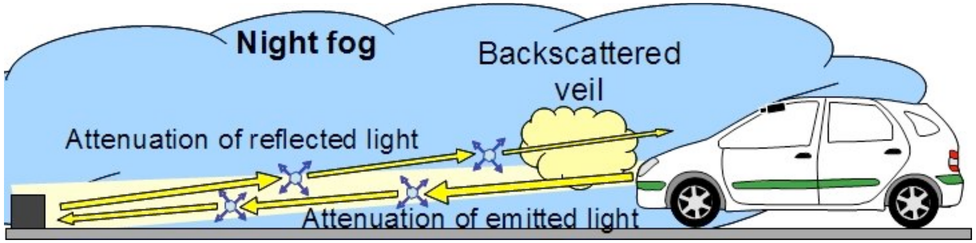
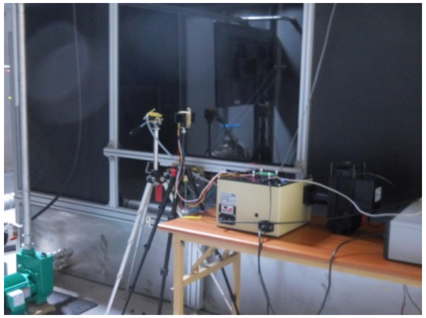
Related works

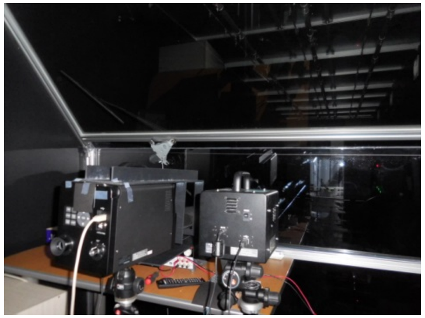
- **Spectral dependence vs Visibility**:
  - Empirical relationships between extinction coefficient and visibility in fog: Extinction coefficient in the IR radiation
    - $\sigma_{ext}(\lambda) = A\lambda^{-q}, A = \frac{3.91}{V}(0.55)^q$
    - $q = \begin{cases} 0 & V < 500m \\ V - 0.50 & 500m \leq V < 1km \\ 0.16V + 0.34 & 1km \leq V < 6km \end{cases}$
  - Impact of fog on apparent luminance
    - Double attenuation of light for night time driving conditions
    - $L \approx \left(R \cdot \left(\frac{I_L + I_R}{d^2} e^{-\sigma d}\right)\right) \cdot e^{-\sigma d}$



Gallen, R., Dumont, E., Hautiere, N.: "A conventional approach to nighttime visibility in adverse weather conditions," ISAL, 2011

Adverse weather simulation chamber





Size

- 12.5 m (L) x 3 m (W) x 3 m (H)
- aluminium profiles and black PVC foam boards

Equipment

- two different water pipe and nozzle systems, one for artificial fog and the other for artificial rain
- 4 electrical ventilating fans and shutter grilles

Control

- Input water flow control by valves
- Fan speed control by voltage regulator
- Grill opening control

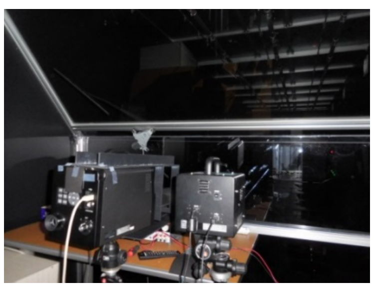
Transmittance under adverse weather condition (Monochromator)

Spectroradiometer
(Minolta, CS 2000)
2D Color Analyser
(Minolta, CA 2000)

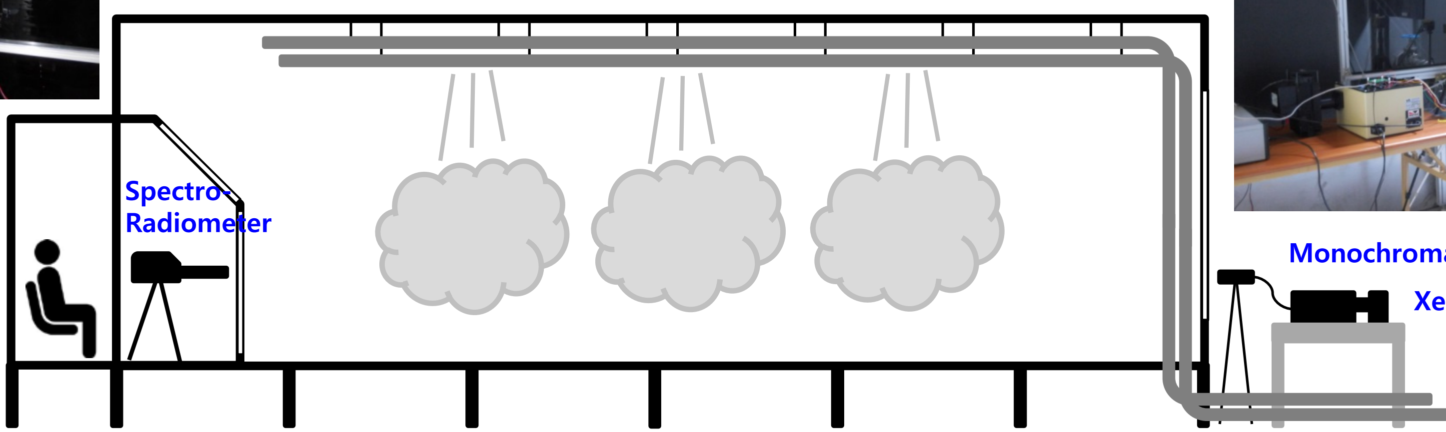

550 nm in Fog Condition

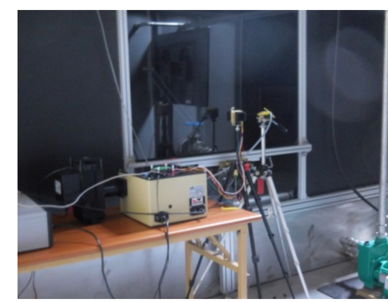

590nm in Rain Condition

Monochromator
(Bentham, TMc300)
Xenon illuminator
(Bentham, IL7)

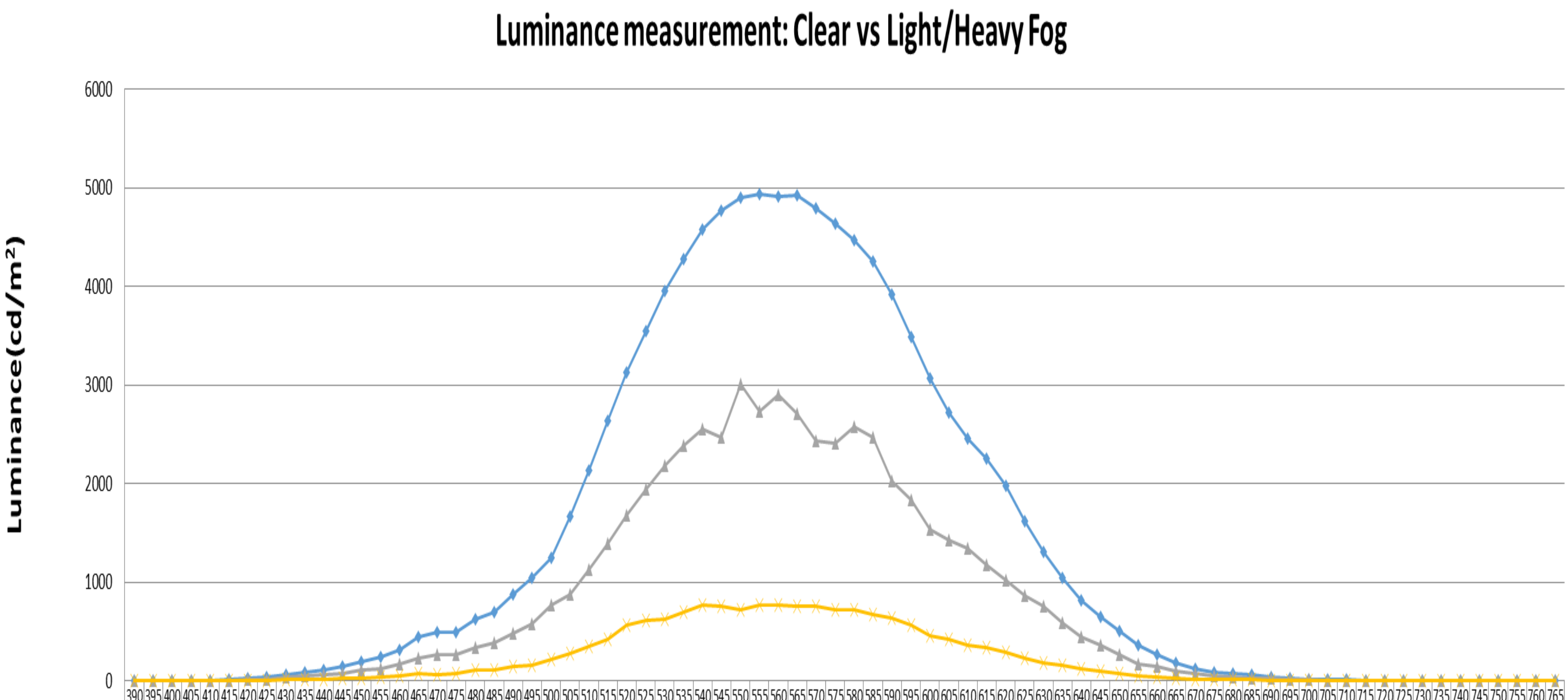


Weather Simulation Chamber





Luminance measurement results (fog)



	390	395	400	405	410	415	420	425	430	435	440	445	450	455	460	465	470	475	480
Clear Weather	3.8	3.9	4.4	5.2	7.6	13	22	37	60	85	113	143	198	237	318	443	496	494	628
Light Fog Average	2.1	2.3	2.6	3	4.4	6.2	12	20	33	45	59	79	112	126	167	231	262	266	338
Heavy fog Average	0.6	0.7	0.8	0.9	1.3	1.9	3.6	6	8.7	14	20	24	30	39	49	69	67	79	108

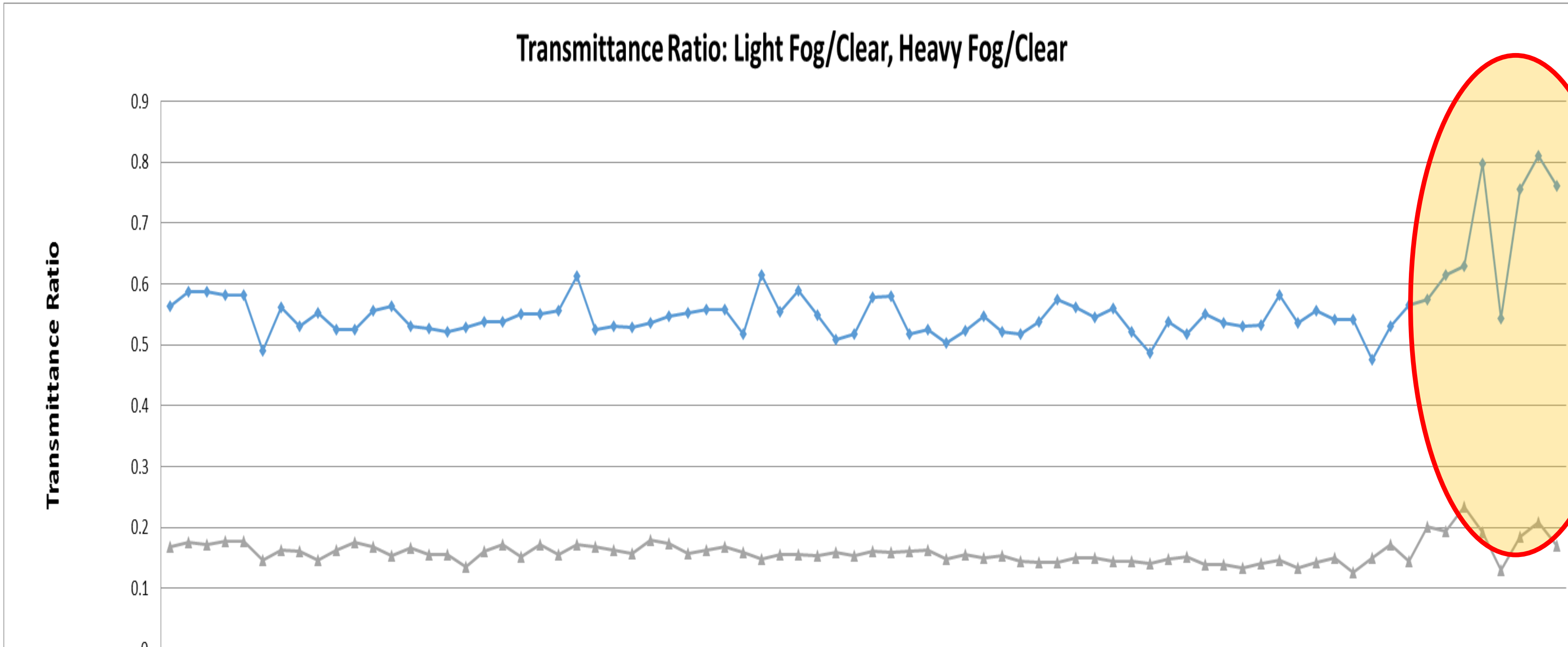
	485	490	495	500	505	510	515	520	525	530	535	540	545	550	555	560	565	570	575
Clear Weather	694	882	104	124	167	212	263	313	355	395	428	458	476	489	493	491	492	478	464
Light Fog Average	382	486	578	763	876	112	139	167	194	218	238	255	246	300	273	289	270	243	240
Heavy fog Average	105	151	163	214	282	347	417	562	614	623	695	771	759	725	763	763	756	761	716

	580	585	590	595	600	605	610	615	620	625	630	635	640	645	650	655	660	665	670
Clear Weather	446	425	392	349	306	271	245	224	197	162	130	104	812	652	509	361	261	186	127
Light Fog Average	258	246	203	183	154	142	134	117	102	870	753	589	443	364	266	176	140	96	70
Heavy fog Average	717	679	633	567	452	423	367	344	287	230	187	157	121	95	74	51	38	28	18

	675	680	685	690	695	700	705	710	715	720	725	730	735	740	745	750	755	760	765
Clear Weather	92	73	60	44	28	17	13	11	8.1	4.7	3.7	3.2	2.4	2	1.3	1.6	1.1	0.9	0.9
Light Fog Average	49	39	32	26	15	9.6	6.8	6.1	3.9	2.5	2.1	1.9	1.5	1.2	1	0.8	0.8	0.7	0.7
Heavy fog Average	13	9.8	8.5	6.4	3.8	2.5	1.9	1.4	1.2	0.8	0.5	0.7	0.5	0.5	0.2	0.2	0.2	0.2	0.2

Spectral range: from 390nm to 765 nm with 5nm interval

Transmittance measurement results (fog)



	390	395	400	405	410	415	420	425	430	435	440	445	450	455	460	465	470	475	480
Light Fog Avg/Clear	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Heavy fog avg. / Clear	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2

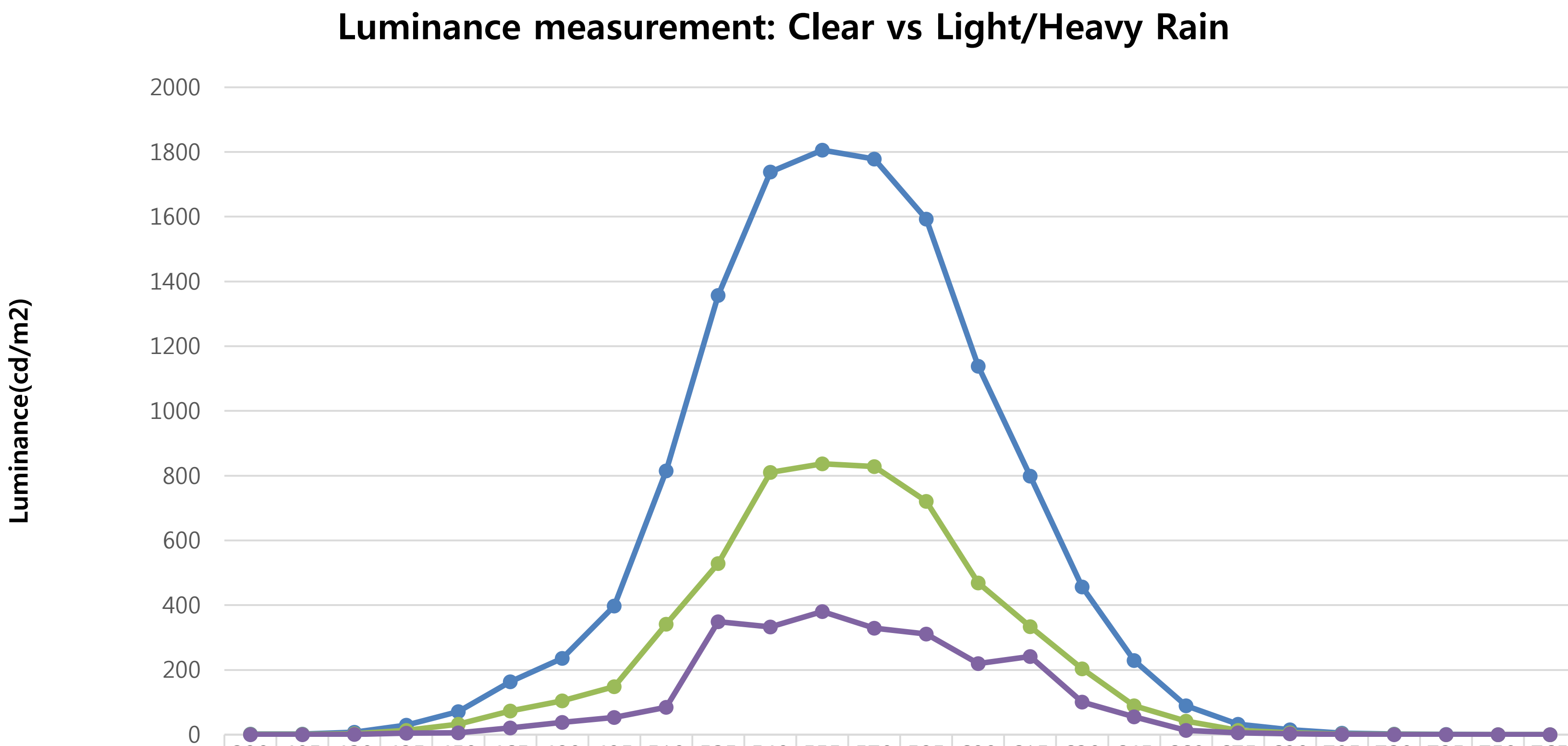
	485	490	495	500	505	510	515	520	525	530	535	540	545	550	555	560	565	570	575
Light Fog Avg/Clear	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.5	0.5	0.5
Heavy fog avg. / Clear	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2

	580	585	590	595	600	605	610	615	620	625	630	635	640	645	650	655	660	665	670
Light Fog Avg/Clear	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.6
Heavy fog avg. / Clear	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1

	675	680	685	690	695	700	705	710	715	720	725	730	735	740	745	750	755	760	765
Light Fog Avg/Clear	0.5	0.5	0.5	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.8	0.5	0.8	0.8	0.8
Heavy fog avg. / Clear	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2

Long wavelength shows higher transmittance in light fog whereas heavy fog shows less dependence of the wavelength

Luminance measurement results (rain)

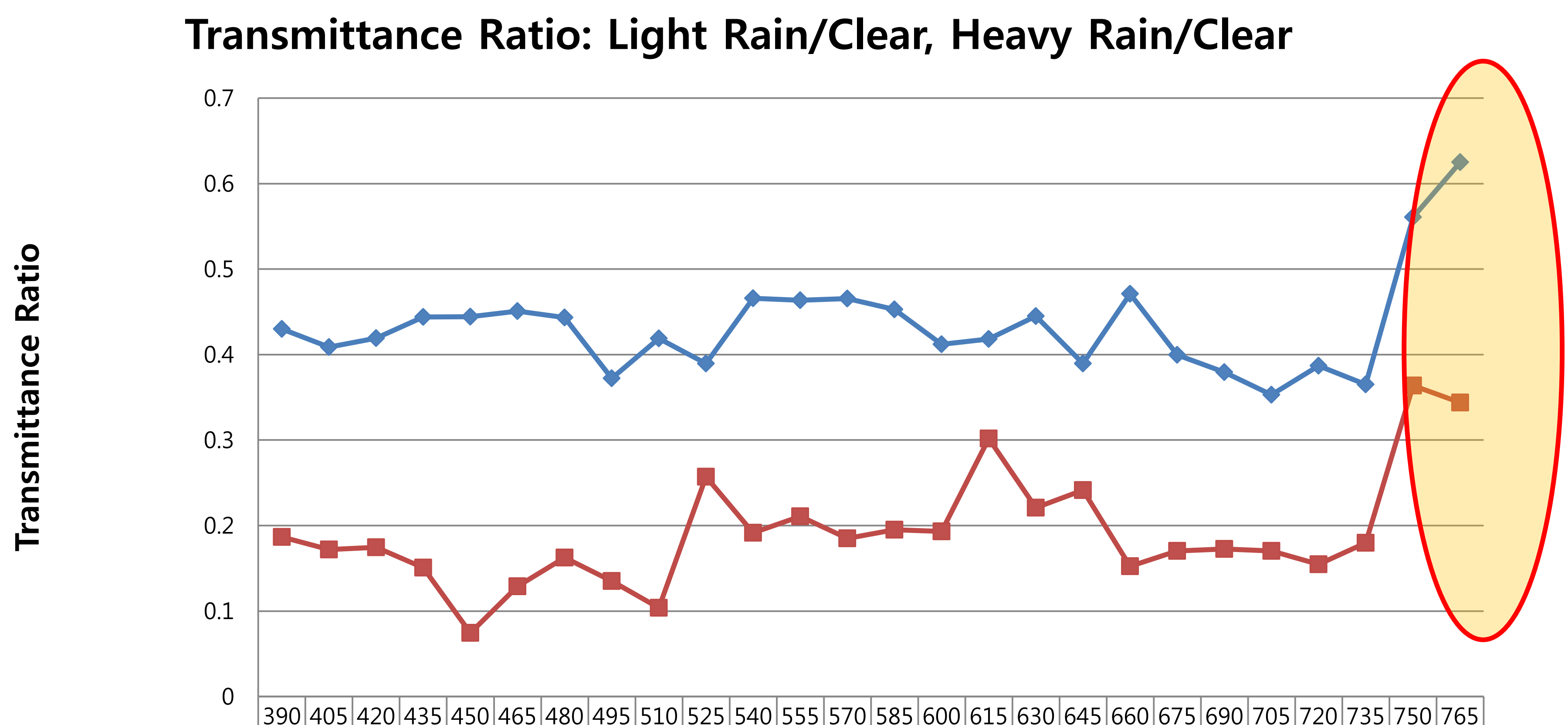


	390	405	420	435	450	465	480	495	510	525	540	555	570
Clear Weather	1.5	1.86	7.62	29.7	71.8	163	235	398	815	1357	1738	1806	1778
Light Rain	0.65	0.76	3.2	13.2	31.9	73.6	104	148	341	529	810	837	828
Heavy Rain	0.28	0.32	1.33	4.48	5.34	21.1	38.3	53.7	84.6	349	333	381	329

	585	600	615	630	645	660	675	690	705	720	735	750	765
Clear Weather	1593	1138	799	457	229	89.5	32.4	15.4	4.52	1.81	0.89	0.33	0.32
Light Rain	721	469	334	203	89.3	42.1	13	5.85	1.6	0.7	0.33	0.19	0.2
Heavy Rain	311	220	241	101	55.3	13.6	5.52	2.66	0.77	0.28	0.16	0.12	0.11

Spectral range: from 390 nm to 765 nm, 15 nm step interval

Transmittance measurement results (rain)



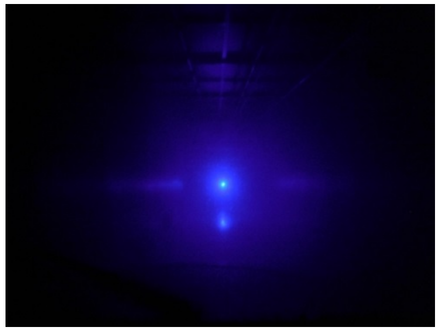
	390	405	420	435	450	465	480	495	510	525	540	555	570
Light Rain /Clear	0.43	0.41	0.42	0.44	0.44	0.45	0.44	0.37	0.42	0.39	0.47	0.46	0.47
Heavy Rain /Clear	0.19	0.17	0.17	0.15	0.07	0.13	0.16	0.13	0.1	0.26	0.19	0.21	0.18

	585	600	615	630	645	660	675	690	705	720	735	750	765
Light Rain /Clear	0.45	0.41	0.42	0.44	0.39	0.47	0.4	0.38	0.35	0.39	0.37	0.56	0.63
Heavy Rain /Clear	0.19	0.19	0.3	0.22	0.24	0.15	0.17	0.17	0.17	0.15	0.18	0.36	0.34

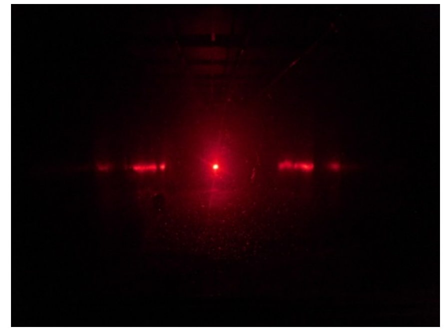
Long wavelength shows higher transmittance in light and heavy rain

Transmittance under adverse weather condition (Flat Panel RGB LEDs)

Spectroradiometer
(Minolta, CS 2000)
2D Color Analyser
(Minolta, CA 2000)

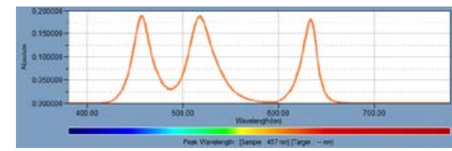


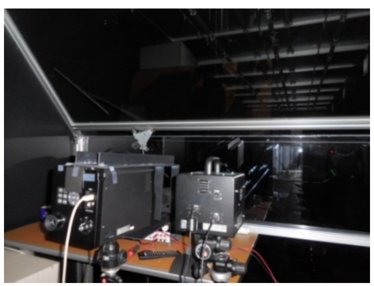
Blue in Fog Condition



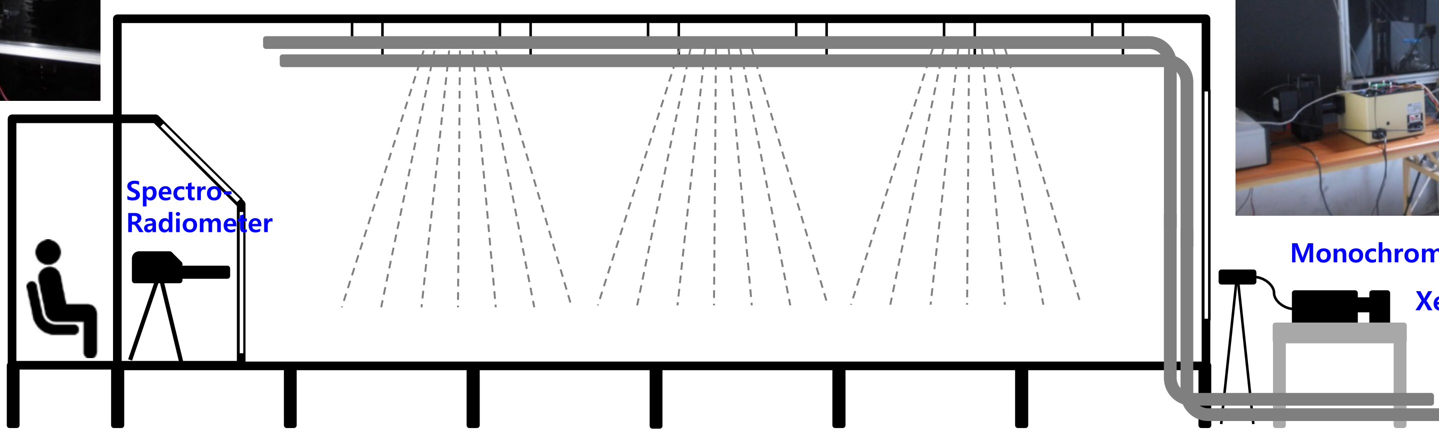
Red in Rain Condition

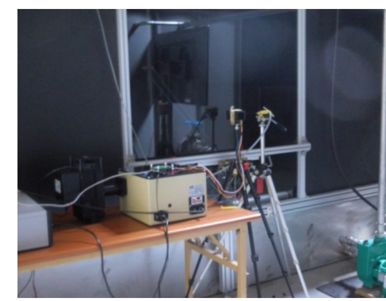
Flat Panel RGB LEDs
(Avago tri-color power LED with 1W power each
- Peak wavelength:
635nm, 519 nm, 454 nm)



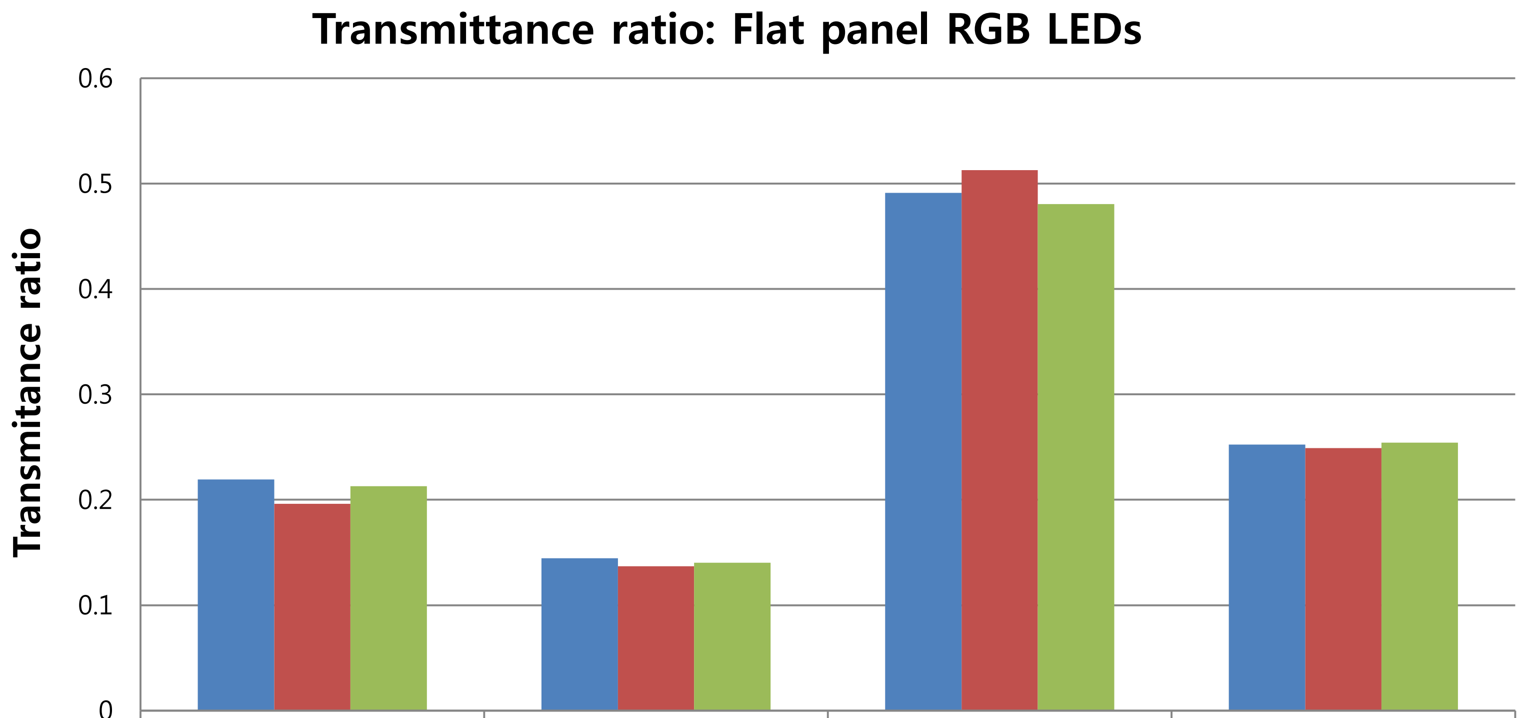


Weather Simulation Chamber





Transmittance measurement results(RGB LEDs)



	Light Fog/Clear	Heavy Fog/Clear	Light Rain/Clear	Heavy Rain/Clear
Blue	0.219160185	0.144597589	0.491230536	0.252299192
Red	0.196101128	0.136955743	0.512848726	0.248909054
Green	0.212848846	0.140249194	0.480712781	0.254123839

NO significant difference in RGB LEDs in adverse weather condition

Transmittance characteristics under fog/rain conditions

- Transmittance under light fog and rain condition may different in very long wavelength (close to near-IR)

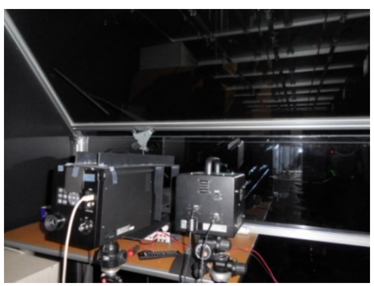
- We need further investigation how that long wavelength can be used for visual performance improvement since the spectral sensitivity of human visual system in very low in the long wavelength spectrum especially in mesopic vision

→ Lighting for sensors

Scattering characteristics under adverse weather condition (Monochromator+Collimator, Radiometer)

Spectroradiometer
(Avantes, AvaSpec-ULS2028XL)

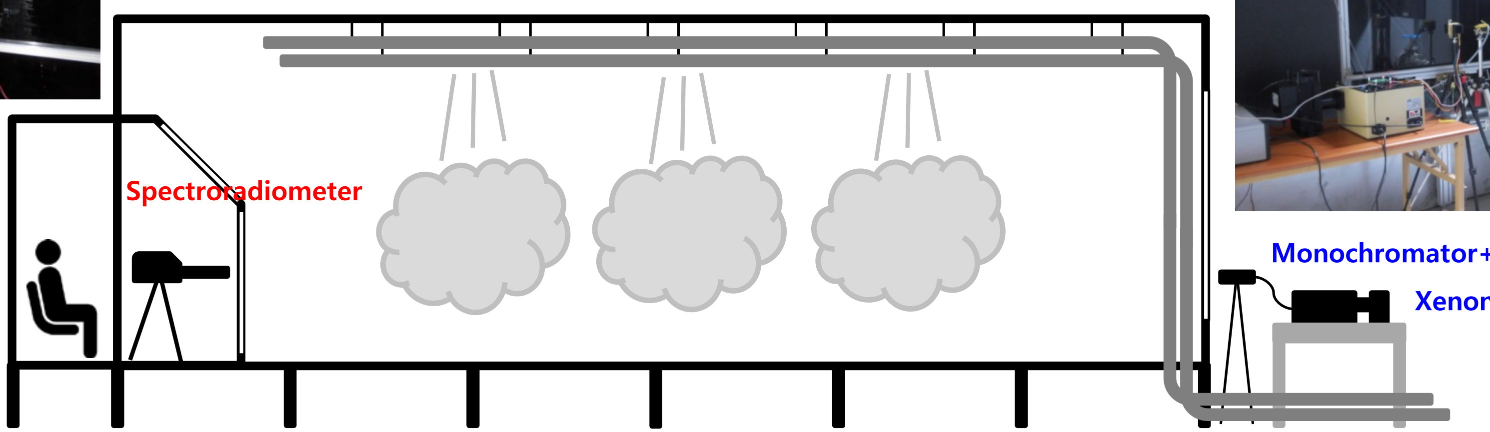
Monochromator
(Bentham, TMc300)
Xenon illuminator
(Bentham, IL7)
Collimator
(Bentham, COL3)

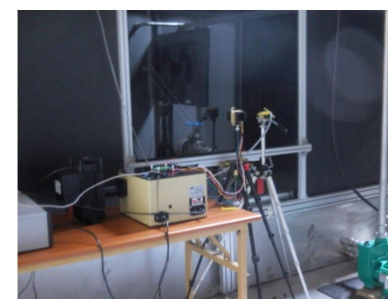


550 nm in Fog Condition

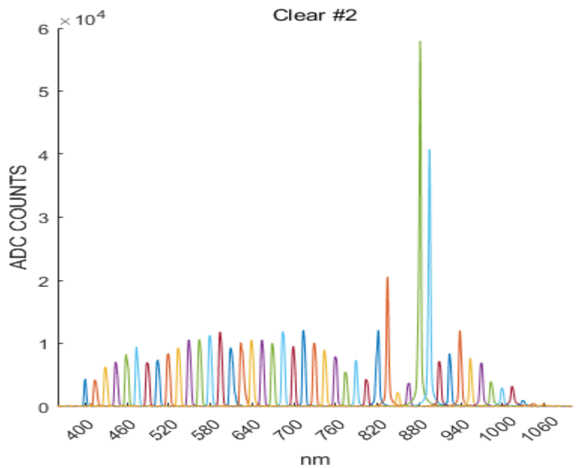
590nm in Rain Condition

Weather Simulation Chamber

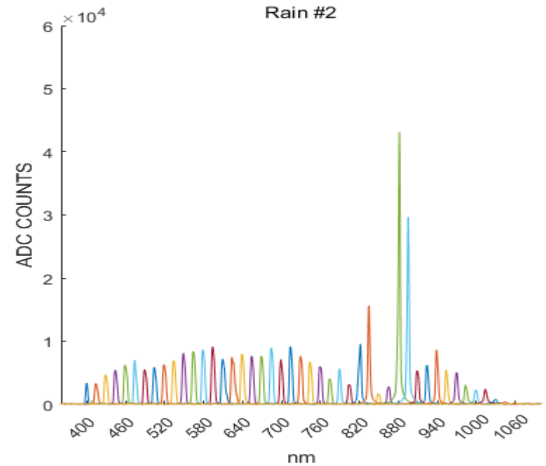




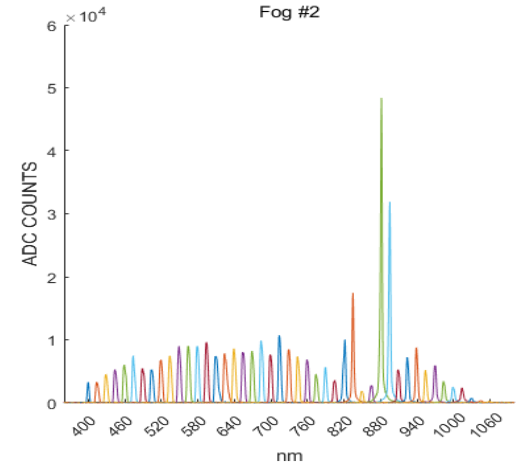
Measurement of spectroradiometer(fog&rain)



(a) Clear

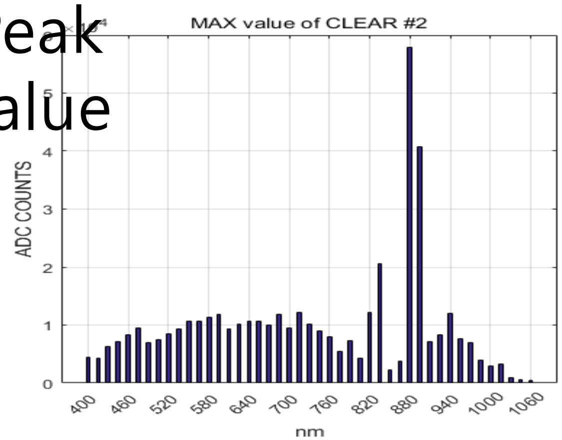


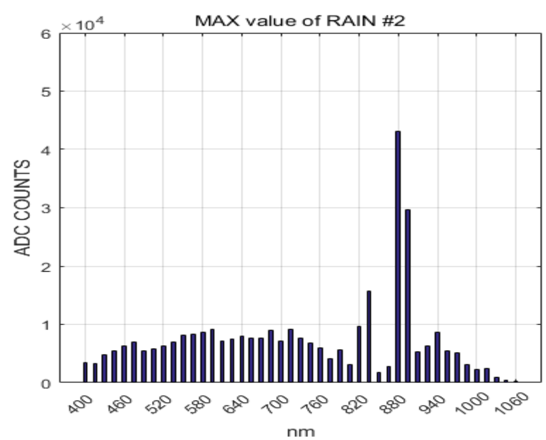
(b) Rain

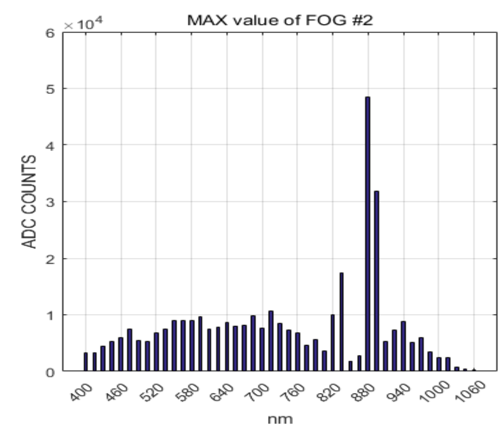


(c) Fog

Peak value

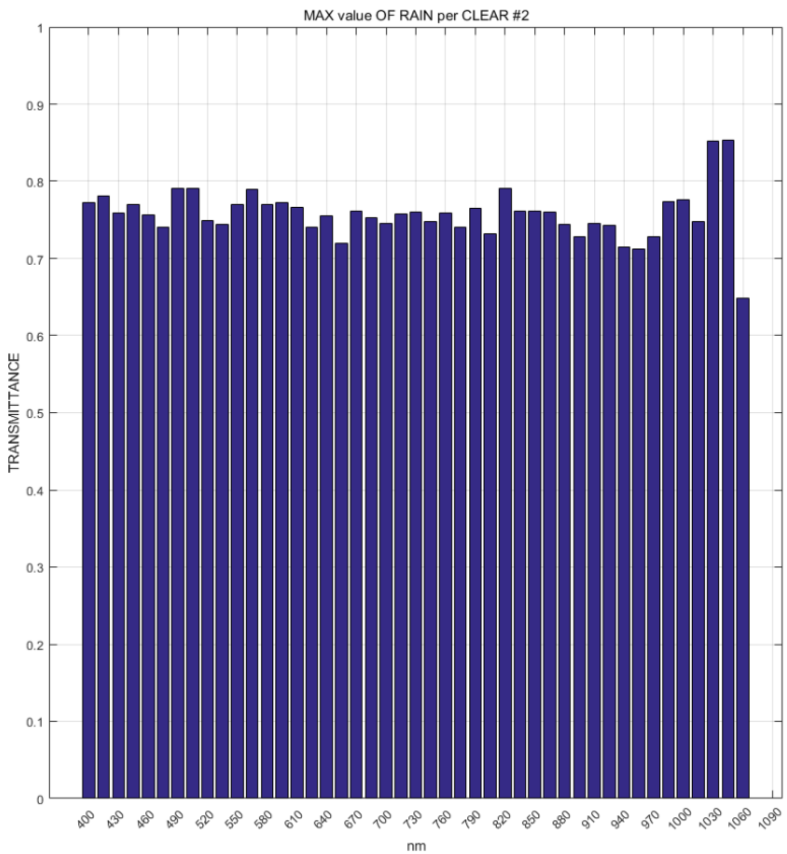




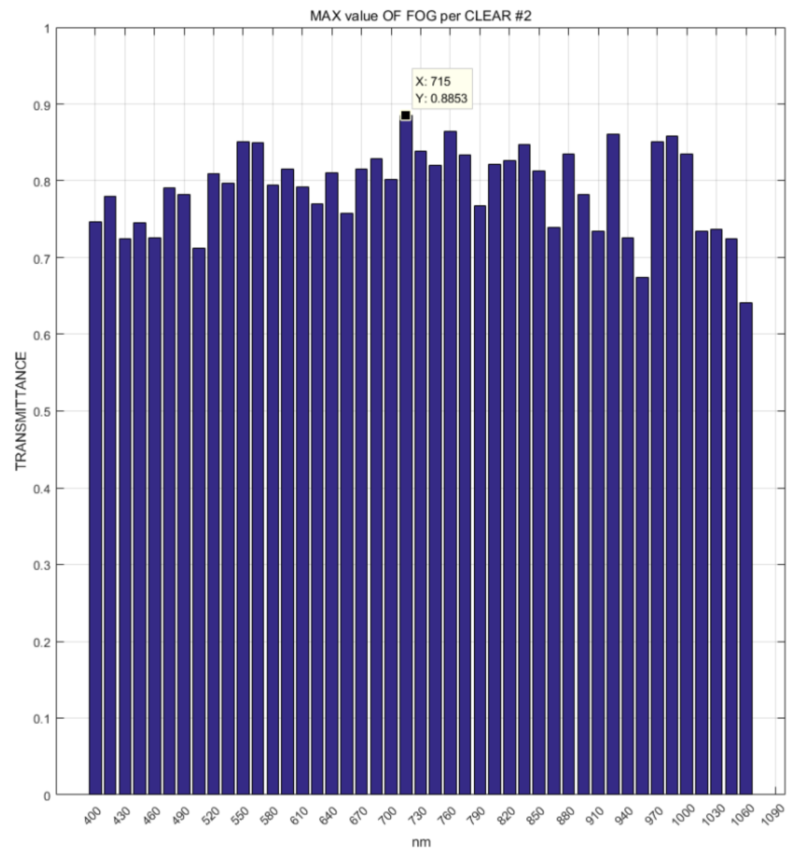


Spectral range: from 400nm to 1100 nm with 20nm interval

Transmittance evaluation results (fog &rain)

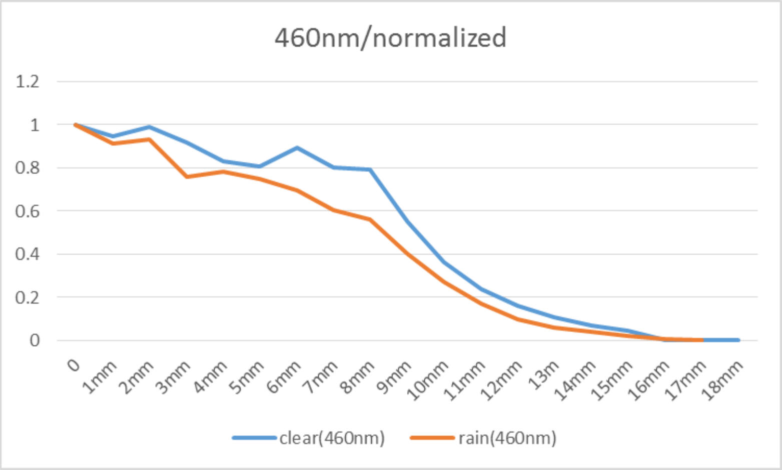


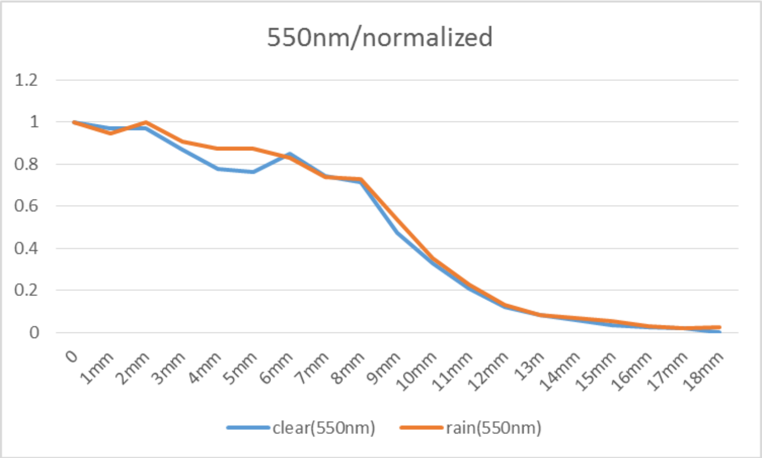
Transmittance of rain
(Rain/Clear)

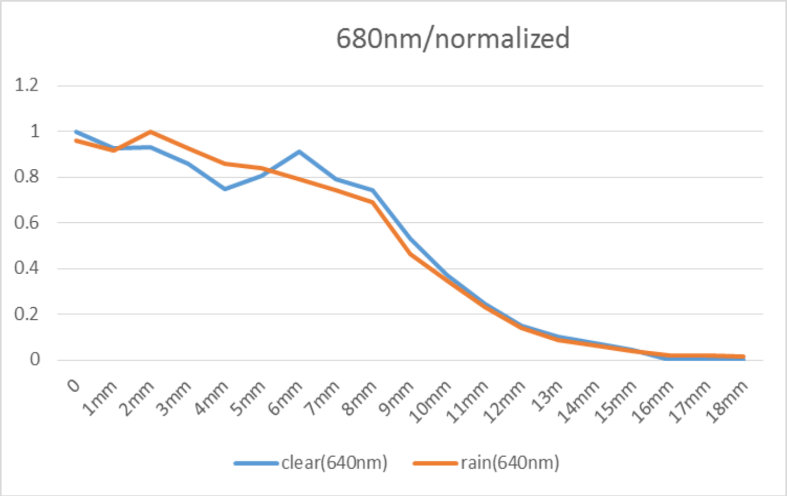


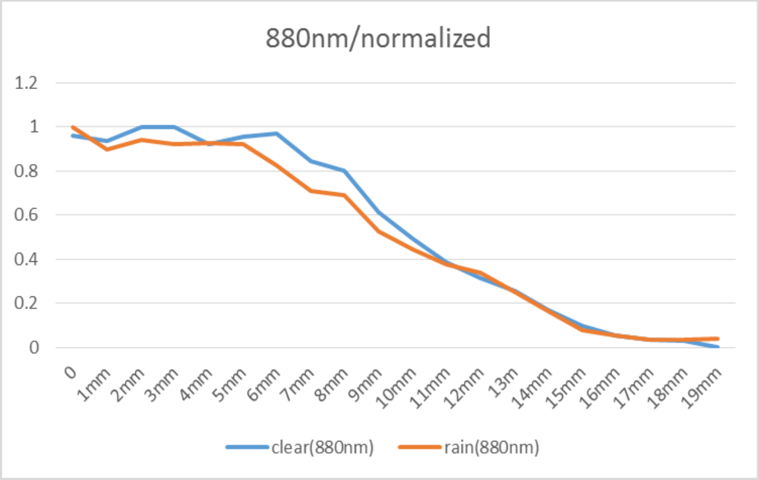
Transmittance of fog
(fog/Clear)

Scattering characteristics of fog/rain









Relative intensity change in different spatial location in different wavelength

Scattering characteristics under adverse weather conditions

- Transmittance in different spectrum in rain and fog shows some difference of transmittance in different wavelength.
- To measure the scattering characteristics, the spatial profile of the maximum intensity in different spatial location was measured.
- We need further study to clarify the different scattering and transmittance characteristics under adverse weather condition.

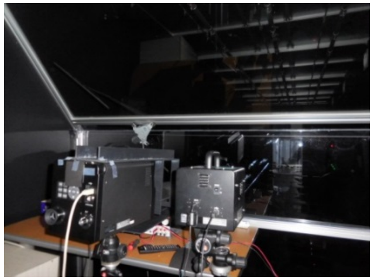
Contents

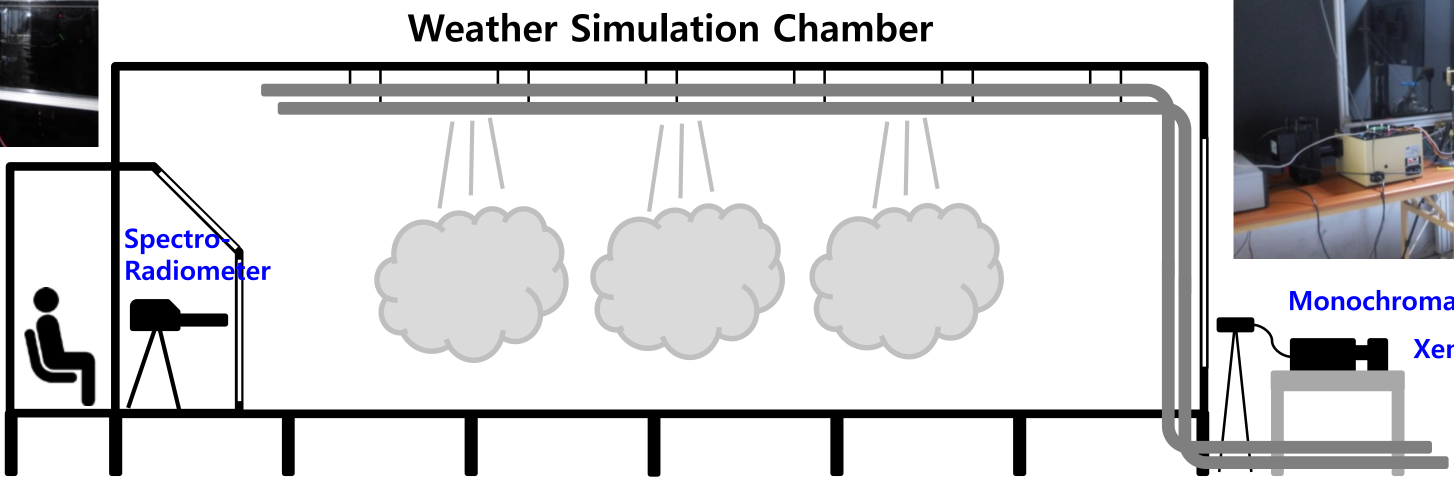
Spectral characteristics under adverse weather condition (Color temperature controlled LED headlamp)

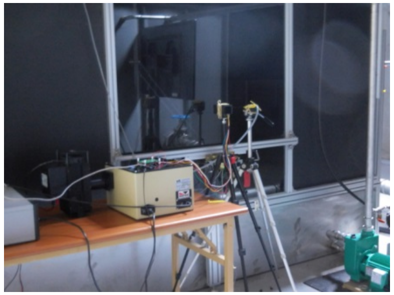
Spectroradiometer
(Minolta, CS 2000)
2D Color Analyser
(Minolta, CA 2000)

Low CCT
(2980K)
+ Hig CCT
(6840K)

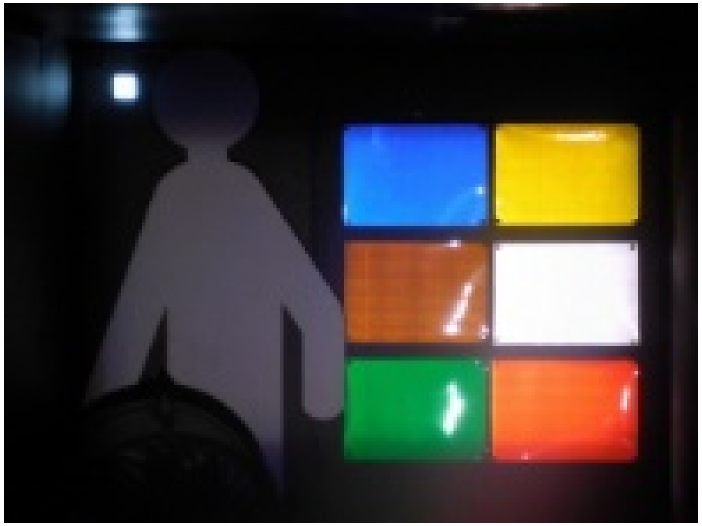
Monochromator
(Bentham, TMc300)
Xenon illuminator
(Bentham, IL7)







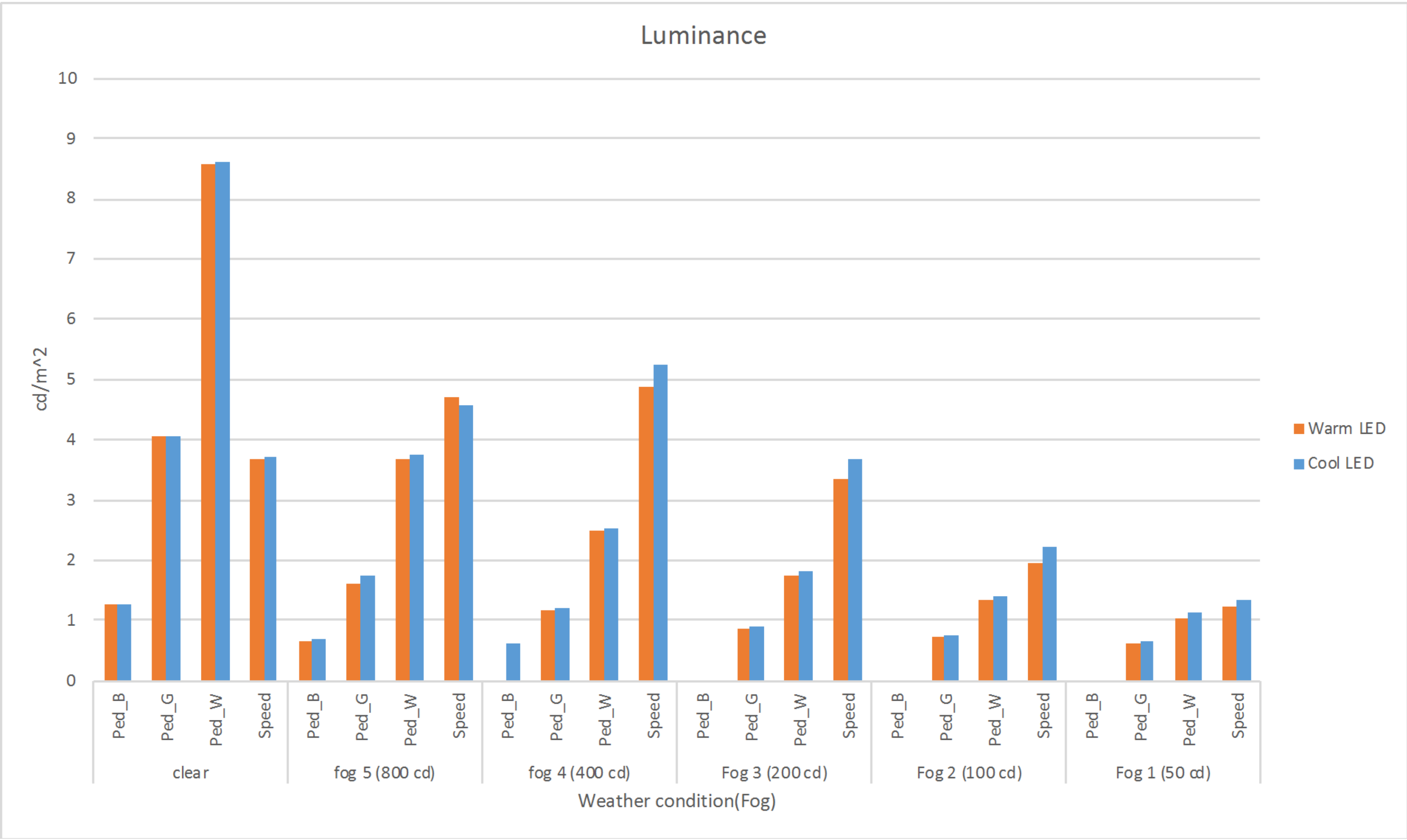
Target Types



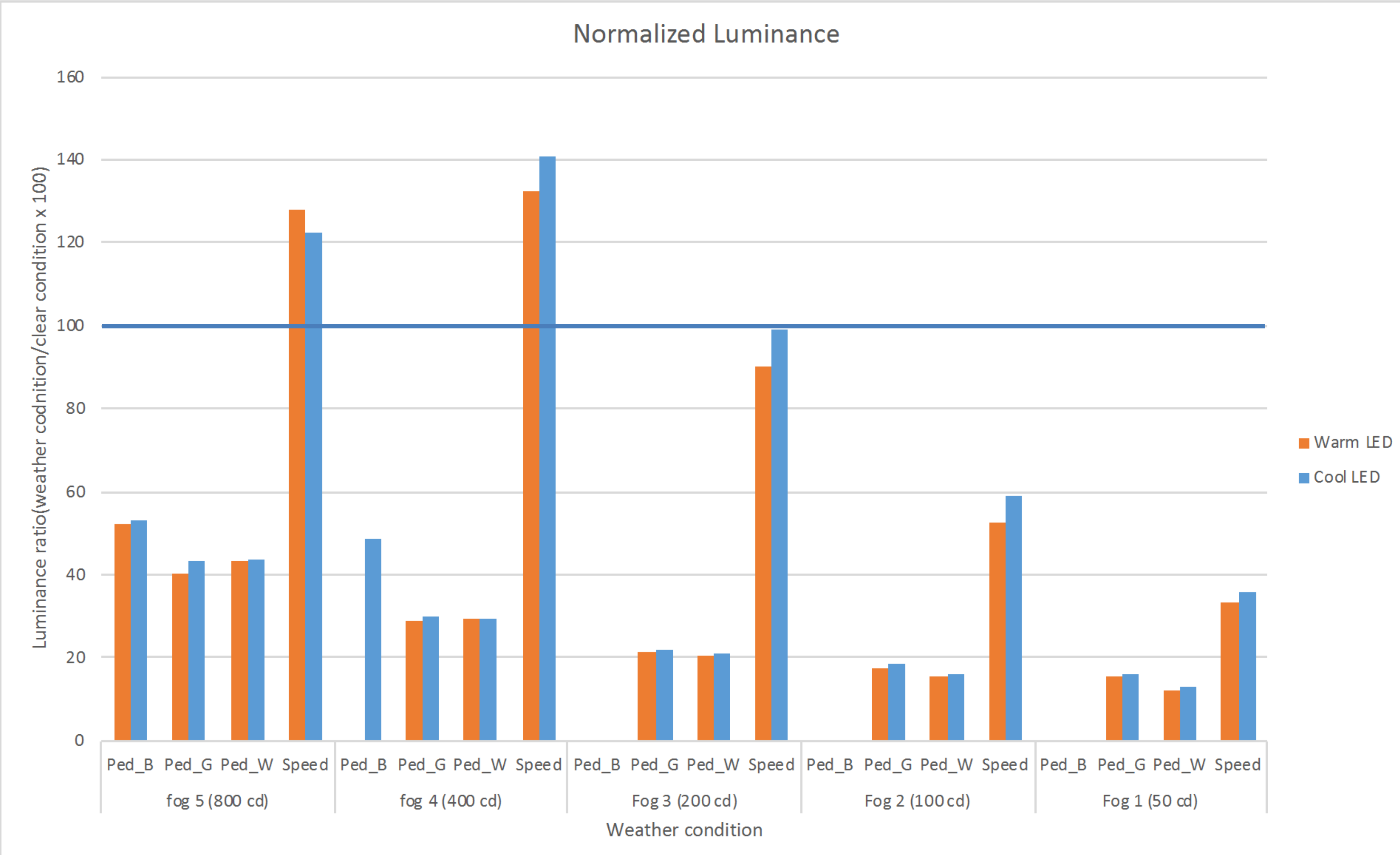
- White, red, green, blue, yellow, brown reflective targets, and traffic sign are also used

- **White, grey, black pedestrian targets are used to evaluate visibility under adverse weather conditions**
- Adrian targets are arranged in different distance

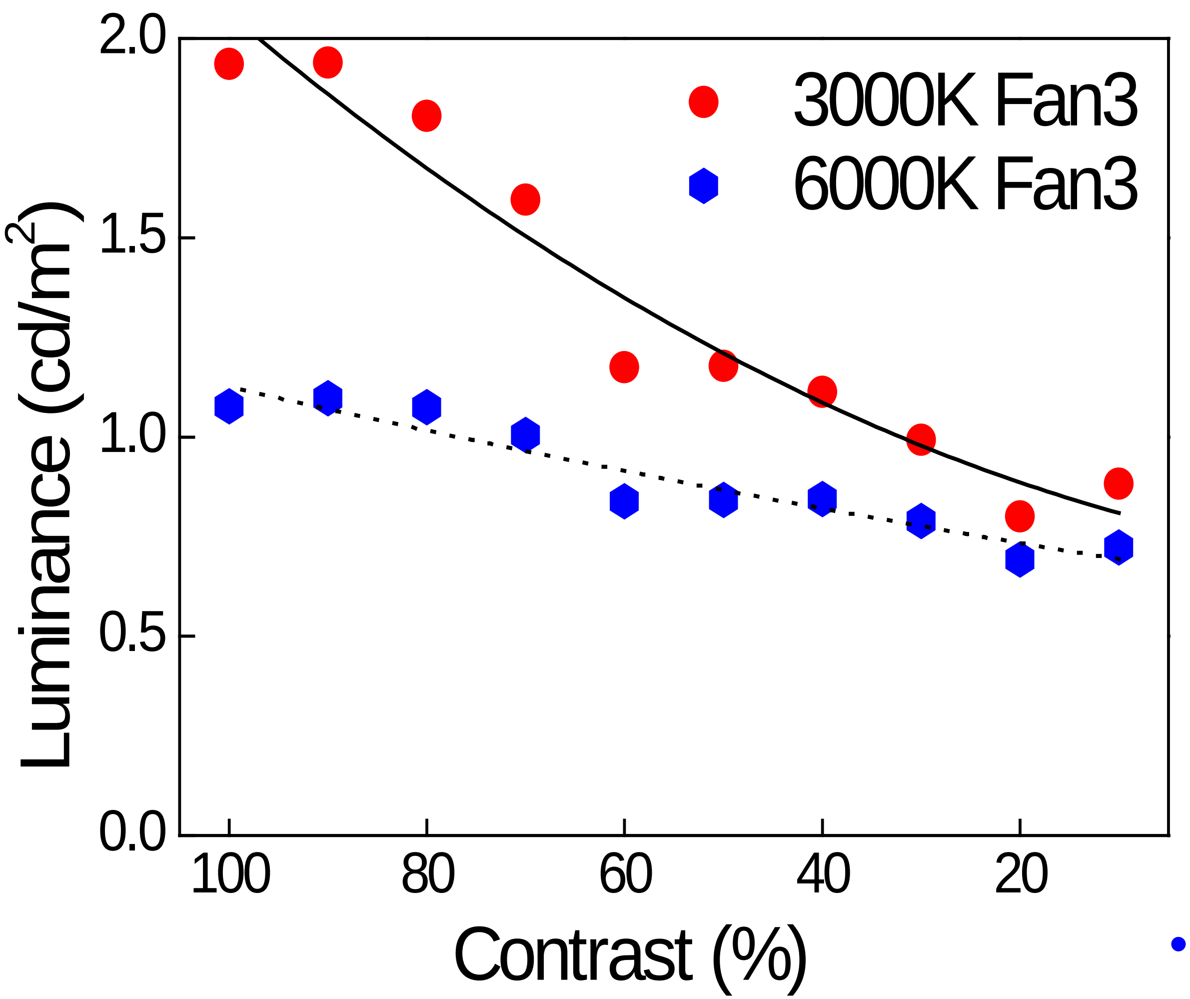
Luminance difference in different CCT(fog)

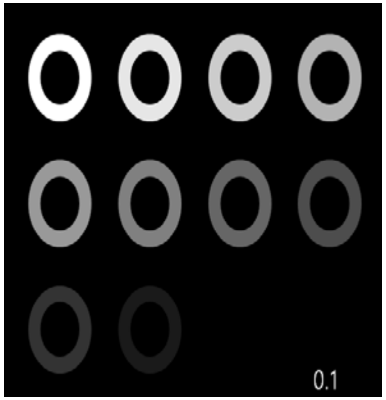


Luminance difference in different CCT(fog)



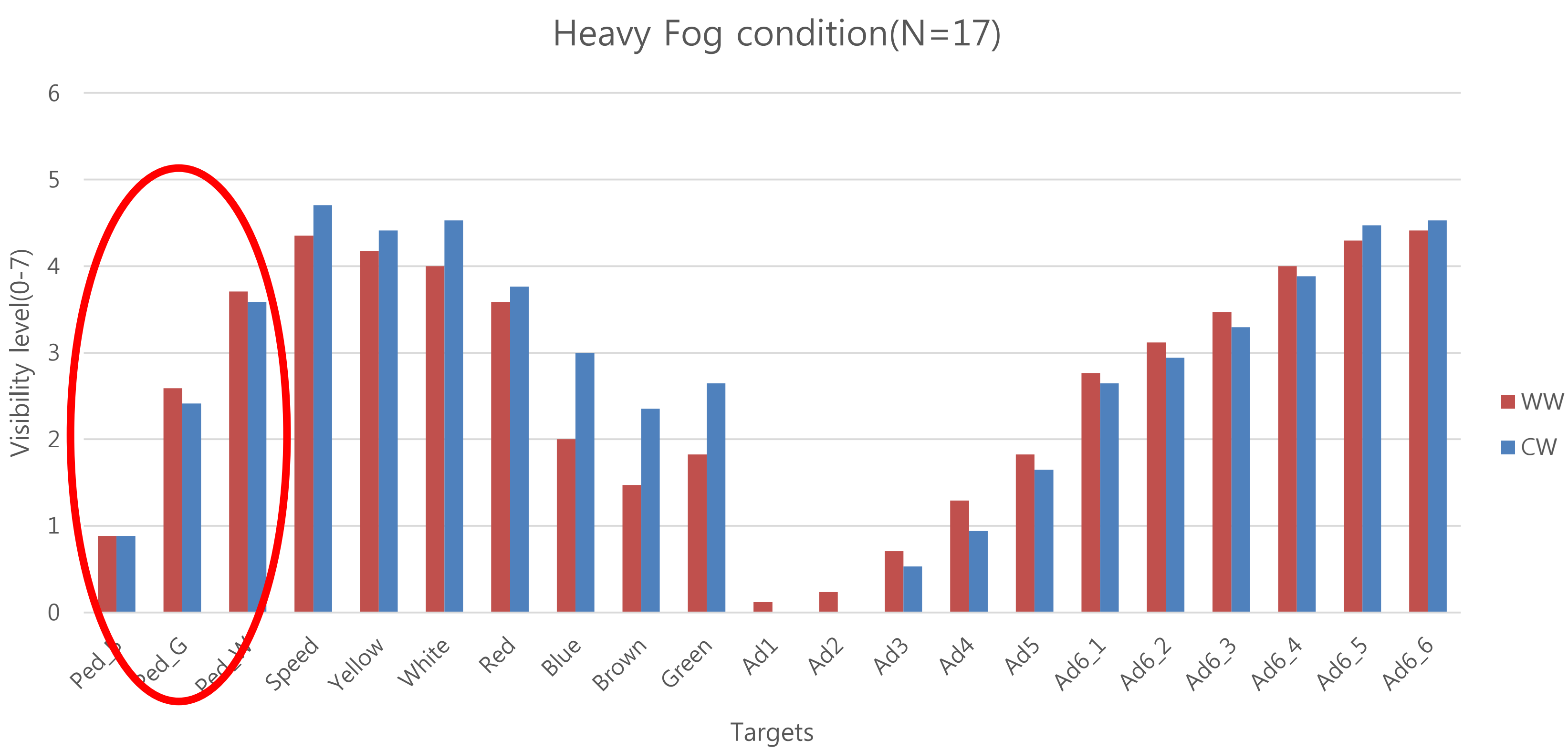
Contrast evaluation in different CCT(fog)



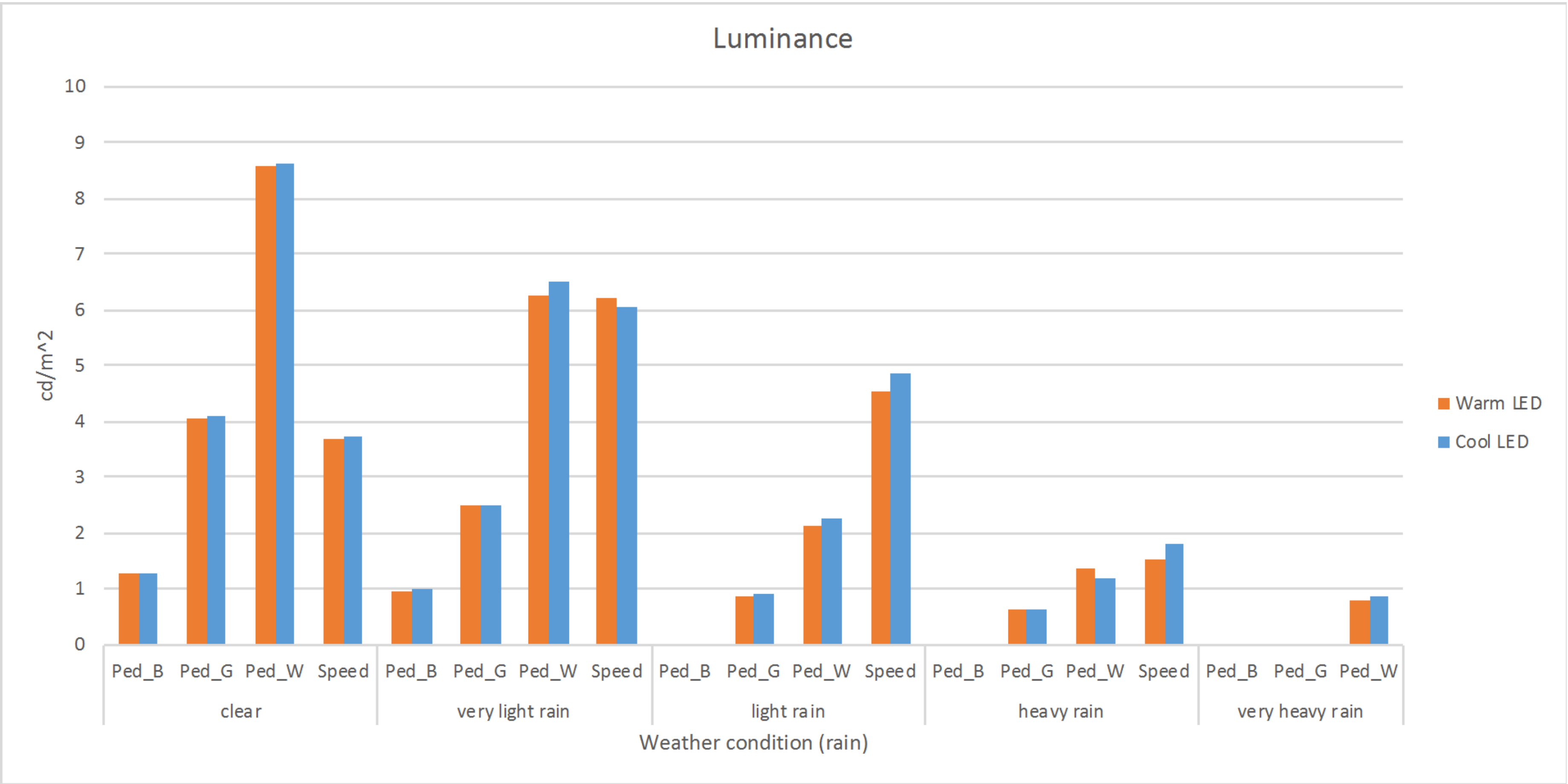


- Experiment with KonYang University

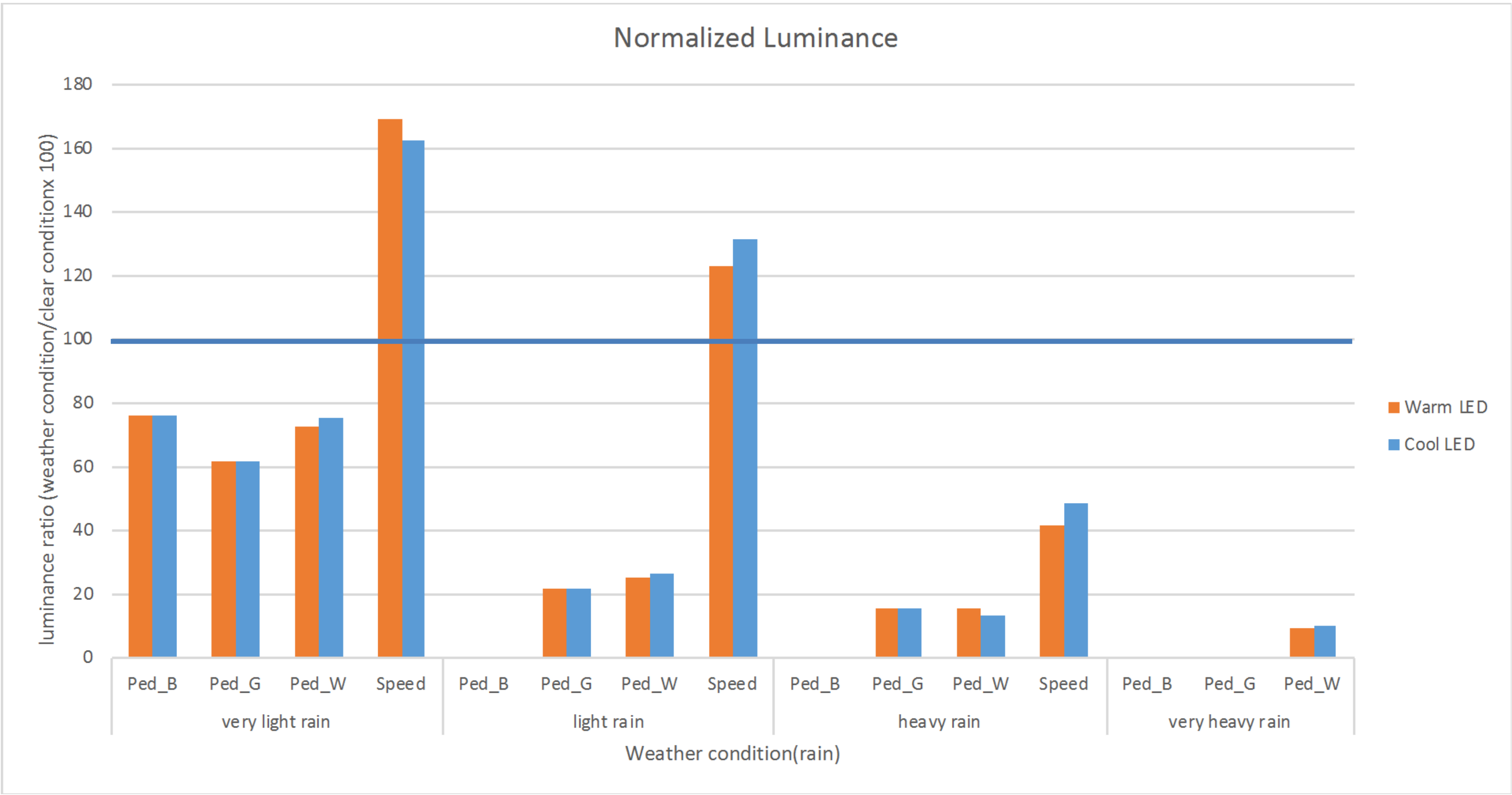
Subjective evaluation of visibility in different CCT under fog condition



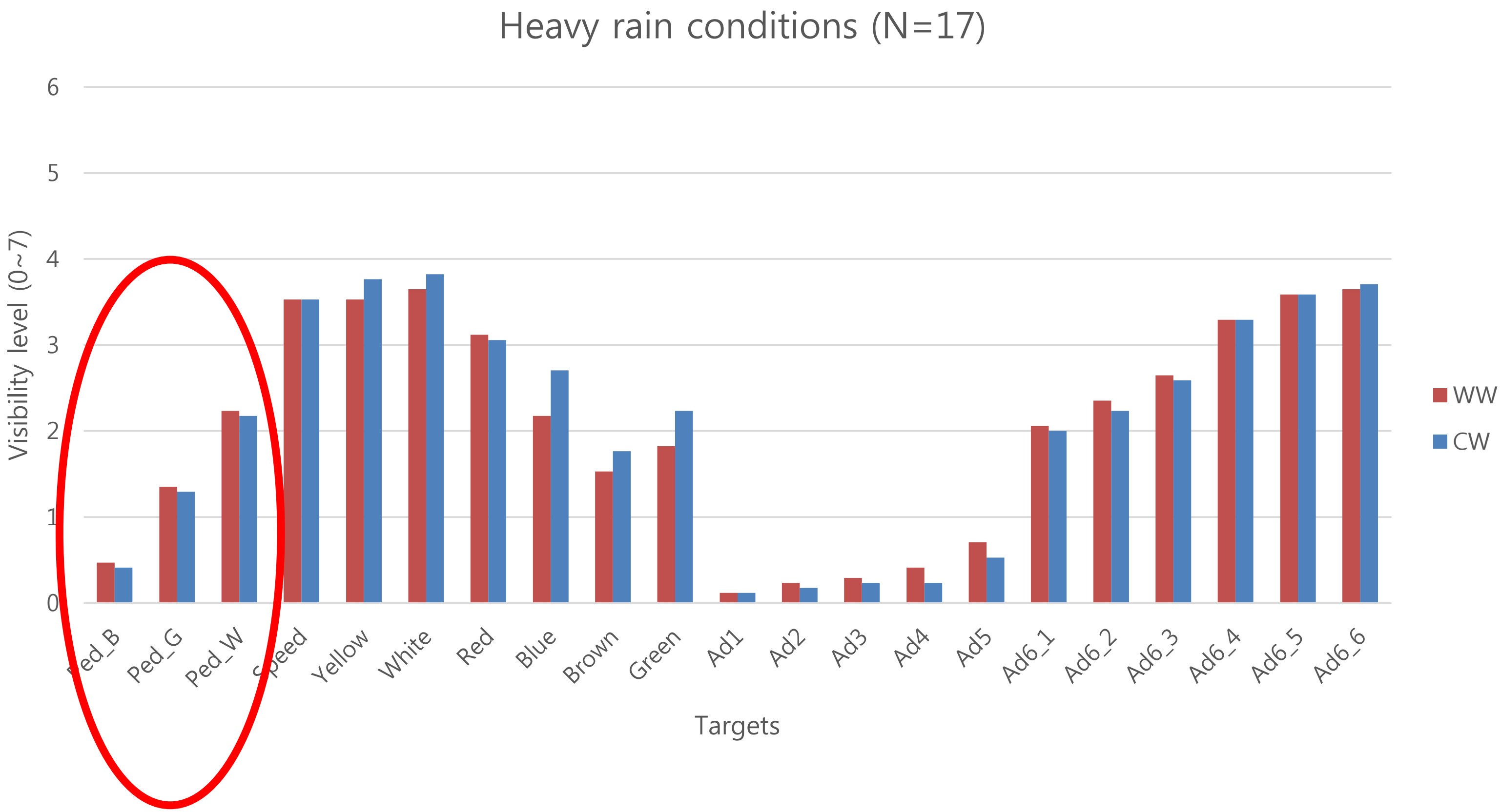
Luminance difference in different CCT(rain)



Luminance difference in different CCT(rain)

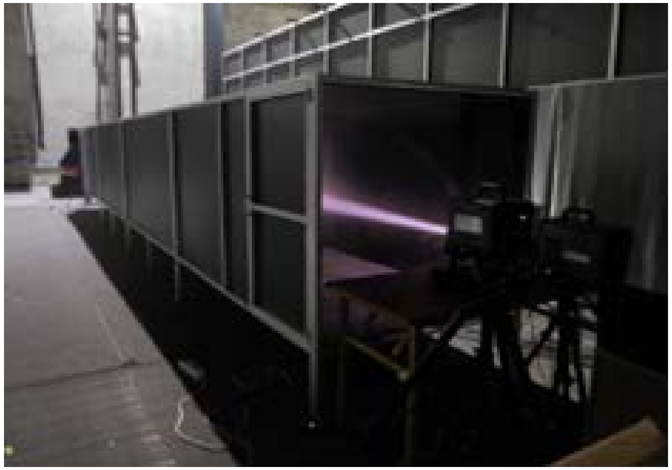


Subjective evaluation of visibility in different CCT under rain condition



Spectral characteristics under yellow dust weather condition(Color temperature controlled LED headlamp)

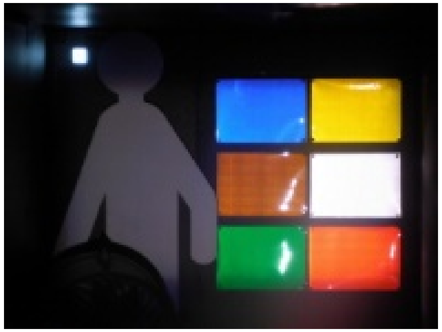
- Test Environment
  - A new yellow dust testbed was built apart from the existing weather simulation testbed made with high density polystyrene (fomex) and aluminum profile, and glass, and 2 air circulators (1.2 m x 1.2 m x 9.6 m)
  - Some amount of grinded desert sand and yellow soil powder (700 mesh = 20 micron)
  - Visual targets: a white colored non-reflective human shaped panel (100 cm height) and high reflective 6 color (red, white, green, blue, brown, yellow) sheets used for the traffic signs on the road (20 cm x 30 cm).



Method

- **Measurement**
  - LED high-beam headlamps based on two different CCT PKG.
  - Three CCT conditions (Warm, Warm+Cool, Cool) with equal luminance (lx) and two yellow dust conditions (Light, Heavy)
  - Luminance measuring device: 2D colour analyser (Konica-Minolta, CA-2000)
  - Five times of luminance measurements in each conditions and the average luminance values were used for comparison.

Warm CCT



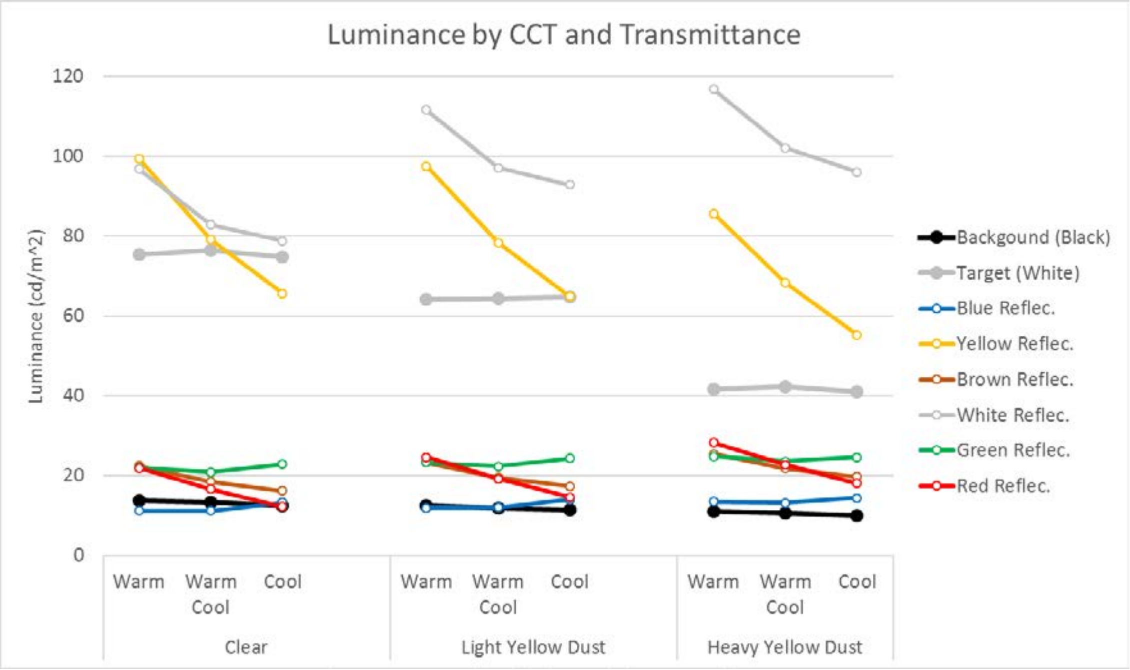
Warm + Cool CCT

Cool CCT

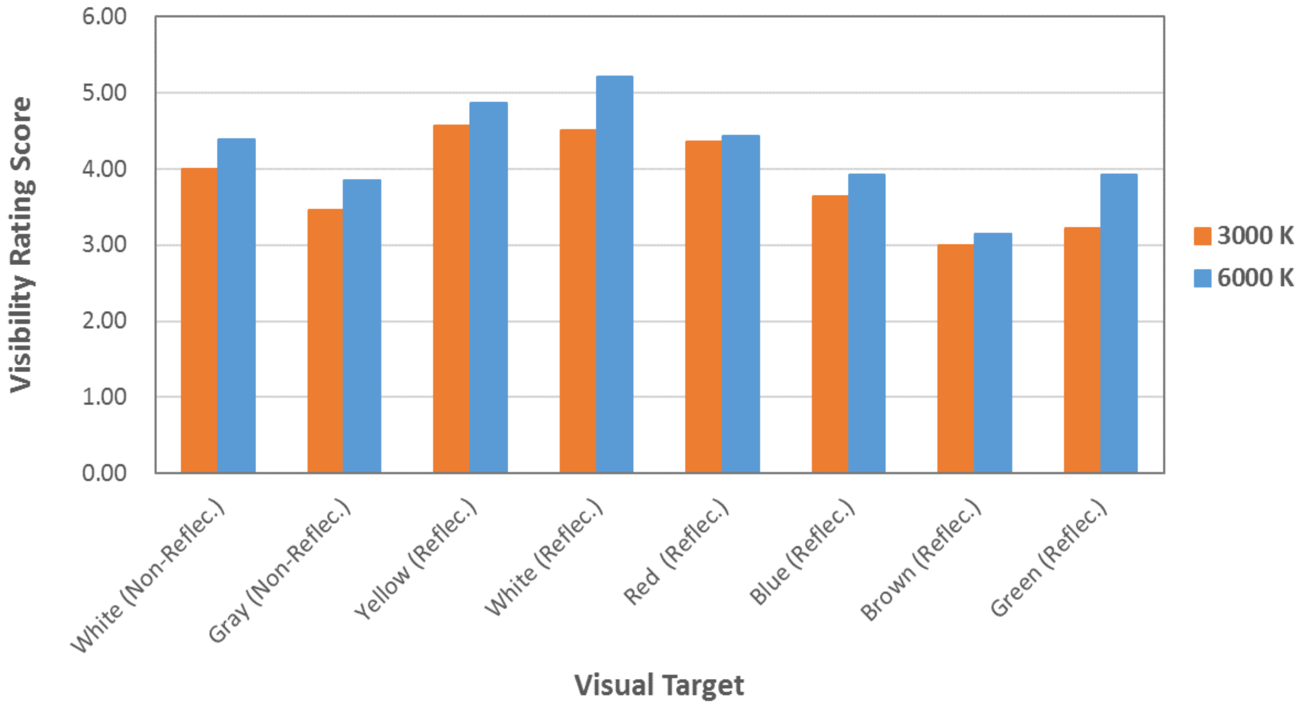
Visual Targets in Different CCT under Clear Weather Condition

Luminance measurement in different CCT(Yellow Dust)

- Luminance Measurement
  - Luminance of non-reflective targets (pedestrian) was decreased with the density of yellow dust.
  - But, reflective colored targets except yellow showed increased luminance with the density of yellow dust.
  - When CCT increased, luminance decreased or unchanged.



Luminance difference in different CCT(Yellow Dust)



Result of subjective evaluation with warm and cool white LED headlamp

Method

- **Subjective Evaluation**
  - Twenty-eight university students participated (15 males, 13 females, 24.2 years old in average)
  - Required Task: 2 or 3 AFC(alternative forced choice)
  - Repeated observation of the lighting conditions under the yellow dust condition.
  - They had to choose one of the CCT conditions that is suitable for the yellow dust atmosphere.

Warm White

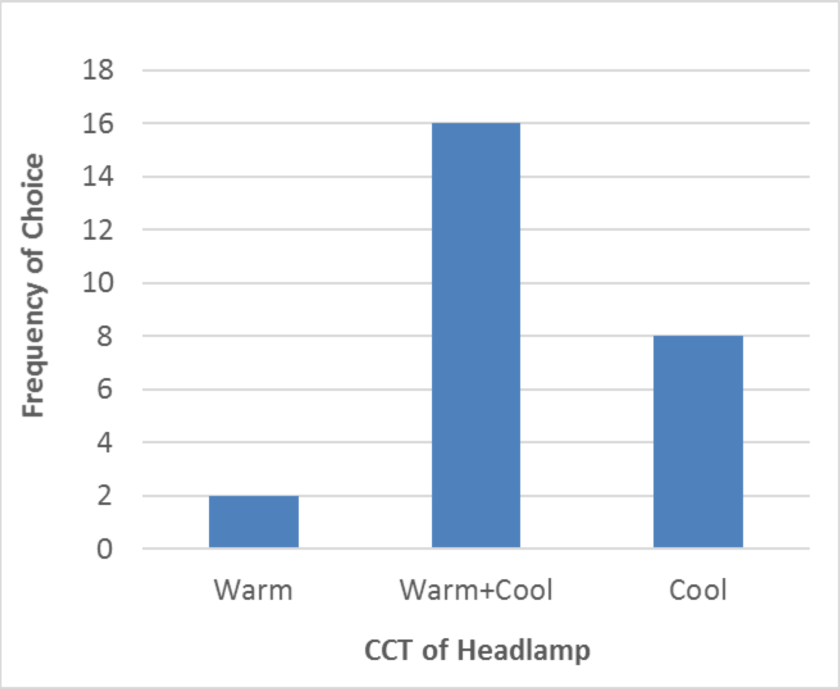
Warm+Cool White

Cool White

Visual Targets in Different CCT under Yellow Dust Condition

Luminance difference in different CCT(Yellow Dust)

- Subjective Evaluation
  - Unlike in luminance and contrast measurements, the result of subjective evaluation showed the higher preference at the intermediate level of CCT (Warm+Cool) than extreme levels of CCT (Warm or Cool).



Luminance difference in different CCT(Yellow Dust)

- Luminance of non-reflective target (pedestrian) was decreased with the density of yellow dust regardless of the CCT of headlamp.

- However, the luminance of the reflective colored targets was different according to their colors and showed a tendency that increased luminance when the density of yellow dust increase.

- The subjective evaluation showed a preference at the intermediate and higher CCT under yellow dust condition.

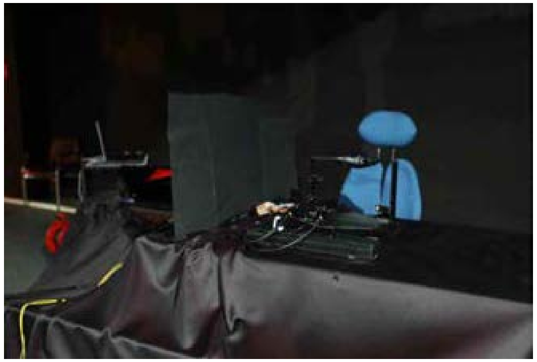
Contents

ALLICE

Automotive Lighting LED-IT Convergence Education

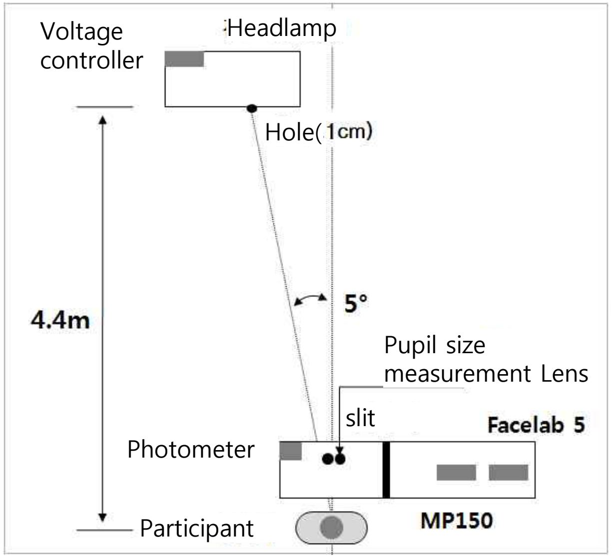
Ergonomic Glare Evaluation Model based on Automobile Headlamp Condition and the level of driver's psycho-physiological response (Halogen, HID, and LED headlamp)

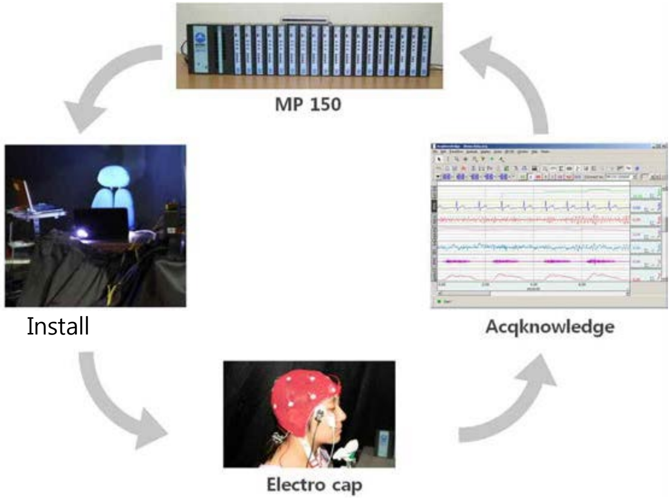
EEG measurement (BIOPAC, MP150)
Eye Tracker (Seeing Machines, Facelab 5)



Participant & equipment

Glare generation by Headlamp





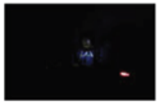
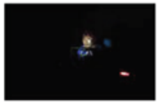
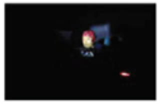
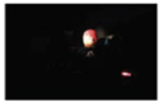
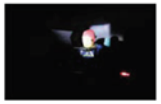
Experiment system set-up

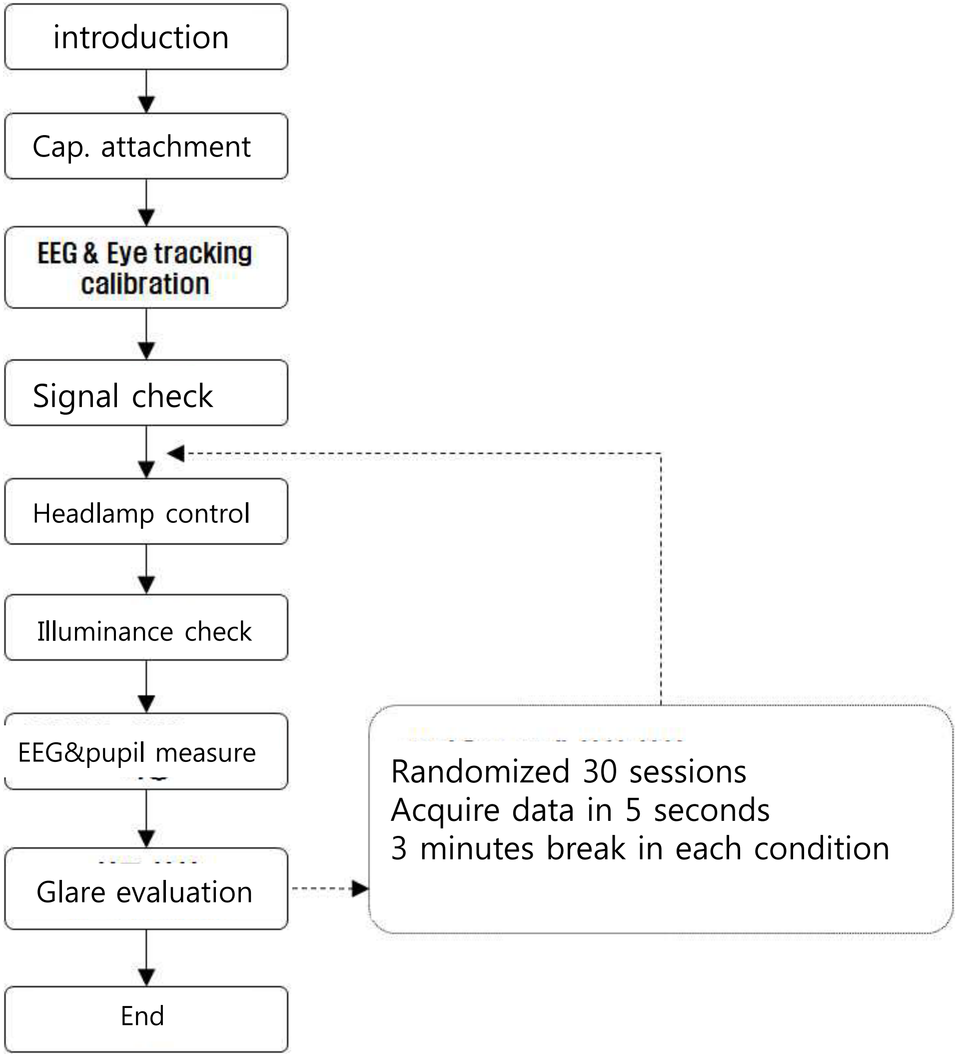
Ergonomic Glare Evaluation Model based on Automobile Headlamp Condition and the level of driver's psycho-physiological response (Halogen, HID, and LED headlamp)

Experiment Setup for glare evaluation

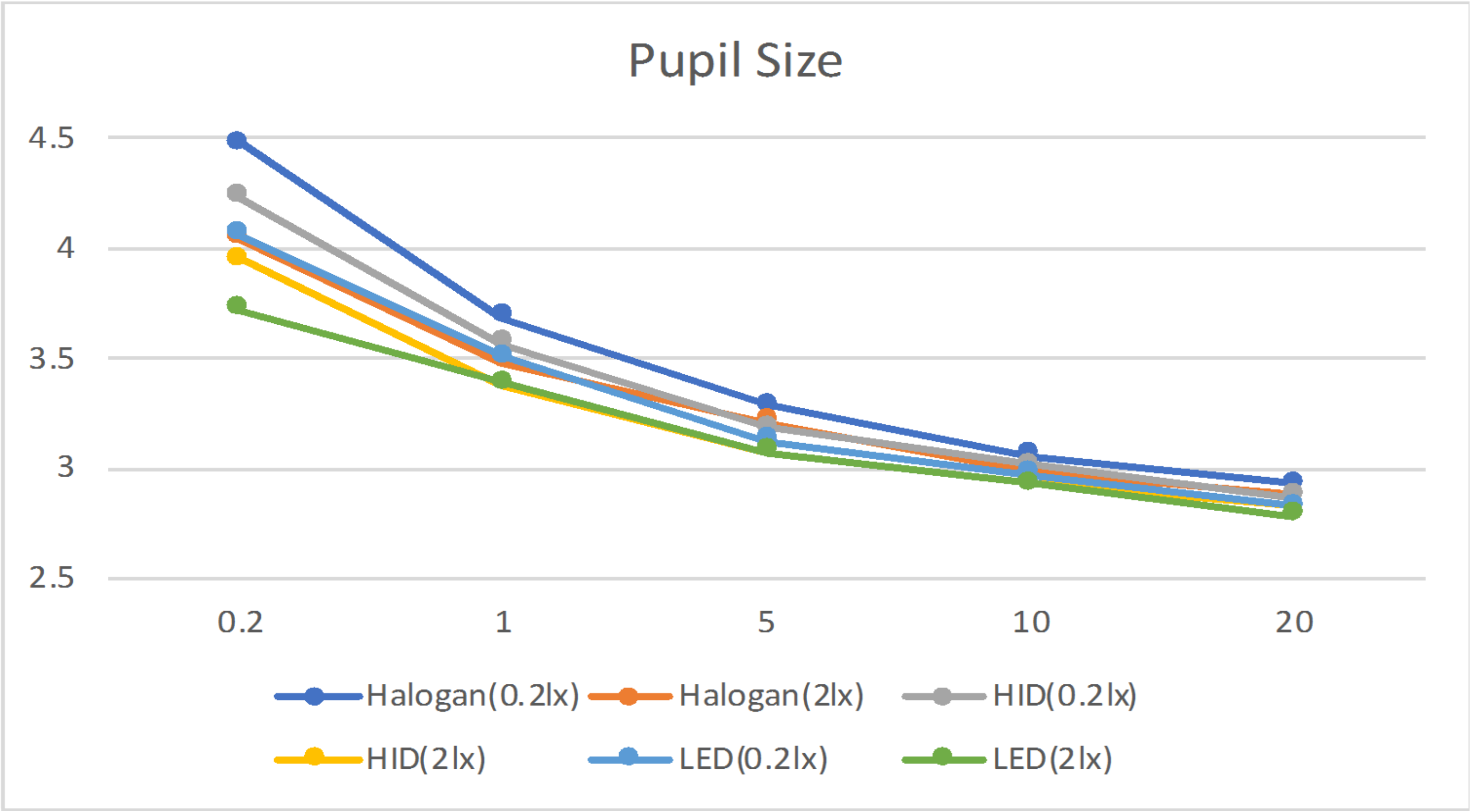
Experiment conditions and procedures

3 headlamp source types x
5 illuminance levels x
2 ambient luminance levels
= 30 sessions for each subject

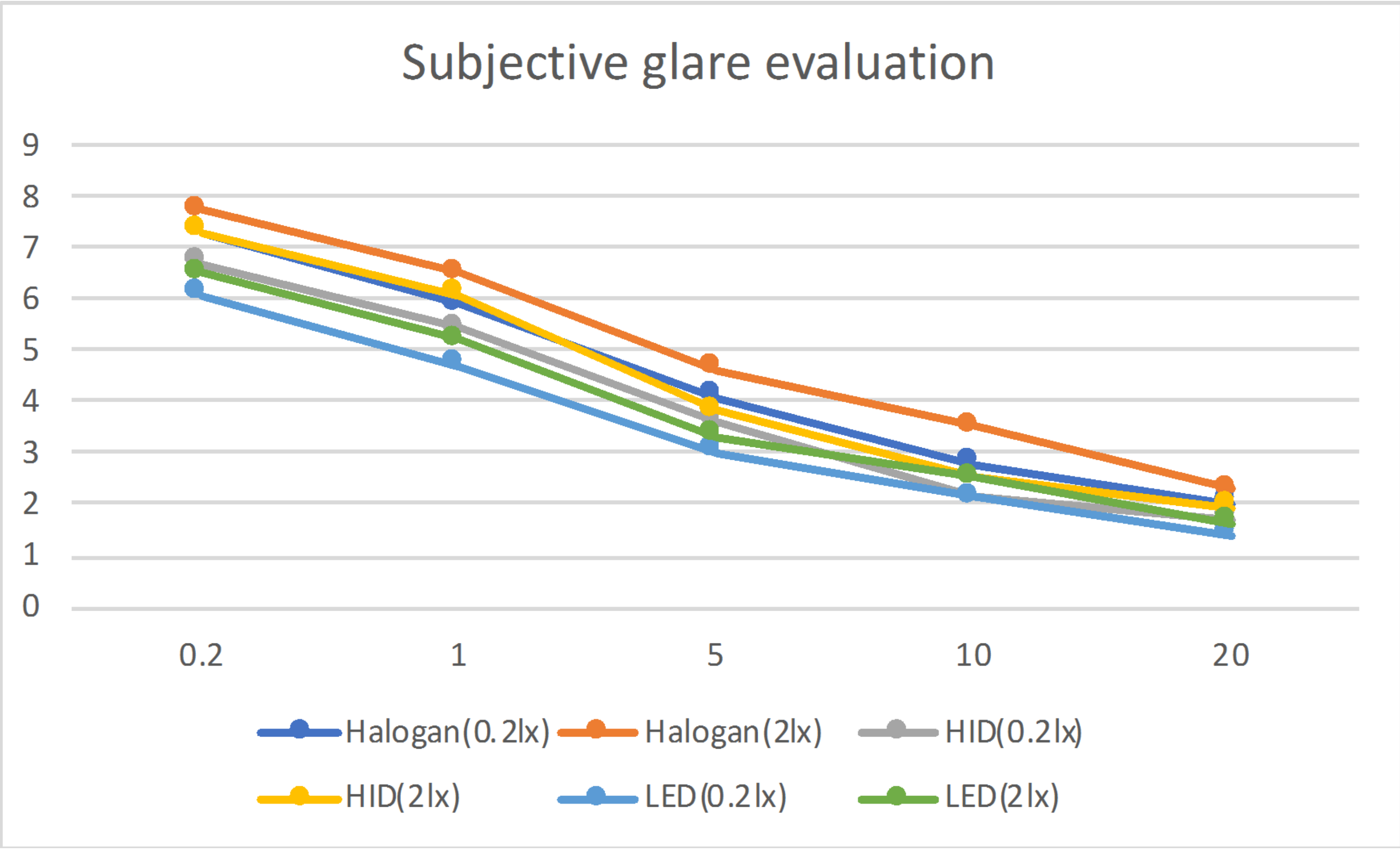
HD type	Halogen	HID	LED	Illuminance measure	Range of Illuminance measure
0.2 lx					0.2±0.02 lx
1 lx					1±0.1 lx
5 lx					5±0.3 lx
10 lx					10±0.5 lx
20 lx					20±0.5 lx



Pupil size according to illuminance, headlamp types



Subjective evaluation of glare



Development of glare level model

$$Y_{(\text{deBoer index})} = 7.719 - 0.543X_1 - 0.017X_2 - 0.223X_3 - 1.997X_4 + 0.045X_3X_4 + 0.003X_3^2$$

where,

$$X_1 = \begin{cases} 1\,(types\ of\ headlamp = \text{LED} \\ 0\,(others) \end{cases}$$

$$X_2 = \begin{cases} 1\,(types\ of\ headlamp = \text{HID} \\ 0\,(others) \end{cases}$$

$$X_3 = \text{Illuminance}\ (lx)$$

$$X_4 = \text{Aminent luminance}\ (cd/m^2)$$

The accuracy of the model in calculating de Boer Index score was 83.3 %

Development of pupil size model

$$Y_{(Pupil\ Size)} = 0.514 - 0.013X_1 - 0.021X_2 - 0.029X_3 - 0.084X_4 + 0.031X_3X_4$$

where,

$$X_1 = \begin{cases} 1\ (types\ of\ headlamp = \text{LED}) \\ 0\ (others) \end{cases}$$

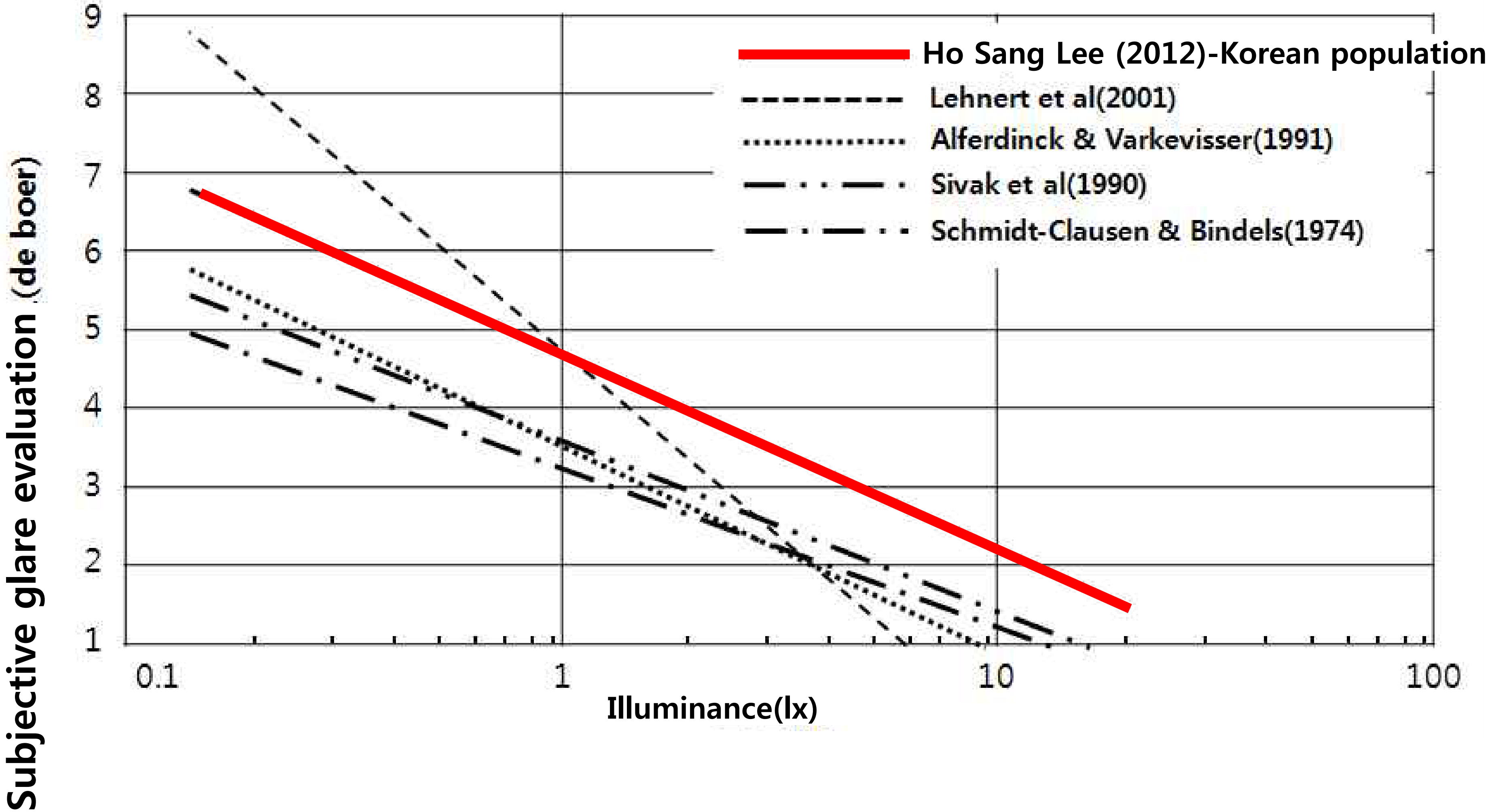
$$X_2 = \begin{cases} 1\ (types\ of\ headlamp = \text{HID}) \\ 0\ (others) \end{cases}$$

$$X_3 = \text{Illuminance} = \log(lx)$$

$$X_4 = \text{Ambient luminance} = \log(cd/m^2)$$

The accuracy of the model in calculating pupil size was 80.1 %.

Comparison of subjective glare evaluation



Korean is less sensitive to glare by 1.5~2 de Boer index

Ergonomic Glare Evaluation Model

- propose glare testing and build static models using psychophysiological analysis and qualitative interviews
- The results showed that each of the main factors (headlamp type, illumination, ambient light) could affect the pupil size
- The subjective survey shows that headlamp type, illumination, ambient light affect the impression of glare
- Koreans are 1.5 ~ 2 less sensitive to glare than non-Koreans according to the de Boer Index
- The accuracy of the model in calculating de Boer Index score was 83.3 % and in calculating pupil size it was 80.1 %

Contents

Summary

- We need further investigation to evaluate spectral characteristics of transmittance and scattering characteristics in automotive headlamp under adverse weather condition

- Our experiment results shows that good CCT of headlamp to improve visibility depends on weather conditions

	Weather Conditions			
Headlamp CCT	Fog	Rain	Yellow Dust	Fog + Rain
3000 K	Good	Good		Good
6000 K			Good	
Evaluation Method	Quantitative, Qualitative	Quantitative, Qualitative	Quantitative, Qualitative	Quantitative,

- Asians are less sensitive to glare by 1.5~2 de Boer index

Thank you for your attention.

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