

Preferred Tone Reproduction Curves of Transparent LCDs



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Overview

- Transparent display
- Color models for two types of T-LCD
 - T-LCD (47" transparent LCD)
 - HM-LCD (see-through head-mounted LC display)
- Visual experiments
- Results
- Conclusions



Applications

- Office / Home (ex. Smart table, window)
- Augmented Reality
- Advertisement
- Vehicle HUD
- Education
- Architecture
- Military





Types

- T-LCD
- T-OLED
- See-through HMD (head-mounted display)
- HUD (Head-Up Display)

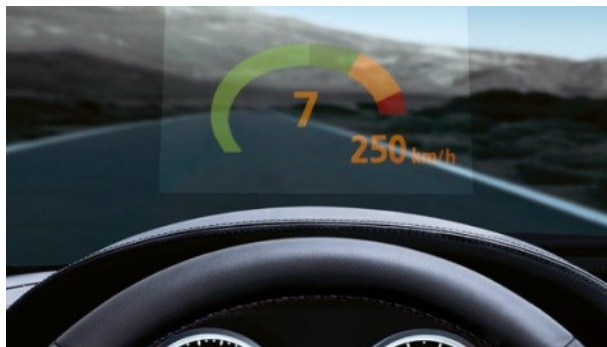




Image quality

- T-LCD
 - The polarizers and color filters block more than 80% of the backlight.
 - Backlighting is needed.



Backlight off



Backlight on



Image quality

- HM-LCD (HMD)
 - A self-illuminated imaging device.
 - Ambient lighting must be reduced.

X



O





Aims

- To illustrate the differences in terms of color characteristics of the two types of devices.
 - The effect of ambient lighting also will be shown.
- To conduct two psycho-visual experiments to derive preferred tone curves under different viewing conditions based on a hybrid S-curve.



T-LCD



HM-LCD



Devices



Item	T-LCD	HM-LCD
Brand	LG	Epson
Model	47TS50MF-B	BT-200
Transmittance (T)	7%	90%
Reflectance (R) at 45/0	0.5%	0.5%
Luminance (Yw)	0 nit	700 nit
gamma	2.54	2.45



Characterization model for T-LCD

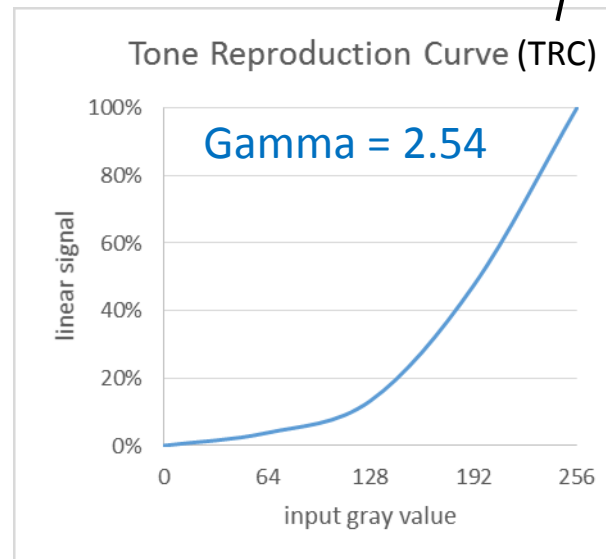
Transmittance

Backlight

Normalized 3 by 4 color mixing matrix including the XYZ values of RGB and black.

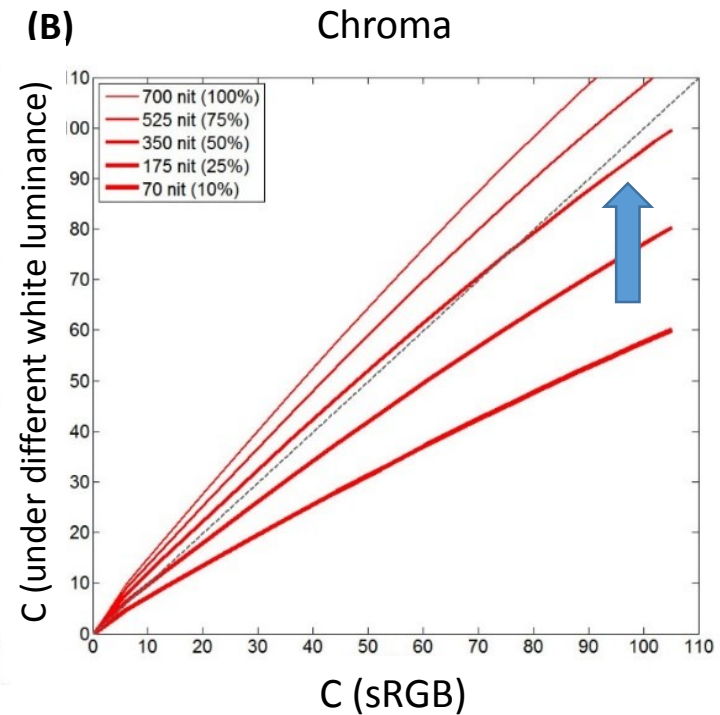
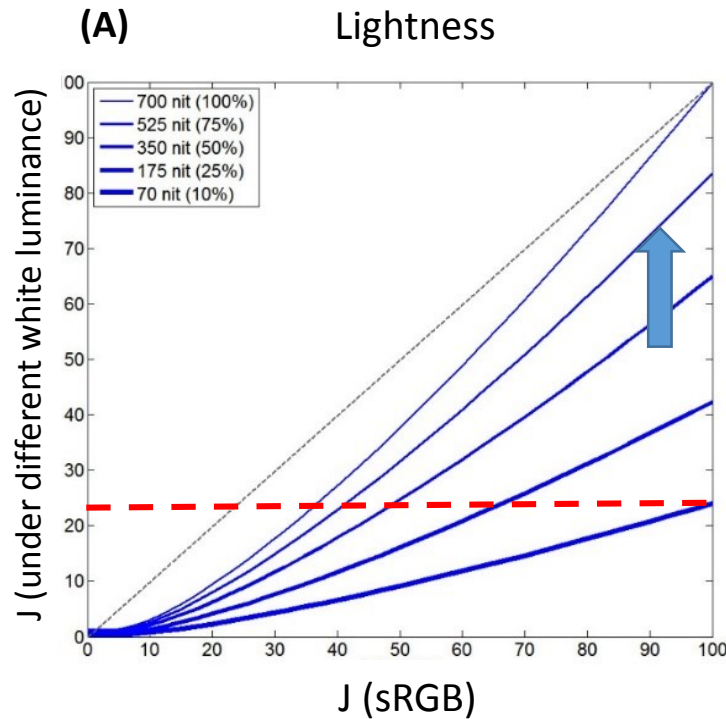
Front light reflection

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{View}} = T \begin{bmatrix} X_{BL} & 0 & 0 \\ 0 & Y_{BL} & 0 \\ 0 & 0 & Z_{BL} \end{bmatrix} \begin{bmatrix} X_{R\%} & X_{G\%} & X_{B\%} & X_{K\%} \\ Y_{R\%} & Y_{G\%} & Y_{B\%} & Y_{K\%} \\ Z_{R\%} & Z_{G\%} & Z_{B\%} & Z_{K\%} \end{bmatrix} \begin{bmatrix} TRC(R) \\ TRC(G) \\ TRC(B) \\ 1 \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_f \quad (1)$$





sRGB vs. T-LCD under different whitepoint-surround luminance ratio





Characterization model for HM-LCD

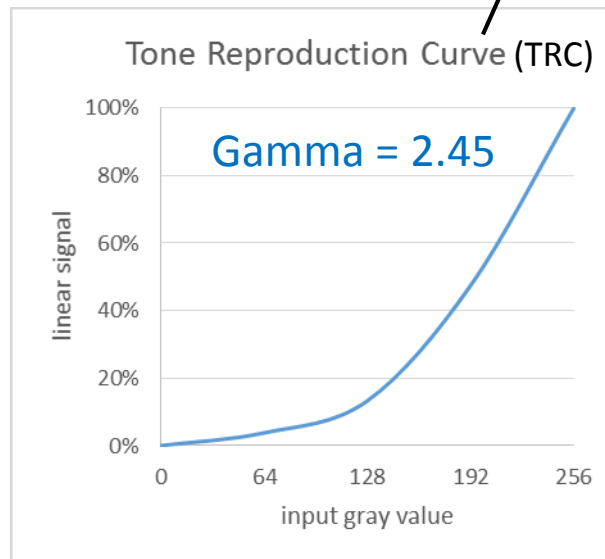
Transmittance

Back light transmission

3 by 4 color mixing matrix including the XYZ values of RGB and black.

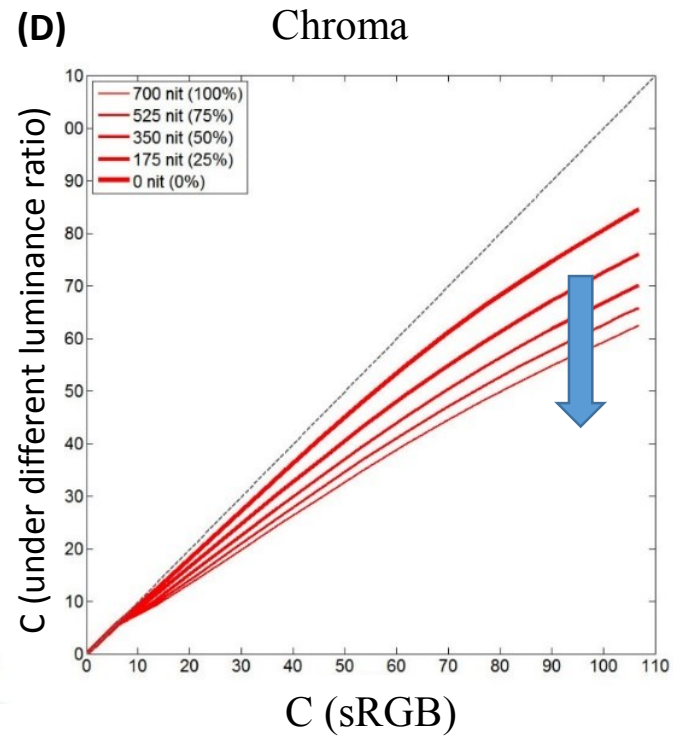
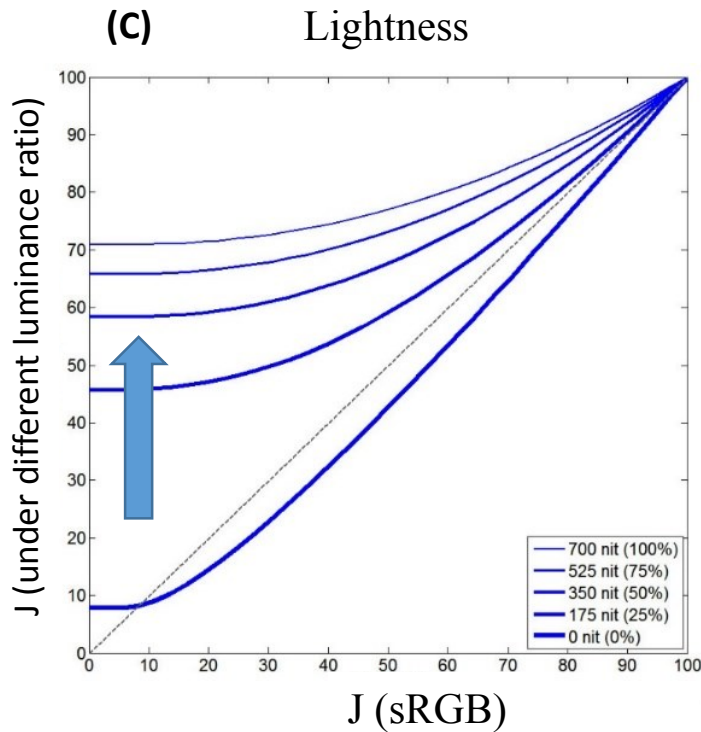
Front light reflection

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{View} = T \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{BL} + \begin{bmatrix} X_R & X_G & X_B & X_K \\ Y_R & Y_G & Y_B & Y_K \\ Z_R & Z_G & Z_B & Z_K \end{bmatrix} \begin{bmatrix} TRC(R) \\ TRC(G) \\ TRC(B) \\ 1 \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_f \quad (2)$$



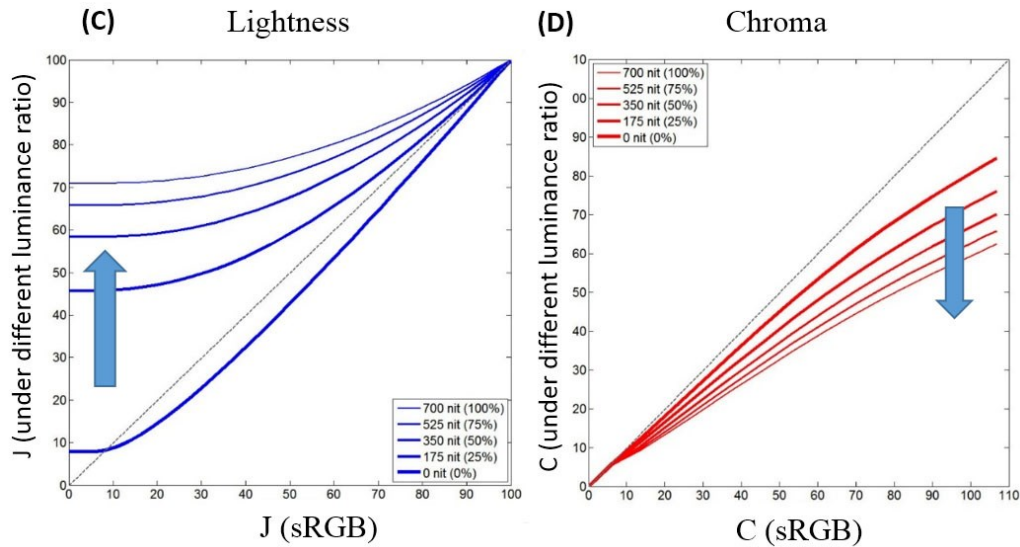
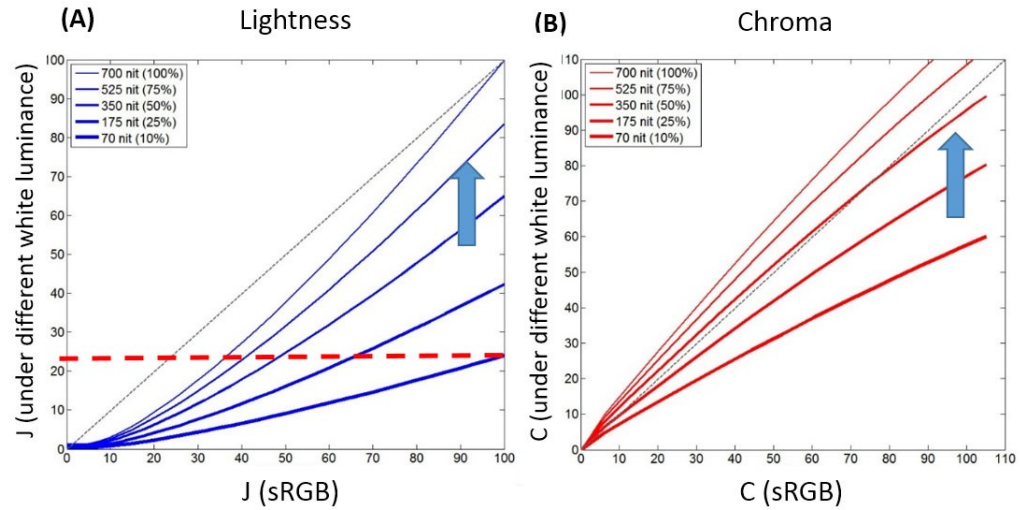


sRGB vs. HM-LCD under different whitepoint (dark)-surround luminance ratio





T-LCD vs. HM-LCD





Visual Experiment: T-LCD





Visual Experiment - T-LCD

Ambient lighting:

Illuminance: 2,000 lux

CCT: 3,320K

White point luminance :

248 cd/m² & 35 cd/m²
(backlight adjustment)

Tone parameters :

Brightness (Gamma)

Contrast (S-curve)

Chroma (gain)

Interactive tuning

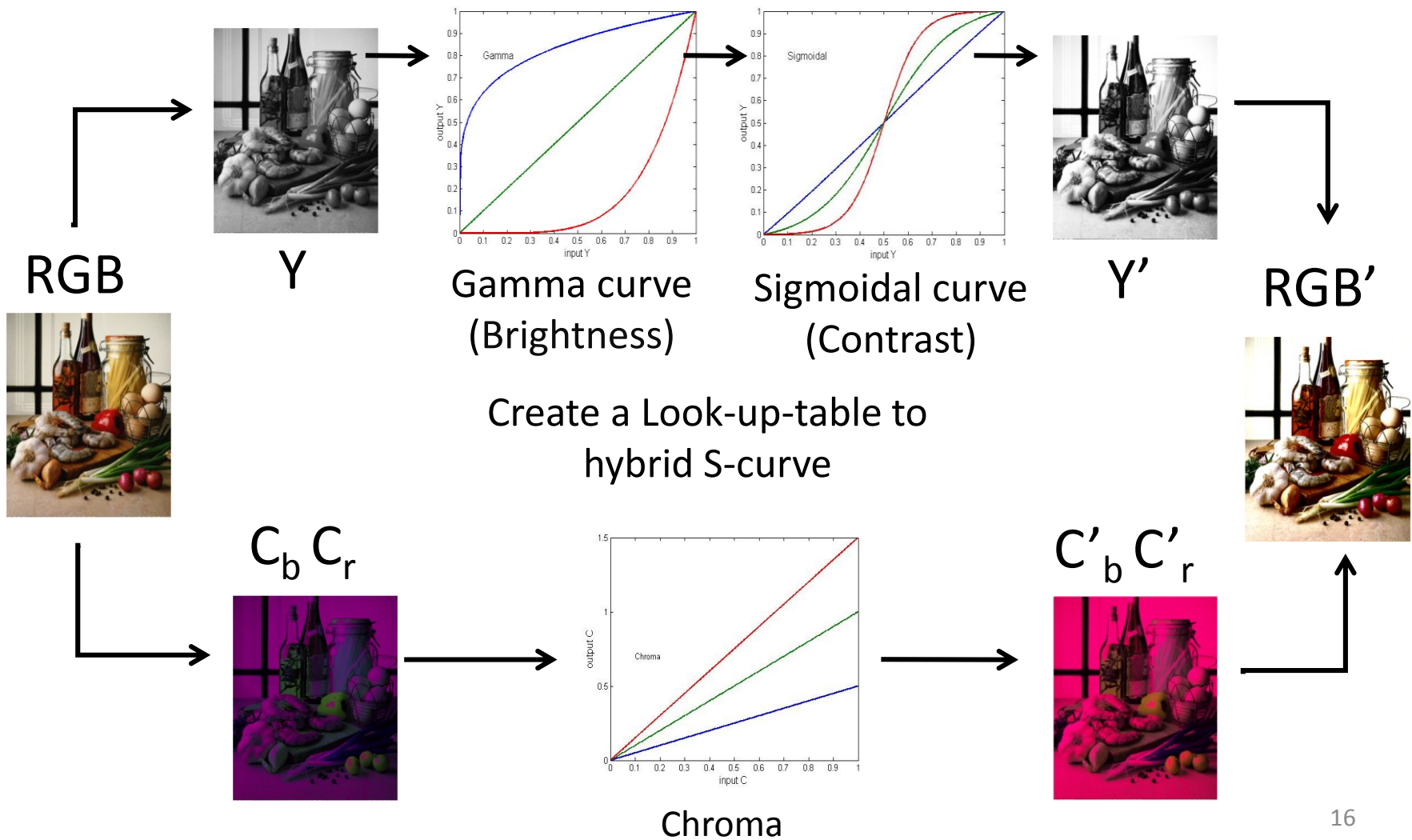
Observers:12

Test images: 6



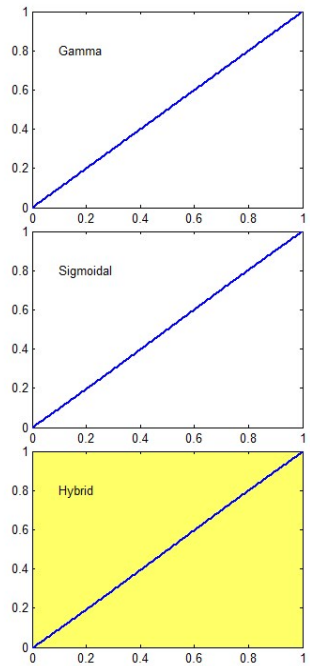
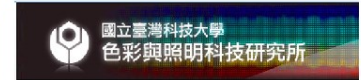
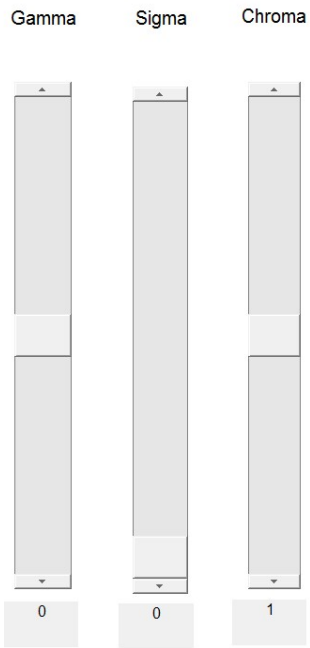


Color tuning





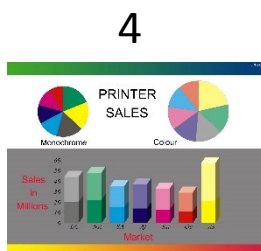
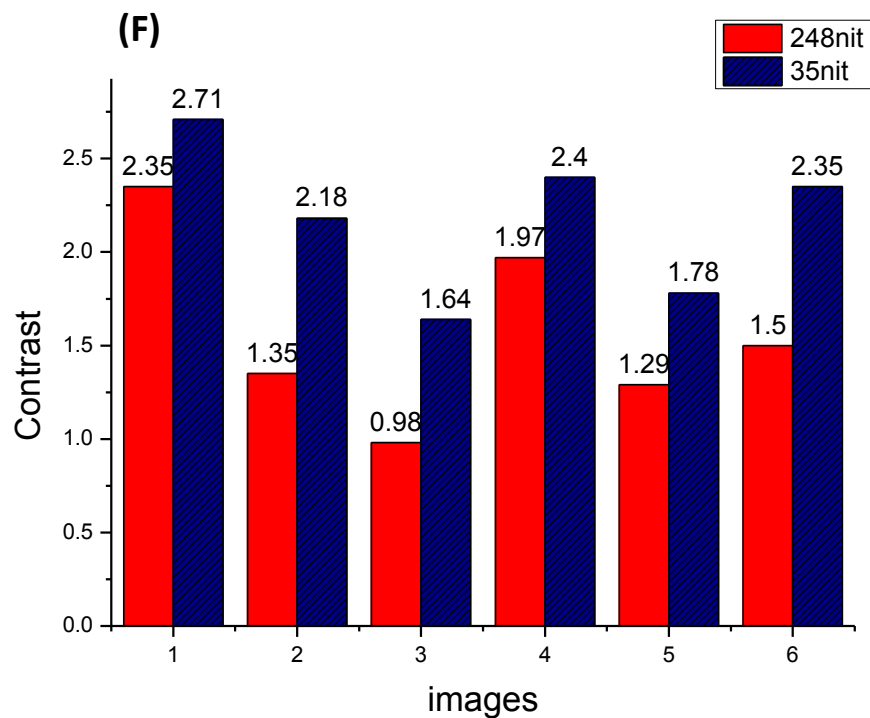
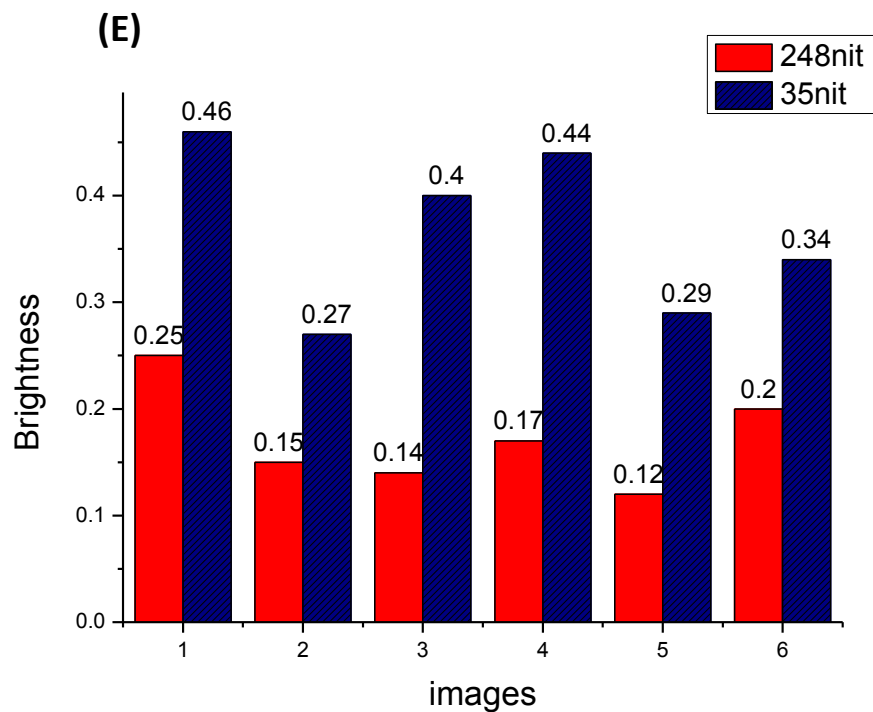
GUI of the T-LCD experiment



Next



Result - T-LCD

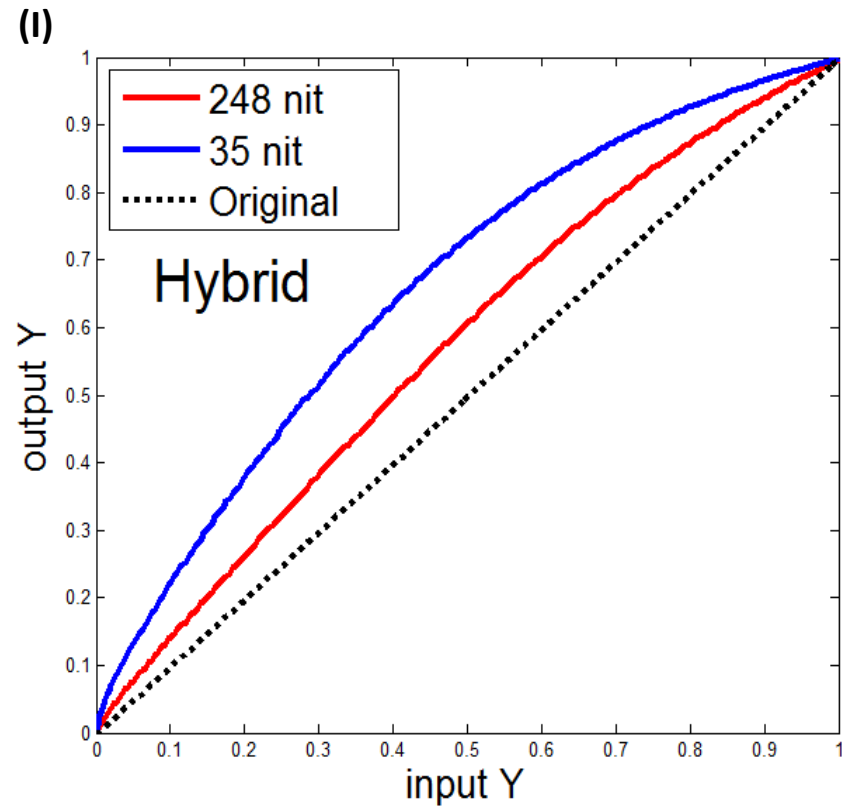
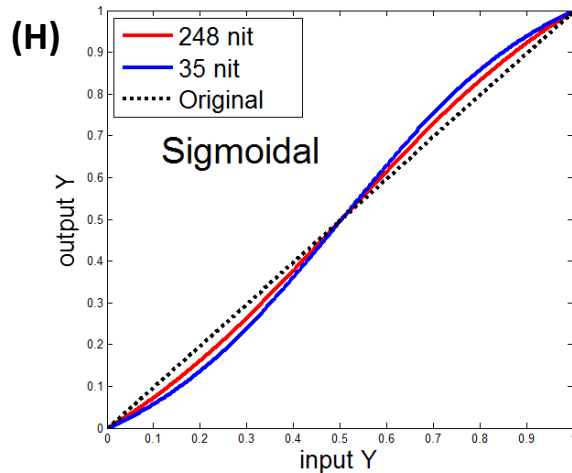
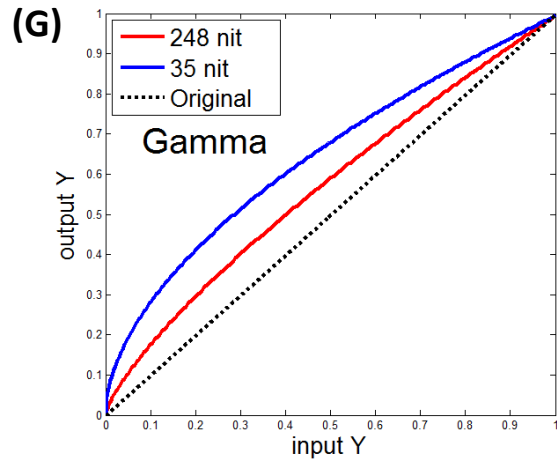


6 test images



Result - T-LCD (tone)

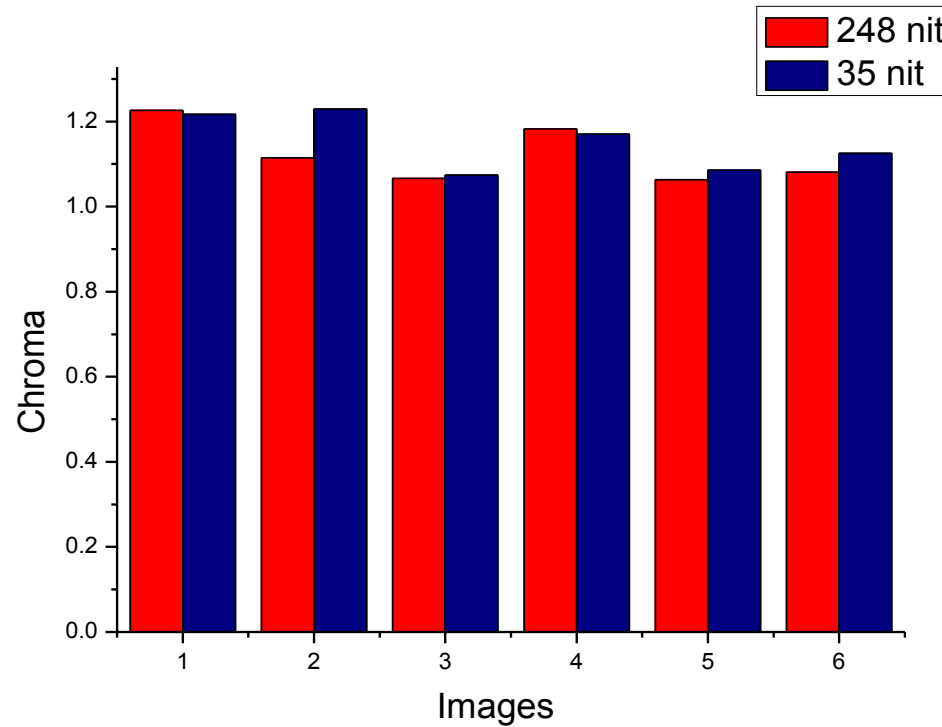
Preferred tone reproduction curves for T-LCD





Result - T-LCD (chroma)

(G)



1



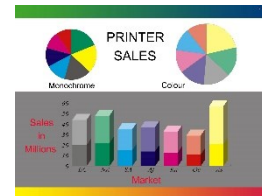
2



3



4



5



6



6 test images



Summary

- For T-LCD
 - When the backlight was darker, then the brightness of the images must be increased.
 - Contrast also need to be heighten in a darker condition.
 - Chroma has no significant impact.



Visual Experiment: HM-LCD





Psycho-Visual Experiment - HM-LCD

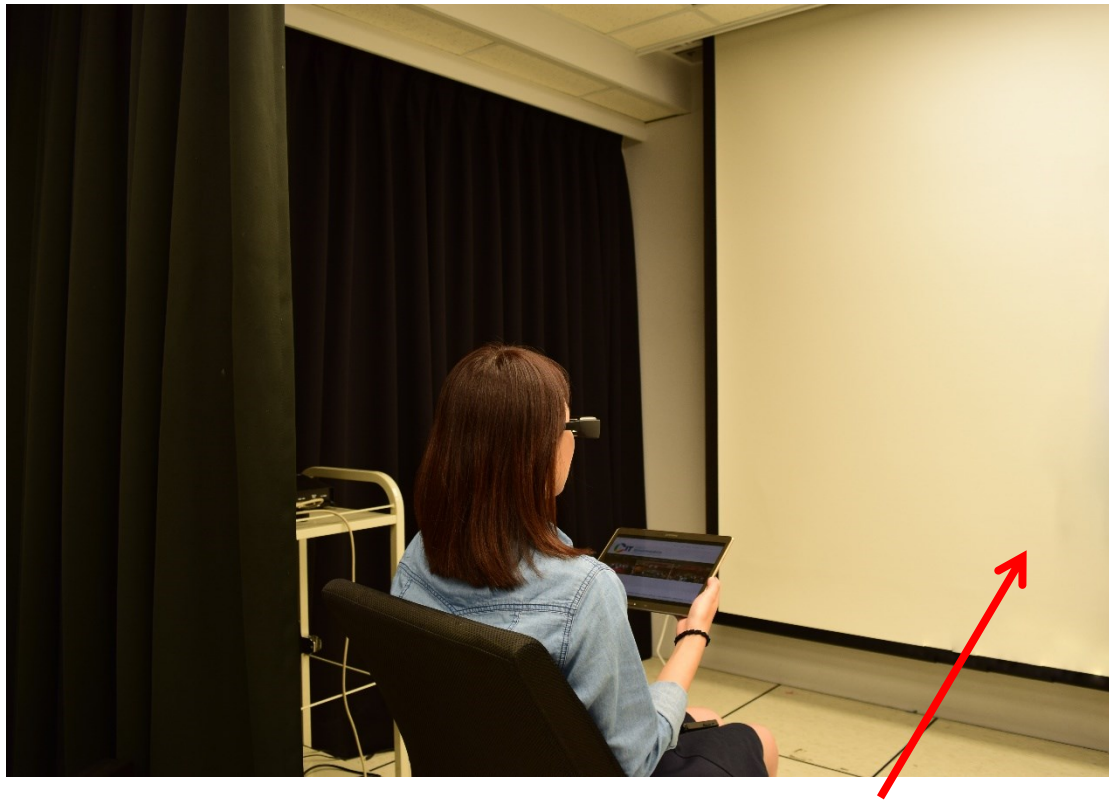
Ambient luminance:
800 cd/m² (6,000 lx)
300 cd/m² (2,300 lx)
0 cd/m² (0 lx)

Ambient CCT: 3,880K

Image manipulation: 5

Categorical judgement
Rating scale: 1-6

Observers:12
Test images: 6



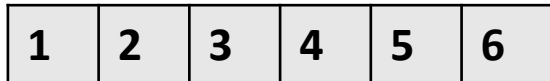
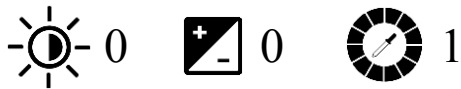
A diffuse projection screen



Image manipulation and rating scale



Original

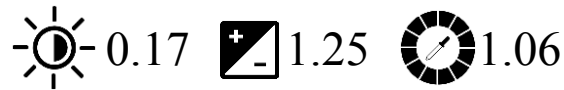


Worse

Better



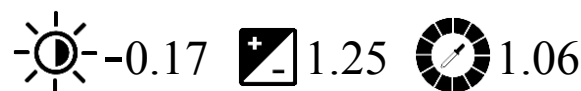
Increase the brightness



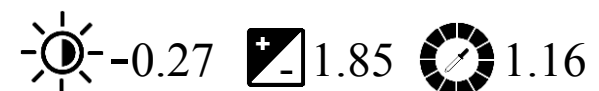
Increase the contrast



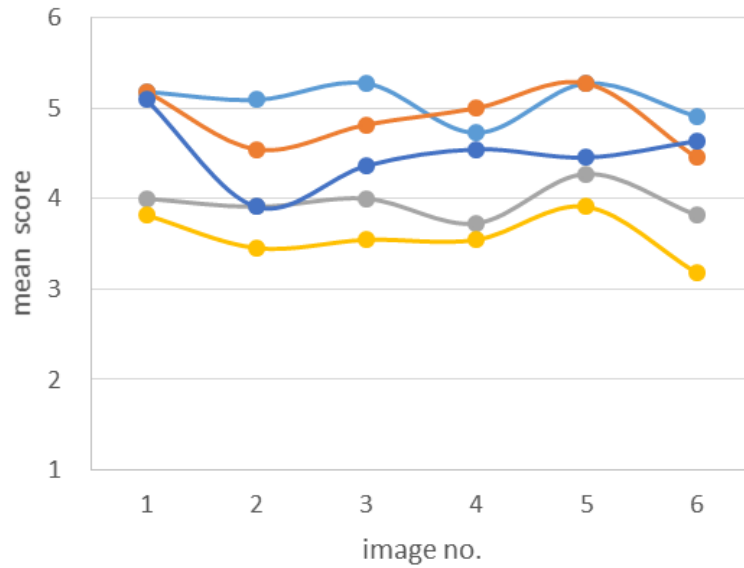
Decrease the brightness



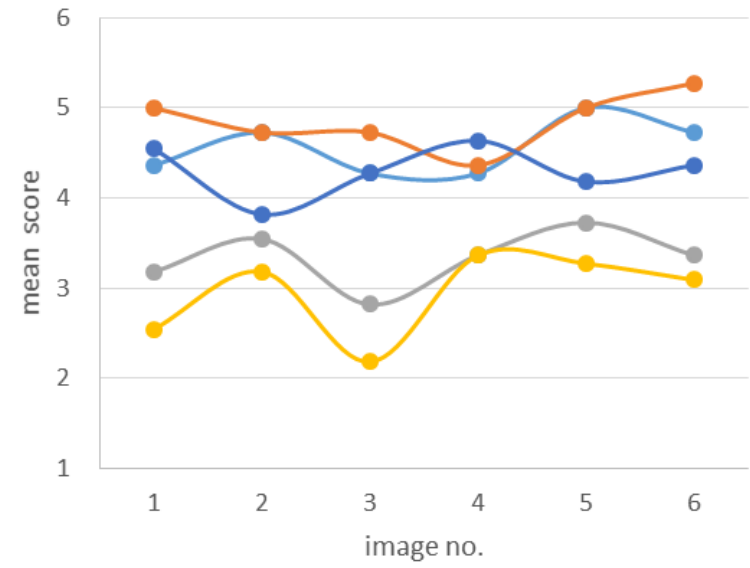
Decrease the brightness



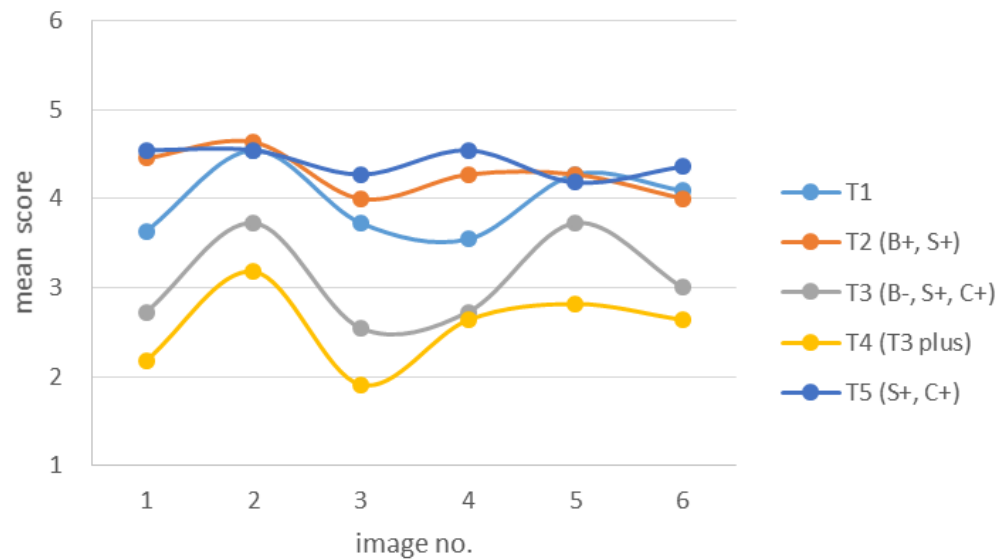
Ambient 0 nit (T:D = 0.0: 1.0)



Ambient 300 nit (T:D = 0.4: 1.0)



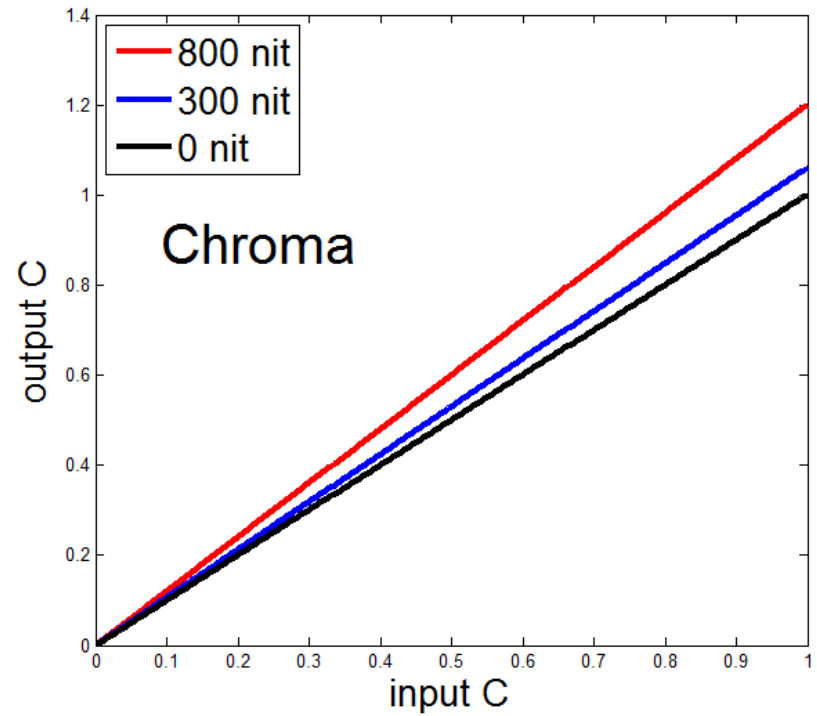
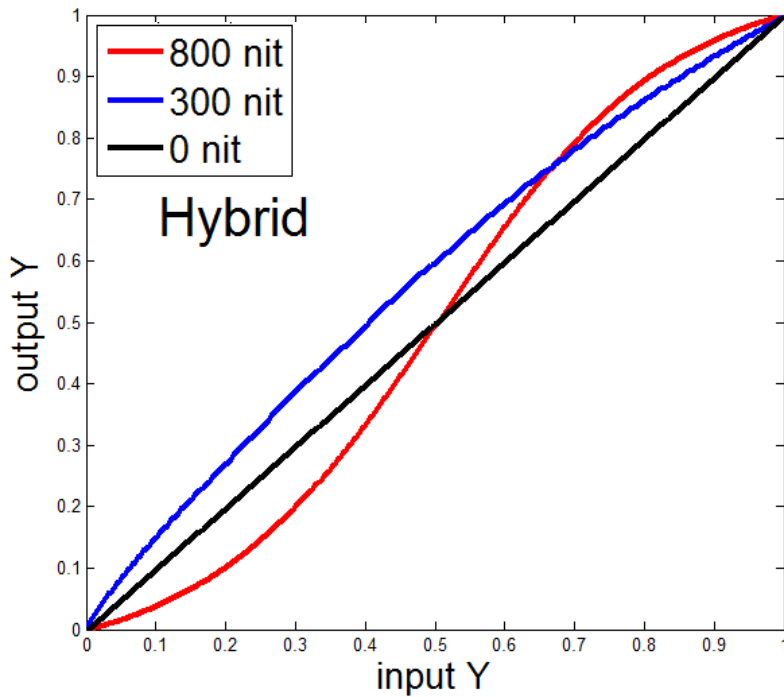
Ambient 800 nit (T:D = 1.1: 1.0)





Result - HM-LCD

Preferred tone reproduction curves for HM-LCD





Summary

1. For bright surround condition:

- Score differences increased.
- Highest score decreased.
- Facial image degraded significantly by darkening the image.

2. Recommendations:

- No compensation for dark surround condition.
- Brighten the image for normal indoor condition.
- Enhance contrast for bright surround condition.



Conclusions

1. Methods for characterizing the colors of T-LCD and HM-LCD under various lighting conditions are introduced. **The color characteristics of the two devices are quite different.**
2. We **derive preferred tone reproduction curves of images** for the transparent display (T-LCD) and see-through head-mounted display (HM-LCD) under different viewing conditions.
3. For T-LCD, the brightness and contrast of the images must be increased under low backlight luminance condition.
For HM-LCD, we recommend the follows:
 - No compensation for dark surround condition.
 - Brighten the image for normal indoor condition.
 - Enhance contrast for bright surround condition.