LightSim: A testbed for evaluating color calibration kits

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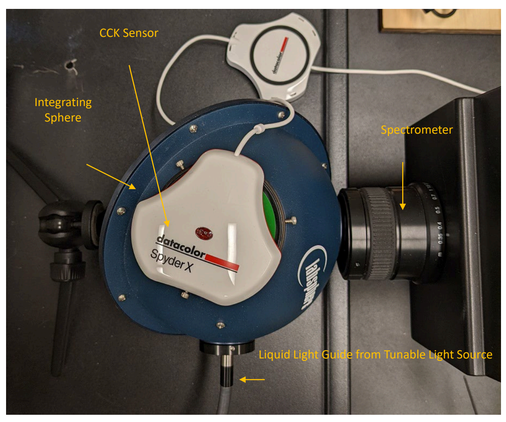
Abstract

Since remote work became common due to the pandemic, professionals relying on high-quality color displays, such as pathologists, have lost regular access to professionally calibrated devices. A potential mitigation is the use of consumer-grade display calibration sensors to conduct routine quality assurance or quality control tasks. A testbed based on a tunable light source was developed to emulate arbitrary display for evaluating such display calibration sensors.

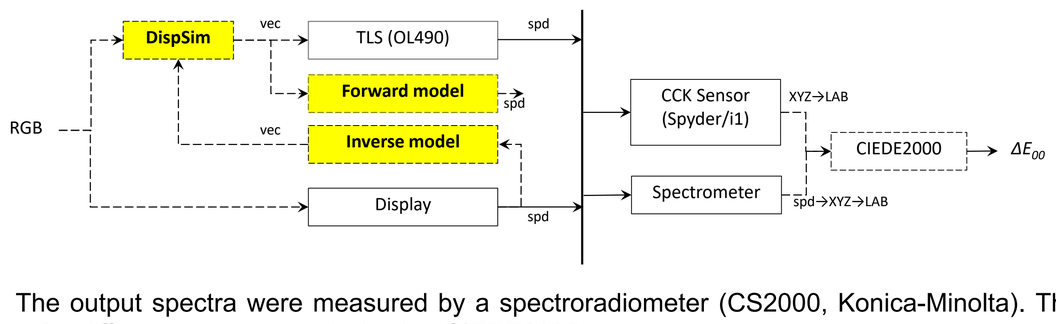
Hardware/Software Components

The testbed consists of a tunable light source (OL490, Gooch & Housego) for generating the target spectrum, an integrating sphere for diffusing the light for the color calibration sensor, and a spectroradiometer for measuring the output spectrum.

The tunable light source (TLS) used 1,024 columns of a digital light processor (DLP) to selectively reflect the dispersed light coming from a xenon lamp after passing through the grating.



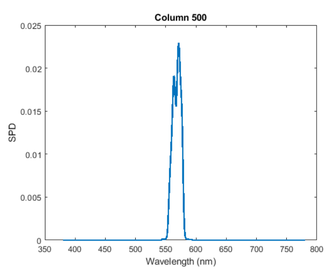
The main software components include the forward model, inverse model, and display simulator.



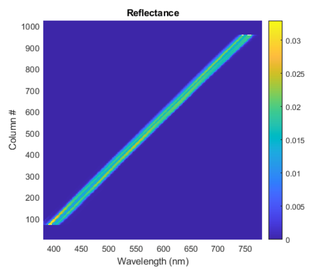
The output spectra were measured by a spectroradiometer (CS2000, Konica-Minolta). The color difference was computed using CIEDE2000.

Characterization

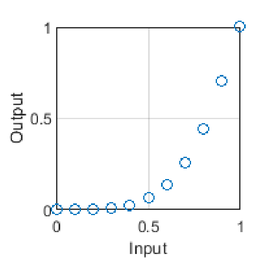
The tunable light source was characterized as a 1-pixel, 1,024-primary, 40,000-level reflective display.



Spectrum of primary #500



Spectra of all 1024 primaries

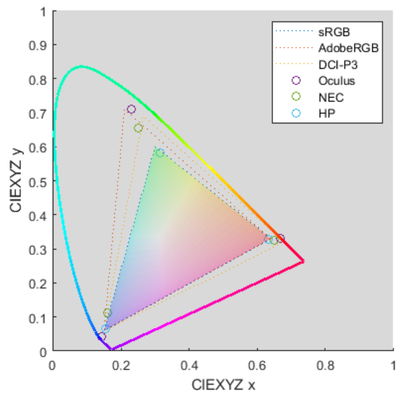


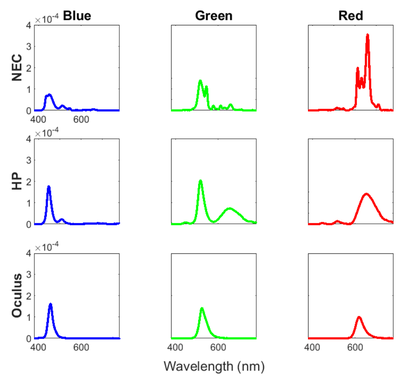
Normalized gamma curve of the 40,000 levels

Displays Emulated

Three displays were emulated to represent various spectra and color gamut sizes.

NEC PA271	Professional-grade	LCD/CCFL	AdobeRGB
HP Z24X	Consumer-grade	LCD/LED	sRGB
Oculus Rift	Virtual reality	OLED	DCI-P3





Sensors Tested

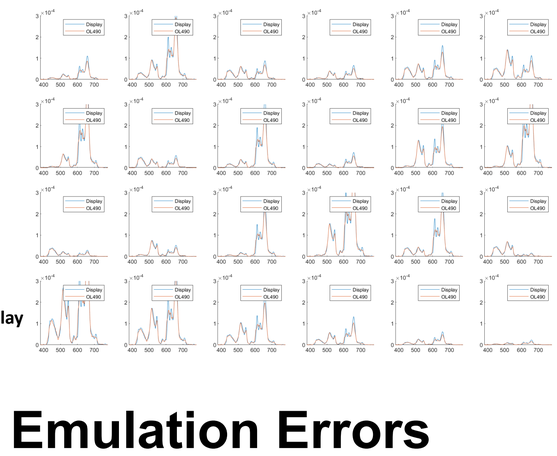
The output stimulus was measured by four instruments of various precision levels.

Spyder X	CCK colorimeter	$250	
Eye-One Pro	CCK photometer	$2,000	**Ambient light mode*
CL500	Spectrophotometer	$10,000	
CS2000	Spectroradiometer	$25,000	**Ground truth*

Test Target

Twenty-four patches from ColorChecker were reproduced to test the sensors.

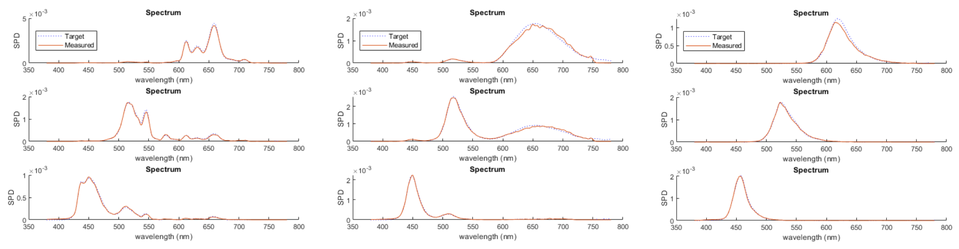
Spectra reproduced to mimic ColorChecker shown on the NEC display (blue: target, red: measured)



Emulation Errors

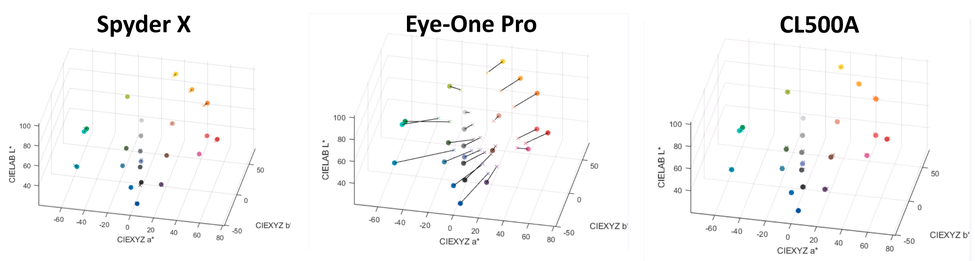
The errors of emulating display primary colors were evaluated with PSNR. The testbed performed worse for the red primaries and the HP display (LCD with LED backlighting).

PSNR	NEC	HP	Rift	mean
Red	82.24	82.89	88.76	85.29
Green	91.54	85.12	93.34	90.00
Blue	98.63	94.83	95.73	96.40
mean	91.47	87.61	92.62	



Results - ΔE

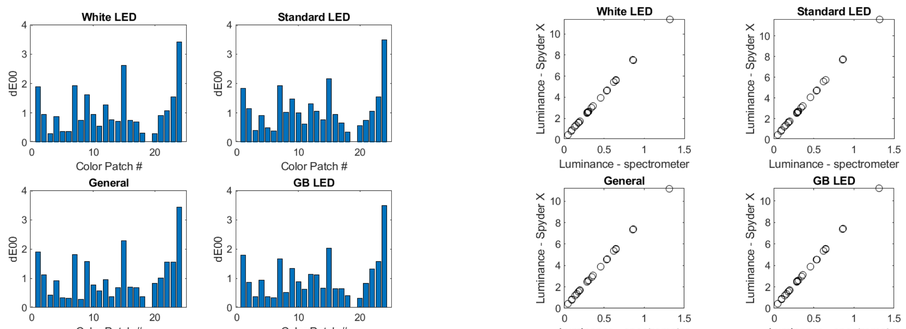
The ΔE values of the three sensors show that the CL500A spectrophotometer performed the best. The Spyder X CCK delivered similar results. The Eye-One Pro CCK, when used in the ambient light mode, generated pronounced errors.



ΔE_{00} = 1.60 **ΔE_{00} = 14.46** **ΔE_{00} = 0.83**

Backlight Modes

Spyder X supports four backlight modes. None of the four modes outperformed the others. All four modes exhibited adequate linearity.



Conclusions

LightSim mimics arbitrary display spectra for testing color calibration kits.
OLED, LCD/LED, and LCD/CCFL displays were emulated closely.
Three display sensors of various precision levels were tested.
Consumer-grade sensor delivered adequate linearity and ΔE accuracy for ColorChecker, but effectiveness of the backlight mode is uncertain.
The exercise demonstrates the utility of LightSim for evaluating color calibration sensors.

Disclaimer