DevCon 2016

Color tuning of a painting by a multispectral lighting system - an iccMAX-based approach

CIT 色彩與照明科技研究所
Graduate Institute of Color and Illumination Technology

Presenter: Wei-Chun Hung, Pei-Li Sun
National Taiwan Univeristy of Science & Technology

ICC

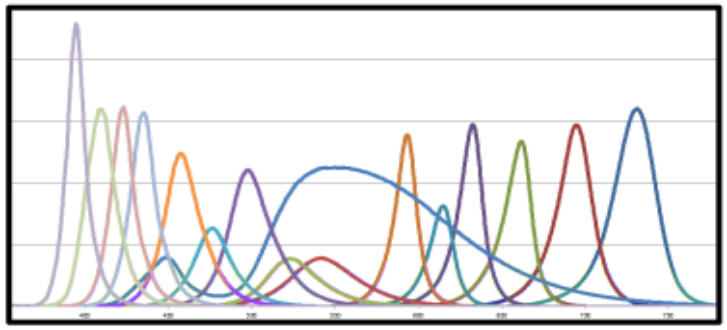
Overview

- Motivation
- Characterization of a Multispectral Lighting System
  - Apparatus
  - iccMAX Implementation
- Color tuning of discolored paintings by the system
  - Experiment
  - Results
- Conclusions

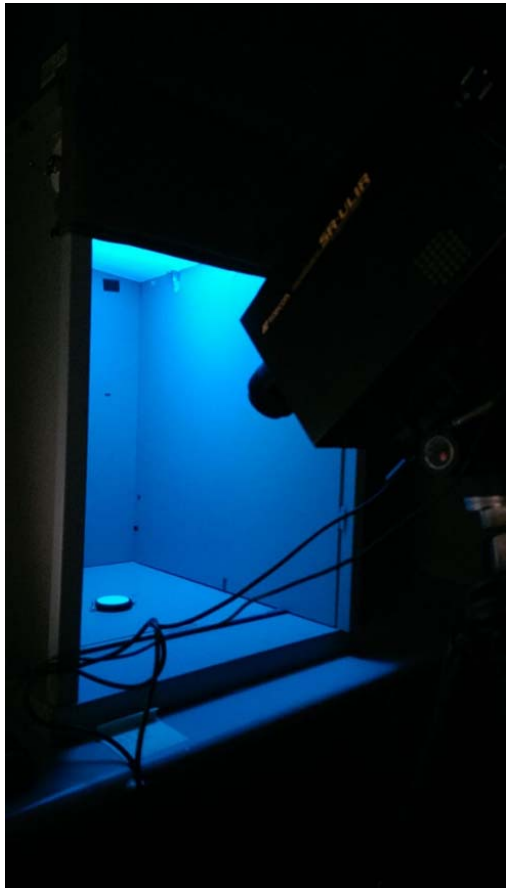
Motivation

- There are several known causes of discoloration problems on painting, such as exposure to light, dust, and air.
- The faded colors are possible to be recovered to some degree by using a multispectral lighting system (MSLS).
- The tunable multispectral LED systems also can be characterized by the iccMAX for converting input signals to the corresponding spectral power.

Characterization of a Multispectral Lighting System



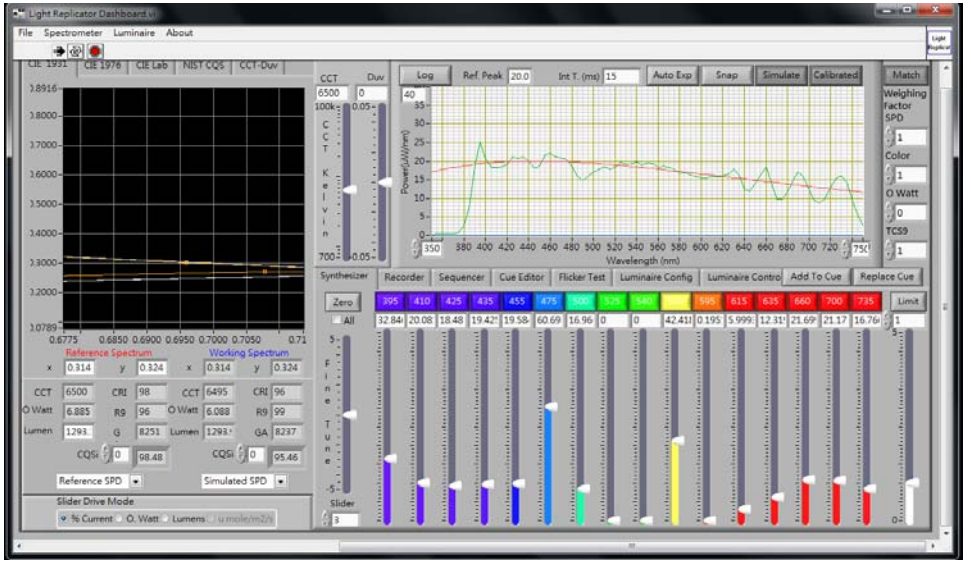
16 independent SPD



Apparatus

Telelumen
Light Replicator

- 16 independent color channels (16 band LEDs)
- capturing dynamic natural light sources



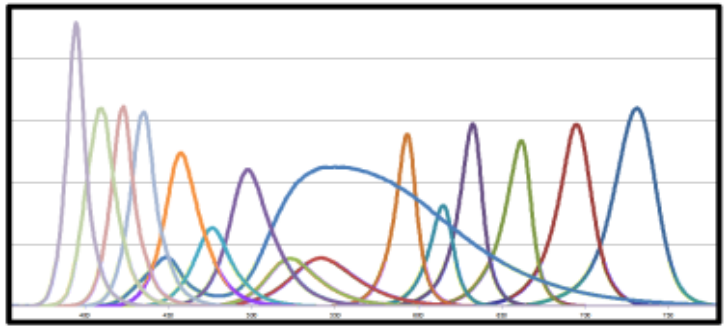
Telelumen Light Replicator Features

- Tunable CCT from 1,000K to 100,000K with CRI>90
- Visual Range Coverage (~395-735nm)
- Color Optimization for Chromaticity
- Dual-channel recording
- Time-Varying Edit/Playback capability
- Multiple Color Spaces
  - CIE xy, u'v', L*a*b
- Simulated optical output display
- Software remote control

Q

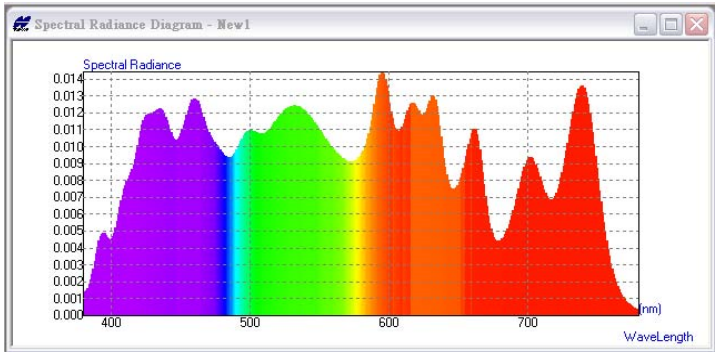
- Additive color mixing

$$1 + 1 \overset{?}{=} > 2$$



16 independent SPD

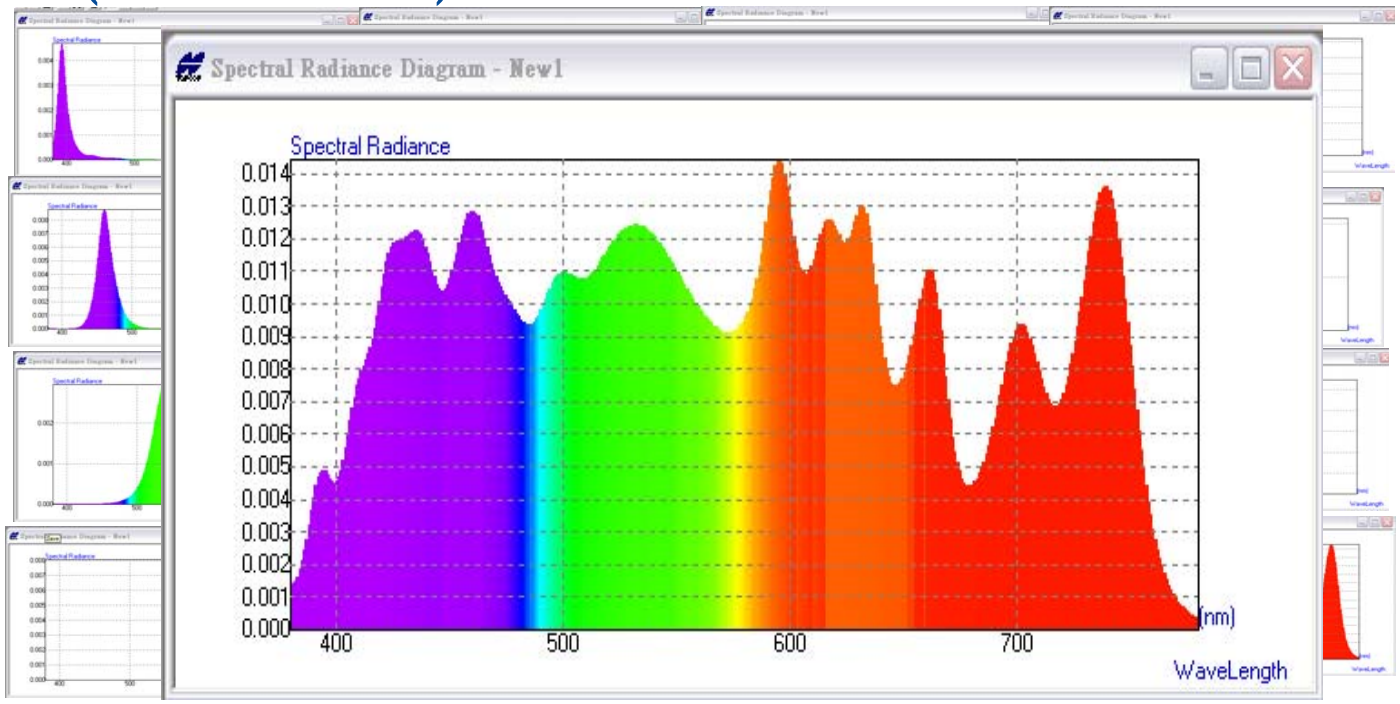
$\overset{?}{=}$



16 all SPD

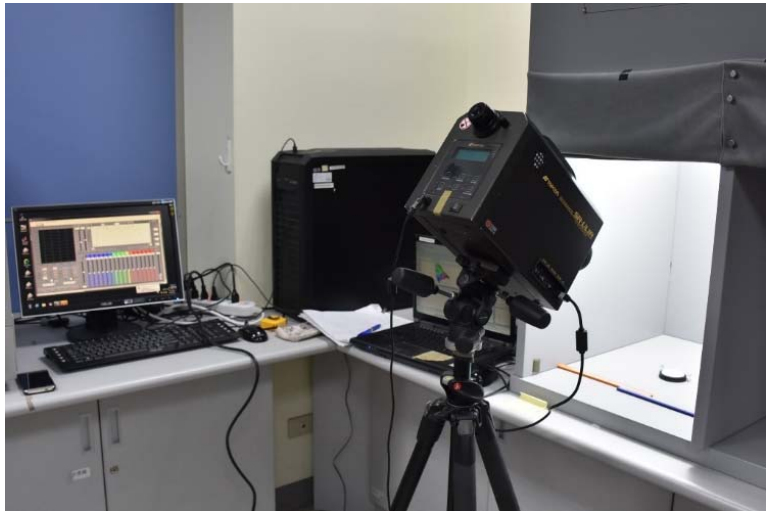
Q

- Tone cure is linear or not
- SPD (individual)



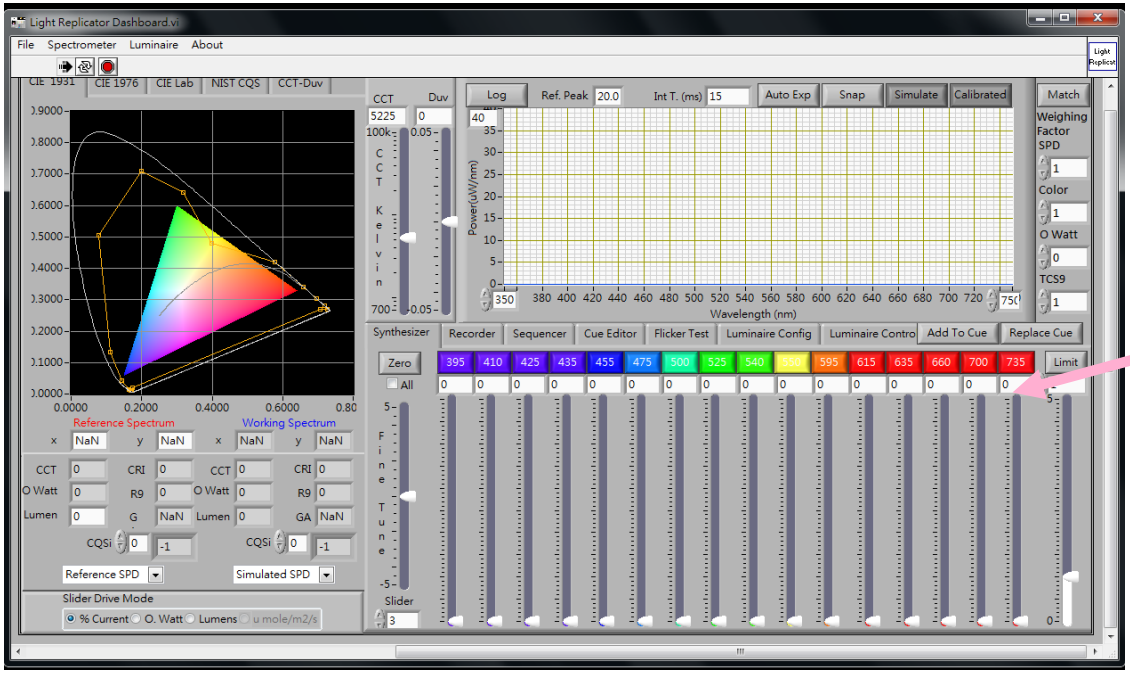
Setting

- Apparatus
  - Telelumen Light Replicator (multispectral LEDs)
- Measurement
  - Topcon-SRUL1R
- Sample: a perfect diffuser



Setting

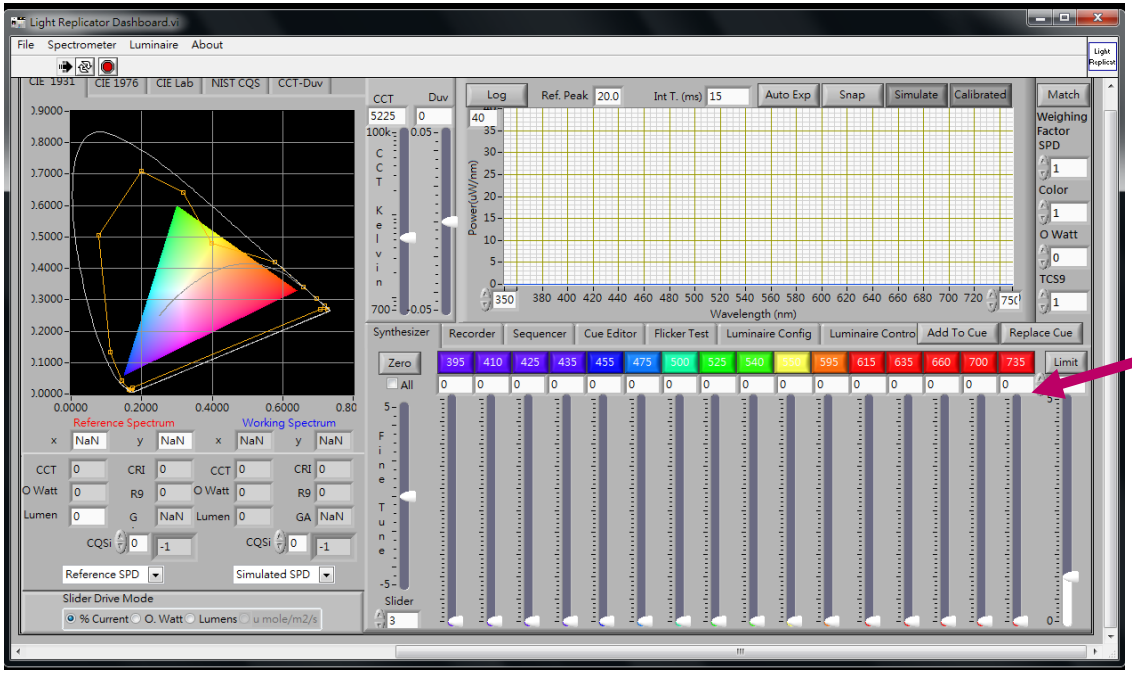
- Telelumen Light Replicator



16 independent color channels: 395,410,425,435,455,475,500,525,540,550,595,615,635,660,700,735

Setting

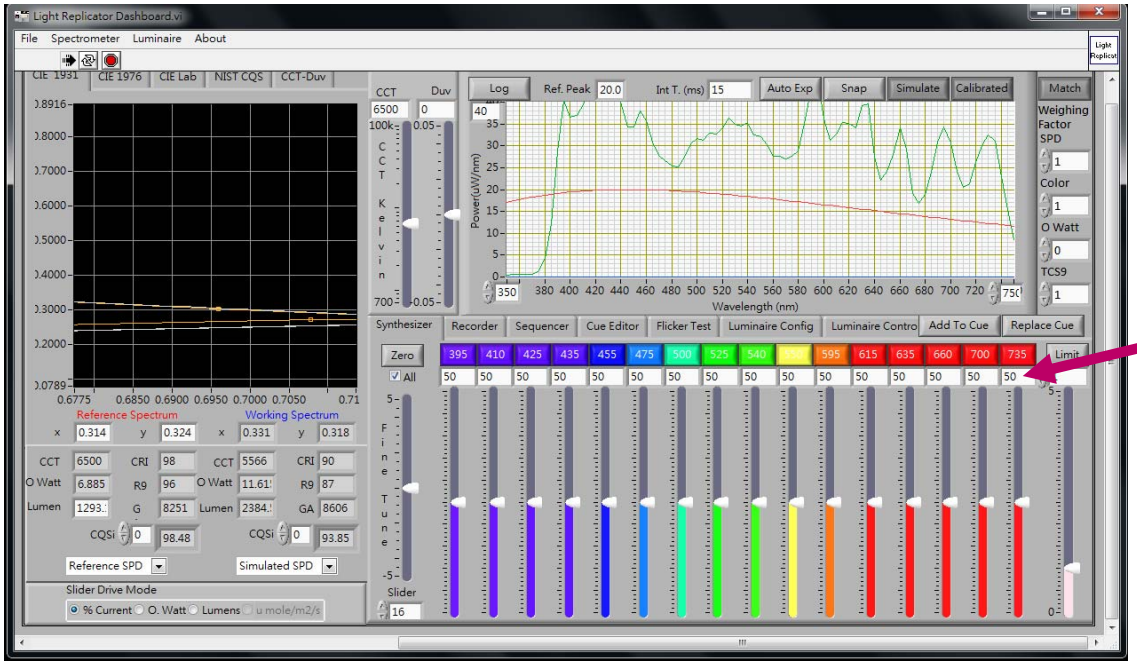
- Telelumen Light Replicator



Input values:0-100

Setting

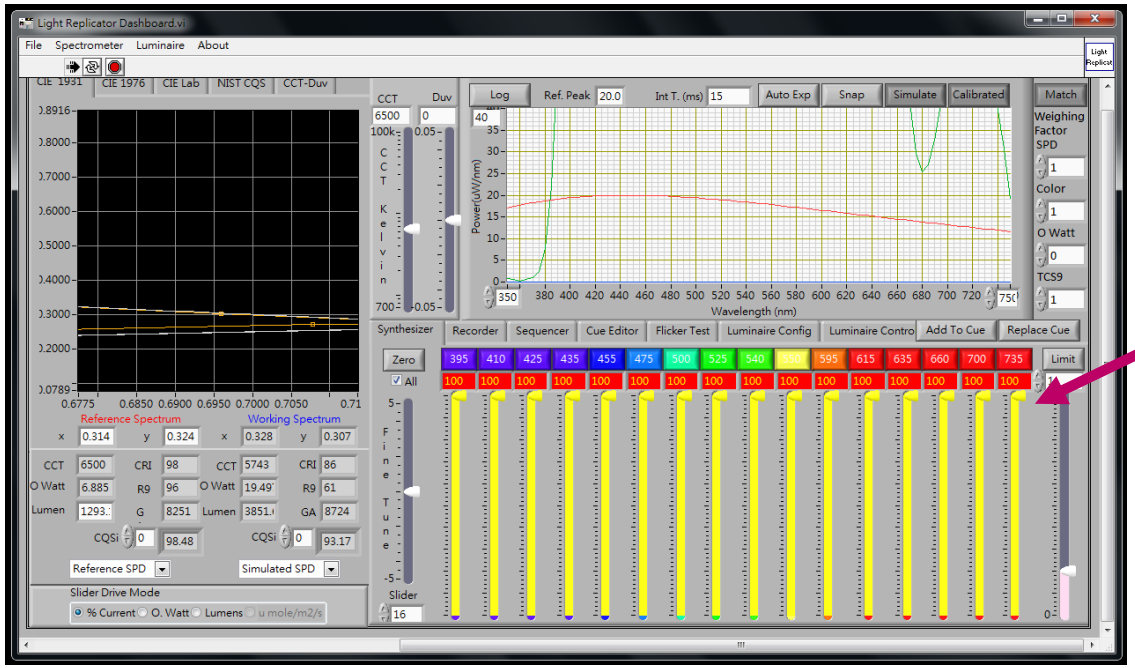
- Telelumen Light Replicator



Input values:50

Setting

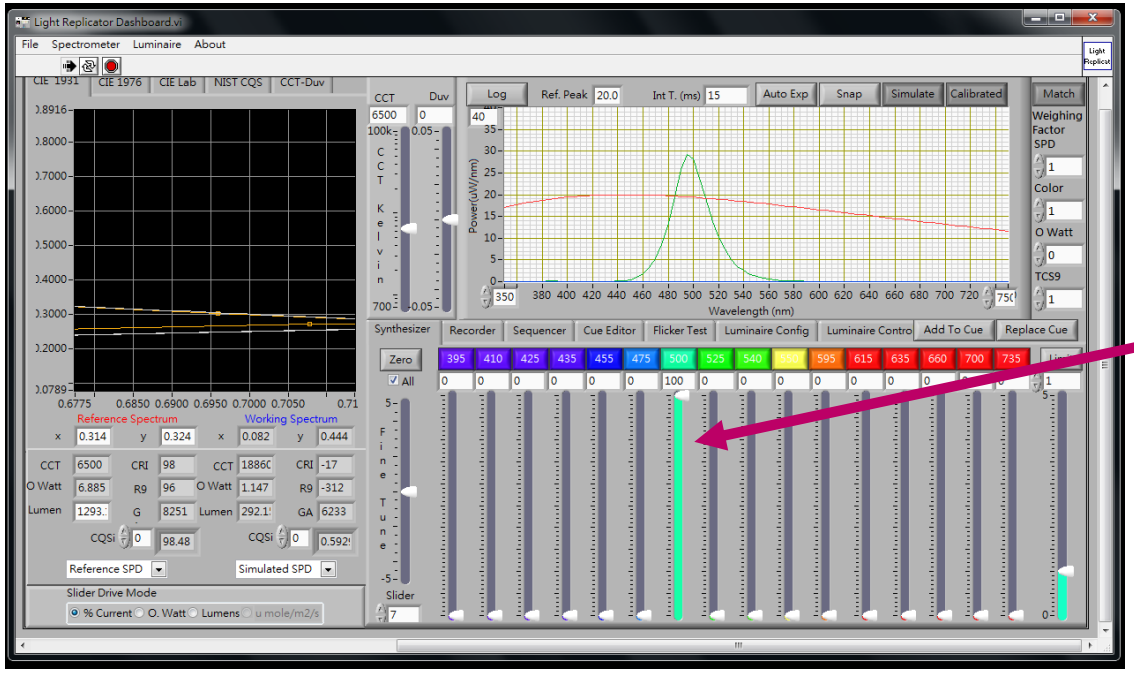
- Telelumen Light Replicator



Input values:100

Setting

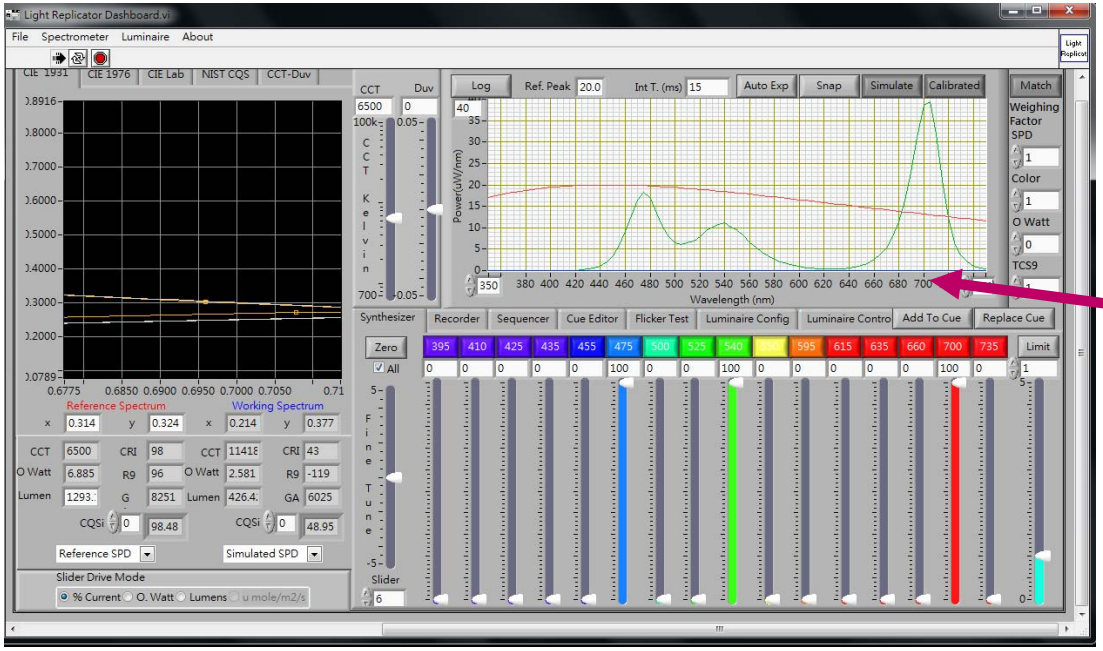
- Telelumen Light Replicator



Input values in 500nm:100

Setting

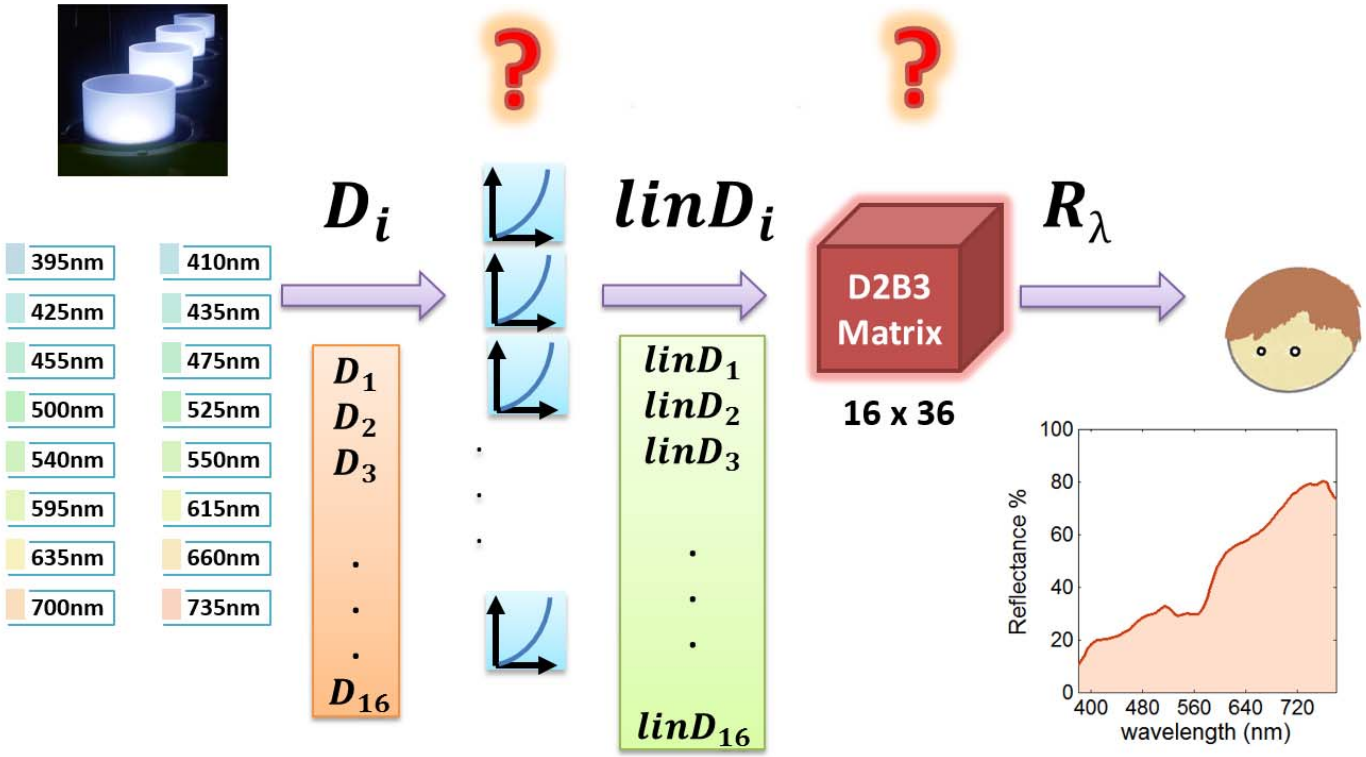
- Telelumen Light Replicator



simulate RGB LED

Workflow

D2B3 conversion



Workflow

- Correct the input values
  - Downscale the input values when the total power exceed the limit of the LED system.
  - To perform tone linearization.
- Derive the color mixing matrix

iccMAX Implementation: D2B3 profile

```
<Header>
    <PreferredCMMType></PreferredCMMType>
    <ProfileVersion>5.00</ProfileVersion>
    <!-- Input Device profile -->
    <ProfileDeviceClass>scnr</ProfileDeviceClass>
    <!-- 16channel profile -->
    <DataColourSpace>nc0010</DataColourSpace>
```

- Input Device Profile (scnr)
- 16 Channel Data Color Space (nc0010)
- D2B3: a forward transform from device space (denoted as D) to SpectralPCS (denoted as B), '3' represents ICC Absolute Colorimetric intent.

iccMAX Implementation

- Correct the input values
  - Depend on the mean input values

$$\begin{cases} S = 1 - 0.835 \cdot \left(\dfrac{\overline{D}_i - 0.5}{0.5} \right) \text{ when } \overline{D}_i > 0.5 \\ S = 1 \text{ when } \overline{D}_i \le 0.5 \end{cases}$$

```
<CalculatorElement InputChannels="16" OutputChannels="36">
<SubElements>
<!--Element 0 -->
        <CalculatorElement InputChannels="16" OutputChannels="17">
            <MainFunction>{ in(0,16) copy(16) tput(0,16)
              sum(16) 16 div tput(16,1)
              tget(16,1) 0.5 gt
                if{tget(16,1) 0.5 sub 0.835 mul 0.5 div -1 mul 1 add}
                else {1}
              tput(16,1)
              tget(0,17)
            out(0,17) }</MainFunction>
        </CalculatorElement>
    <!--Element 1 -->
```

iccMAX Implementation

Tone curve estimation

- To perform tone linearization.
  - Use **Calculator Elements** to apply gamma, gain and offset to the input signals.
  - SegmentedCurve is recommended.
  - **FormulaSegment**: uses predetermined parameters

iccMAX Implementation

Tone curve estimation

- D_i: the input camera signal
- $linD_i$: the linearized camera signal
- γ, a, b, c, d: parameters of the tone function

- FormulaSegment : iccMAX provides 4 function types

$$linD_i = (a \cdot D_i + b)^{\gamma} + c \quad (1)$$

$$linD_i = a \cdot \log\left(b \cdot D_i^{\gamma} + c\right) + d \quad (2)$$

$$linD_i = a \cdot b^{c \cdot D_i + d} + e \quad (3)$$

$$linD_i = a \cdot \left(b \cdot D_i + c\right)^{\gamma} + d \quad (4)$$

iccMAX Implementation

Tone curve estimation

- Three FormulaSegments to construct a SegmentedCurve.

```
<SegmentedCurve>
    <FormulaSegment Start="-inf" End="0.0" FunctionType="0">1.0 0.0 0.0 0.0
    </FormulaSegment>
    <FormulaSegment Start="0" End="1.0" FunctionType="0"> γ a b c
    </FormulaSegment>
    <FormulaSegment Start="1.0" End="+inf" FunctionType="0">1.0 0.0 0.0 1.0
    </FormulaSegment>
</SegmentedCurve>
```

Tone curve estimation

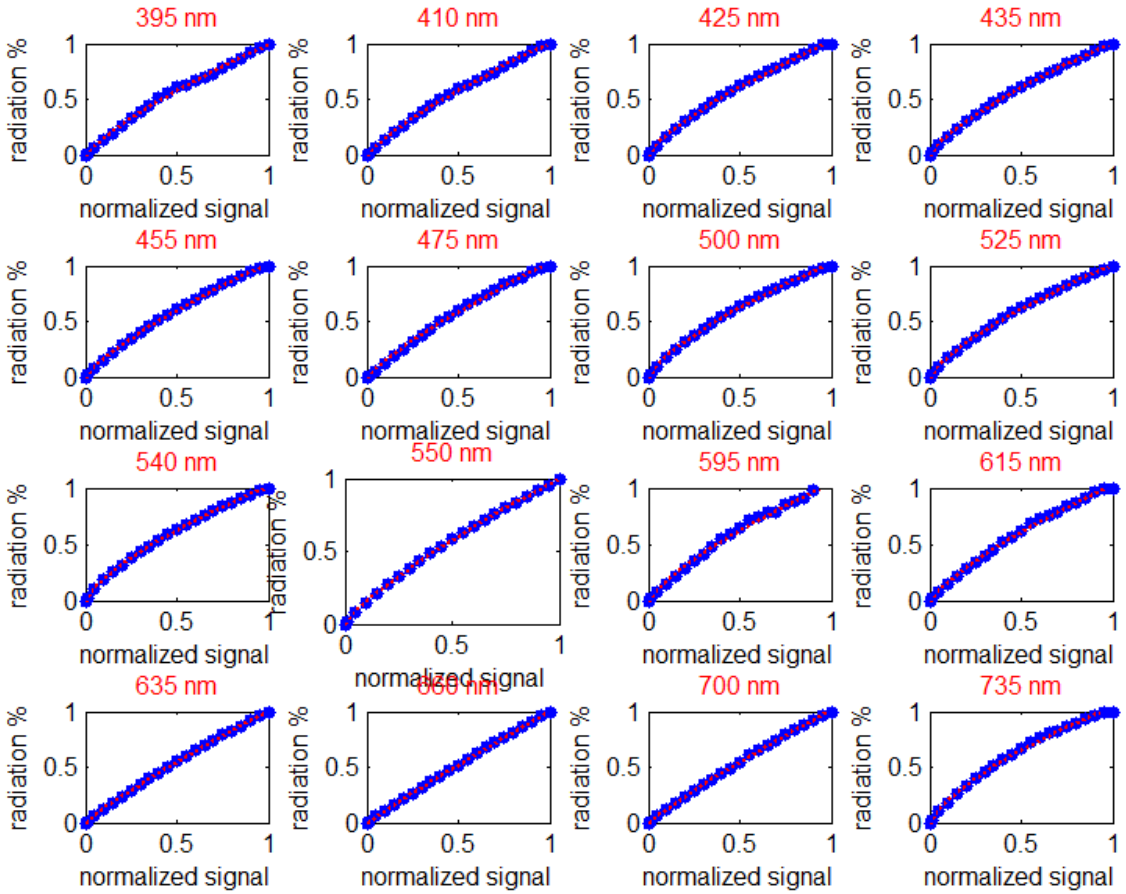
$$linD_i = (a \cdot D_i + b)^{\gamma} + c$$

- Estimating the parameters of the Equation 1

  - linDi = Ri / Rmax,i
- Apply least squared curve fitting using a Matlab function (lsqcurvefit).
- using 4 parameters for Equation would cause overfitting.
- adding a constraint (b= 0) in the curve fitting.

	gamma	a	c
395	0.76	1.02	-0.02
410	0.78	1.04	-0.02
425	0.72	1.07	-0.02
435	0.73	1.04	-0.02
455	0.75	1.06	-0.02
475	0.79	1.08	-0.03
500	0.69	1.07	-0.02
525	0.71	1.05	-0.02
540	0.69	1.05	-0.02
550	0.78	1.02	-0.01
595	0.72	1.11	-0.03
615	0.75	1.08	-0.02
635	0.88	1.02	-0.01
660	0.95	1.01	0.00
700	0.89	1.03	-0.01
735	0.65	1.12	-0.03
mean	0.77	1.05	-0.02

$$linD_i = (a \cdot D_i + b)^{\gamma} + c$$



- **Blue spots:** radiance of the 16 channels.
- **Red lines:** add a constraint (b= 0)

iccMAX Implementation

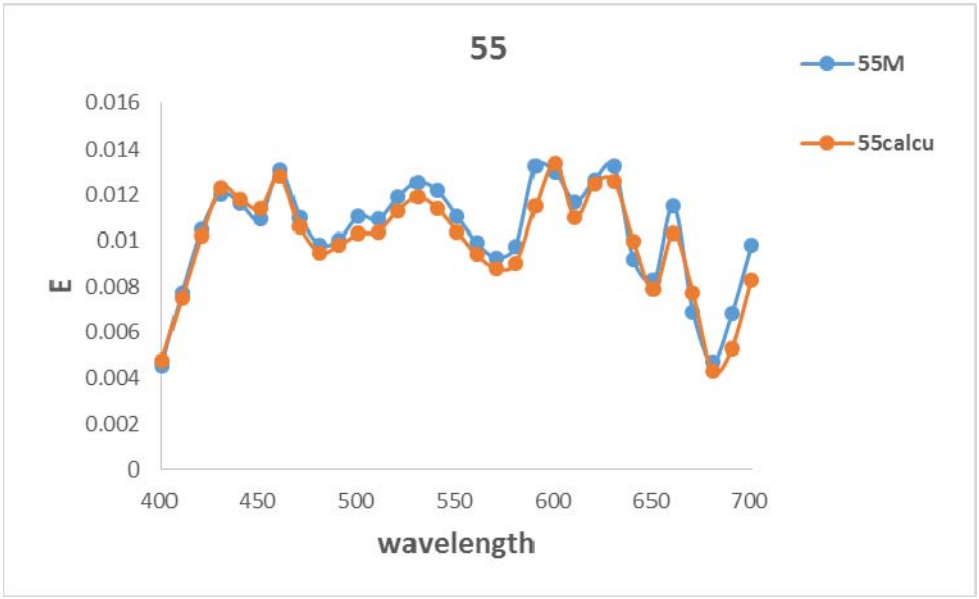
- MSLS-to-SpectralPCS
  - ICC provides tools, named RefIccMAX, for users to generate and apply binary iccMAX profiles by way of text XML data.
  - generated a set of iccMAX profile based on MultiProcessElements using 3 SubElements:CalculatorElement, CurveSetElement and MatrixElement.

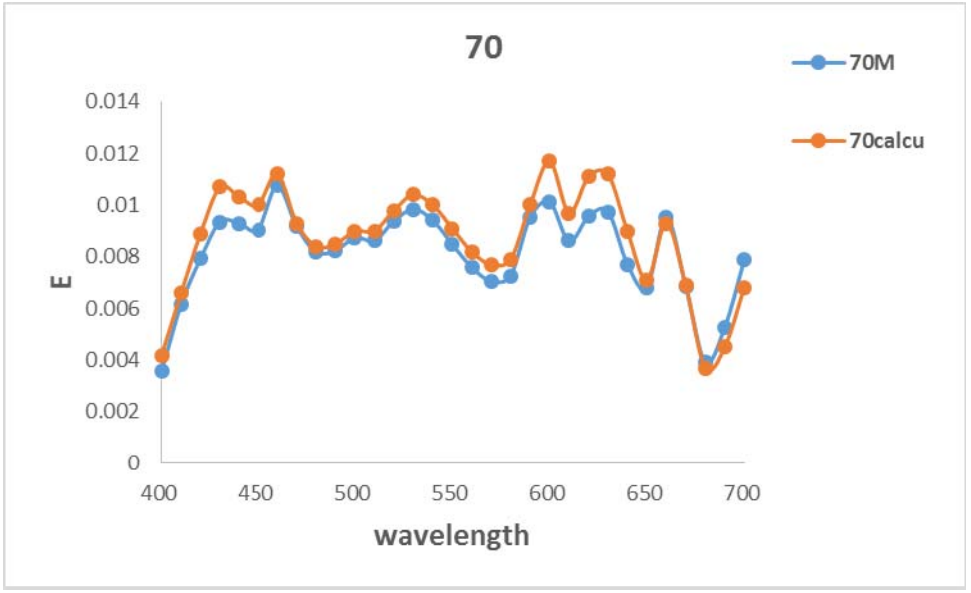
iccMAX Implementation

- MSLS-to-SpectralPCS

```
<multiProcessElementType>
    <TagSignature>D2B3</TagSignature>
    <MultiProcessElements InputChannels="16" OutputChannels="36">
        <CalculatorElement InputChannels="16" OutputChannels="36">
        <SubElements>
        <!--Element 0 -->
                <CalculatorElement InputChannels="16" OutputChannels="17">
              <!--Element 1 -->
                <CurveSetElement InputChannels="16" OutputChannels="16"> <!-- curv[0] -->
              <!--Element 2 -->
                <MatrixElement InputChannels="16" OutputChannels="36">  <!-- mtx[1] -->
            </SubElements>
            <MainFunction> {
            in(0,16)
            calc(0)
            copy(1,36) tput(0,36)
            curv(1) mtx(2) tget(0,36) mul(36)
            out(0,36) }
            </MainFunction>
        </CalculatorElement>
    </MultiProcessElements>
```

Result

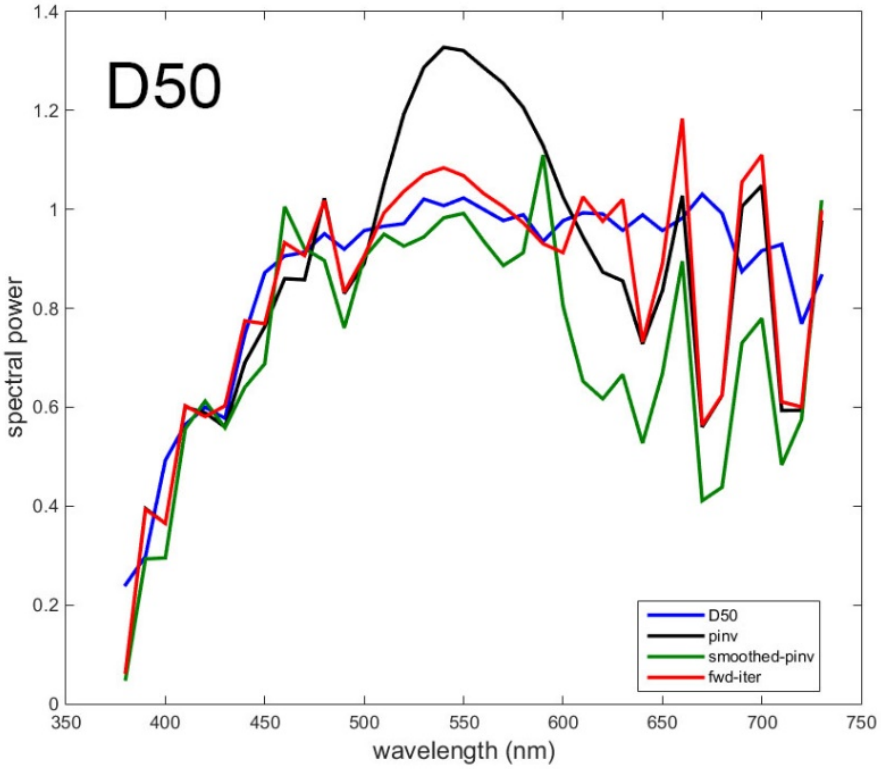

55
55M
55calcu
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
E
400
450
500
550
600
650
700
wavelength

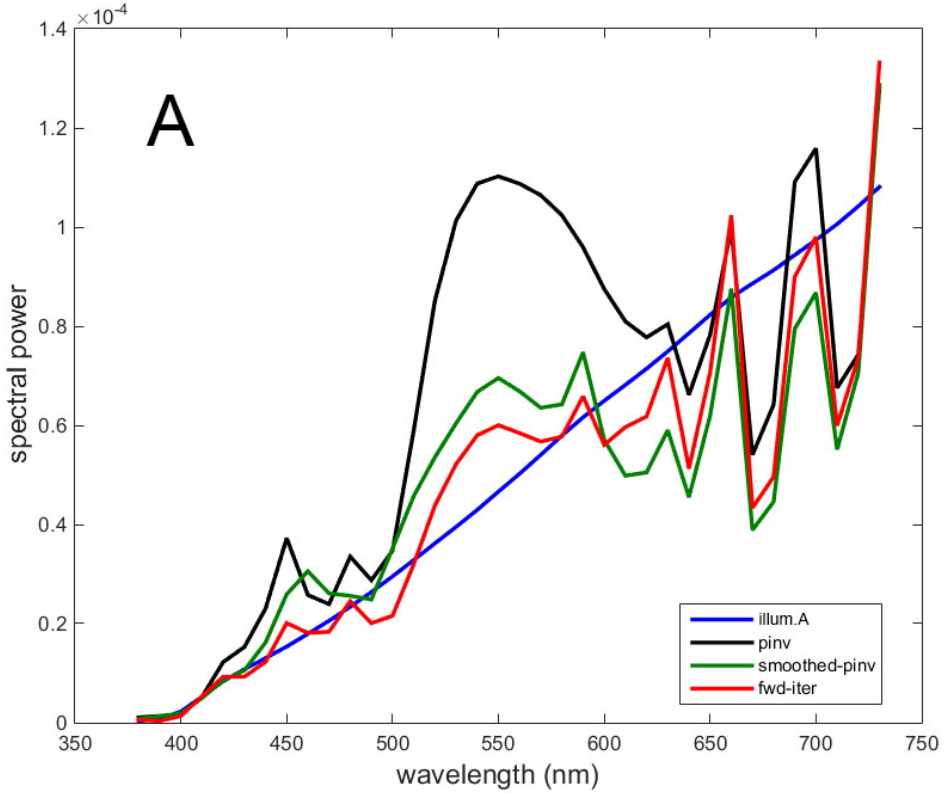

70
70M
70calcu
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
E
400
450
500
550
600
650
700
wavelength

LED Spectral fitting

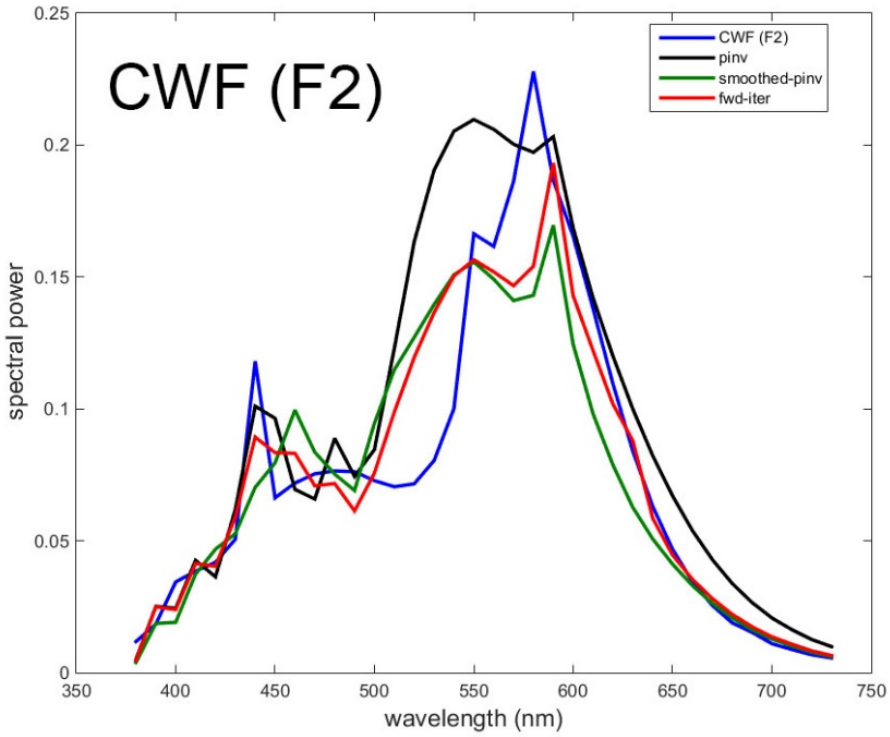
- Use the MSLS to reproduce certain light spectrum.
- Apply B2D3 rendering (inverse model) using iccMAX.
- Pseudo-inverse matrix would result in significant vibrations in the inversed signal prediction.
- Solution
  - Using the inverse signals as initial inputs. Fine-tune the inputs iteratively to minimize the spectral errors use its forward model.
  - Divide the spectrum into several zones to reduce computation cost.
- Broadband light source are more accurate in the light spectrum reproduction.

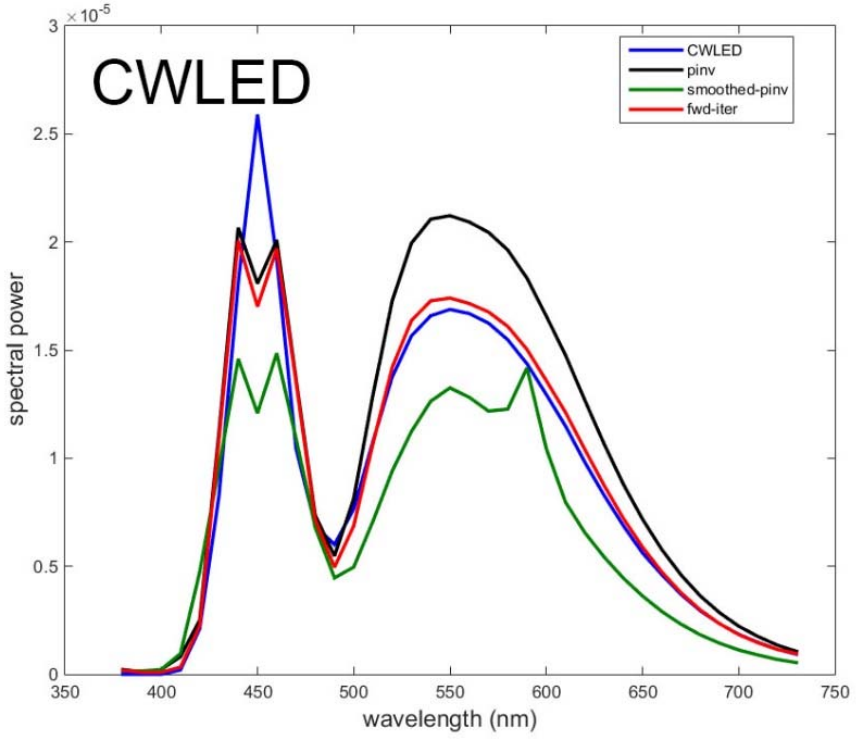
LED Spectral fitting





LED Spectral fitting





Color tuning using the multispectral lighting system

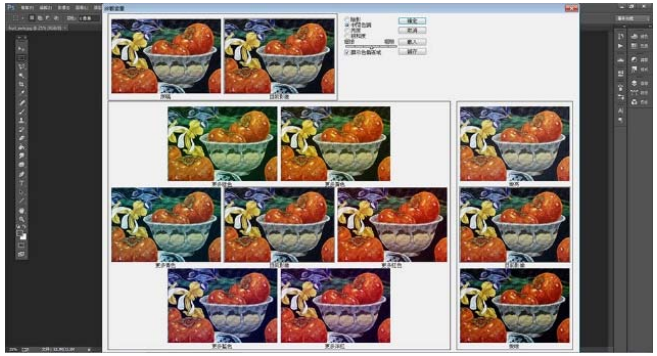
- Experiment design
- Test images
- Multispectral image acquisition
- Optimization – Workflow
- Results

Reference targets

Oli Painting

Watercolor Painting

Color manipulation using Photoshop



Printed by an Inkjet printer

Epson T1100

MSC image acquisition

Paper

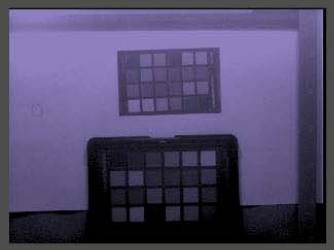
Multispectral Camera

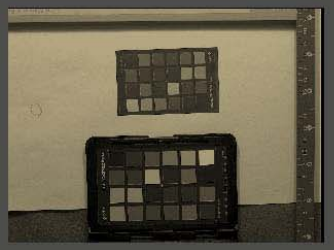
- A filter-based MSC.
- 8-band capturing under illuminant A.
- Apply iccMax profile D2B3 spectral rendering.
- Our related publication

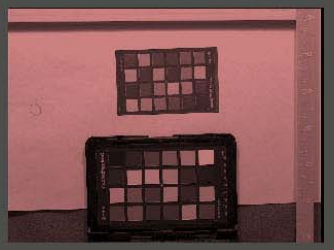
Optimizing color accuracy of a filter-based multispectral camera via iccMAX framework for digital achieves, Electronic Imaging 2016, Color-313

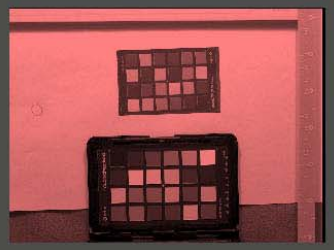
Pixelteq
SpectroCam VIS-NIR

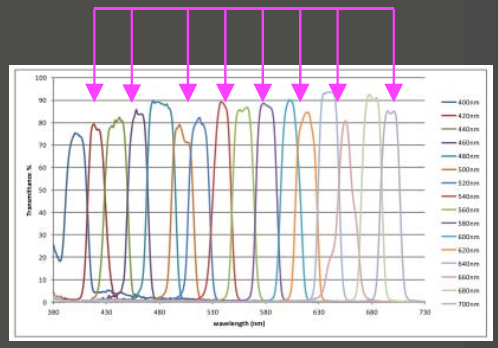
8-band capturing









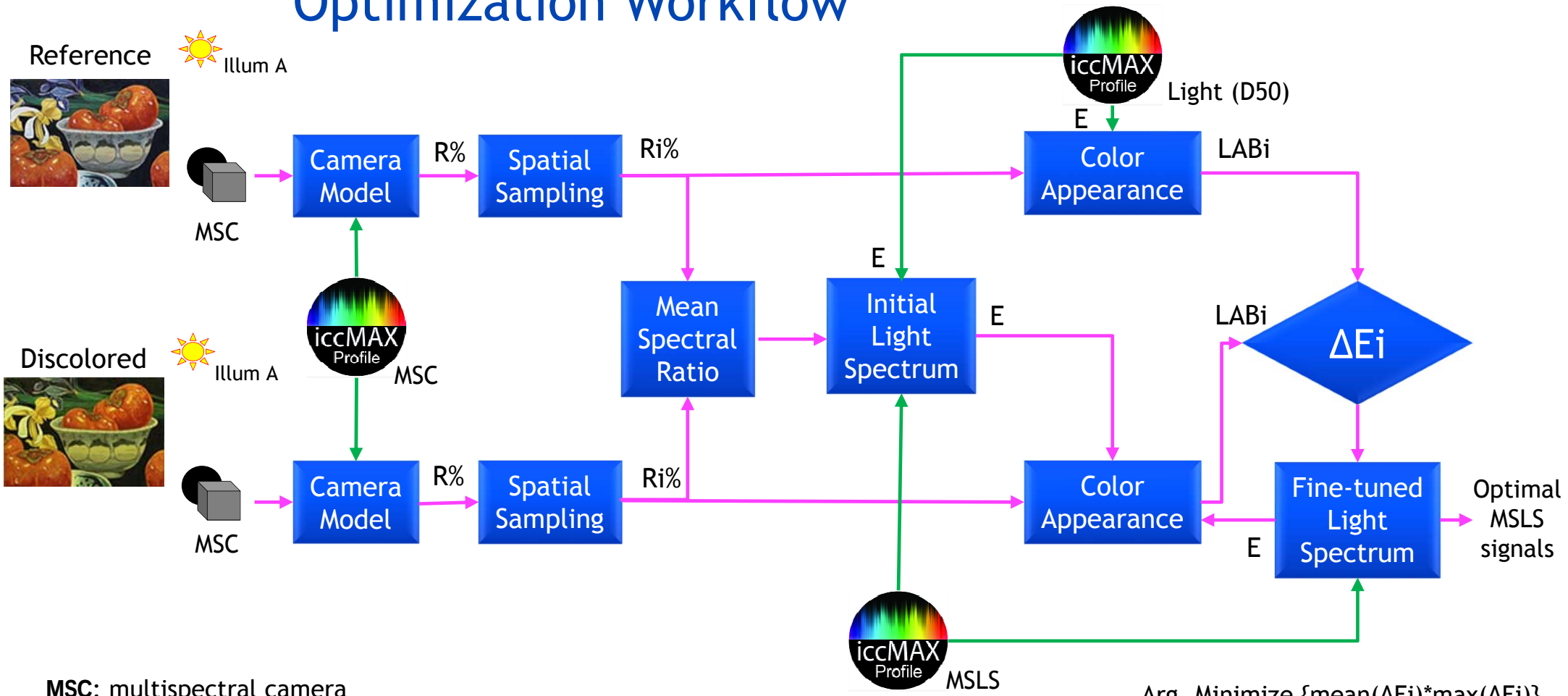


Color tuning using the multispectral lighting system

1. Measure reference image and discolored test images by the MSC under illuminant A.
2. Spatial sampling: apply mean filter and skip high variation areas.
3. Calculate spectral reflectances of paired samples from the spectral images.
4. Determine initial LED input signals based on the spectral estimation. D50 is the reference illuminant.
5. Optimize the input signals by an iterative approach.

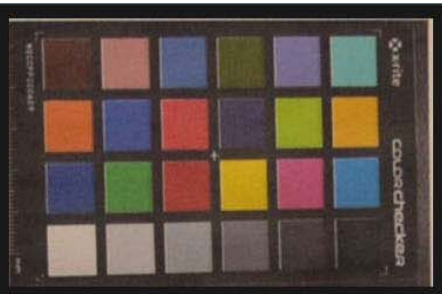
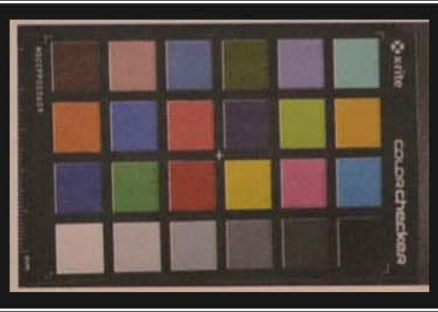
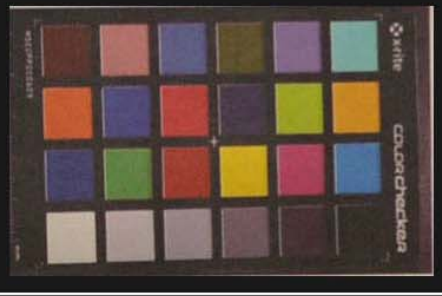
- The camera and the LED system can be characterized spectrally by iccMax.

Optimization Workflow

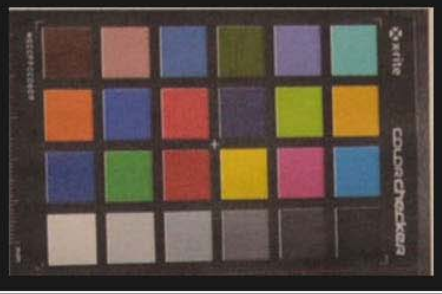
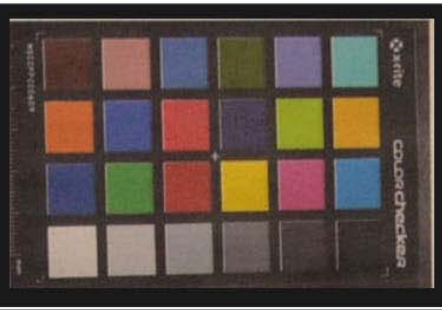
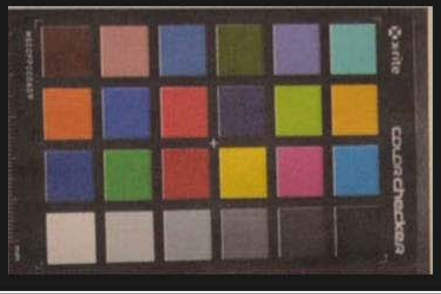
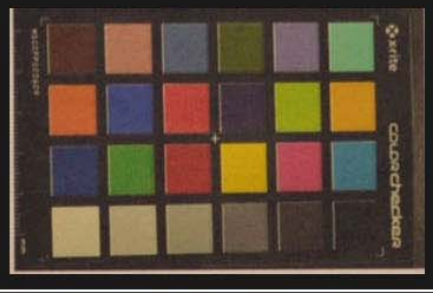
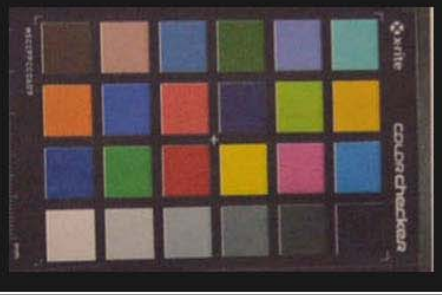
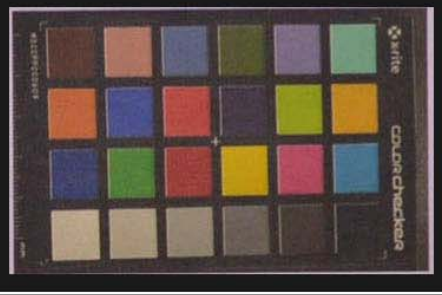
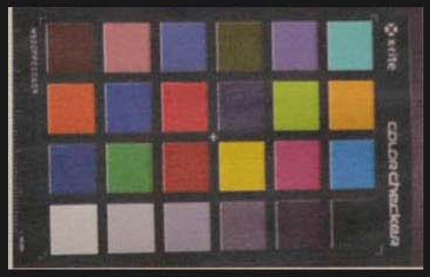


MSC: multispectral camera
MSLS: multispectral lighting system

RESULTS

	Case 1	Case 2	Case 3
Reference			
Discolored			
Light Corrected			

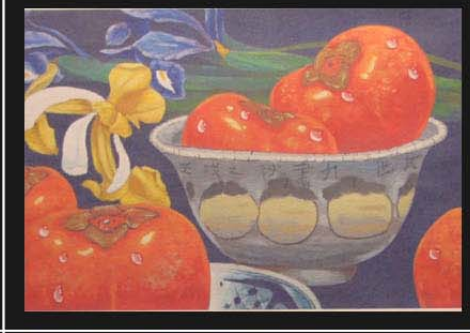
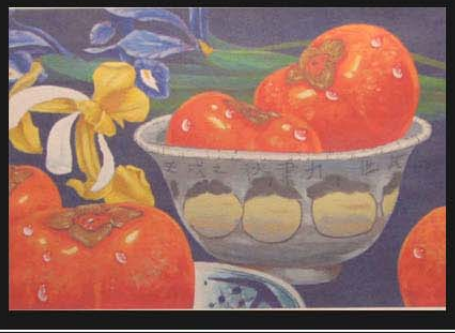
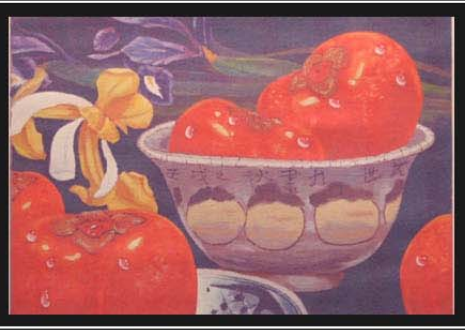
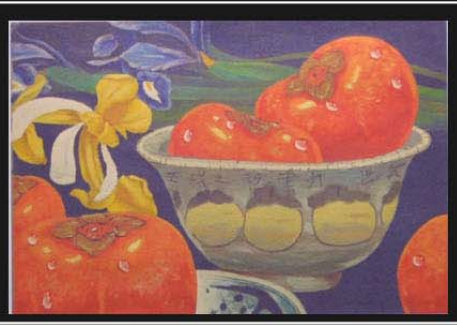
RESULTS

	Case 4	Case 5	Case 6
Reference			
Discolored			
Light Corrected			

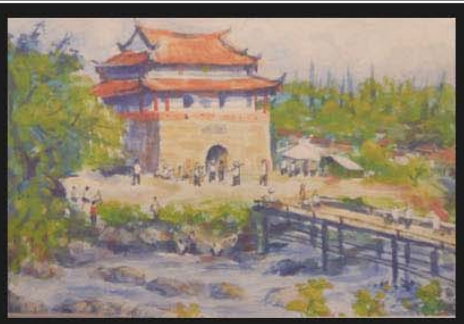
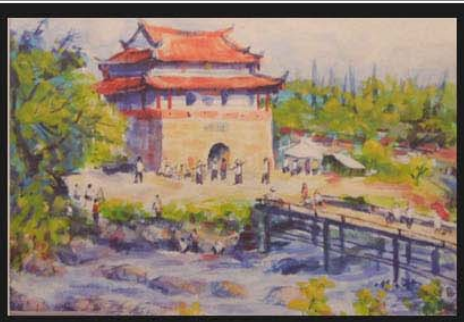
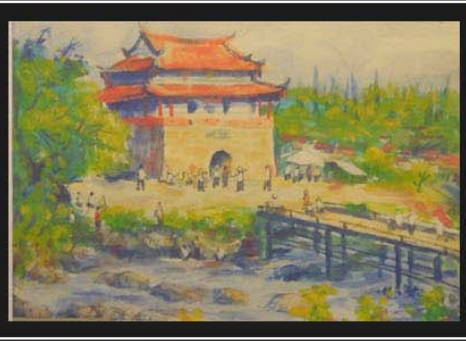
RESULTS

	Case 1	Case 2	Case 3
Reference			
Discolored			
Light Corrected			

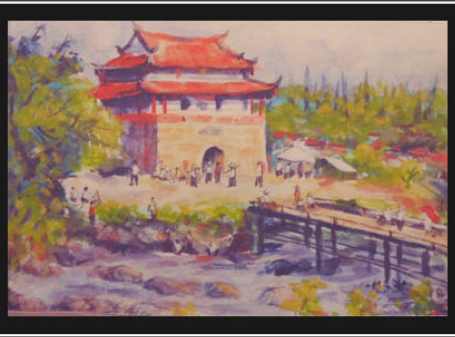
RESULTS

	Case 4	Case 5	Case 6
Reference			
Discolored			
Light Corrected			

RESULTS

	Case 1	Case 2	Case 3
Reference			
Discolored			
Light Corrected			

RESULTS

	Case 4	Case 5	Case 6
Reference			
Discolored			
Light Corrected			

Conclusions

- A LED-based color-tuning system has be successfully developed for improving color accuracy of discolored prints (paintings). iccMax profiles are used for MSC characterization, MSLS characterization, and spectral calculation.
- Mean and Max. color differences reduced 36% and 40% respectively in 6 cases. However, the errors cannot be reduced in some cases (e.g., contrast reduction, blanching…).

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THANK YOU!

Pei-Li Sun
plsun@mail.ntust.edu.tw
Wei Chun Hung
m10325009@mail.ntust.edu.tw