

High Dynamic Range Display Calibration

EE362 Project
2006 Winter Quarter

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Introduction

- The world's first High Dynamic Range (HDR) display is introduced by BrightSide Technology.
- Since the first model is available in this project, I would like to explore how such a high dynamic range rendering is achieved.
- As a first step, I tried calibrate the this novel HDR display. No one have calibrated this HRD in the lab. Thus this is the first calibration .

Object

- Calibrating the HDR display
 - Gamma
 - Gamut

Those are two of major factors to define display characteristics.

- Through this project, gain a better understanding of a display technology

Background: BrightSide's HDR display technology

- LCD displays filter light coming from a backlight, which consists of fluorescent tubes behind the LCD glass.
- This backlight is replaced by white light emitting diodes (LEDs).

Background: BrightSide's HDR display

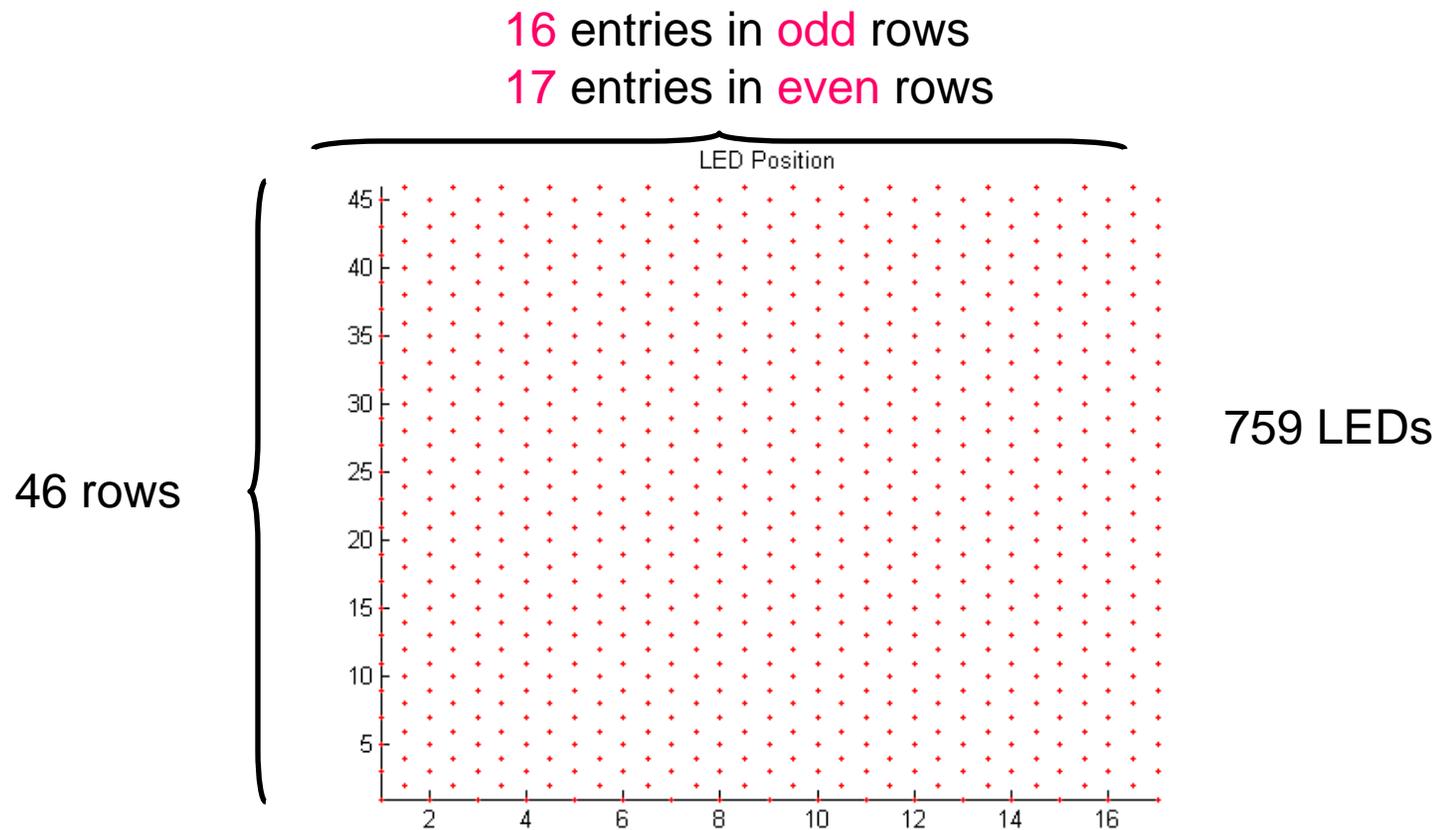
- The LCDs
 - Resolution 1280 X 1024
 - Dynamic range 500:1 (Spec)
 - 18.1 L.G. Philips LCD flat panel

Background: BrightSide's HDR display

- The LEDs
 - 759 LEDs arranged in hexagonal matrix
 - Each LEDs individually controlled.
 - Intensity 7 to 8 bit. (Maximum 150)
 - 8,500 cd/m² at maximum and zero at minimum.
 - 12mm Lumiled Luxeon 1 Watt white LEDs (LXHL-PWO1)

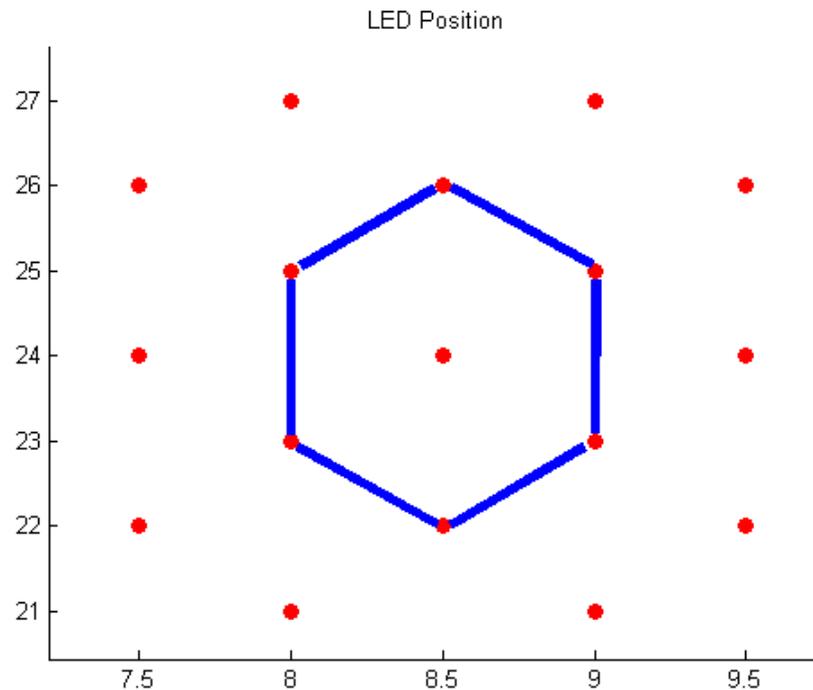
Background: BrightSide's HDR display

- The LEDs Array



Background: BrightSide's HDR display

- The LEDs Arrangement on **hexagonal matrix**



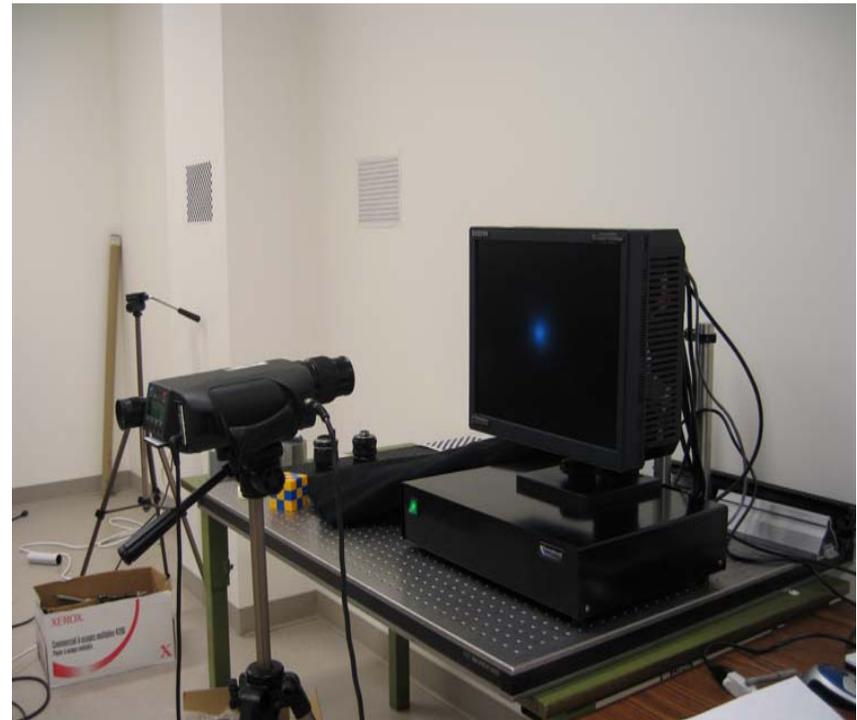
Background: BrightSide's HDR display

- Each LED backlights a small region of the LCD panel.
- The luminance of this display is provided by multiplying the modulation of the LCD and the LEDs. This is the key technology to accomplishing high dynamic range.

(<http://www.brightsidetech.com/tech/bstech.php>)

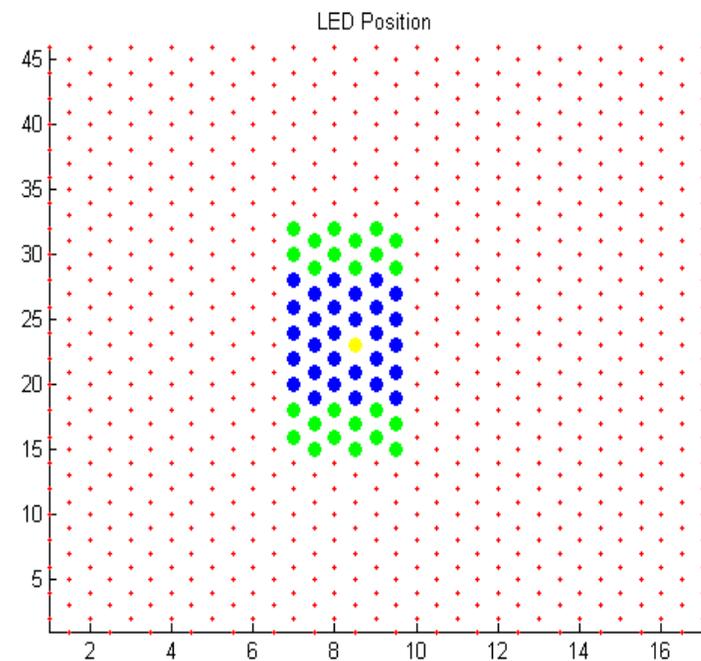
Method for measuring Gamma

- Equipment:
SpectraScan PR650
- Auto measurement
by Matlab program
- Environment: dark
room



Method for measuring Gamma

- Illuminated LEDs
 - 3x9 LEDs ● ● ●
 - 3x5 LEDs ●
 - The single LED ●
- Why ?
 - All LEDs on caused flickers due to the shortage of power supply
 - Each LED's emitting region overlaps each other so the luminance changes in respect to the number LEDs illuminated



Method for measuring Gamma

- Stimulus Level

- LCD levels: 16 to 255 16 intervals 16 points

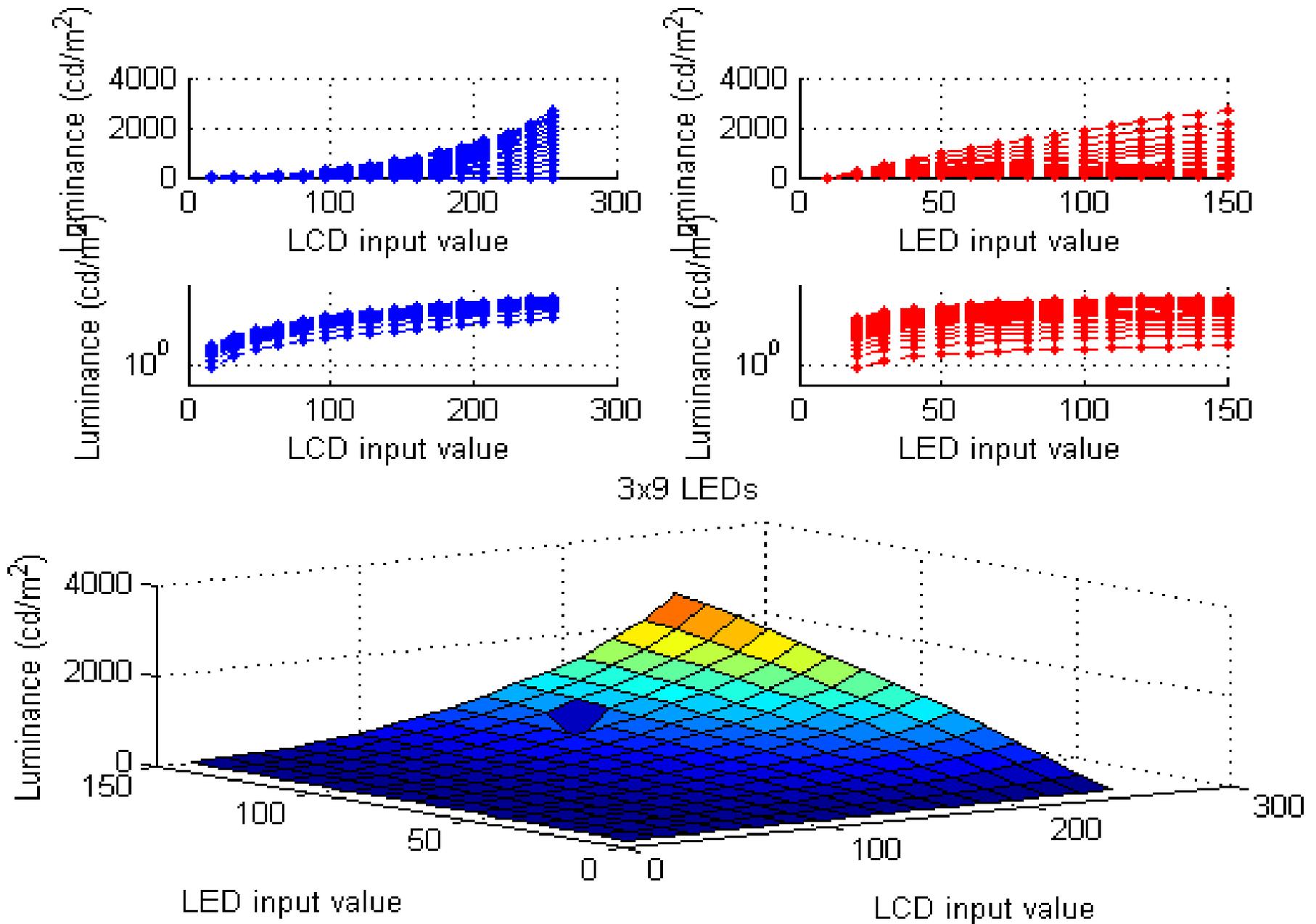
16	32	48	64	80	96	112	128	144	160	176	192	208	224	240	255
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- LED levels: 10 to 150 (max) 10 intervals 15 points

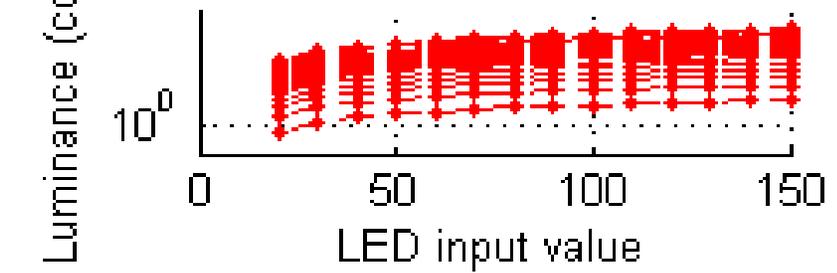
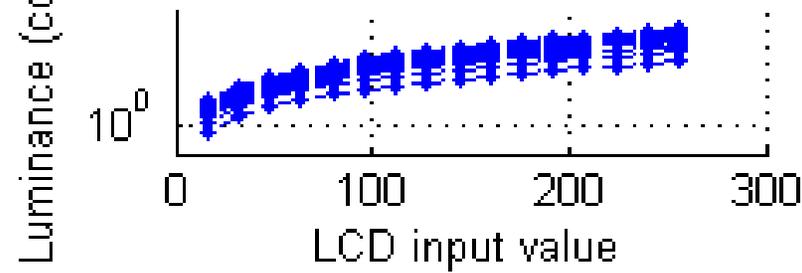
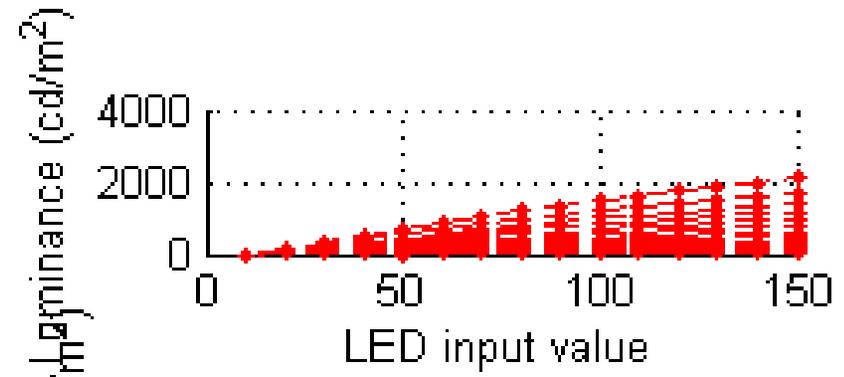
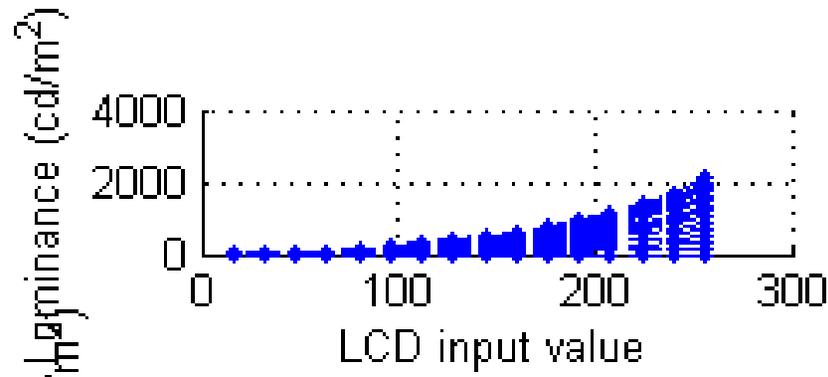
10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
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- Combination of each LCD and LED level **240 points**
- Stimulus order is **randomized** to avoid the influence of sequence of regular luminance change

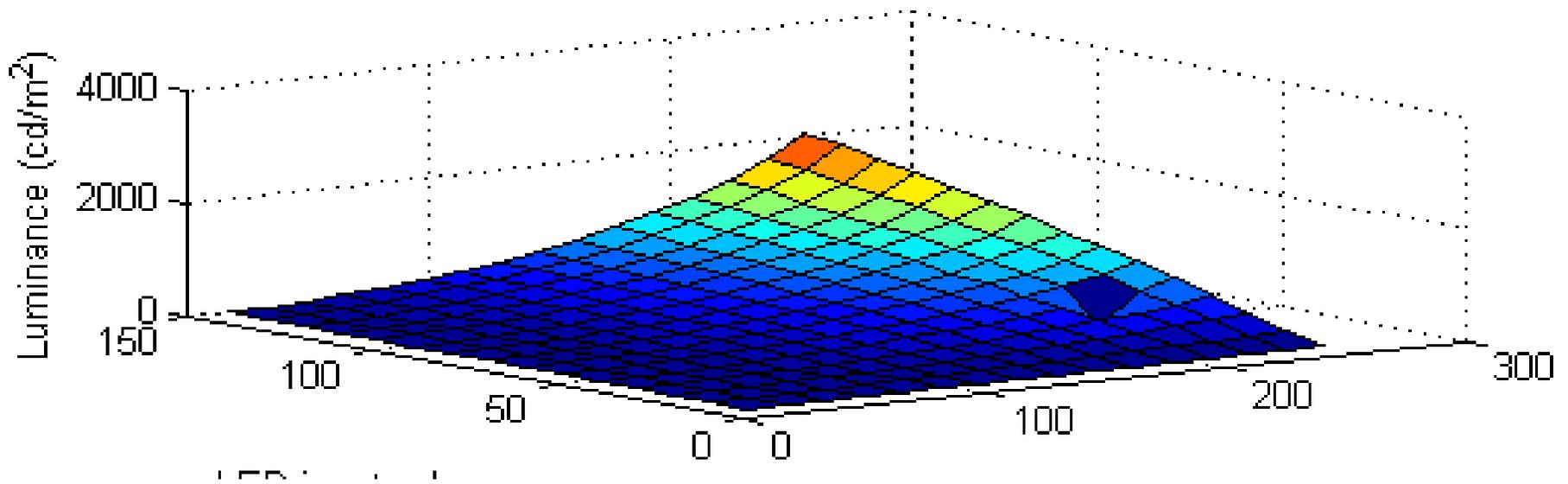
Result: 3x9 LEDs measurement



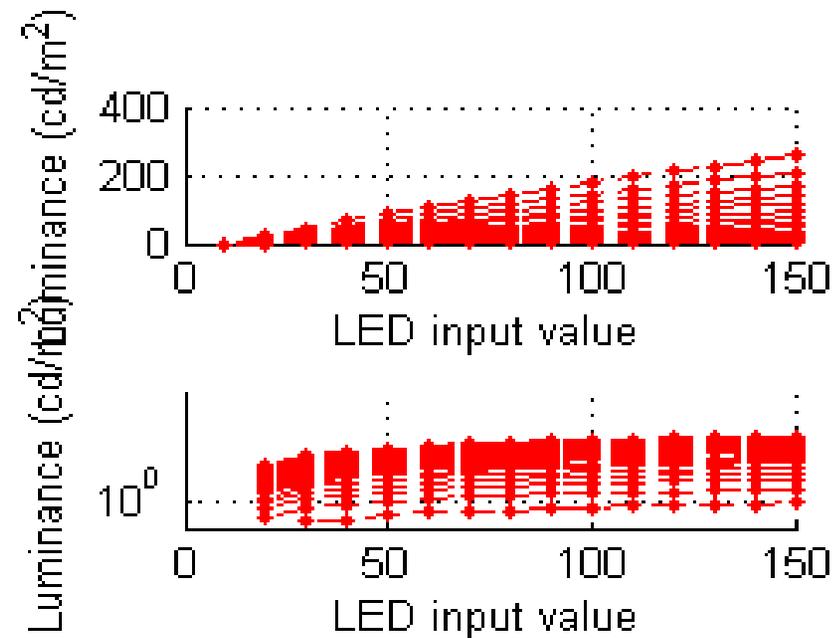
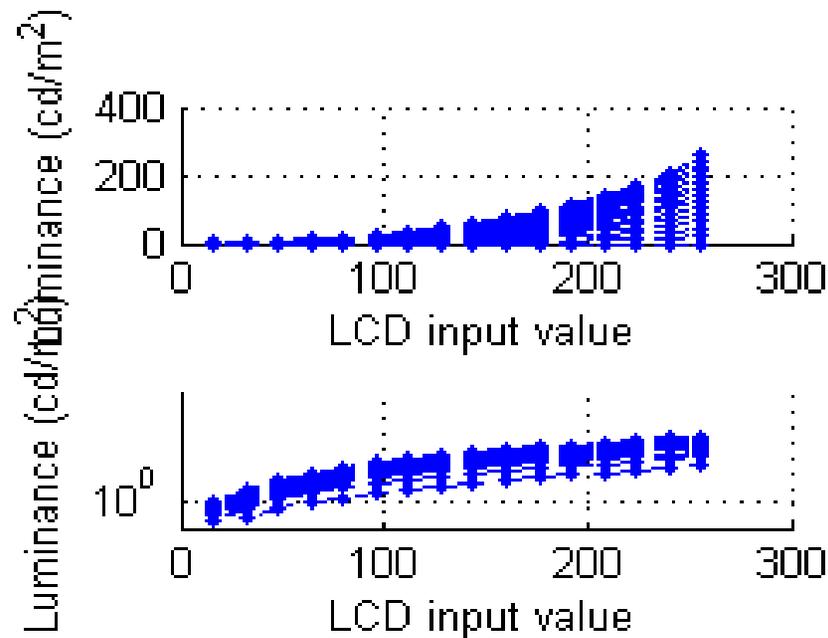
Result: 3x5 LEDs measurement



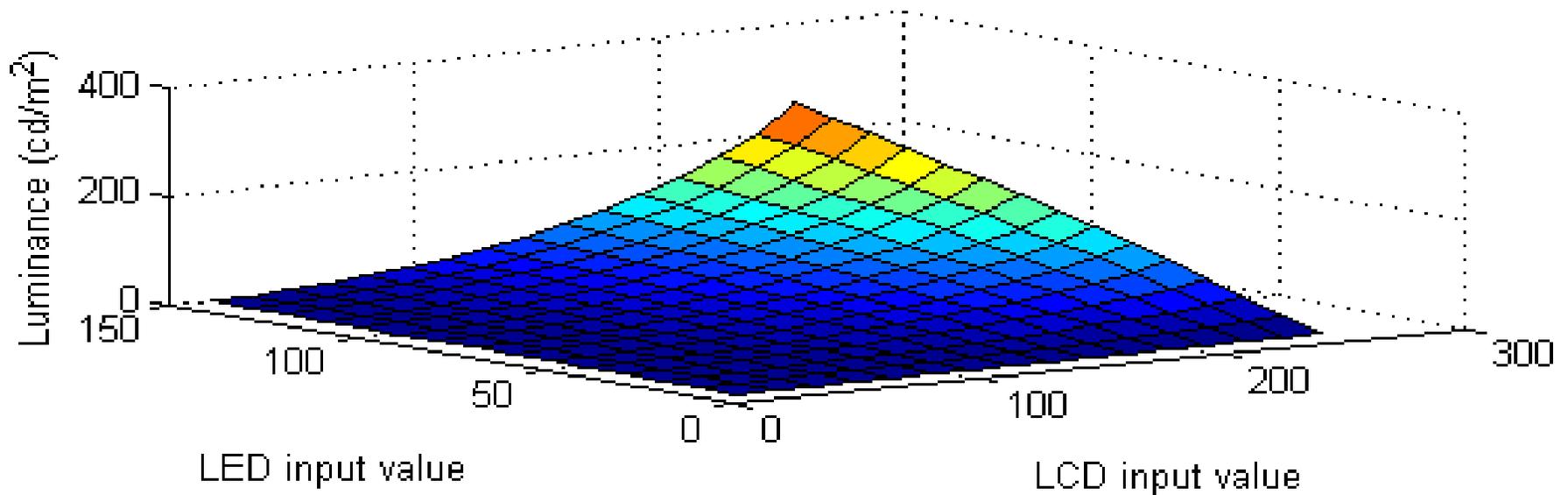
3x5 LEDs



Result: The single LEDs measurements



The single LEDs

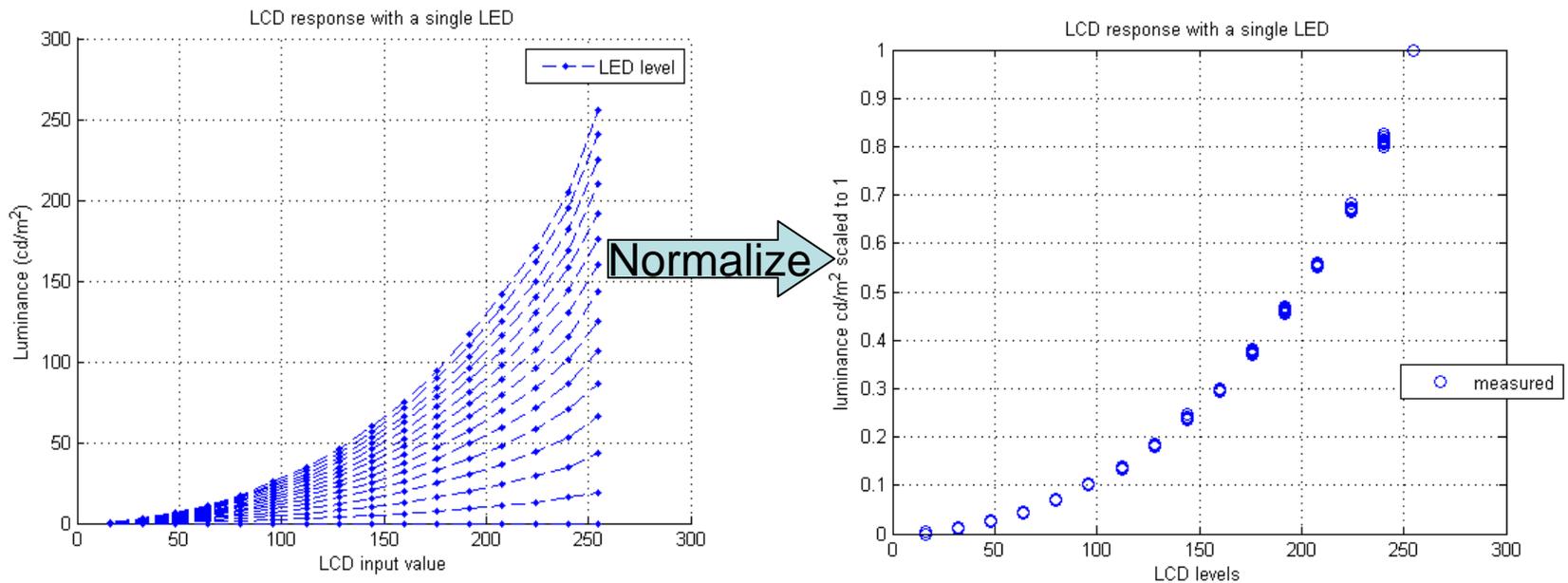


Measurement Result (Gamma)

The number of LEDs	The maximum Luminance
3x9	2700 cd/m ²
3x5	2100 cd/m ²
1	256 cd/m ²

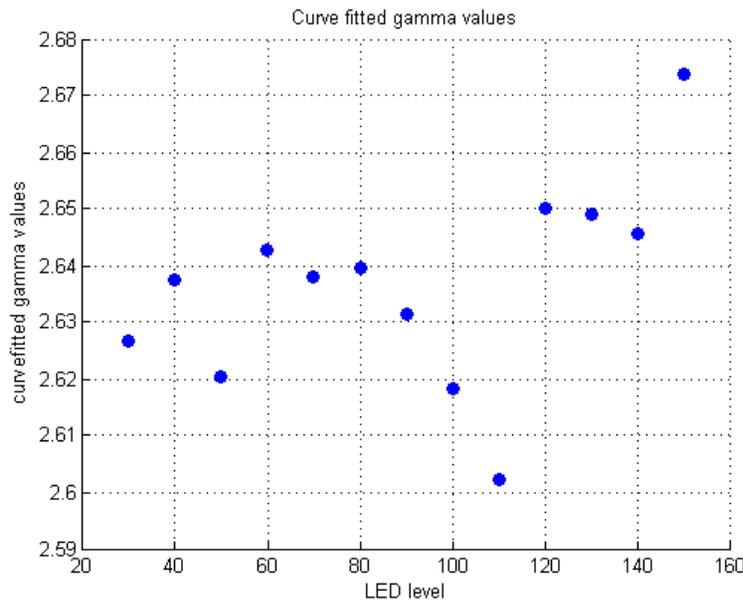
Measurements Analysis (LCD)

- Normalize the LCD responses at each LED level to 1. (single LED)



Measurements Analysis (LCD)

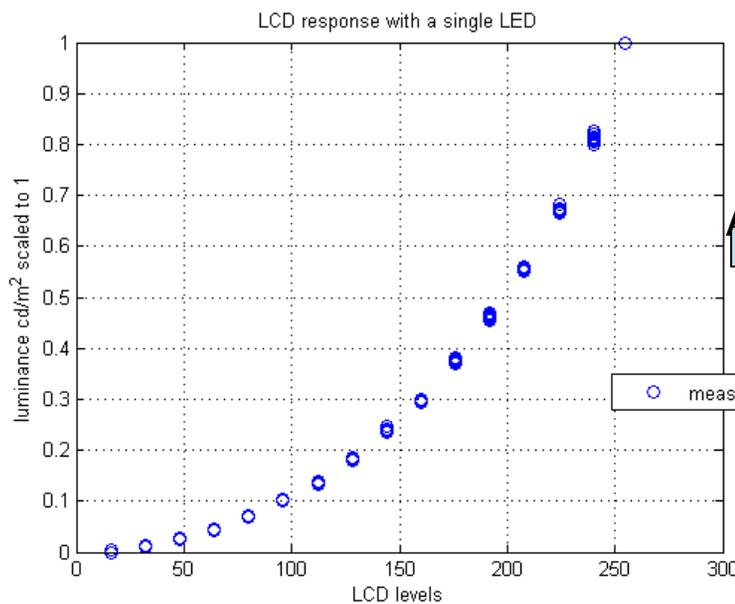
- Approximate a gamma value
 - *lsqcurvefit –gamma* (matlab)
 - search a gamma value that fits with the measured data curve



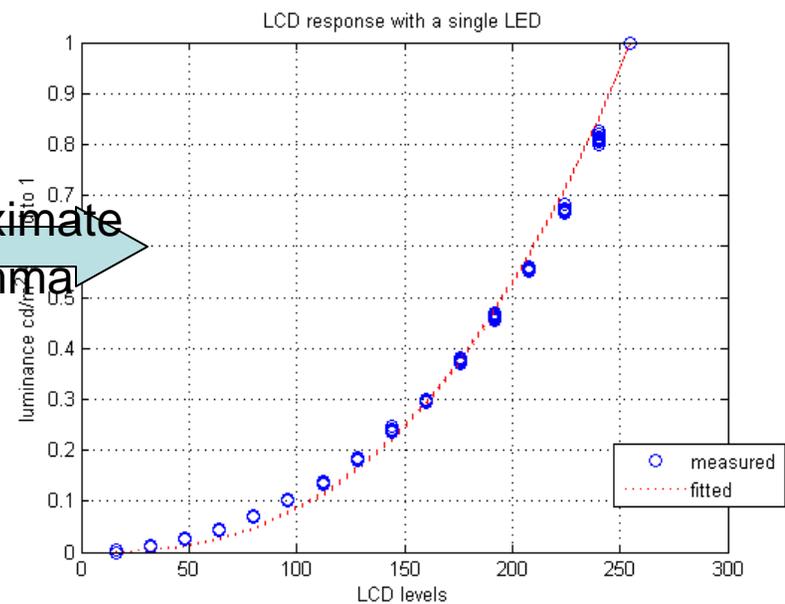
Gamma	LED level
2.596	20
2.6267	30
2.6375	40
2.6203	50
2.6428	60
2.6381	70
2.6396	80
2.6315	90
2.6183	100
2.6021	110
2.6501	120
2.649	130
2.6457	140
2.6738	150
2.6637	mean

Measurements Analysis (LCD)

- Approximate a gamma value
 - Mean Gamma = 2.663

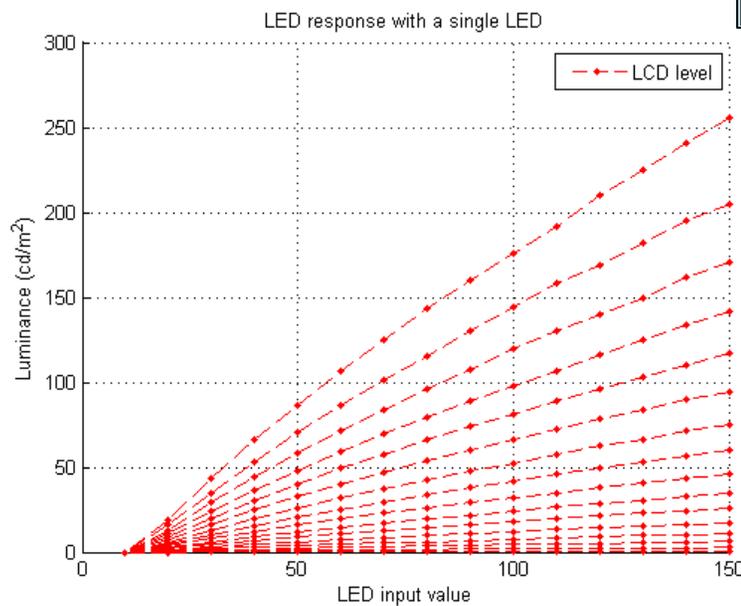


Approximate
Gamma

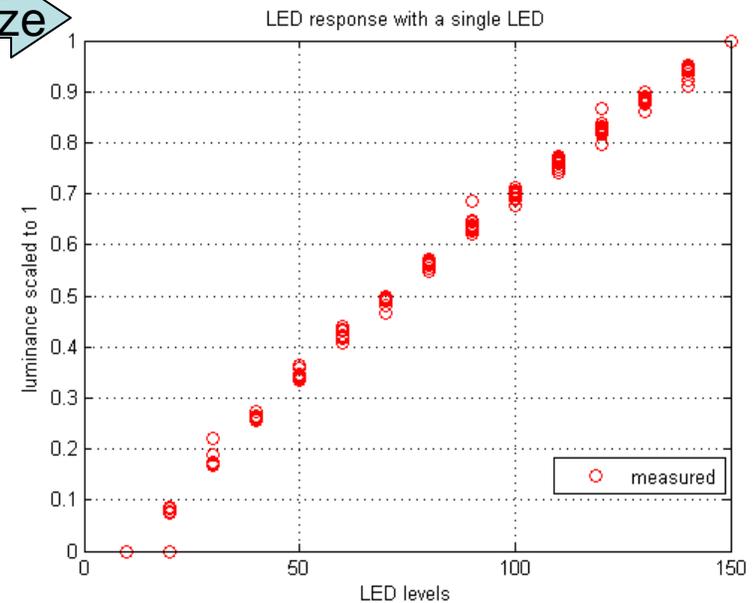


Measurements Analysis (LED)

- Normalize the LED responses at each LCD levels to 1. (single LED)

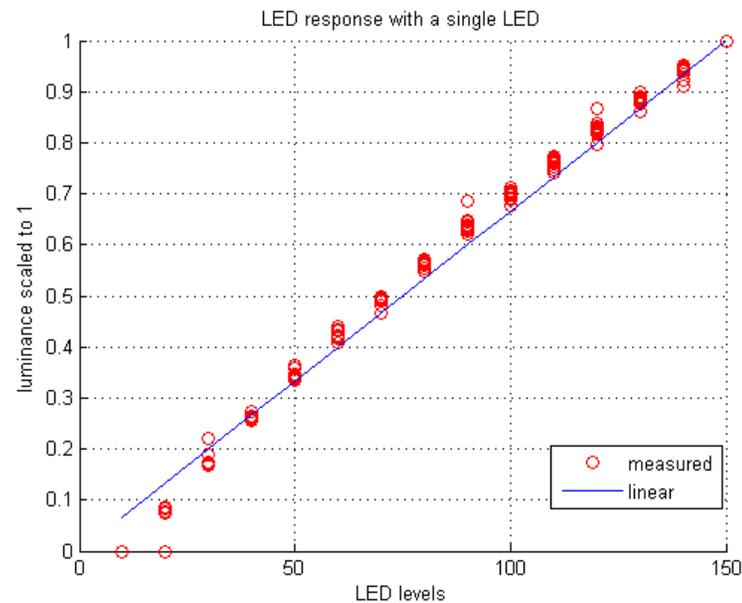


Normalize



Measurements Analysis (LED)

- Normalize the LED responses is almost linear



Measurements Analysis (summary)

- The LCD response is about **gamma 2.66**
- The LED response is **linear**
- Luminance = LCD response * LED response

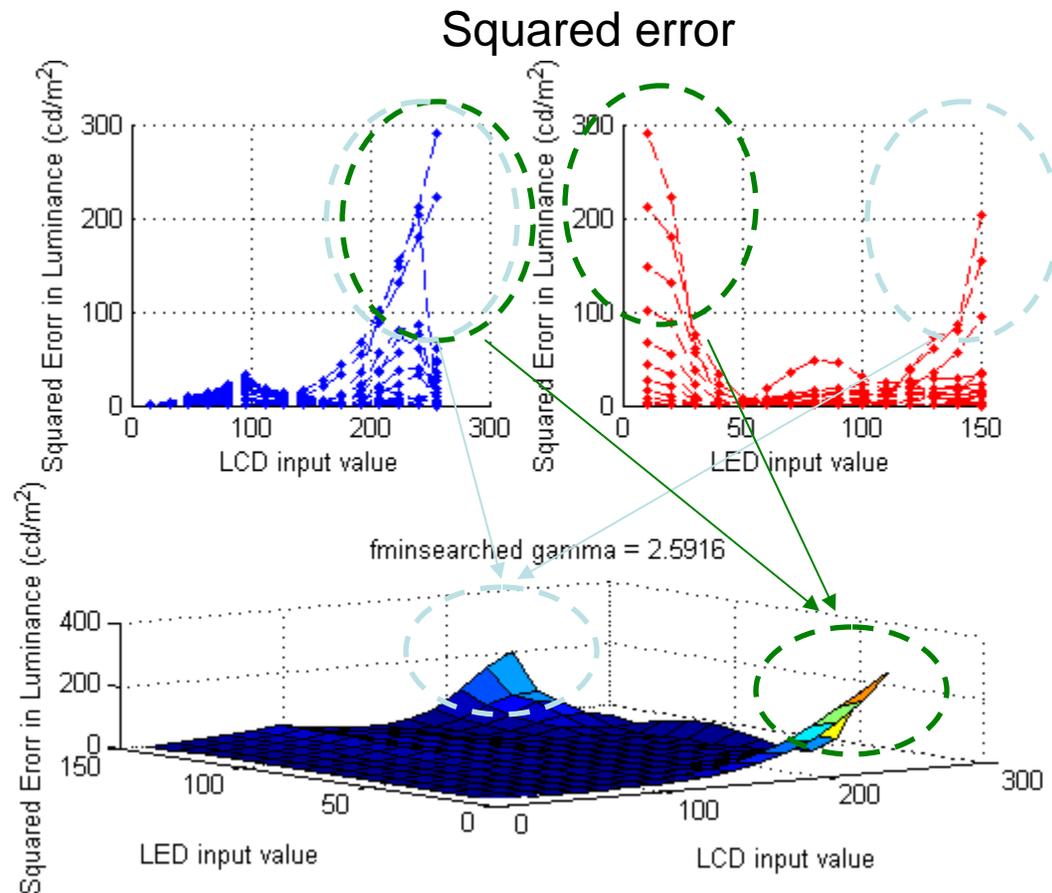
Modeling Luminance Response

- Luminance = LCD response * LED response
 - luminance =
 $\text{LCDintensity}^{\gamma} * \text{LEDintensity} * \text{maxLuminance};$
 - LCDintensity and LEDintensity are scaled to 1
 - gamma is only one free parameter in this model

Modeling Luminance Response

- Try optimize gamma values
 - *fminsearch* (matlab)
 - search a gamma values that minimizes the squared error between observation and estimation
 - Initial gamma is mean value : 2.6337
- Optimized gamma values : 2.5916

Analyzing Luminance Model



- High error at

- Low LED & High LCD

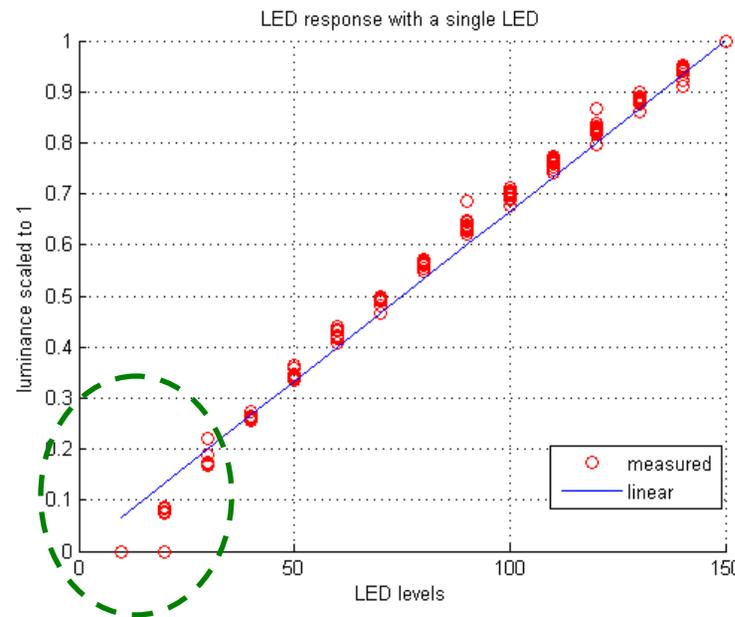
- High LED & High LCD

- MSE in cd/m^2

- 17.8445

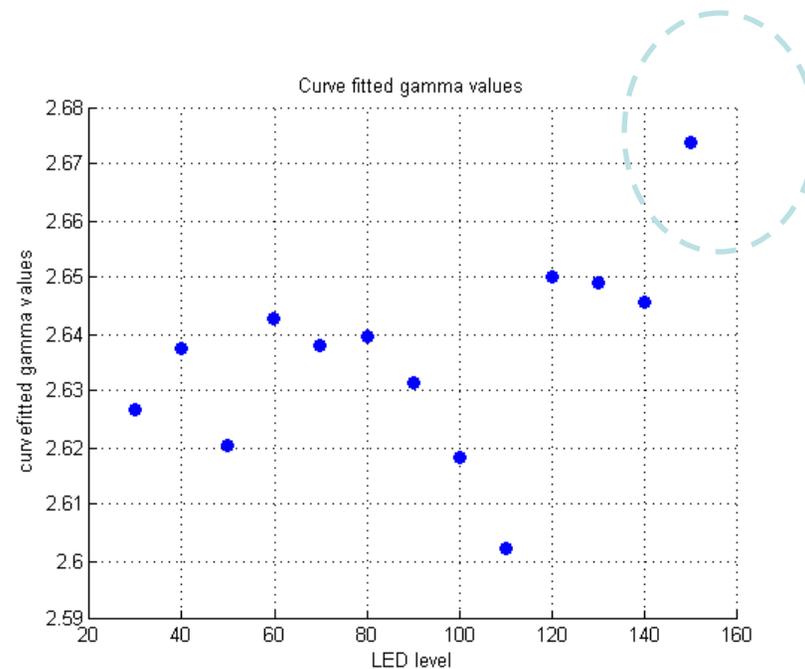
Result: Analyzing Luminance Model

- Squared error high at low level LED
 - LED level 10,20,30 do not come up lineally.



Result: Analyzing Luminance Model

- Squared error high at high level LCD
 - The optimized gamma value is 2.59 is most different from the gamma value 2.67 of the LCD level 150



Method for measuring Gamut

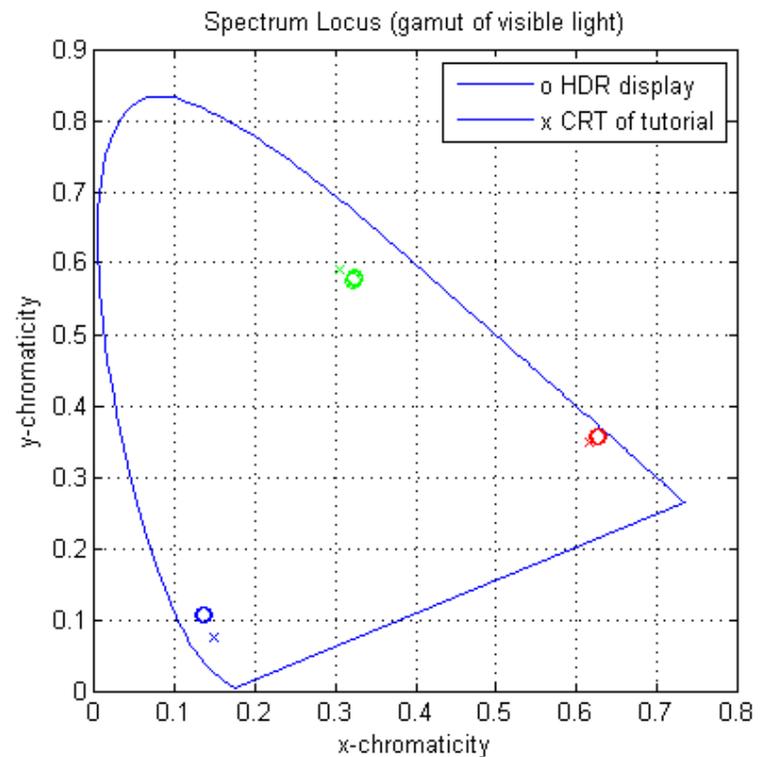
- Illuminated LEDs : 3 x 9
- LCD level : 255
- LED level : 50 to 150 25 intervals 6 points

50	75	100	125	150
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- Measured by XYZ with SpectraScan PR650

Result (Gamma)

- The R, G and B primaries are same among all LED levels
- This shows the LED intensity linearly scales the luminance of LCD, so that it doesn't change chrome.



Conclusion

- Luminance of HDR display
 - LCD response is Gamma (2.6)
 - LED response is liner
 - Luminance is gained by multiplying those two response
- Luminance prediction model
 - Worse at low LED due to the LED characteristic (nonlinearity in low level)
 - Worse high LCD level due to the modeling method (a singe gamma).
 - MSE 17.84 in cd/m^2
 - Does this model provide an accurate prediction?
- Gamut of the HDR display
 - The R, G and B primaries are same among all LED levels

Unsolved matters

- The measurements of LED 3x5 and LED 3x9 contains a 'bump', which has not been investigated whether it is random noise or repeatable defect. Need measurement repeatedly.
- Taking a spectra data of R G B for color gamut modeling.
- The pictures of single LEDs illuminated with a sequence of intensities have not yet analyzed.

Feature study (1)

- Find relationship between local luminance and the number and position of LEDs illuminated
 - LEDs are not uniformly arrayed. The point spread function (PSF) of LED is designed to be Gaussian. The luminance at some point in the display is affected by the number and the position of adjacent LEDs.
- More precise prediction for the LCD response
 - not with a single gamma value but look up table.
- More precise prediction for the LED response
 - LEDs level (< 20) not on the linear line

Feature study (2)

If needed,

- More precise prediction for the LCD response
 - not with a single gamma value but look up table.
- More precise prediction for the LED response
 - LEDs level (< 20) not on the linear line

Feature study (3)

- According to the white paper, thanks to the natural effects of scattered light in the human eye, the blur introduced by the low resolution LED image is imperceptible. I am curious about redoing the experiment.

Feature study (4)

- This measurement reveals that some combination of LCD and LED level results in the same luminance. How are the dynamic range images rendered by effectively using the on this display ?
- Measure contrast ratio. As learned in lecture, there is no standard definition to measure contrast ratio.

Reference

- High Dynamic Range Display Systems, Helge Seetzen, SIGGRAPH 2004,
- <http://www.brightsidetech.com/tech/bstech.php>

Acknowledgement

- Special thanks to Professor Wandel, Joyce, Greg and Sing.
- I started this project by myself, but it was a team project with Greg and Sing. I really appreciate the set up of measurement equipments, telling me programming and data analysis. Owing to you, I learned much more.

Appendix I: Wrong measurements

Other than the above, I conducted measurements which brought wrong results.

1. Measured **a single LEDs** (LED#. 387) on. Tried to compare the a randomized input and regular input. Unfortunately, the measurement file of regular input order was over written. Since the data is Z, instead of Y, the luminance curve is very noisy.

→ We noticed that a single LEDs is not enough to specify the display luminance. Because the illuminated area of each LED overlaps.
2. Measured **all LEDs** on. Tried to compare the a randomized input and regular input.

The status of all LEDs on causes flickers. As well, measurements data is Z. It was unbelievably noisy. In this condition, the comparison of input data order didn't work.

→ Find the maximum the number of LEDs, which don't make flicker.
3. Measured **rectangle area** of LEDs on. Measurements data is Z. The data is still noisy.

→ Finally, we found that the data is Z.