The Norwegian Colour and Visual Computing Laboratory

NTNU

An image based multi-angle measurement setup

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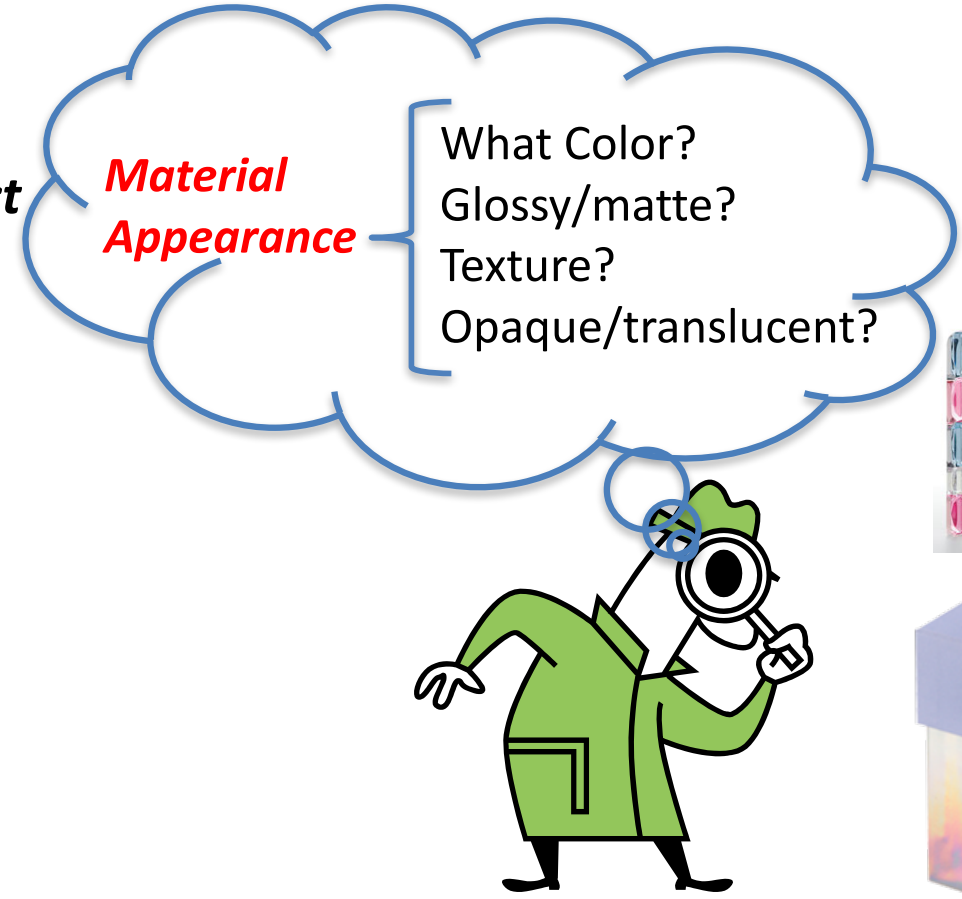
Introduction

Appearance of an object material



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Introduction

Appearance of an object material

Material Appearance

What Color?
Glossy/matte?
Texture?
Opaque/translucent?

Objective description

Physical Measurements

Surface reflectance,
Specular measurement,
texture patterns,
Opacity,
etc.

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Non-diffuse, gonio-chromatic materials

- Used in packaging industry, car paint industry, banknotes etc.
- Created using,
  - Metallic inks,
  - Pearlescent, varnish coatings,
  - Special effect pigments,
  - Holographic foils.
- Produce desirable appearance by shift/change in perceived colour depending upon illumination/viewing geometry.
- Change due to varying reflection at different viewing angles (based on material properties).

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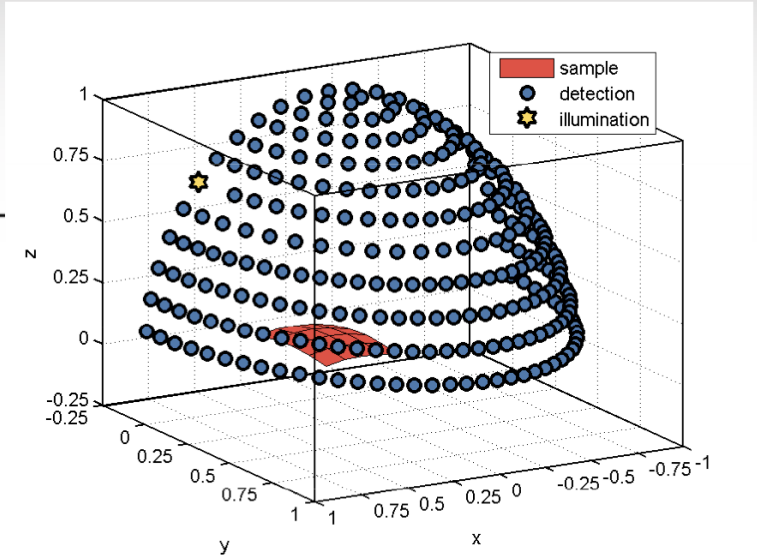
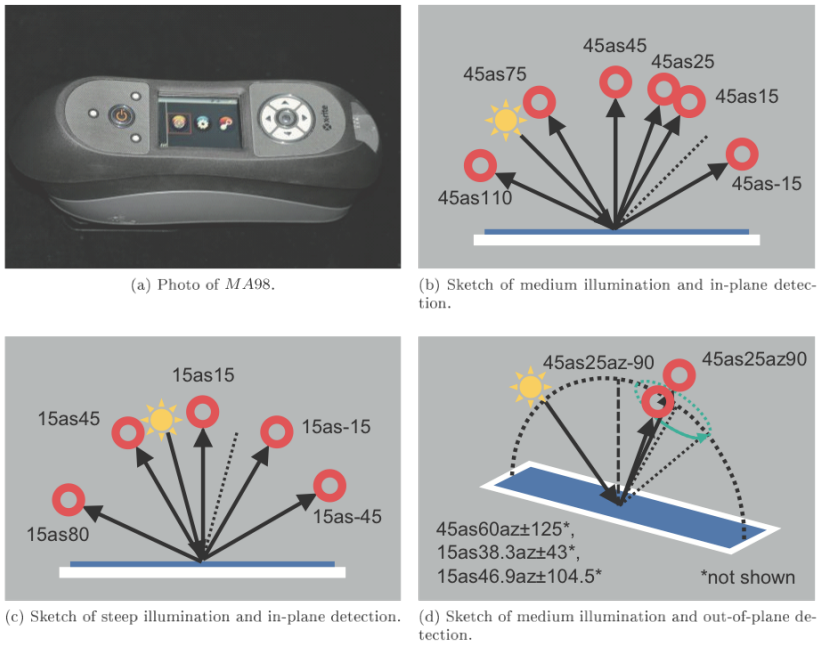
GONIO-MEASUREMENTS / MULTI-ANGLE MEASUREMENTS

- Multi-angle measurement instruments available in the market,
- X-Rite MA98, BYC-MAC, etc,
- Gonio-reflectometers at metrology institutes.

Limitations:

- Measurements are time consuming (especially Gonio-reflectometers),
- Expensive.





(a) Photo of $MA98$.
(b) Sketch of medium illumination and in-plane detection.
(c) Sketch of steep illumination and in-plane detection.
(d) Sketch of medium illumination and out-of-plane detection.

Figure 3.6: Multi-angle spectrophotometer $MA98$.

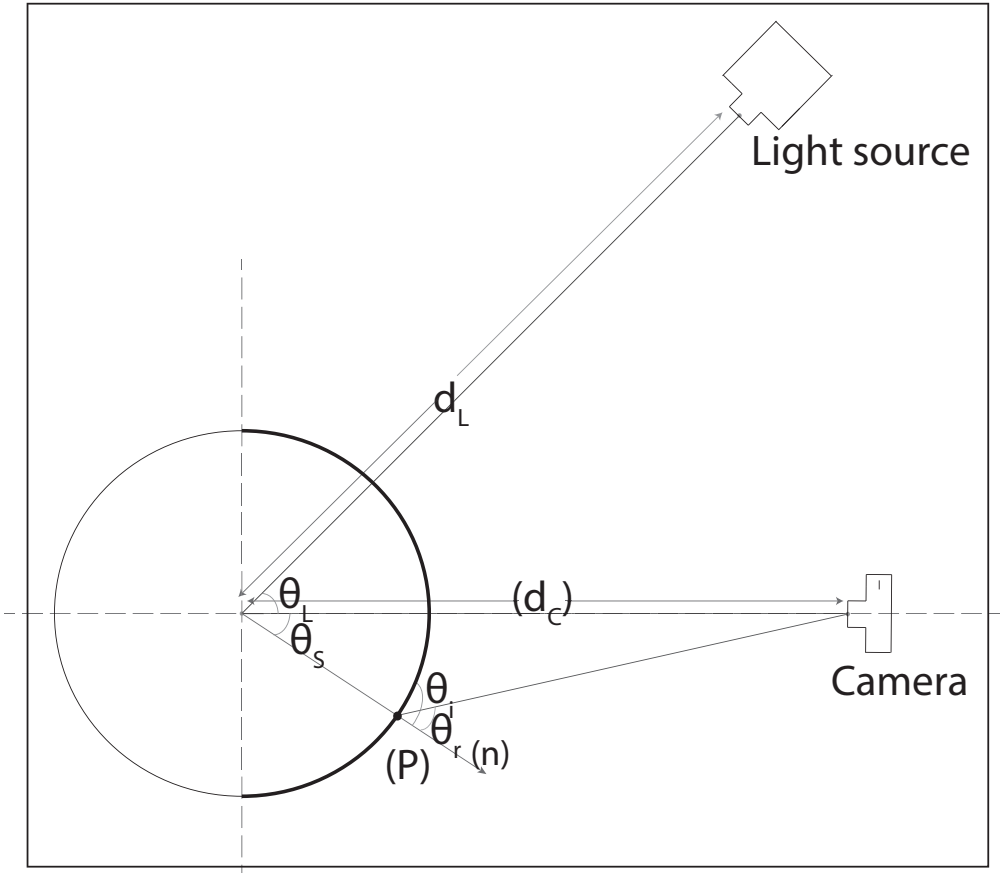
Motivation

- Can we perform multi-angle measurements in a fast and relatively in-expensive way?
- Can the measurements be done online during the reproduction and/or image quality evaluation procedures in the production line?

Image based multi-angle measurement setup[1,2]

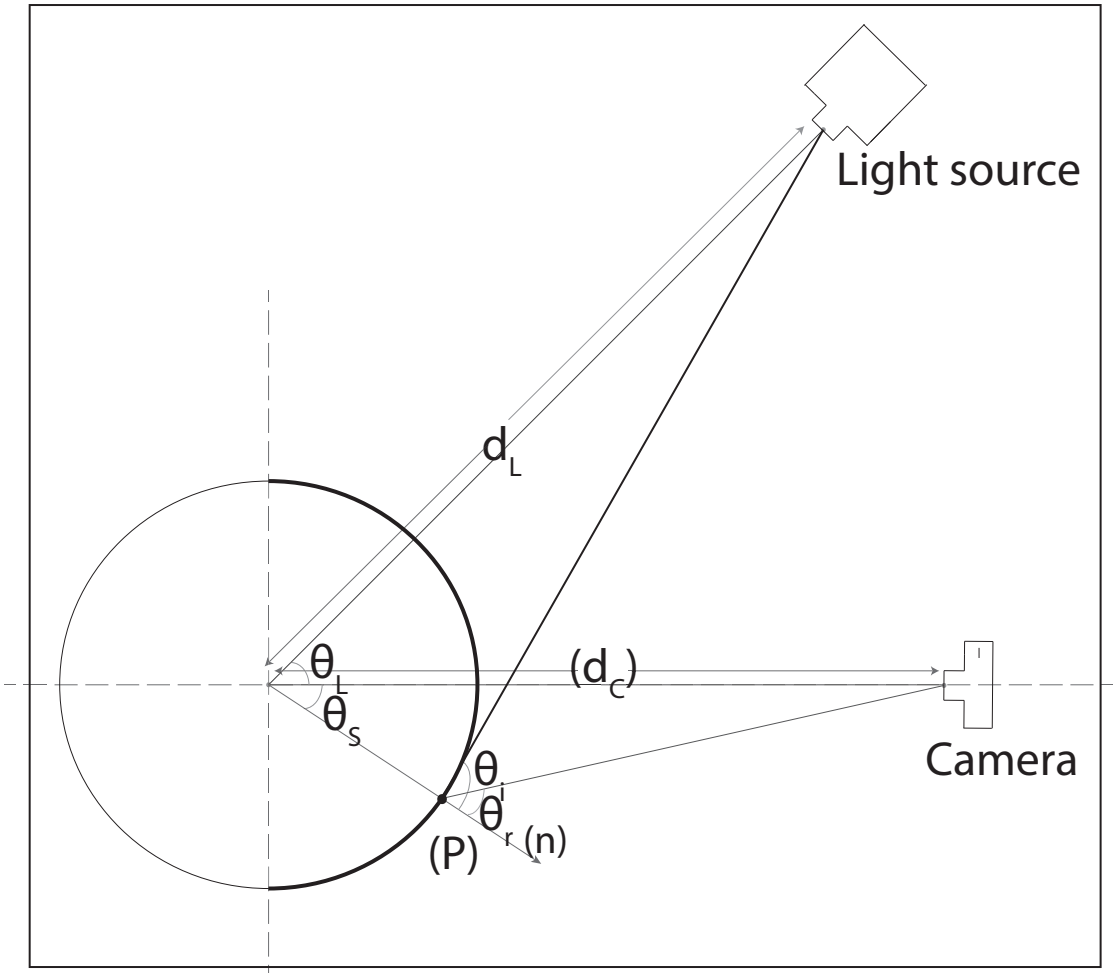
- An image-based multi-angle method for measurement of homogeneous flexible object material
  - Using point light source and a RGB camera,
  - Estimate the incident(θ_i) and reflection(θ_r) angles of a curved sample.

$$\cos\theta_i = \frac{P_L \cdot n}{|P_L|} \qquad \cos\theta_r = \frac{P_C \cdot n}{|P_C|}$$



1. *A. Sole; I. Farup; S. Tominaga, "An image-based multi-directional reflectance measurement setup for flexible objects", Proc. SPIE9398, Measuring, Modeling, and Reproduction Material Appearance 2015, 93980J (March 13, 2015)*
2. *A. Sole, I Farup, S Tominaga, (2014) An image based multi-angle method for estimating reflection geometries of flexible objects, Proc. IS&T/SID 22nd Color Imaging Conference, Boston, Arizona, USA, 91-96.*

Image based multi-angle measurement setup[1,2]



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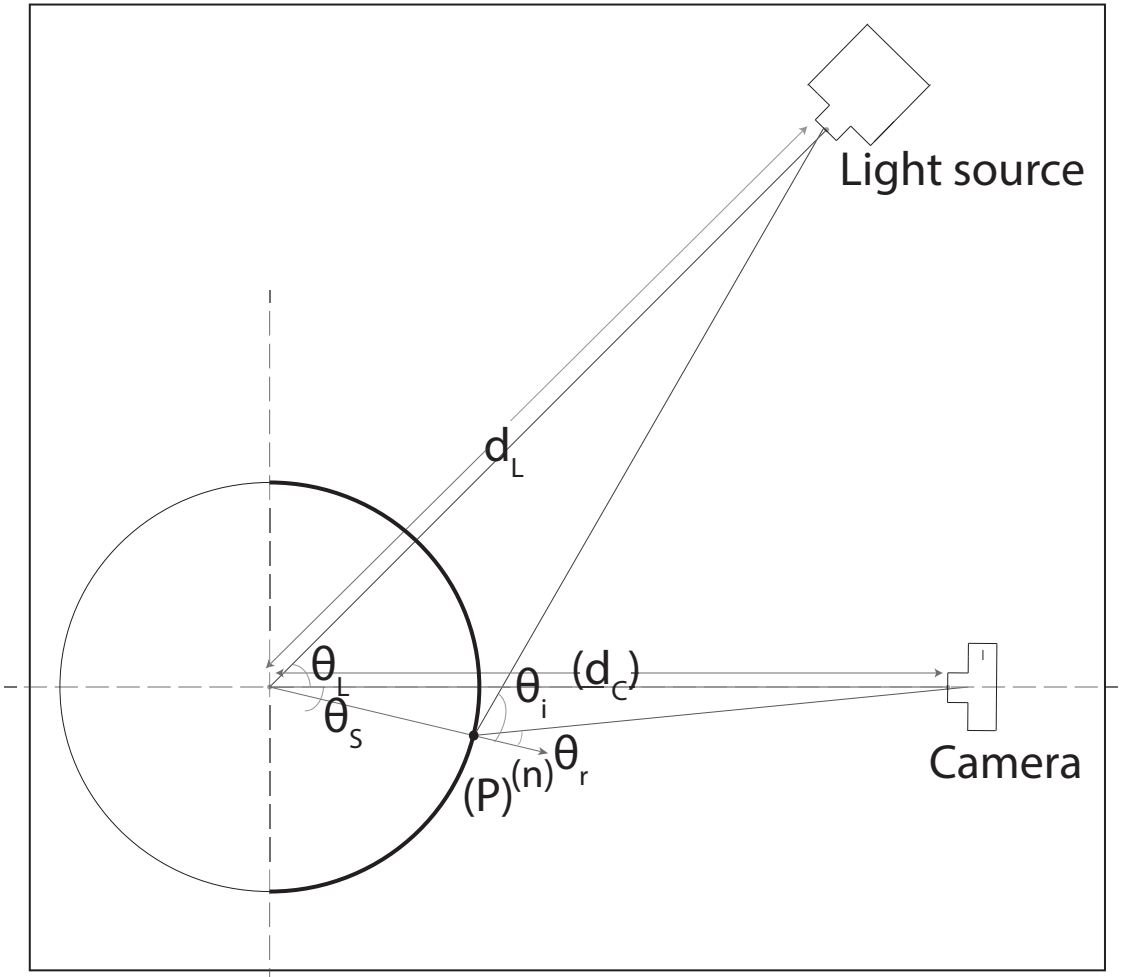

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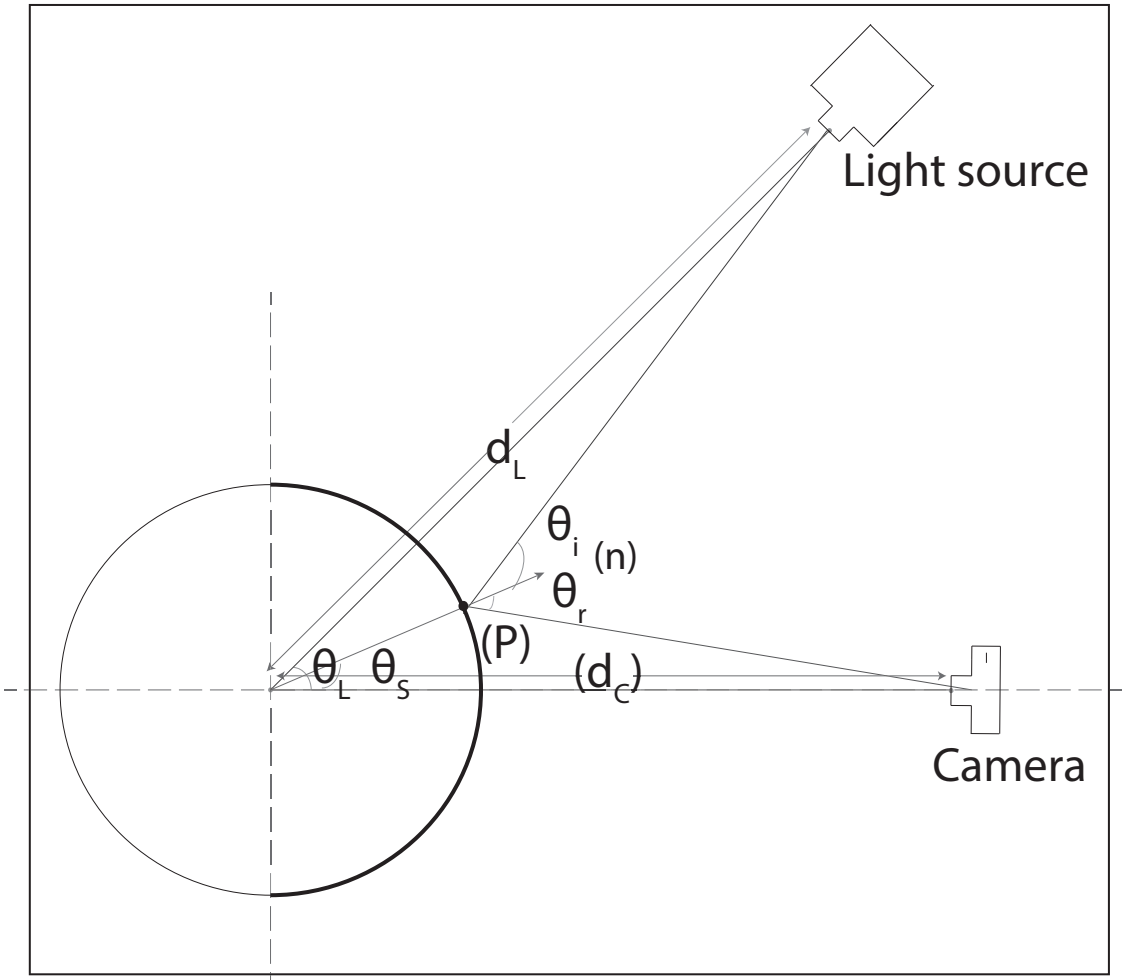

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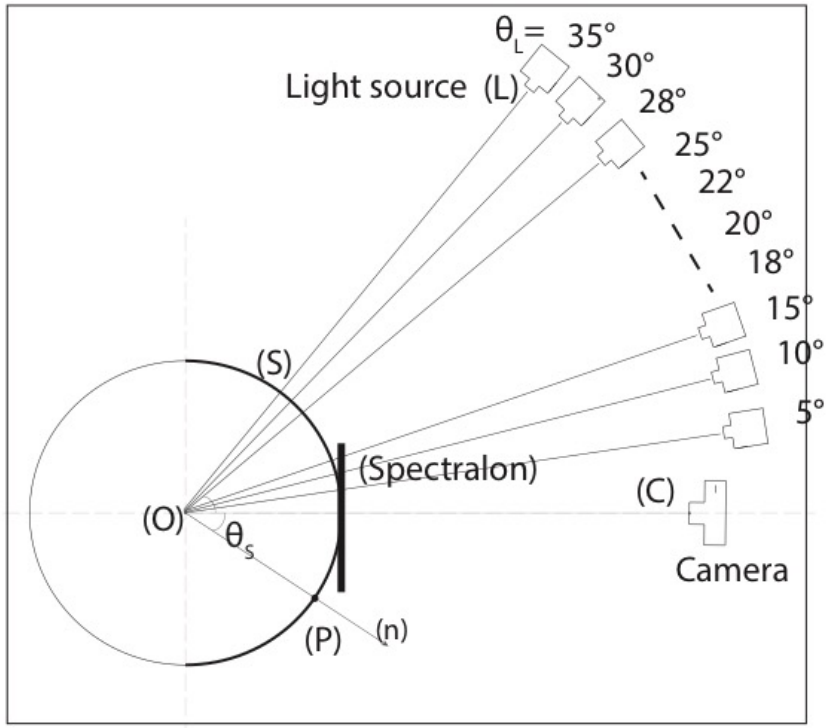
Sample measurement

- Assuming measurement sample to be homogeneous and opaque we measure with:
  - 10 illumination directions,
  - Spectralon tile as reference tile to estimate linear RGB camera response of the incident light,
  - Nikon D200 DSLR camera,
  - Tungsten point light source,
  - Printed packaging sheet as sample



A. Sole, I. Farup, and P. Nussbaum, "Evaluating an image based multi-angle measurement setup using different reflection models", in Material Appearance, vol. 2017, no. 8, pp.101-107, Proceedings IS&T Electronic Imaging, 2017

Surface reflectance using a reflection model

- For example:
  - Phong reflection

    Phong reflection model is an empirical model with two surface reflection components, diffuse reflection of rough surfaces and specular reflection of shiny surfaces

  - Cook-Torrance model

    CT model is a physical model that describes the intensity and spectral composition of the light reflected from the object/material.

  - Isotropic Ward model

    Ward model is a phenomenological model developed with the aim to fit measured reflectance data with a simple empirical formula. It represents both isotropic and anisotropic reflection and uses a gaussian distribution for the specular peaks.

Comparing with Gonio/Multiangle spectrophotometers

Image taken from:
http://www.ebay.com/gds/Nikon-D200-Vs-Nikon-D-Series-D300-/10000000177709780/g.html

Camera Setup – **RGB**

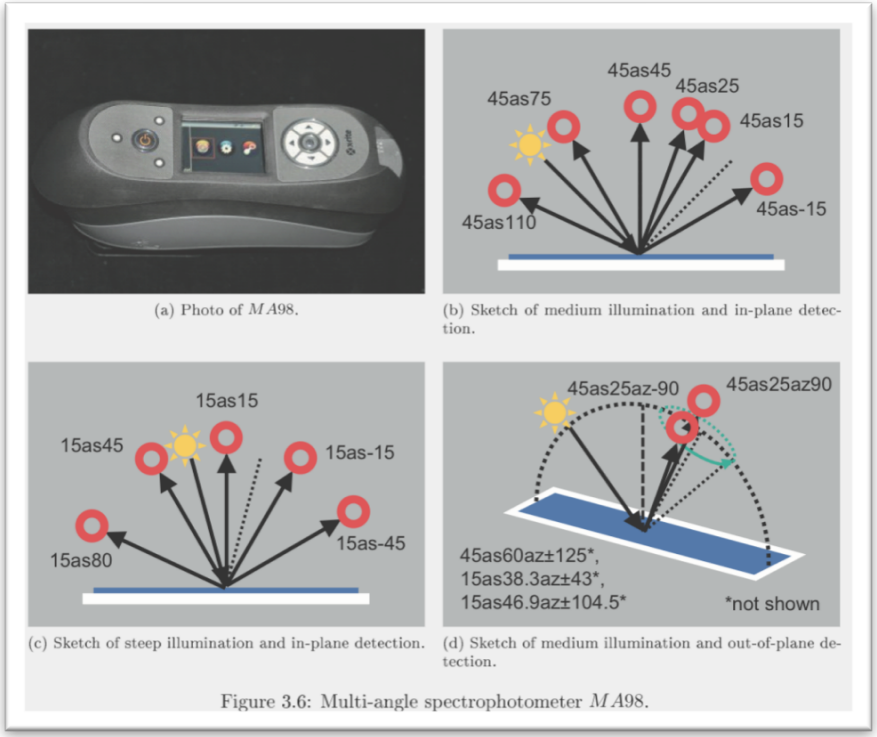


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Figure 3.6: Multi-angle spectrophotometer $MA98$.

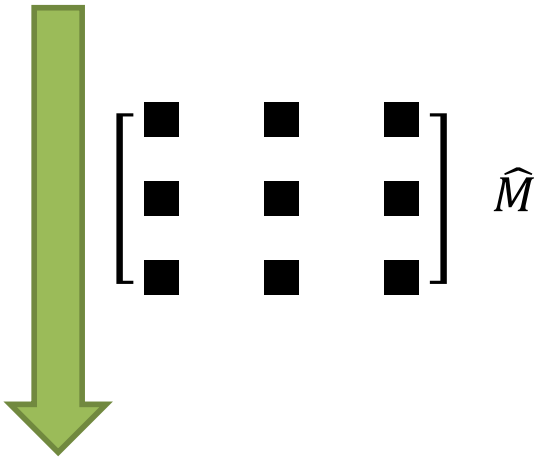
Image taken from:
K. Kehren, *Optical Properties and Visual Appearance of Printed Special Effect Colors*, PhD thesis, Technischen Universität Darmstadt, Darmstadt, Germany, April 2013.

Multi-angle/Gonio spectrophotometer Setup – **Spectral 400 – 700nm**

Comparing with Gonio-spectrophotometers

Camera Measurement

RGB



XYZ

Multi-angle/Gonio spectrophotometer

Spectral reflectance

400 nm . . . . . 700 nm

$$X = \sum_{400}^{700} \overline{Cr}(\lambda)Re(\lambda)$$

$$Y = \sum_{400}^{700} \overline{Cg}(\lambda)Re(\lambda)$$

$$Z = \sum_{400}^{700} \overline{Cb}(\lambda)Re(\lambda)$$

XYZ

XYZ = XYZ reflectance,

RGB = Illuminant independent camera response of the sample material,

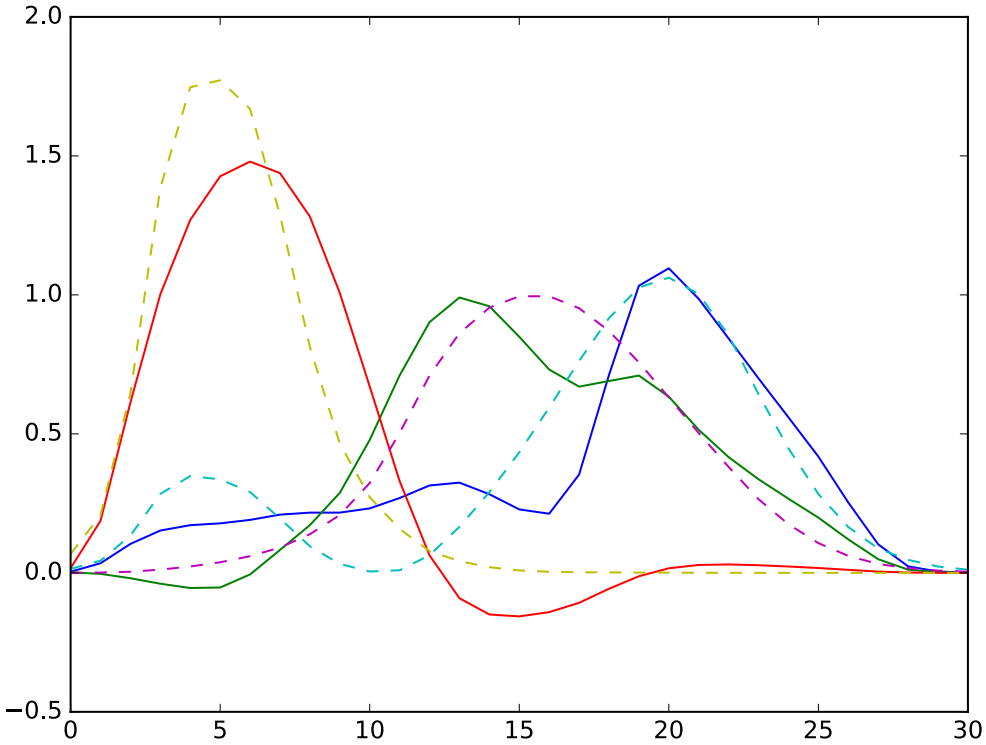
Re(λ) = spectral reflectance,

$\widehat{\boldsymbol{C}}_{(\overline{\boldsymbol{Cr}}(\boldsymbol{\lambda})\overline{\boldsymbol{Cg}}(\boldsymbol{\lambda})\overline{\boldsymbol{Cb}}(\boldsymbol{\lambda}))}$ = transformed colour matching functions using camera sensitivity functions and 2° ($\bar{x}$, $\bar{y}$, $\bar{z}$) colour matching functions.

Transformation Matrix ($\widehat{M}$) and transformed colour matching functions ($\hat{C}$)

$$\widehat{M} = arg\min_{M} \|C - RM\|_F$$

$$\hat{C} = R\widehat{M}$$



C = 31 x 3 matrix (CIE 2° colour matching functions),

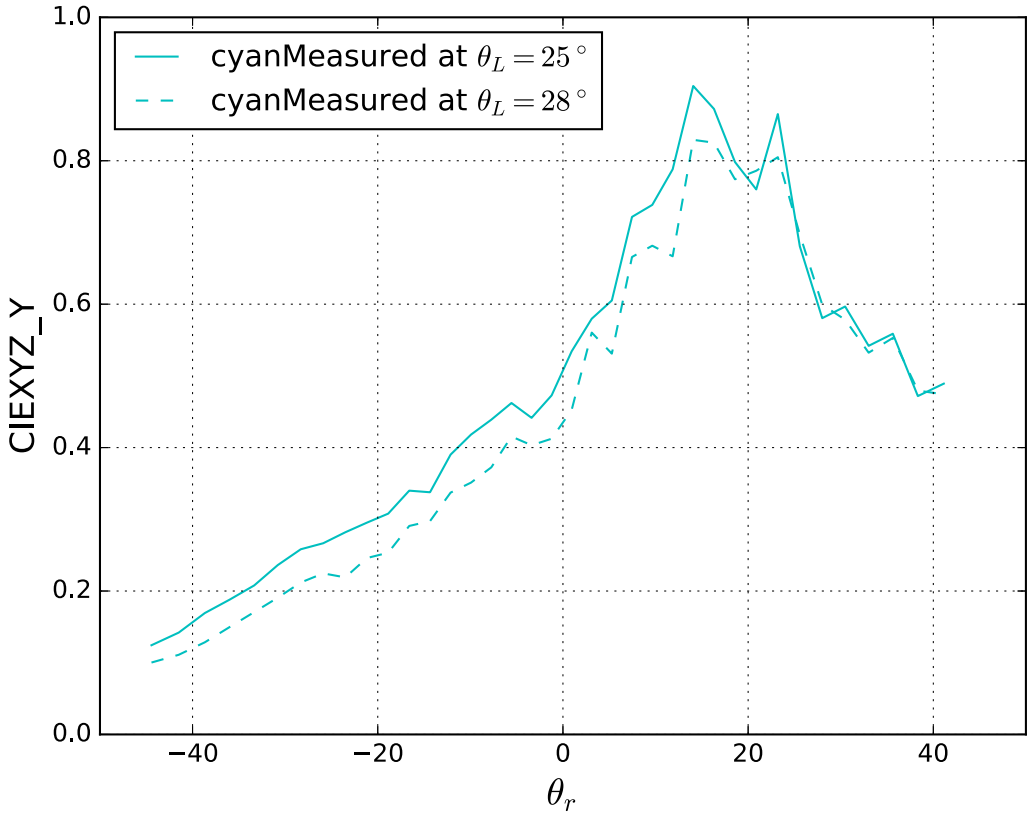
R = 31 x 3 matrix (camera sensitivity functions $(r(\lambda), g(\lambda), b(\lambda))$,

$\widehat{M}$= 3 x 3 transformation matrix,

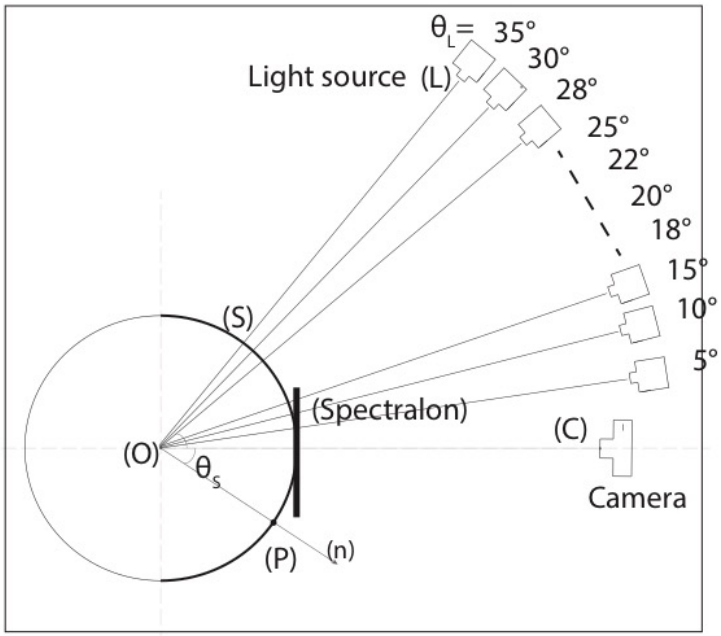
$\hat{C}$= 31 x 3 matrix (transformed colour matching functions),

A. Sole, I. Farup, and S. Tominaga, "Image based reflectance measurement based on camera spectral sensitivities," in Measuring, Modeling and Reproducing Material Appearance 2016 (M. V. O. Segovia, P. Urban, and F. H. Imai, eds.), vol. 2016, no. 9, pp.1 – 8, Proceedings IS&T Electronic Imaging, 2016.

Sample



XYZ_Y value of Cyan sample



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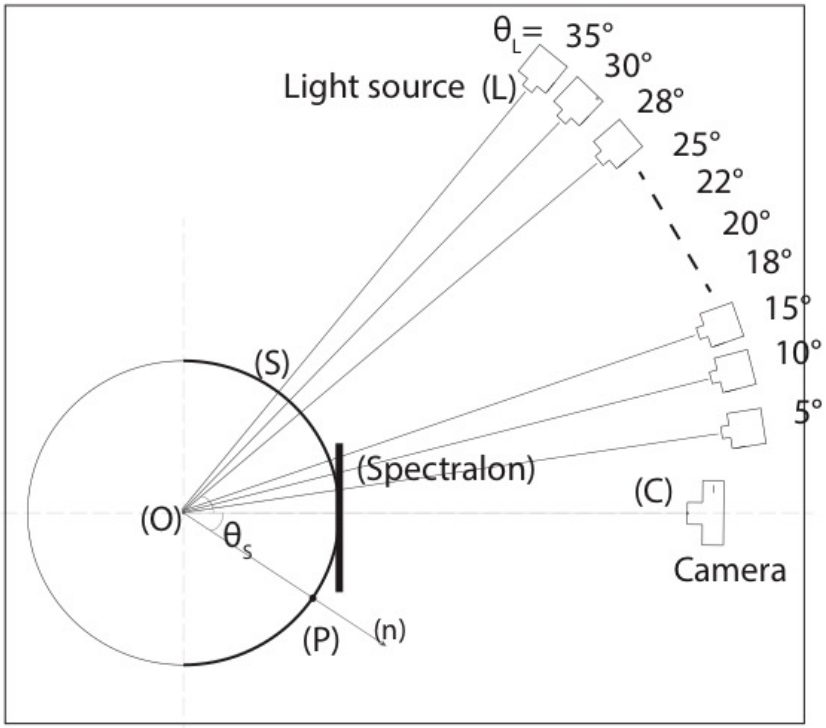
Training of the reflection models

- Measurement data divided into training and test data set
- Training set: 5˚, 15˚, 20˚, 25˚ and 30˚
- Training of Cook-Torrance and Isotropic Ward model



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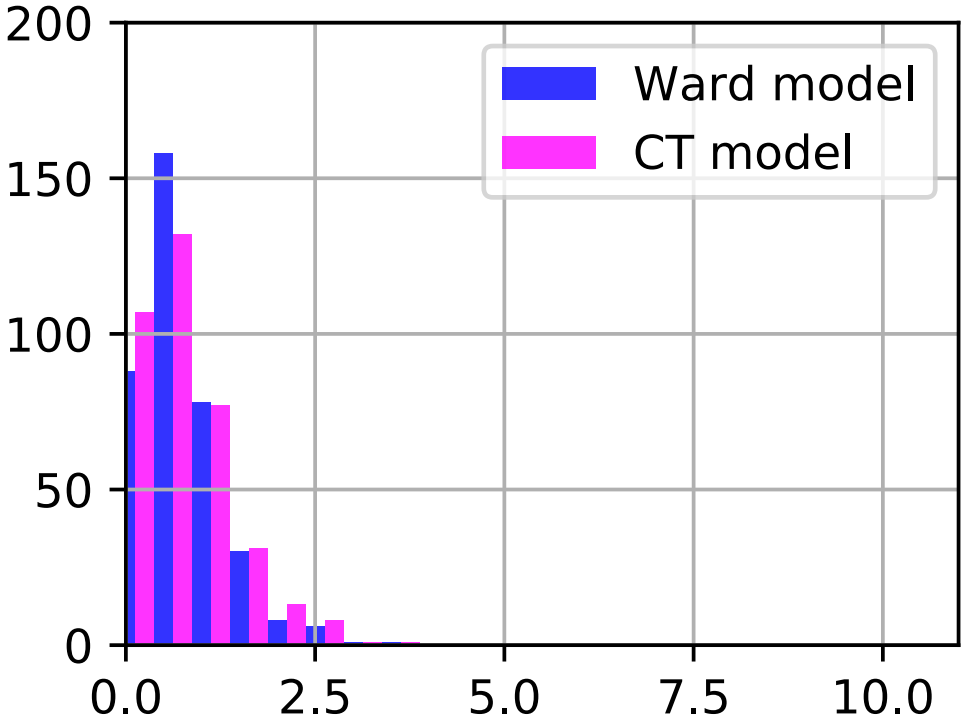
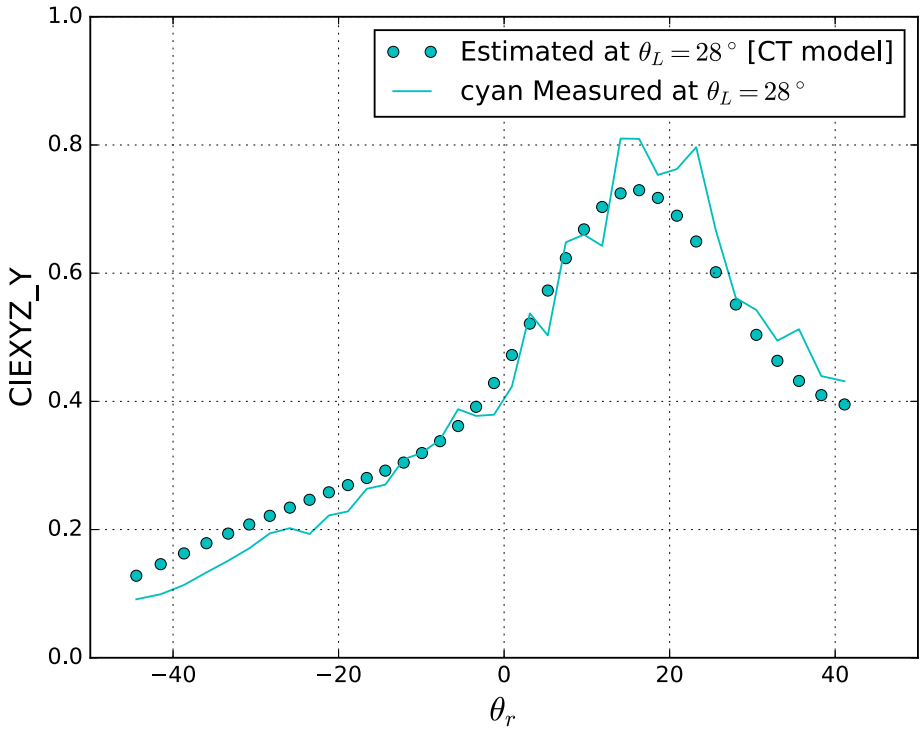
Result

Cyan sample

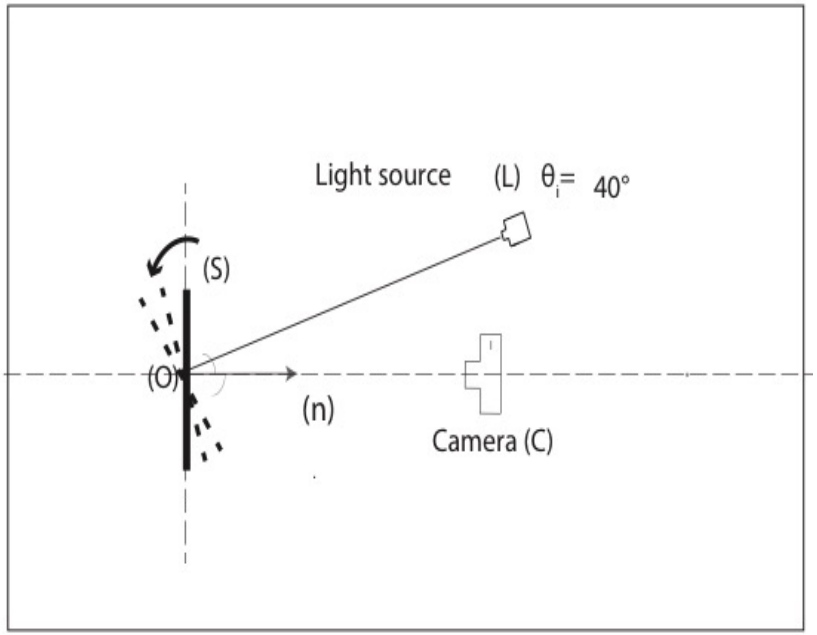
Histogram Cyan Sample CT and Ward model

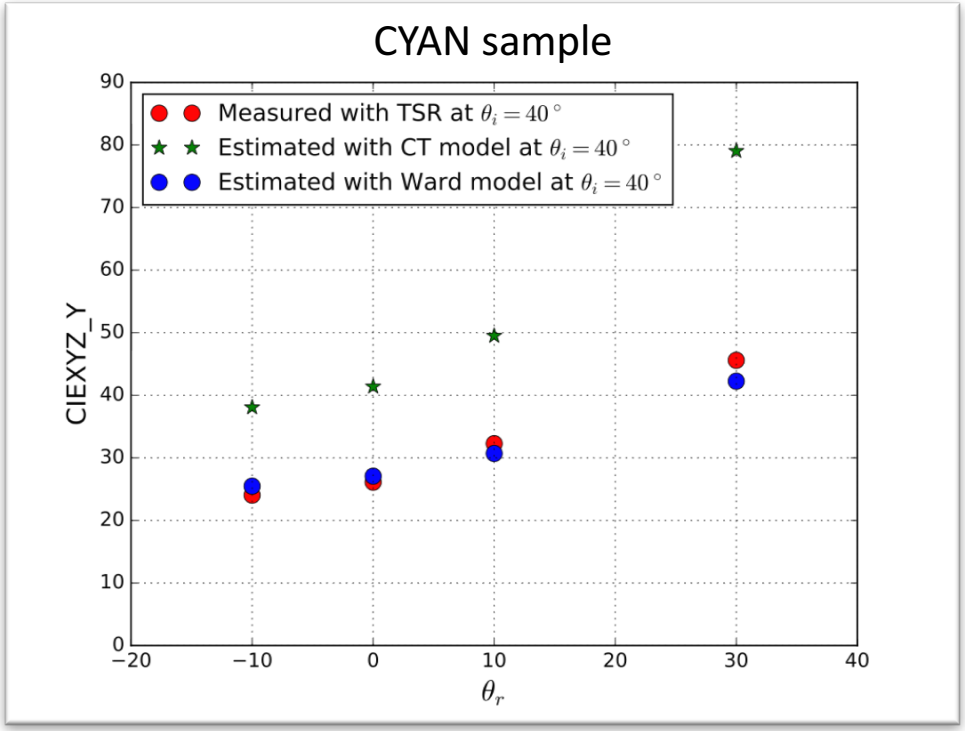




Physical measurements using radiometer

- CYAN sample measured using tele-spectro-radiometer
  - $Incident\ direction\ (\theta_i) = 40^{\circ}, Viewing\ directions\ (\theta_r) = -10^{\circ}, 0^{\circ}, 10^{\circ}, and\ 30^{\circ}$
- Trained CT and Ward models used to estimate the CIE Y value at these same incident and viewing directions





Conclusion

- For the sample materials used in this paper
  - ➢ Satisfactory performance of both the reflections models for the given set of sample materials
  - ➢ Directional reflection properties of the material can be estimated directly in the colorimetric space,
  - ➢ Ward model estimates CIE Y values well for the measurements made with the tele-spectro-radiometer

Future work

- To evaluate the setup, perform sample measurements with the setup and compare with gonio-spectrophotometer measurements.
- Implement the method on highly specular and gonio-chromatic samples.
- Use the setup to measure specular materials along with more complex BRDF reflection models.

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Thank you for your attention

Contact information:

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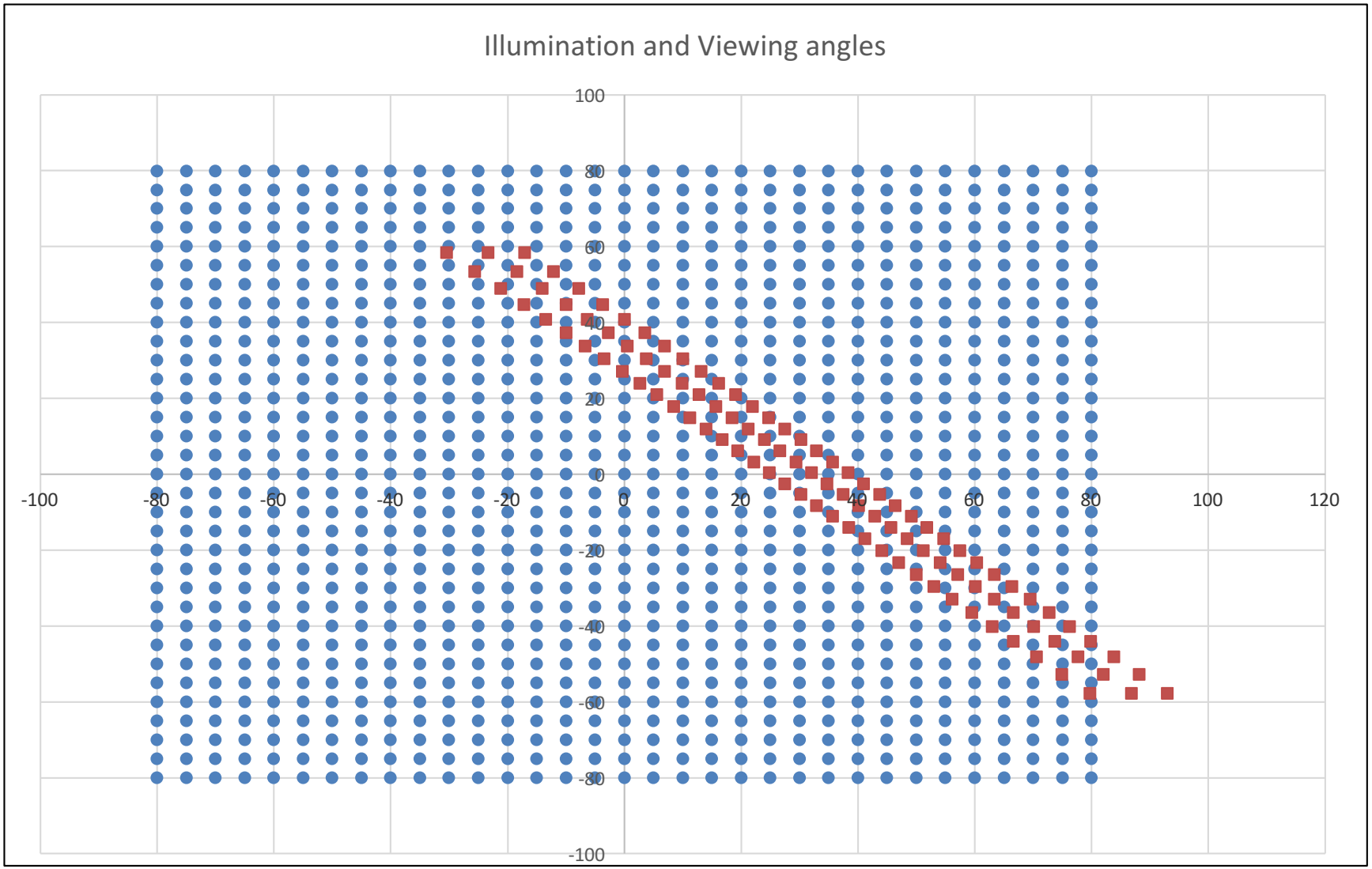
Illumination and Viewing angles
100
80
60
40
20
0
-20
-40
-60
-80
-100
-100
-80
-60
-40
-20
0
20
40
60
80
100
120