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On the Acquisition and Reproduction of Material Appearance

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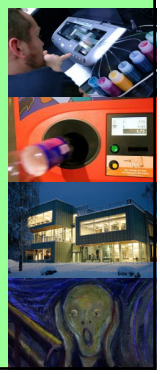

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Appearance of an object or material

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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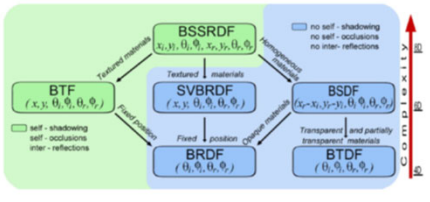
Physics and computer graphics



Guarnera, D., Guarnera, G.C., Ghosh, A., Denk, C. and Glencross, M. (2016), **BRDF Representation and Acquisition**. *Computer Graphics Forum*, 35: 625–650. doi:10.1111/cgf.12867

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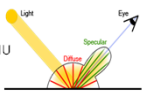
Project: MUVApp – Measuring and Understanding Visual Appearance

- FRIPRO Toppforsk project 2016-2021
  - 25 MNOK (ca 3M$) – joint funding by the Research Council of Norway and NTNU
  - Project leader: Prof. Jon Y. Hardeberg
  - WP Leaders: Peter Nussbaum and Marius Pedersen
  - Project Secretary: Aditya Sole
- From colour to appearance
  - Colour, gloss, translucency, texture
  - Fundamental research from vision science to computer graphics
  - Applications: product design and quality control, 3d printing, computer graphics++



The Research Council of Norway

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MUVApp Project Partners

- Yale University
  - USA
  - Holly E. Rushmeier
  - Computer Graphics
- Justus-Liebig Universität Giessen
  - Germany
  - Karl Gegenfurtner
  - Vision
- Conservatoire National des Arts et Metiers
  - France
  - Gaël Obein
  - Metrology
- Chiba University
  - Japan
  - Shoji Tominaga and Takahiko Horiuchi
  - Imaging

Yale — JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN — le cnam — CHIBA UNIVERSITY

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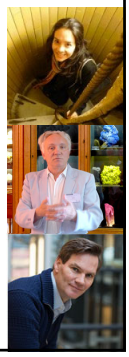
MUVApp Advisory Board

- Dr. Maria V. Ortiz Segovia,
  - Image processing lead scientist, OCE Canon Group, Créteil, France
  - Appearance in printing
- Dr. Patrick Callet,
  - Researcher, Mines ParisTech and Ecole Centrale de Paris, France
  - Materials and appearance
- Prof. Theo Gevers,
  - University of Amsterdam, The Netherlands
  - Appearance in Computer Vision



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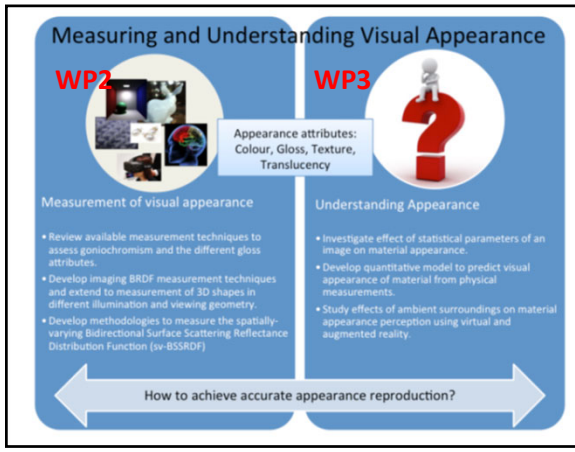
MUVApp Primary research goals

- To gain new knowledge of how human beings perceive the visual appearance of materials, objects, and scenes, and
- To develop new methodologies for measuring and communicating visual appearance and appearance-related material and object properties



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MUVApp key researchers

- 2 new PhD students
  - Davit Gigilashvili
    - Translucency Constancy and Factors Impacting Translucency Perception
    - Supervisors: Jon Y. Hardeberg and Marius Pedersen
  - Helene Midtfjord
    - Measurement and modeling of appearance
    - Supervisors: Phil Green and Peter Nussbaum
- 2 ongoing PhD students
  - Aditya Sole
    - Soft metrology for non-diffuse materials
    - Supervisors: Peter Nussbaum and Ivar Farup
  - Gregory High
    - A model for Consistent Colour Appearance
    - Supervisors: Phil Green and Peter Nussbaum

- 3 Postdoctoral researchers
  - Jean-Baptiste Thomas,
  - Claudio Guarnera,
  - Dar'ya Guarnera
- 2 Affiliate Professorships
  - Shoji Tominaga
  - Philipp Urban

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Selected recent and ongoing MUVApp research

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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.

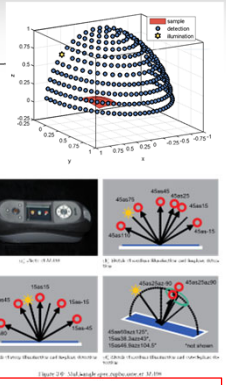

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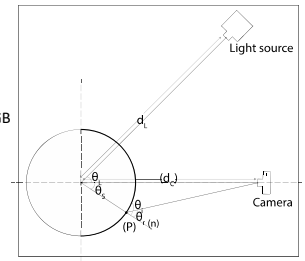
Image based multi-angle measurement setup[1,2]

- 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. Aditya S. Sole; Ivar Farup; Shoji Tominaga, "An image-based multi-directional reflectance measurement setup for flexible objects", Proc. SPIE9398, Measuring, Modeling, and Reproduction Material Appearance 2015, 93980U (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.

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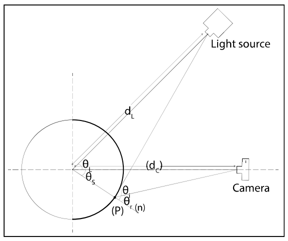
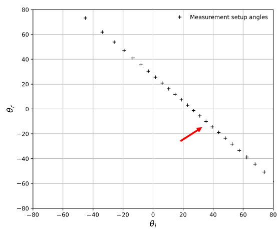
Image based measurement setup[1,2]





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)
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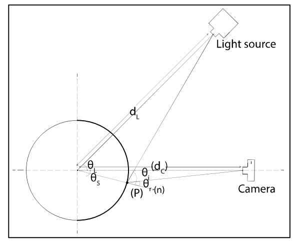
Image based measurement setup[1,2]



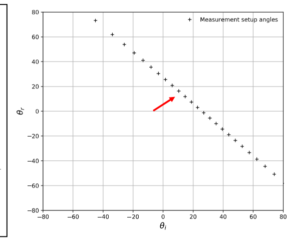


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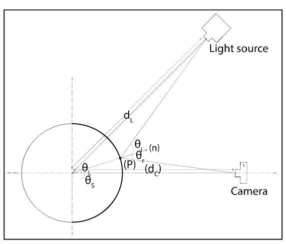
Image based measurement setup[1,2]



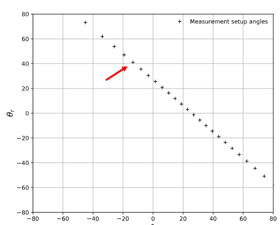


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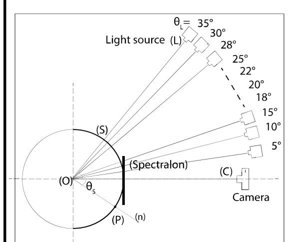
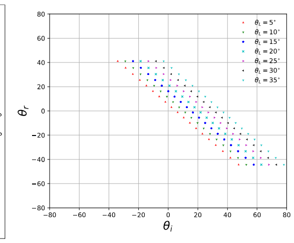
Image based measurement setup[1,2]





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)
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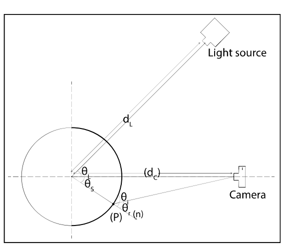
Comparing with Gonio/Multiangle spectrophotometers



Measurement setup – **RGB**

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

Image taken from:
1. http://www.perkinelmer.com/no/product/lambda-1050-uv-vis-nir-spectrophotometer-l1050
2. http://www.avaangrouppuce.com/murakami/goniospectro-3b.php

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Comparing with Gonio/Multiangle spectrophotometers

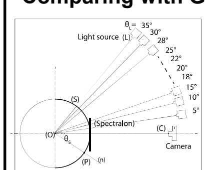
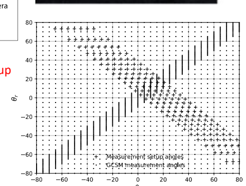


Image-based measurement setup



Gonio-spectrophotometer

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Comparing with Gonio-spectrophotometers

Camera Measurement

RGB

$\begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \hat{M}$

XYZ

XYZ = XYZ reflectance,
RGB = Illuminant independent camera response of the sample material,
$\hat{M}$ = transformation matrix

Multi-angle/Gonio spectrophotometer

$f_r(\theta_i, \theta_r, \lambda)$

$L_r(\theta_i, \theta_r, \lambda) = f_r(\theta_i, \theta_r, \lambda).E_i(\theta_i, \lambda)$

$L_r(\theta_i, \theta_r, \lambda)$

$\begin{pmatrix} Cal_R(\theta_i, \theta_r) \\ Cal_G(\theta_i, \theta_r) \\ Cal_B(\theta_i, \theta_r) \end{pmatrix} = \begin{pmatrix} \sum L_r(\theta_i, \theta_r, \lambda).\bar{r}(\lambda) \\ \sum L_r(\theta_i, \theta_r, \lambda).\bar{g}(\lambda) \\ \sum L_r(\theta_i, \theta_r, \lambda).\bar{b}(\lambda) \end{pmatrix}$

$Cal_{RGB}(\theta_i, \theta_r)$

$\begin{bmatrix} \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \\ \blacksquare & \blacksquare & \blacksquare \end{bmatrix} \hat{M}$

XYZ

A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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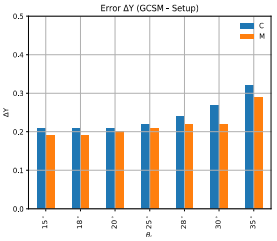
Error



$Error_{\Delta Y} = \frac{\sqrt{(Y_{Gonio} - Y_{Setup})^2}}{Y_{Gonio}}$

A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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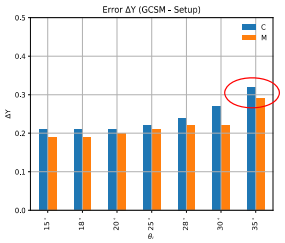

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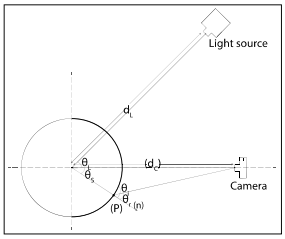
Measurement setup – Error analysis

- Geometrical (setup) error
- Colorimetric (camera characterization) error



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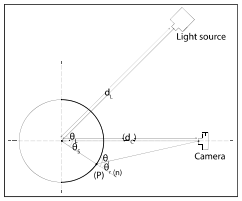
Measurement setup – Error

Geometrical error



- Uncertainty in estimating θ_i and θ_r using error propagation

	Setup Parameters	Uncertainty
Calculated	θ_i	±7.6°
	θ_r	±7.4°
	θ_S	±6.7°

A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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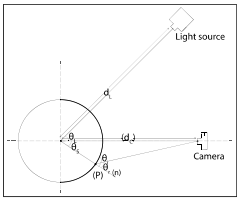
Measurement setup – Error

Geometrical error



- **Uncertainty and error propagation in estimating θ_i and θ_r**

	Setup Parameters	Uncertainty
Calculated	θ_i	±7.6°
	θ_r	±7.4°
	θ_S	±6.7°

A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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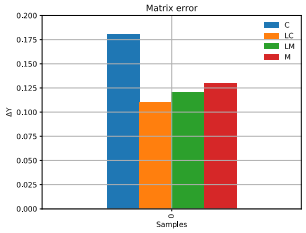
Measurement setup – Error

Colorimetric error

$$\Delta Y = \frac{\sqrt{(Y_{(\hat{M}-RGB)} - Y_{(L_r-CIE2^\circ)})^2}}{Y_{(L_r-CIE2^\circ)}}$$

- $Y_{(\hat{M}-RGB)} = \hat{M}$ and $\boldsymbol{Cal_{RGB}(\theta_i, \theta_r)}$
- $Y_{(L_r-CIE2^\circ)} = \boldsymbol{L_r(\theta_i, \theta_r, \lambda)}$ and CIE 2° CMFs



A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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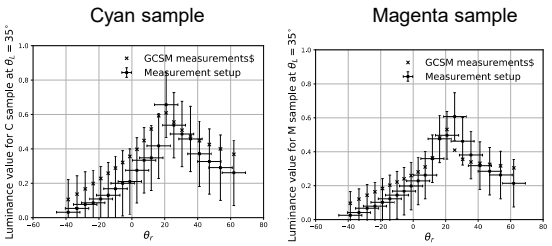
Result



A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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Conclusions so far

- Uncertainty in calculating θ_i and θ_r is large. More precise measurements are required.
- Setup can be used to perform fast measurements for simulations and understanding material properties.
- Setup not ideal for precise measurements (medical, security, traceability, etc) with the achieved errors.

A. Sole, I. Farup, P. Nussbaum, and S. Tominaga, "Evaluating an image-based bidirectional reflectance distribution function measurement setup," Appl. Opt. 57, 1918-1928 (2018).

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Understanding gloss – a preliminary experiment

Thomas, Jean-Baptiste; Hardeberg, Jon Yngve; Gabiele, Simone. (2017) Image Contrast Measure as a Gloss Material Descriptor. Computational Color Imaging - 6th International Workshop, CCIW 2017, Milan, Italy, March 29-31, 2017, Proceedings.

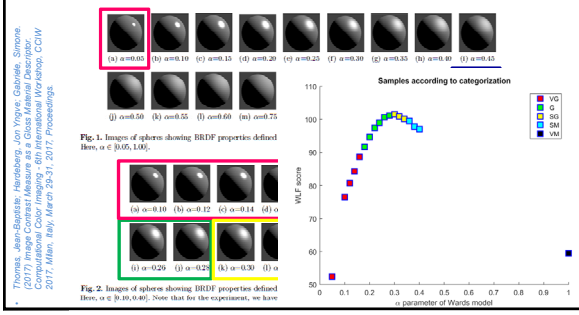

Fig. 1. Images of spheres showing BRDF properties defined Here, $\alpha \in [0.05, 1.00]$.

Fig. 2. Images of spheres showing BRDF properties defined Here, $\alpha \in [0.10, 0.40]$. Note that for the experiment, we have

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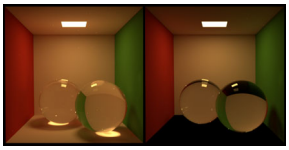
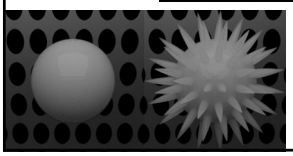
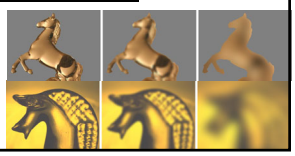
Impact of X on translucency perception







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YULIO VR KiSP

Giuseppe Claudio Guarnera, Peter Hall, Alain Chesnais, and Mashhuda Glencross. *Woven Fabric Model Creation from a Single Image*. ACM Transactions on Graphics (TOG), Volume 36 Issue 5, October 2017 Article No. 165. Presented at SIGGRAPH 2018.

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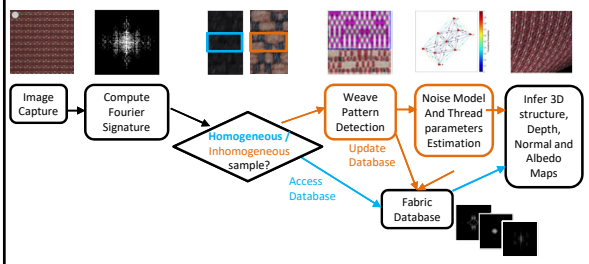
Pipeline overview



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YULIO VR

KiSP

Results

(a) Input Image (cut out). (e) Cut-out rendering. (f) Couch rendering. (g) Couch rendering, close-up.

(h) Input Image (cut-out). (l) Cut-out rendering. (m) Couch rendering. (n) Couch rendering (close-up).

(o) Input Image (cut out). (s) Cut-out rendering. (t) Couch rendering. (u) Couch rendering, close-up.

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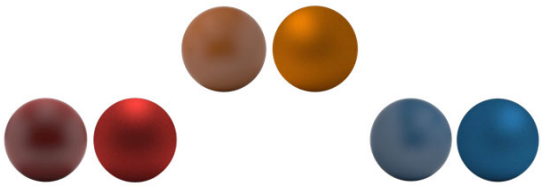
Same material model, different software



Renderings by Martin Böckenfeld, invenio Virtual Technologies GmbH

Guarnera D, Guarnera GC, Toscani M, Glencross M, Li B, Hardeberg JY, Gegenfurtner K. Perceptually Validated Cross-Renderer Analytical BRDF Parameter Remapping. IEEE Transactions on Visualization and Computer Graphics. 2018 Dec 14.

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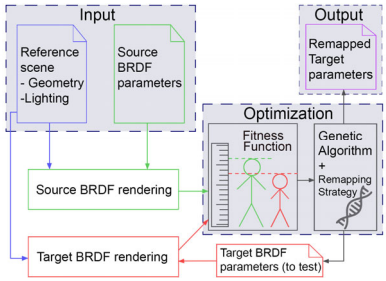
Pipeline



Guarnera D, Guarnera GC, Toscani M, Glencross M, Li B, Hardeberg JY, Gegenfurtner K. Perceptually Validated Cross-Renderer Analytical BRDF Parameter Remapping. IEEE Transactions on Visualization and Computer Graphics. 2018 Dec 14.

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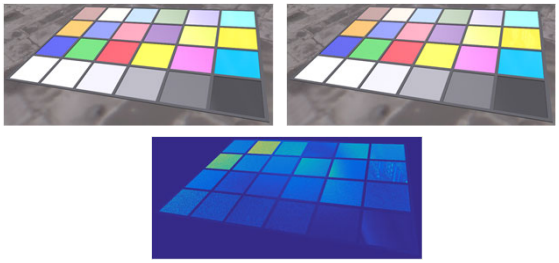
Results



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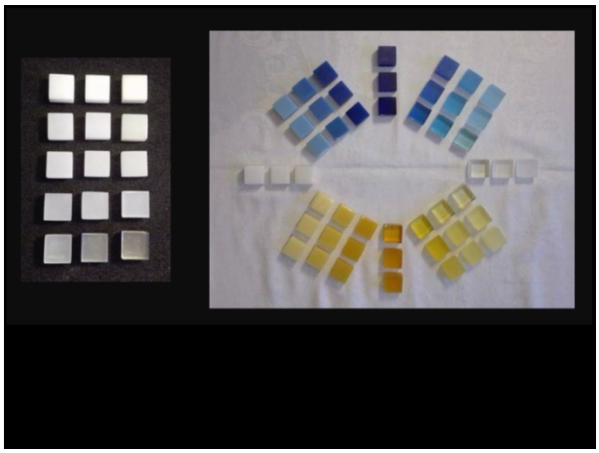
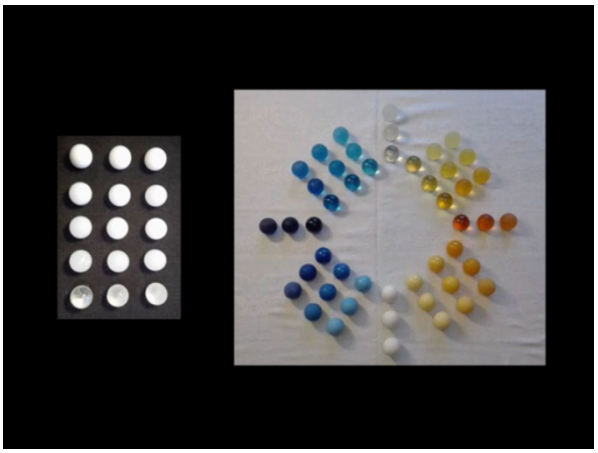
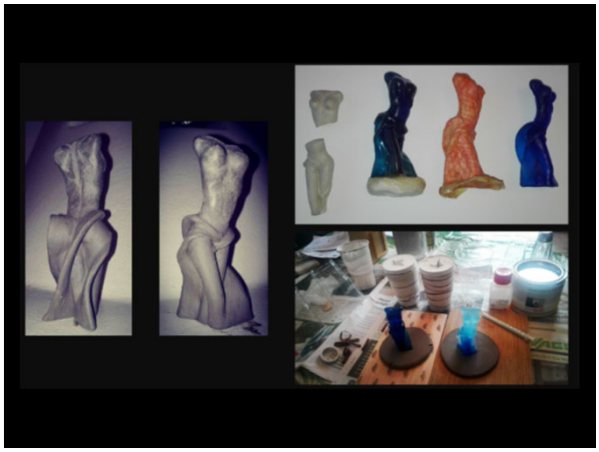
But what about real-world objects?

- Why?
  - Generate research hypotheses through qualitative research methods
  - Verify quantitative models – Fast prototyping
  - Evaluate and develop measurement methods
  - Experience visual perception (for researchers)
  - Communicate about visual perception (to others)
- Thomas, J.B., Deniel, A., Hardeberg, J.Y.: The *Plastique* collection: A set of resin objects for material appearance research. In: Proceedings of the XIV Conferenza del Colore. pp. 1-12 (2018)







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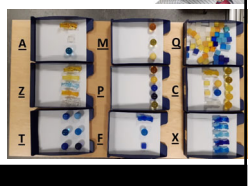
Behavioral Investigation of Visual Appearance Assessment

- Experiments investigating appearance assessment using real objects in uncontrolled conditions.
- Videos recorded
- Quantitative results analyzed
- Cross-individual differences found in appearance cues and vocabulary
- Hypotheses for further research identified
  - Including EI2019 paper
- Gigilashvili, D., Thomas, J.B., Hardeberg, J.Y., Pedersen, M.: Behavioral investigation of visual appearance assessment. CIC2018



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MUVApp Associated projects

- AVIT project on Goniometric Multi- and Hyperspectral Imaging
- Michele Conni, Industrial PhD with Barbieri Electronic on texture measurements
- Kumiko Kikuchi, visiting researcher from Shiseido working on face appearance
- Hilda Deborah's FRIPRO Mobility project with University of Iceland: «METRIcS-Metrological texture analysis for hyperspectral images»
- Vlado Kitanovski hired as postdoc in 2019 for 3 years with NTNU-internal funding on «colour and appearance»
- ERCIM postdoc Muhammed Safdar working on colour and appearance
- ERCIM postdoc Fereshteh Mirjalili working on texture perception and difference
- Chu Rui Jian collaborative PhD with Univ. Poitiers: Hyperspectral image texture
- IKTPLUSS 2019-2022 project by Claudio Guarnera: «Spectral Skin Modelling and Rendering for Realistic Digital Faces»
- MANER networking project
- ApPEARS ITN EU project

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MANER key facts

- MANER – Material Appearance Network for Education and Research
- Funded through the INTPART 2018 call at the RCN
  - With FRIPRO TOPPFORSK project «MUVApp» as base project
  - Collaborative research and education within Material appearance
- Budget: approx. 5 MNOK
- Timeframe: 3 years – 2019-2021
- Project management team:
  - Project Leader: Jon Y. Hardeberg
  - Project Manager: Aditya Sole
- Leading international partners in *China*, *India*, *Japan* and *USA*.

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MANER Collaboration Partners

- Yale University (YALE)
  - USA
  - Holly E. Rushmeier
  - Computer Graphics
- Xi'an University of Technology (XUT)
  - China
  - Congjun Cao
  - Colour Science
- Indian Institute of Technology Bombay (IITB)
  - India
  - Sharat Chandran
  - Visual computing
- Chiba University (CHIBA)
  - Japan
  - Takahiko Horiuchi
  - Imaging

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MANER Objectives

- Within the field of Material Appearance:
  - Develop a network of well established academic partners
  - Long term research and educational collaboration
  - *Also beyond current MANER partners*

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MANER Work Plan and Activities

- Joint training activities
  - 3 MANER schools
    - Yale 2019, IITB 2020, NTNU 2021
  - 3 Special Sessions in well established conferences
    - Starting at CCIW 2019 in Chiba
- Mobility and joint research activities
  - 28 researcher months of outgoing mobility
  - 27 researcher months of incoming mobility
- Joint development and accreditation of Master Course
  - Visual appearance measurement and understanding

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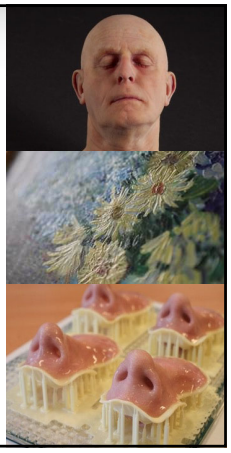
ApPEARS

APPEARANCE PRINTING

European Advanced Research School

http://www.appears-itn.eu



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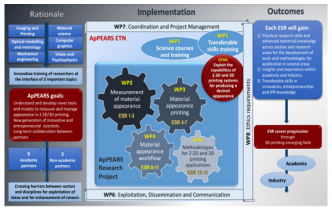
Appearance Printing - European Advanced Research School (ApPEARS)

- The project will train a next generation of researchers within the field of appearance printing, using 3D and 2.5D printing techniques to reproduce objects and materials with **accurate visual appearance match with the original**.
- Interdisciplinary research including:
  - Physics
  - Material/Optical Sciences
  - Computer Graphics
  - Theoretical modelling
- 14 Partner institutions throughout Europe.
- 15 PhD candidate positions
  - Recruiting **now**
  - Starting **September 2019**



More info –> http://www.appears-itn.eu/

Project co-ordinator: Jon Yngve Hardeberg *jon.hardeberg@ntnu.no*

Deputy co-ordinator: Aditya Sole aditya.sole@ntnu.no

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ApPEARS Network

NTNU · University of the West of England, Bristol · Linköping University · Océ, A Canon Company · Fraunhofer · le cnam · DTU Danmarks Tekniske Universitet · University of Leeds · barbieri · Technische Universität Darmstadt · Merck · strataSYS · PTB · Jolliffe Prints

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ApPEARS – ESR Positions (now recruiting)

NTNU · University of the West of England, Bristol · Linköping University · Océ, A Canon Company · le cnam

ESR1 Measurement system for appearance measurement

ESR2 Quality assessment for material appearance

ESR8 3D soft proofing and appearance simulation

ESR11 Image Appearance reproduction workflow using 2.5D printing techniques

ESR14 Optical Properties of Structured Surfaces

ESR6 The development of vector based printing for 2.5D printing

ESR12 Realistic physical patient simulator for surgical training

University of Leeds · Fraunhofer · DTU Danmarks Tekniske Universitet

ESR7 Accurate reproduction of soft tissue prostheses using 3D print technology

ESR4 Modelling Appearance Printing

ESR5 Halftoning for appearance printing

ESR9 Gonio-chromatic Gamut Mapping

ESR10 Representation of material appearance workflow

ESR13 Applications for material appearance reproduction technologies

ESR3 Advanced study of specular peaks of glossy surfaces

ESR15 Practical applications of 3D-printing system for creating novel surfaces

http://www.appears-itn.eu

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Wrap-up

- Material appearance is a very hot (and cool) research topic!
- Examples of ongoing research at NTNU Colourlab in the MUVApp project
- Increasing activity with new MANER and ApPEARS projects
- Interesting direction: Spectral + Appearance?
- Open for discussions and new collaborations
  - jon.hardeberg@ntnu.no
  - http://www.colourlab.no
  - http://www.appears-itn.eu

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