REFLECTANCE-BASED SURFACE SALIENCY

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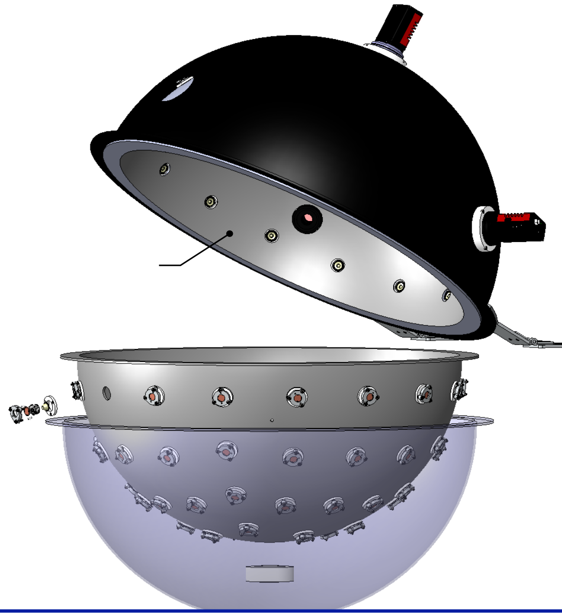
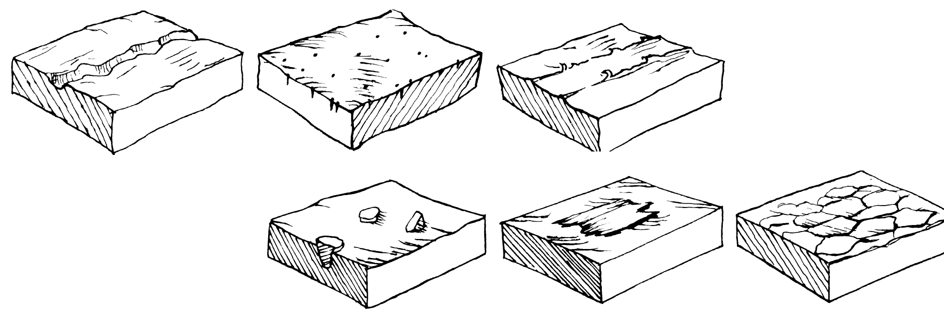
Scope and Objectives

Device + Methods





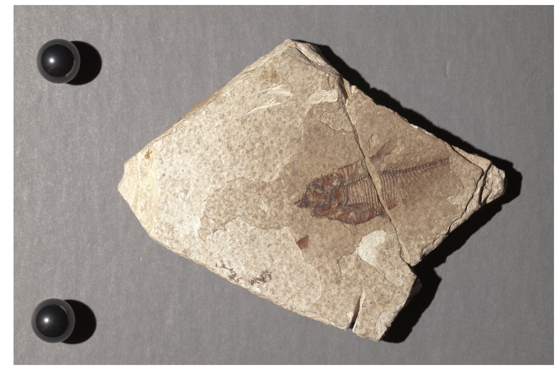
Main aim

➔ Develop an automatic inspection vision system to measure the quality of industrial products

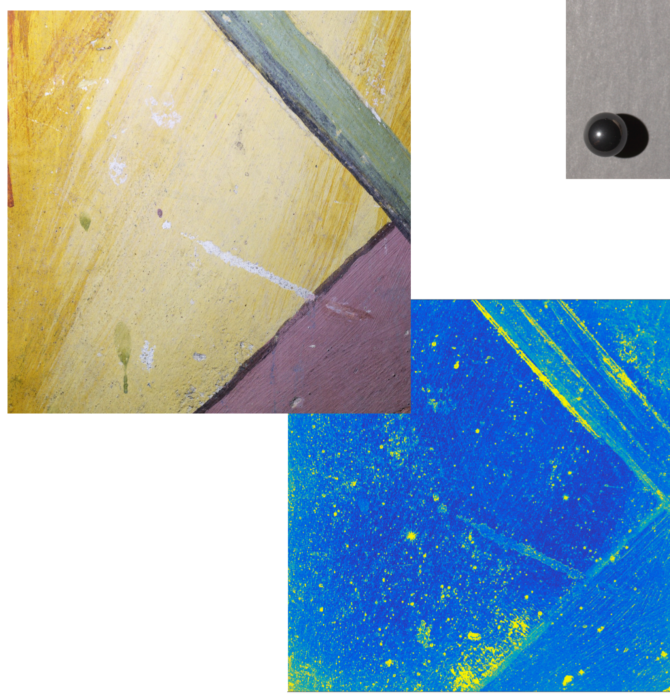
Enlarging the scope to other applications

➔ Detect and quantify the salient features (such as changes and degradations) on the cultural heritage objects using new imaging modalities

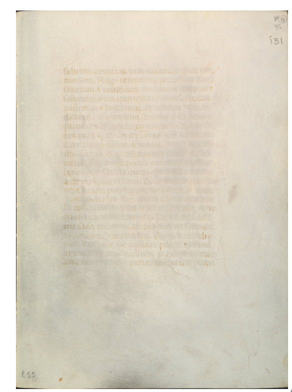
Fossils



Wall paintings



Palimpsests



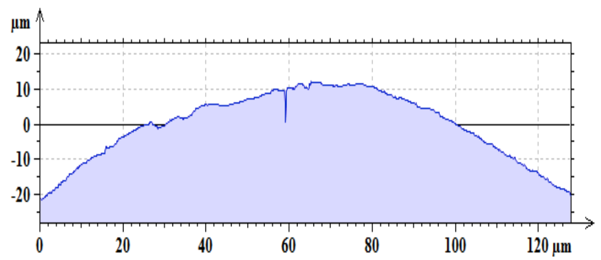
NTNU ColorLab
uB LE2I

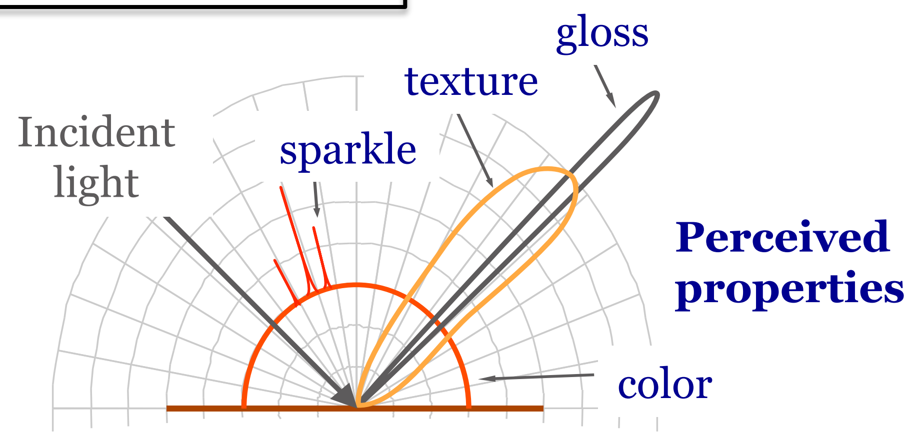
3 ways to address this challenge
Measuring, modeling and controlling:

①
Geometry
Altitudes, normals, and curvatures

②
Spatial BRDF
Angular distribution of the reflected light

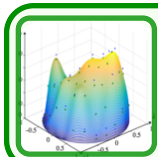
③
Spectral BRDF
Wavelenghts



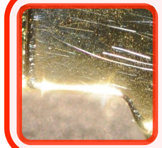


B.R.D.F : Bidirectionnal Reflectance Distribution Function

1. **Reflectance Transformation Imaging**
   - Related works
   - RTI Devices



2. **Modeling the angular reflectance**
   - Angular reflectance modeling
   - Discrete Modal Decomposition

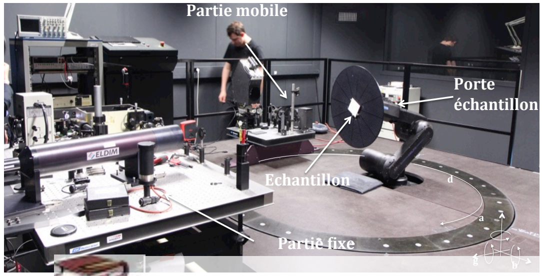


3. **Computing the saliency maps**
   - Rotation-invariant representation
   - Multivariate analysis

4. **Conclusion**

Approaches for BRDF assessment

Methods	Principle	Advantages/ disadvantages
Measuring the BRDF	measures using a goniospectrophotometer	☺ complete characterization of an infinitesimal area element of the surface ☹ total amount of data ☹ data acquisition time
Model-based rendering	analytical BRDF Models, eg. Phong, Cook-Torrance,…	☹ not suitable for the rendering of real-world surfaces
Image-based rendering	reflectance estimated from photometric stereo data	☺ rapid acquisition ☺ not require knowledges of physical and geometrical properties



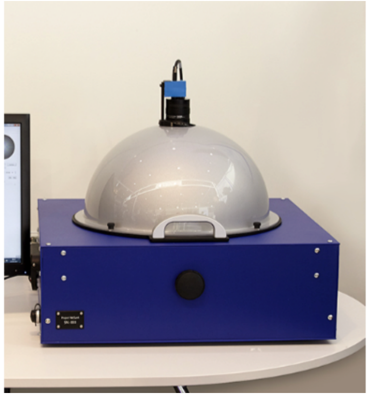
Obein and Al., CNAM

↳ e.g. **Reflectance Transformation Imaging**

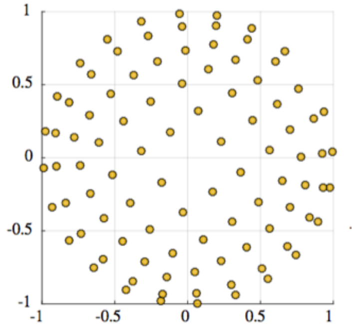
➘ RTI devices ➔ photometric stereo acquisition

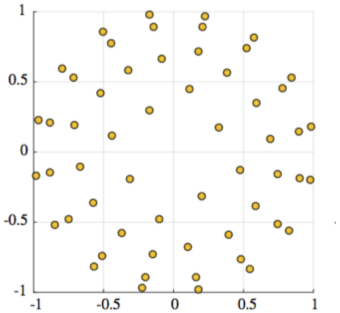
Dome v.1
⌀ 900mm
1 digital camera
96 light sources

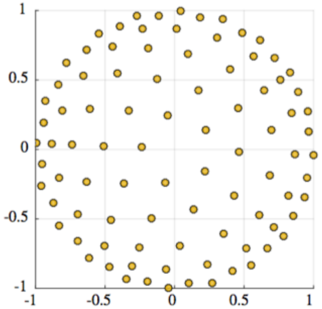
MeSurA Sphere
⌀ 650mm
4 cameras
112 light sources



Dome Opto
⌀ 320mm
1 camera
90 light sources

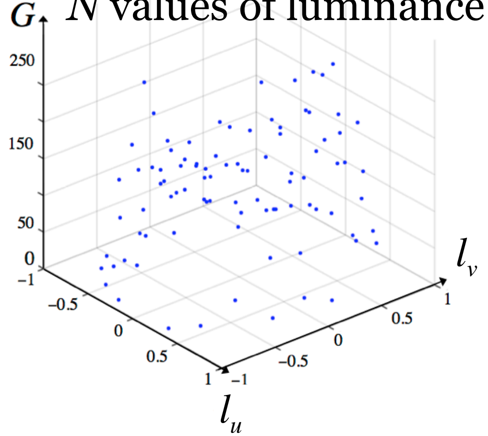






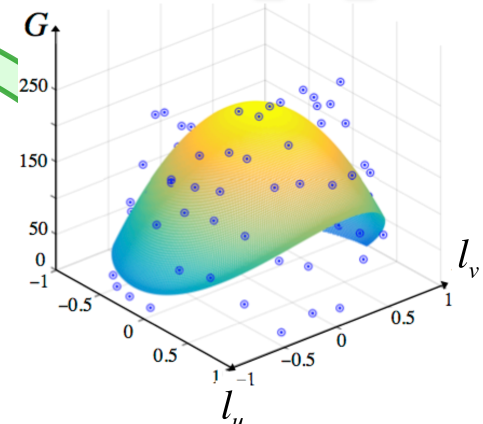
PTM Polynomial Texture Mapping

For each pixel:
N values of luminance



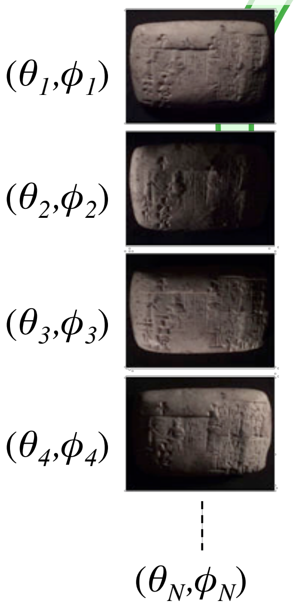
2 – Modeling

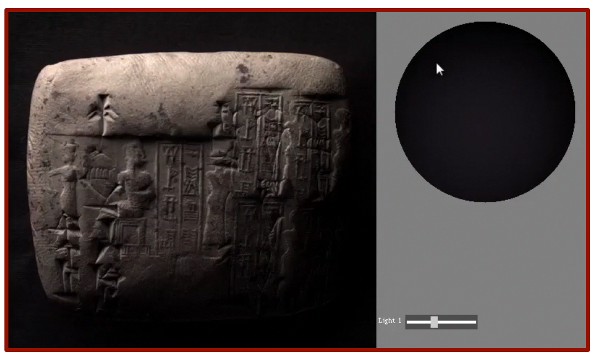
6 polynomial coefficients noted a_0 to a_5



1 – Acquisition

Set of N images





$$L(l_u,l_v) = a_0 + a_1 l_u + a_2 l_v + a_3 l_u l_v + a_4 l_u^2 + a_5 l_v^2$$

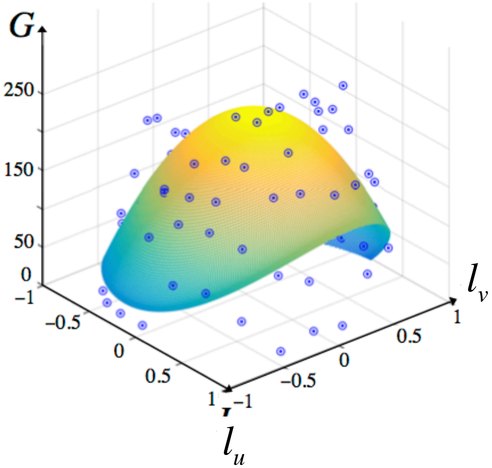
3 – Rendering

Interpolate and re-ligthing the object under a new lighting direction choosen by the user

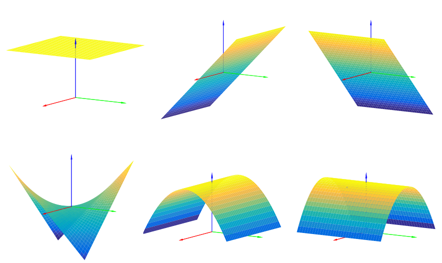
Existing models

Proposed model

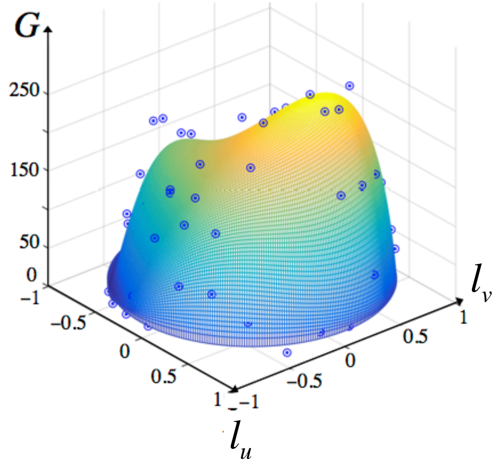
- Polynomial Texture Mapping **PTM**



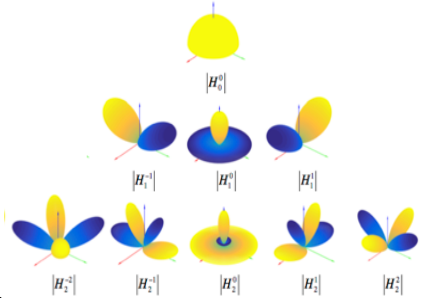
PTM basis



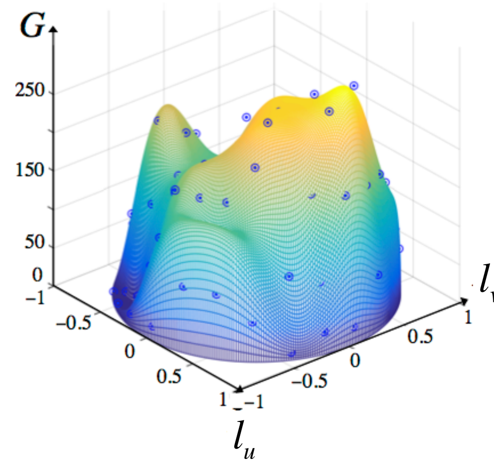
- Hemispherical Harmonics **HSH**



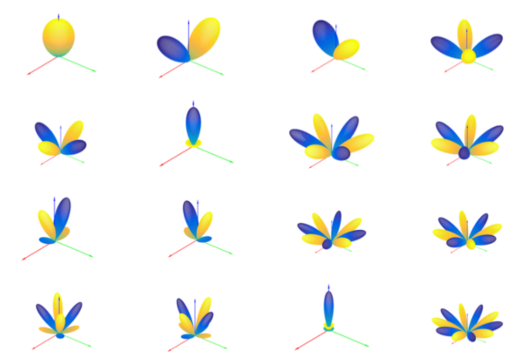
HSH basis



- Discrete Modal Decomposition **DMD**



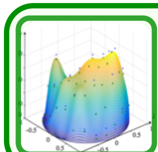
DMD basis



…

GILLES PITARD, et al. "Discrete Modal Décomposition: …".
Machine Visions and Applications, 2017

1. **Reflectance Transformation Imaging**
   - Related works
   - RTI Devices



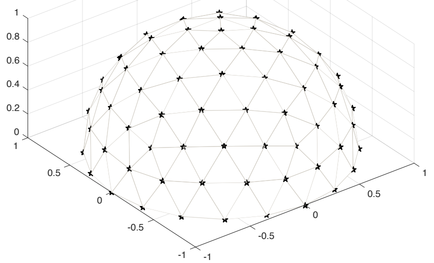
2. **Modeling the angular reflectance**
   - Angular reflectance modeling
   - Discrete Modal Decomposition

3. **Computing the saliency maps**
   - Rotation-invariant representation
   - Multivariate analysis

4. On[illegible]

➔ Proposal for a new R.T.I method, called « Discrete Modal Decomposition »

➘ Basis of projection called « Reflectance Modal Basis »



Discretization of the nominal surface geometry

Classical equations of motion

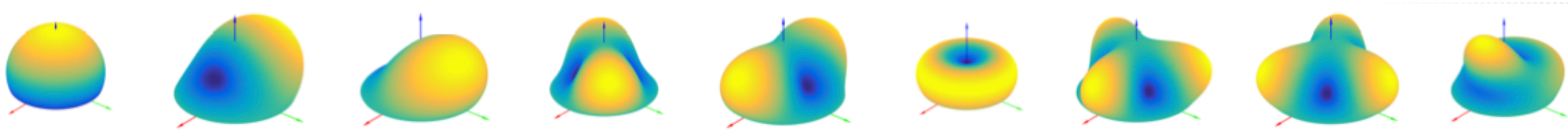
$$M.\ddot{q} + K.q = 0 \quad avec \quad q = q(\theta,\phi,t)$$

$$q(\theta,\phi,t) = \sum_{k=1}^{+\infty} Q_k \cos(w_k t)$$

$$(M^{-1}K - \frac{1}{w_k^2} I)Q_k = 0$$

Calculation of modes Q_k with the pulsation w_k

Q_1 Q_2 Q_3 Q_4 Q_5 Q_6 Q_7 Q_8 Q_9

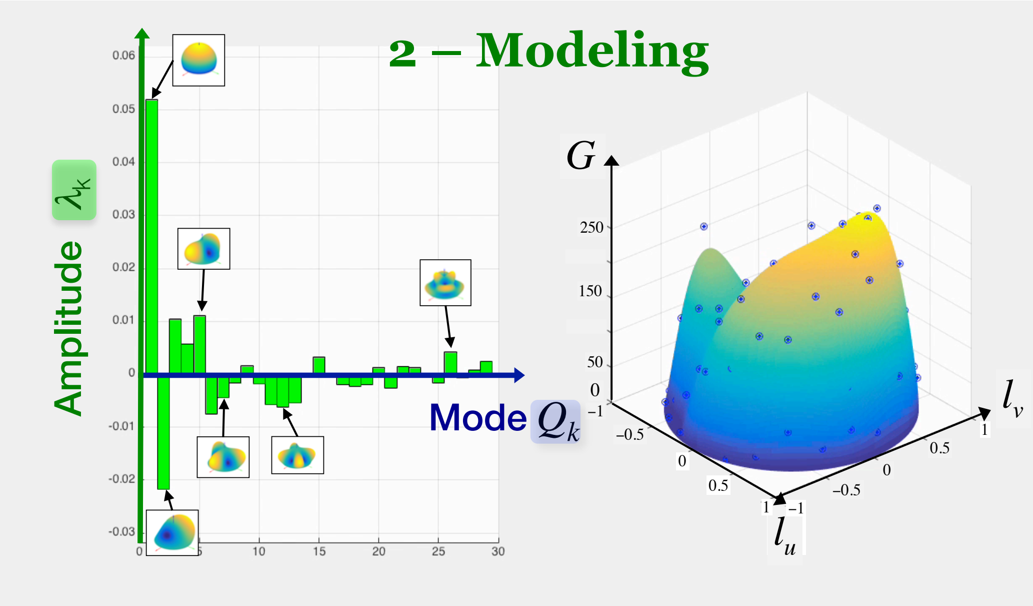


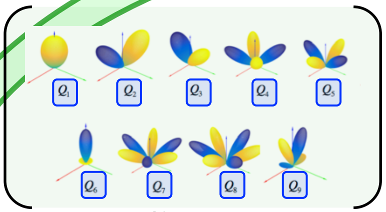
…

2. Modeling the angular reflectance

For each pixel:

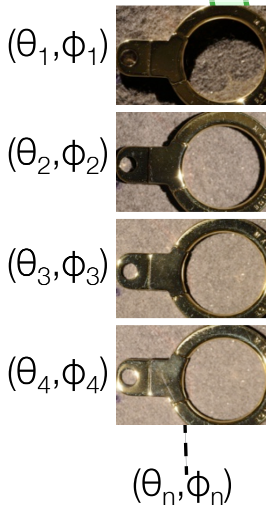
λ_k modal coefficients obtained by projecting the measured luminances L onto each mode Q_k of the basis

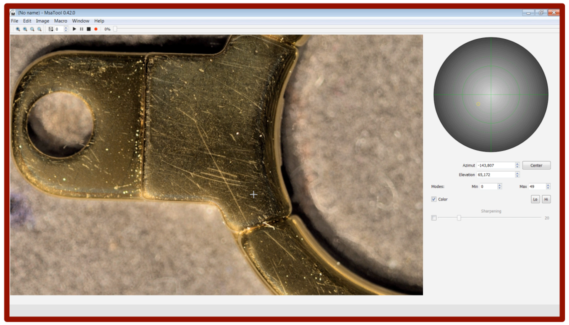




$$f_{(\theta_v,\varphi_v)}(\theta_i,\phi_i) = \sum_{k=1}^{n} \lambda_k(\theta_v,\varphi_v) Q_k(\theta_i,\phi_i) + R_n$$

1 – Acquisition





3 – Rendering

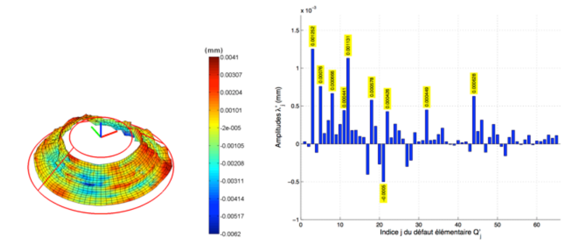
2. Modeling the angular reflectance

- Assessing the image quality of the reconstructed images

Discrete Modal Decomposition

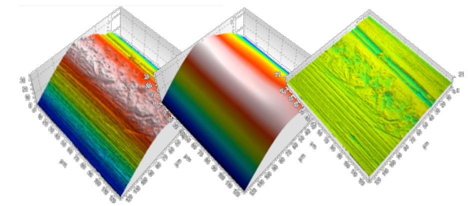
From mechanical vibrations, DMD has notably been applied for:

1. **Characterization and specification of geometric deviations in form,** in the field of geometric tolerancing [1]

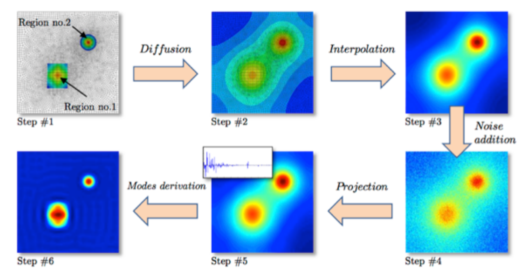


(a) Cartographie des écarts normaux résiduels (b) Spectre modal des amplitudes

2. **The 3D multi-scale topographic measurements of roughness analysis** (form, waviness and roughness) [2]



3. **The estimation of spacial term of a heat diffusion problem** [3]



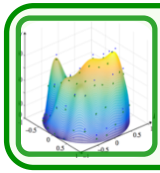
4. **The assessment of the angular distribution of reflectance from RTI data** [4]

Works initiated by **Serge Samper** at SYMME Laboratory and continued by:

[1] H. Favreliere, Modal Tolerancing : From metrology to specifications, Ph.D. thesis, 2009
[2] G. Le Goic and Al., Multi scale modal decomposition of primary form, waviness and roughness of surfaces, Scanning, 2011
[3] T. Pottier and Al., Proposition of a modal filtering method to enhance heat source computation…, IEJS, 2014
[4] G. Pitard and Al., Discrete Modal Decomposition for surface appearance modelling and rendering, Optical Metrology SPIE, 2015

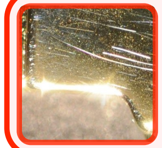
1. Reflectance Transformation Imaging

- Related works
- RTI Devices



2. Modeling the angular reflectance

- Angular reflectance modeling
- Discrete Modal Decomposition



3. Computing the saliency maps

- Rotation-invariant representation
- Multivariate analysis

4. Ongoing works

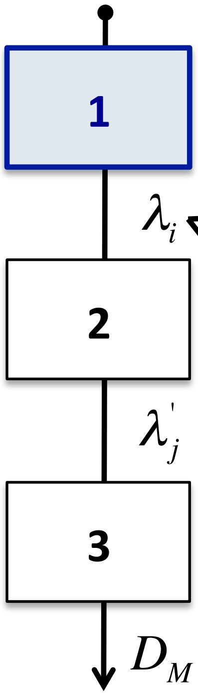
➔ Change the DMD parametrization in a rotation-invariant representation to ease the detection

Proposal

- aim: creation of a detection method based on the modal spectra

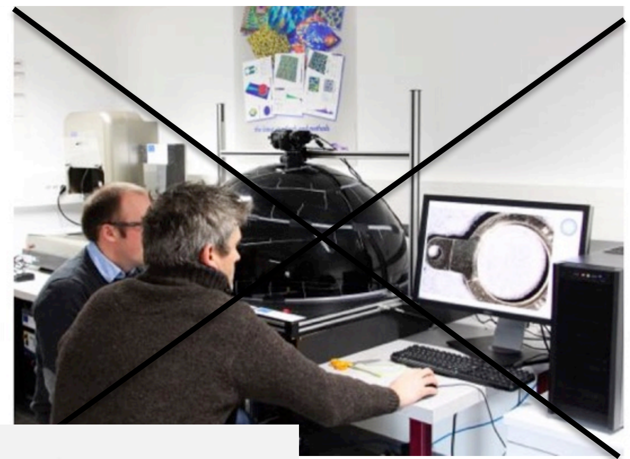
➔ Detecting the significant deviations in the angular reflectance

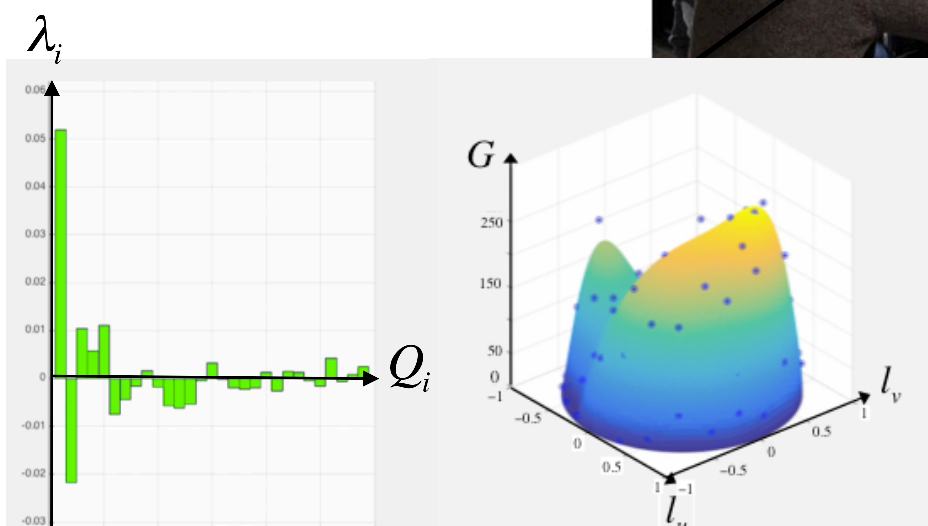
RTI DATA (dataset of images)



Step 1:
Discrete Modal Decomposition

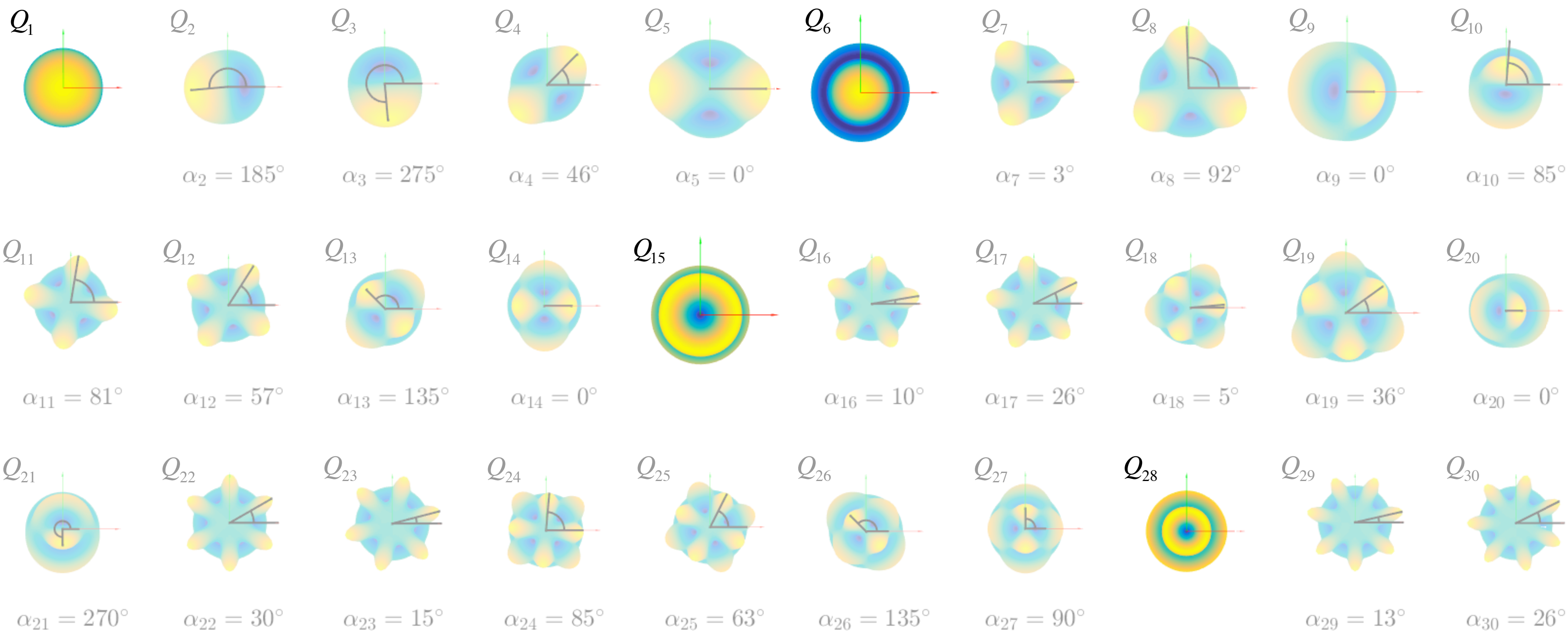
Salience map





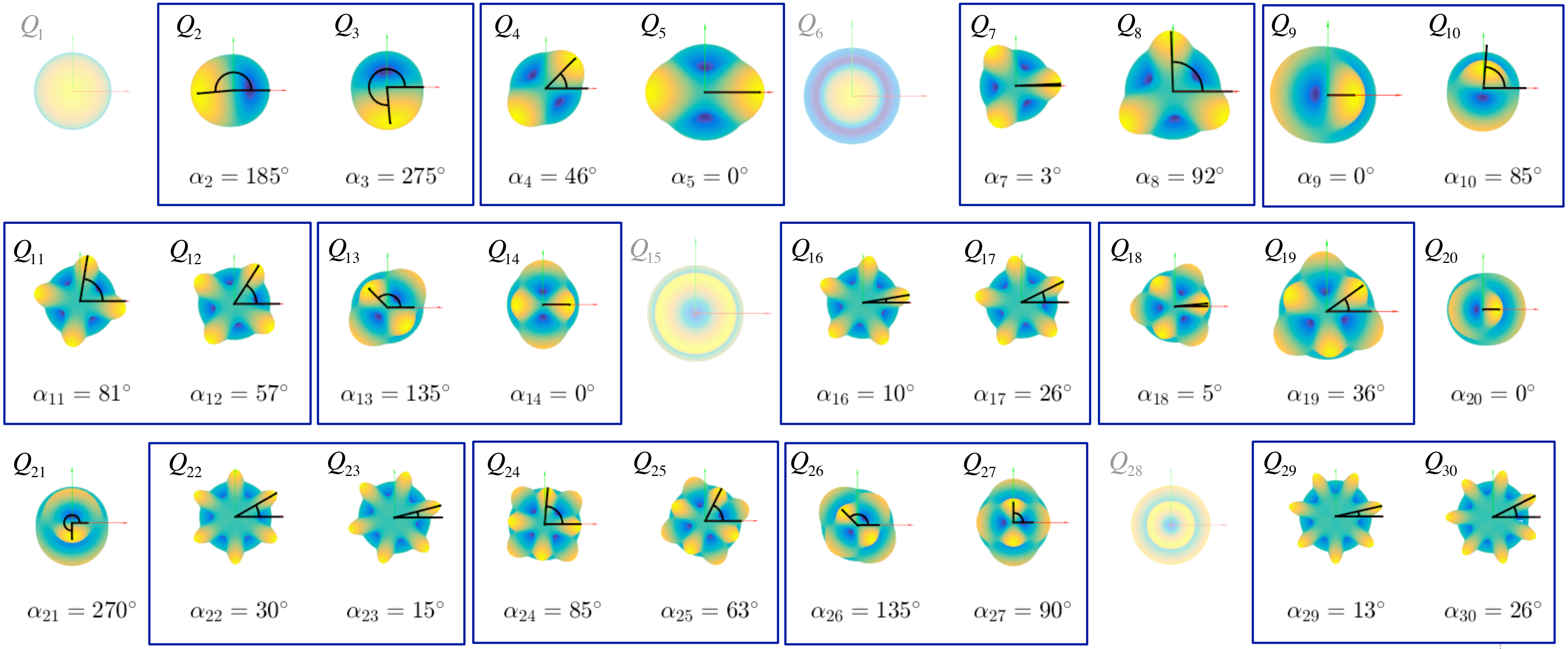
Two families of modes in the RMB

- **Simple modes** ➔ rotation invariants
- **Congruent modes**



Two families of modes in the RMB

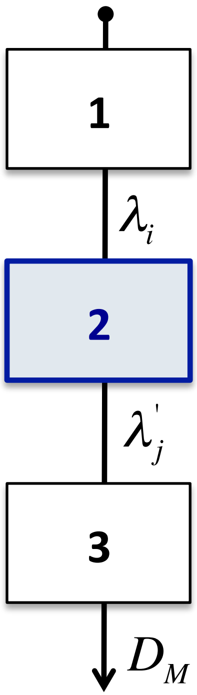
- Simple modes
- **Congruent modes** → pair with the same shape but oriented differently



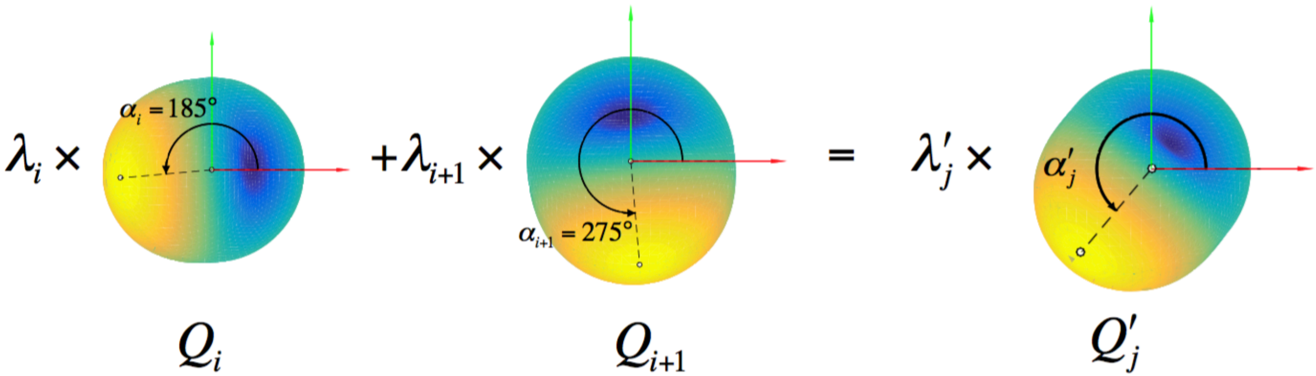
Step 2: changing the parameterization for the congruent modes

➔ Separating *phase-angle* and *amplitude* components

RTI DATA
(dataset of images)



Salience map

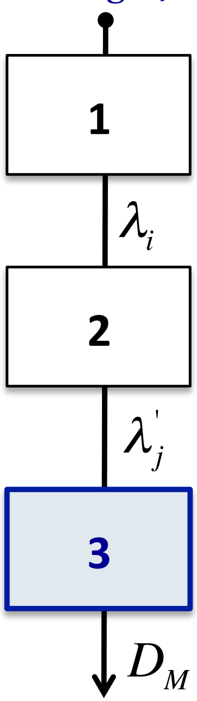


❑ **Amplitude** $\lambda'_j = \sqrt{\lambda_i^2 + \lambda_{i+1}^2}$ ➔ Rotational invariant component

❑ **Phase-angle** ~~$\alpha'_j = \alpha_i + \arctan \frac{\lambda_{i+1} sin(\alpha_{i+1} - \alpha_i)}{\lambda_i + \lambda_{i+1} \cos(\alpha_{i+1} - \alpha_i)}$~~

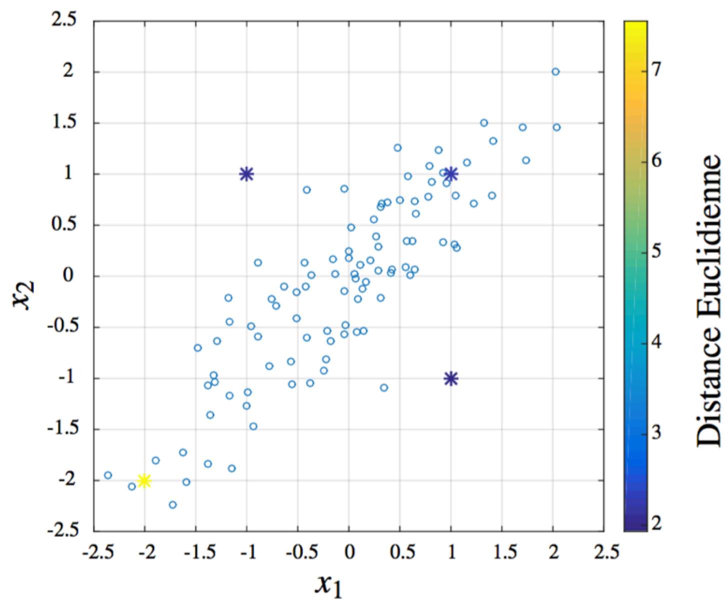
➘ Step 3: multivariate analysis of modal amplitudes $\lambda_j^{'}$

RTI DATA (dataset of images)

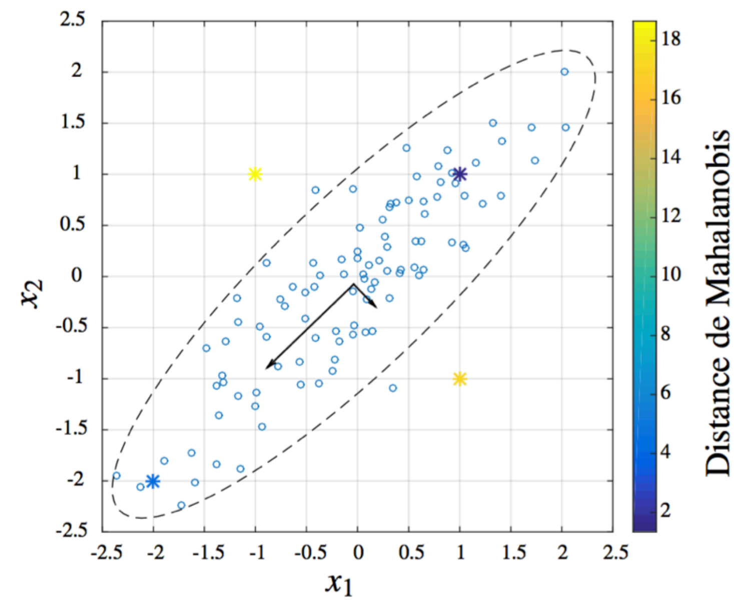


Salience map

✔ **Mahalanobis distance:** taking into account the variance of data, the different scales between the variables, and their correlations

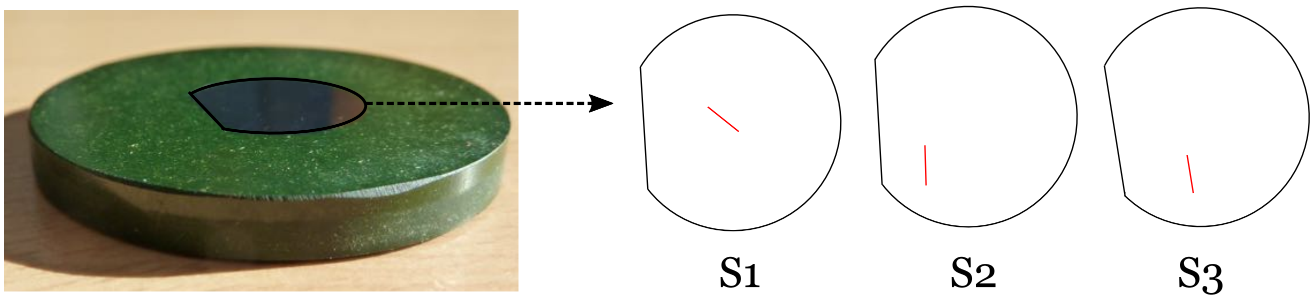


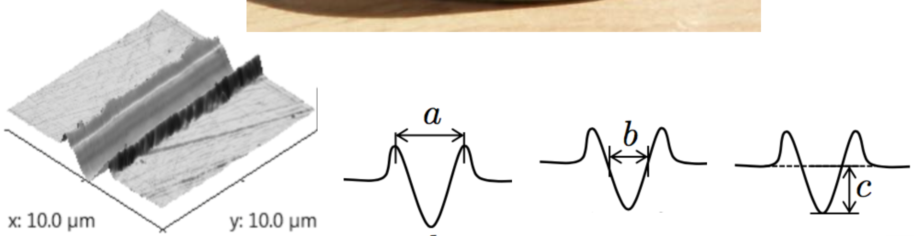
$$d(x) = \|x - \mu\|$$



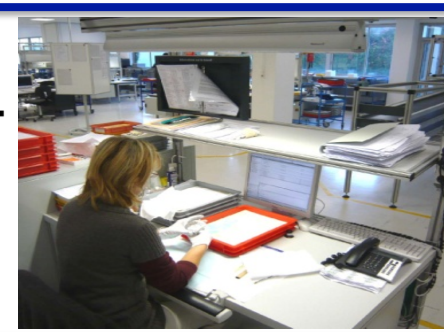
$$D_M(x) = \sqrt{(x-\mu)^T \Sigma^{-1} (x-\mu)}$$

Samples: 3 polished surfaces





Sample	a (μm)	b (μm)	c (μm)	Visibility (%)
$\mathcal{S}_1$	1.25	0.75	58.32	64.6
$\mathcal{S}_2$	0.98	0.61	43.57	14.5
$\mathcal{S}_3$	0.68	0.44	26.1	5

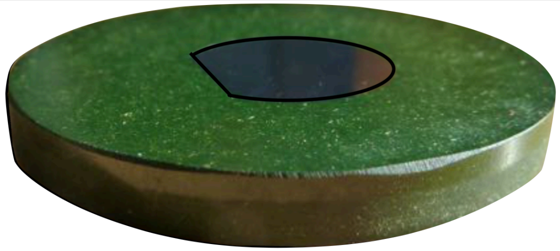


Psychophysical experiments

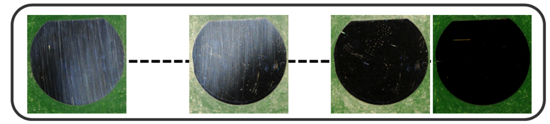
T. Puntous, et al. "Ability of quality controllers to detect standard scratches on polished surfaces," *Precision Engineering*, 2013

3. Computing the saliency maps

Results



RTI data acquisition



RTI DATA
(dataset of images)

1

λ_i

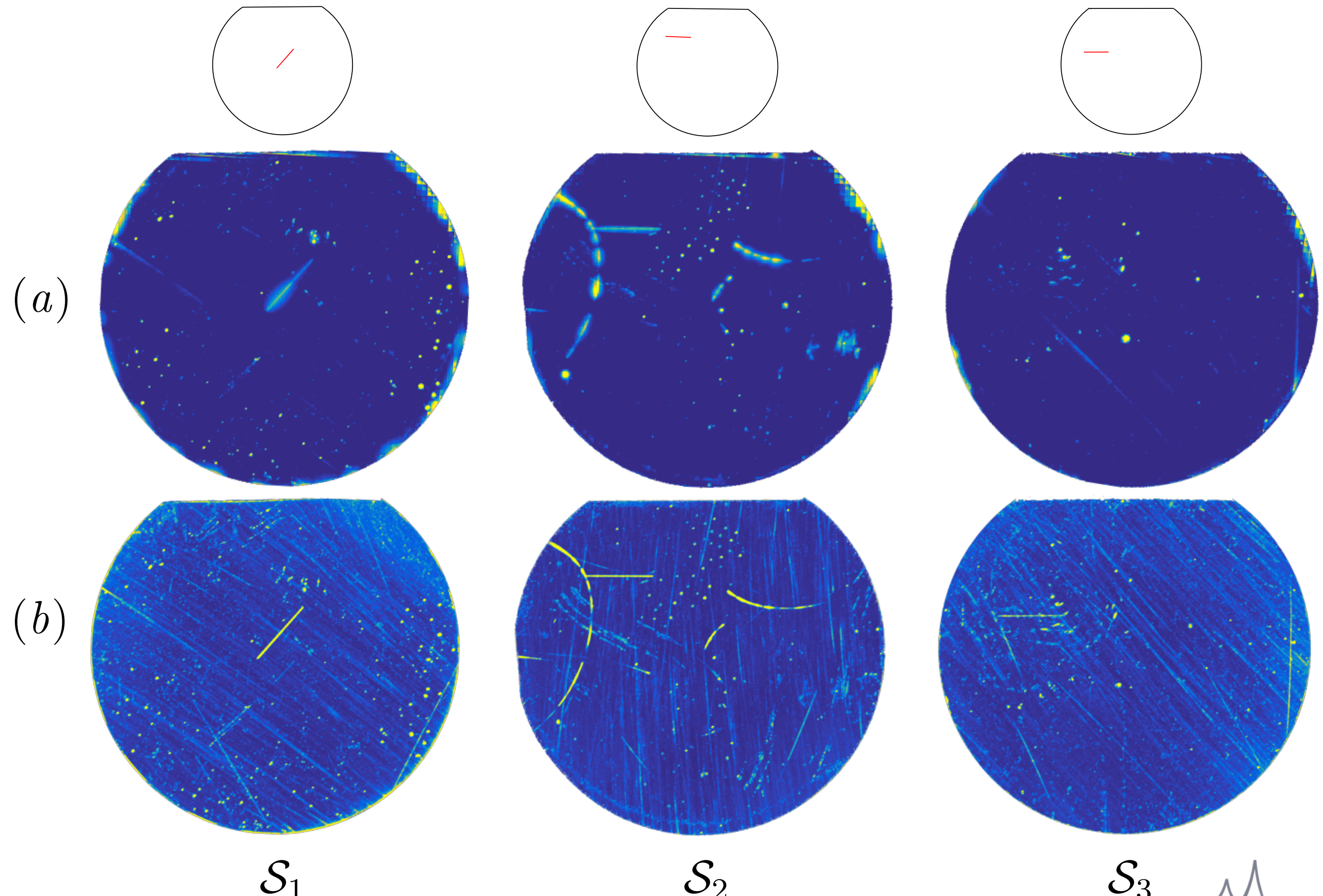
2

λ'_j

3

D_M

Salience map



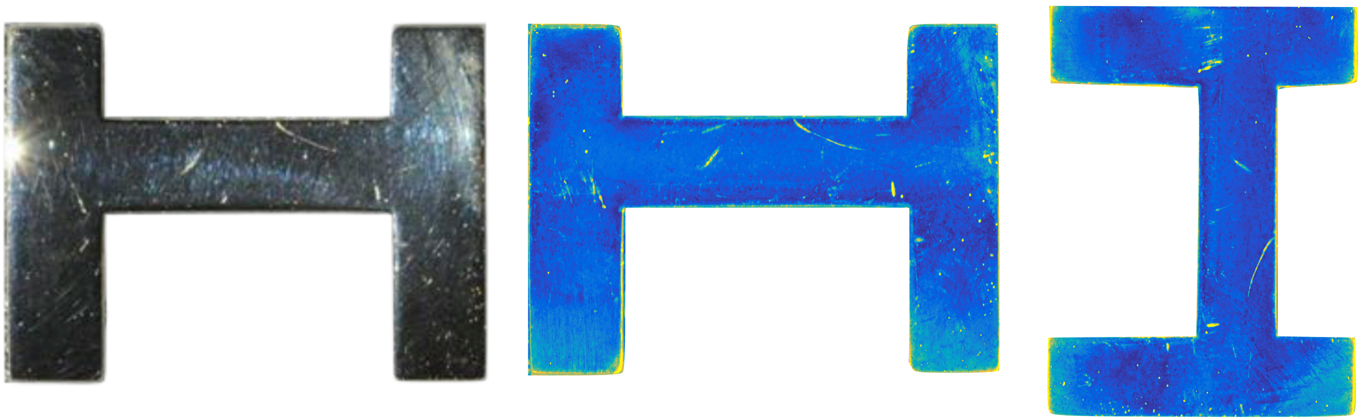
Itti's method

Our

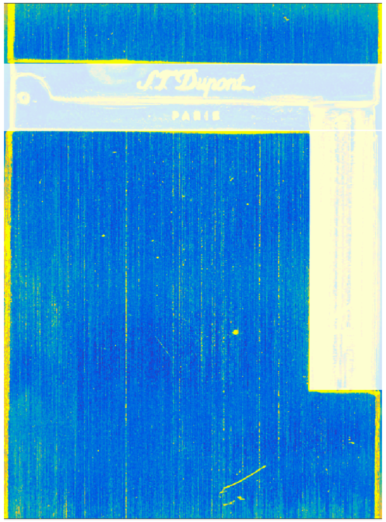
(speedup ≈150 times)

3. Computing the saliency maps

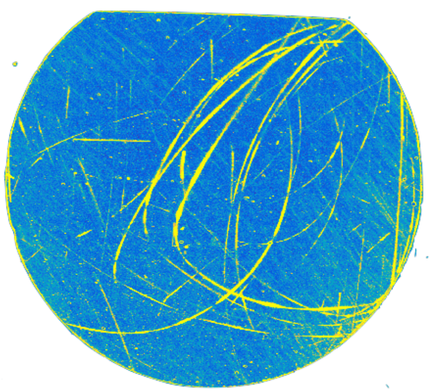
- **Saliency maps obtained from our methodology**



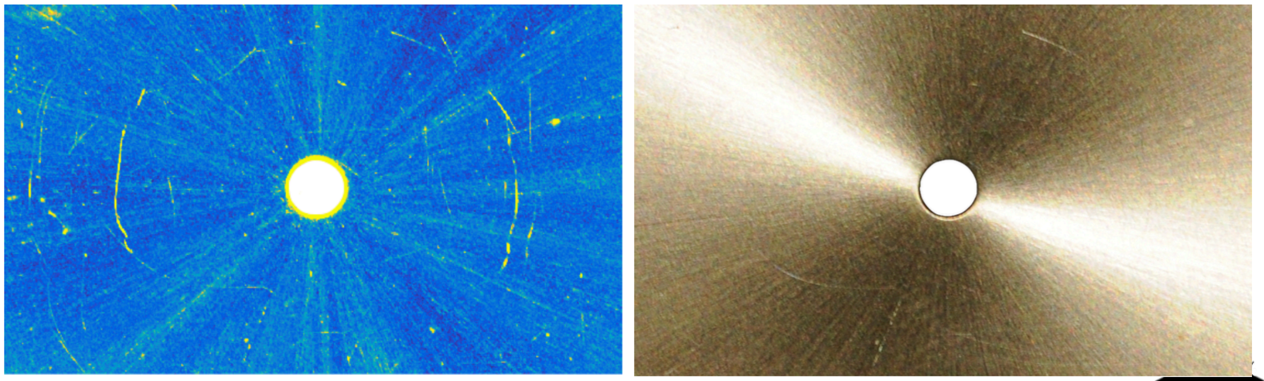
Link in a watch bracelet



Lighter body

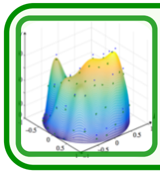


Highly polished surface

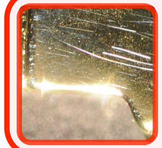


Sunray pattern dial watch

1. Reflectance Transformation Imaging
- Related works
- RTI Devices



2. Modeling the angular reflectance
- Angular reflectance modeling
- Discrete Modal Decomposition



3. Computing the saliency maps
- Rotation-invariant representation
- Multivariate analysis

4. Conclusion

4. CONCLUSION

We claim:

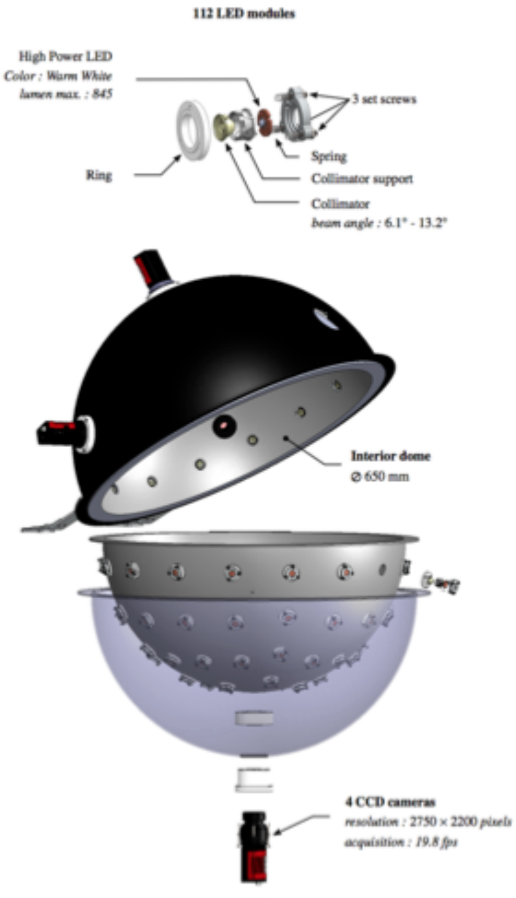
- **A change in the DMD parametrization** of angular reflectances for the comparison of reflectance shapes independently from their spatial orientation

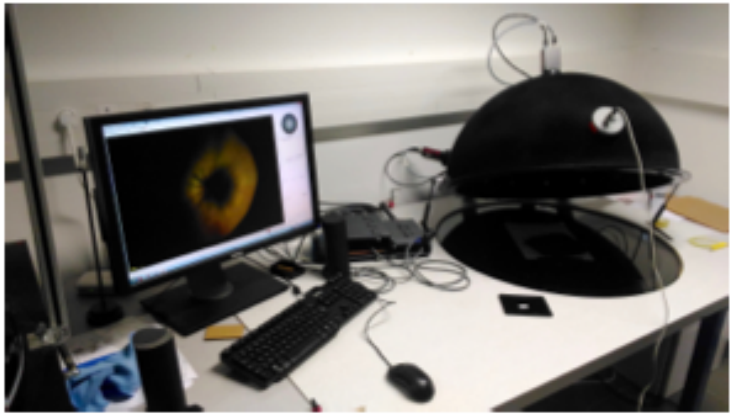
- **Detection and location of changes (saliency maps) in reflectance shape** over the inspected by performing a multivariate analysis in this rotation-invariant space

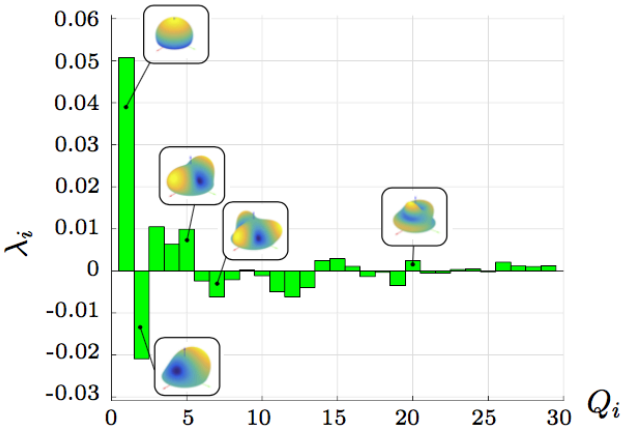
Ongoing tasks:

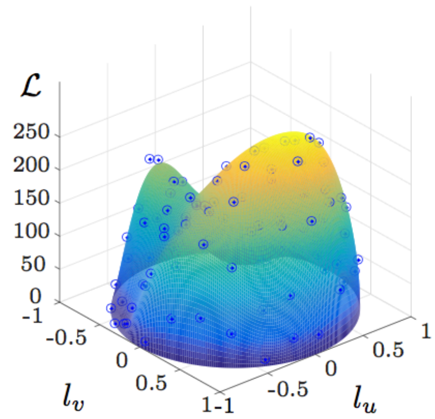
- **Evaluation of the criticity of the detected anomalies** by using several modalities (reflectance, geometry, spectral response)

THANKS !









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