Robust and Fast 3D Shape Matching via Adaptive Algebraic Fitting

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Outline

- Introduction
- Our method
  - Key-point detection
  - Critical net based shape descriptor
- Experimental results
- Applications
- Conclusion and future works

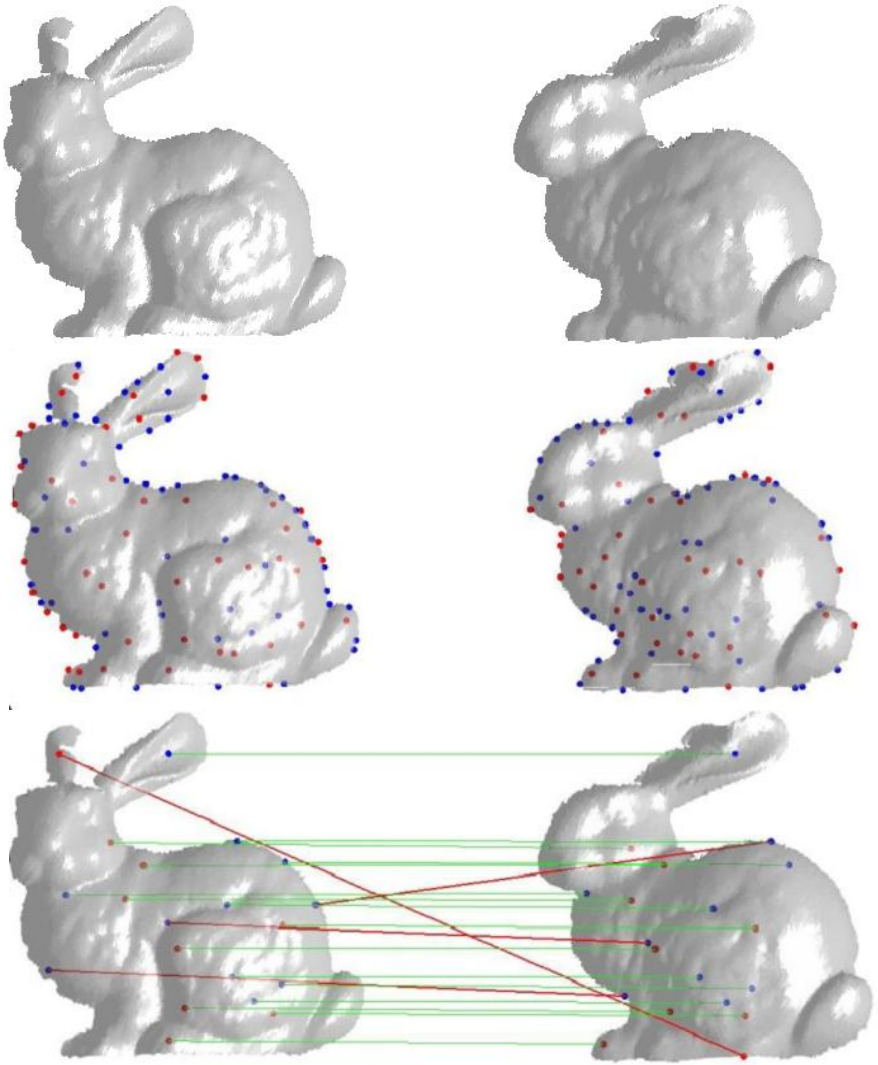
Introduction:

Sparse 3D shape matching

3d shapes

Key points detection and description

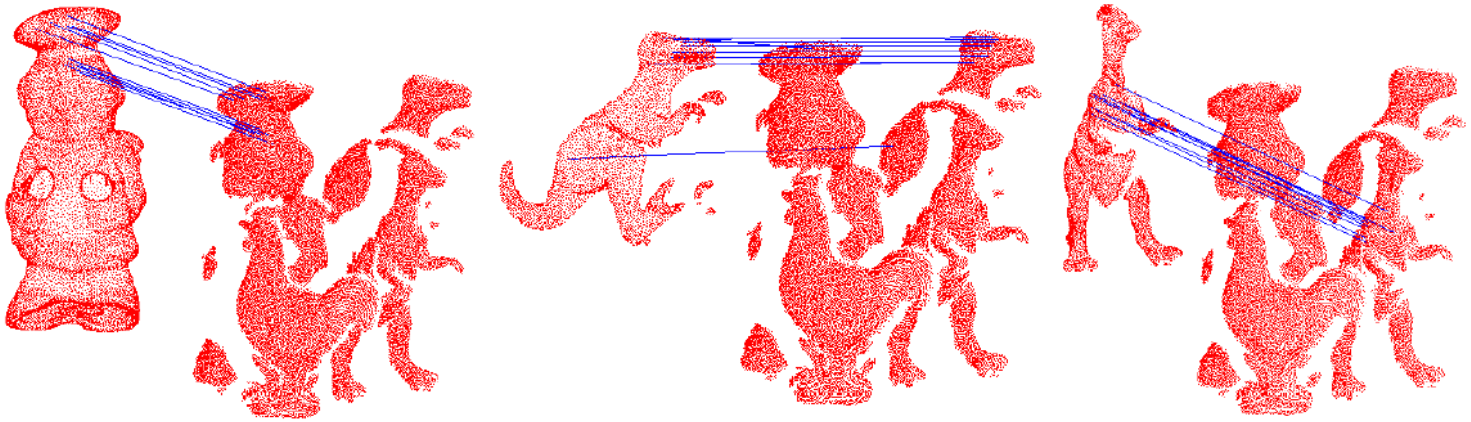
Key points matching



Introduction:

Motivation

- 3D recognition [Mian IJCV 2010]

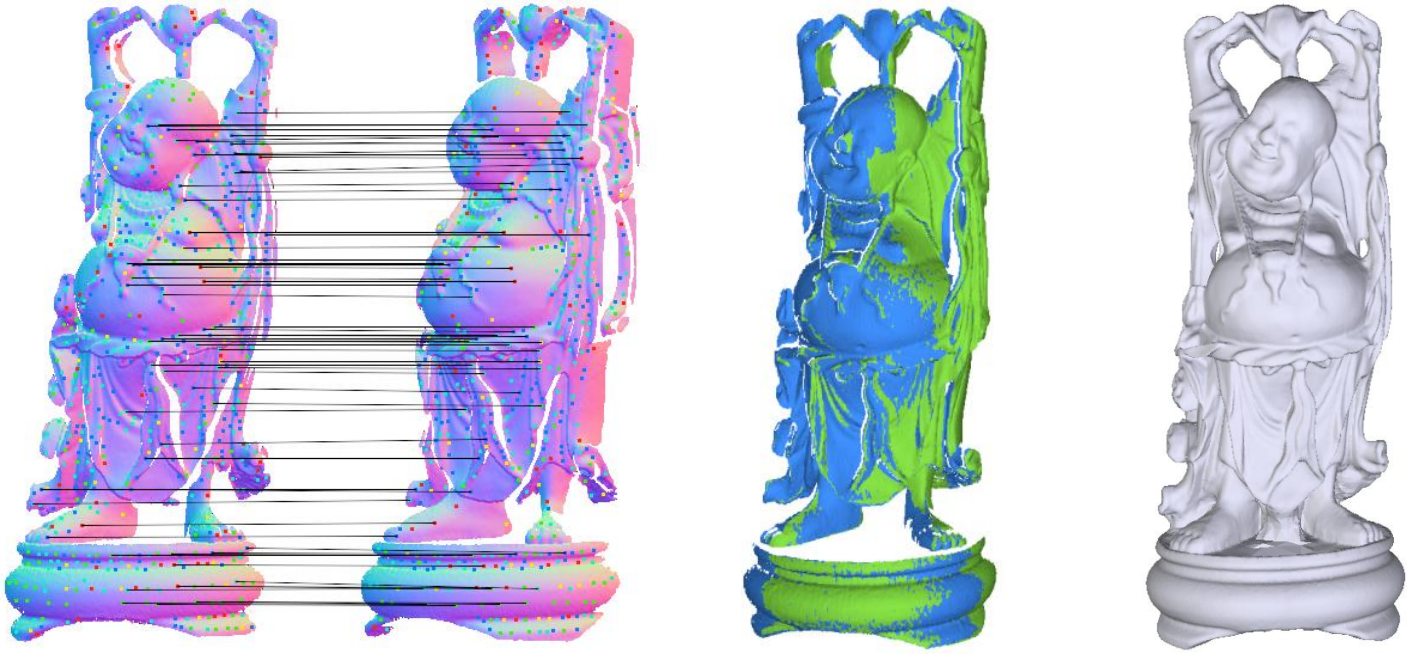


- Model retrieving

Introduction:

Motivation

- Surface registration [Novatnack ECCV 2008]



Introduction:

Motivation

- Digital archiving [Ikeuchi Lab]
  - Digital Bayon Temple project

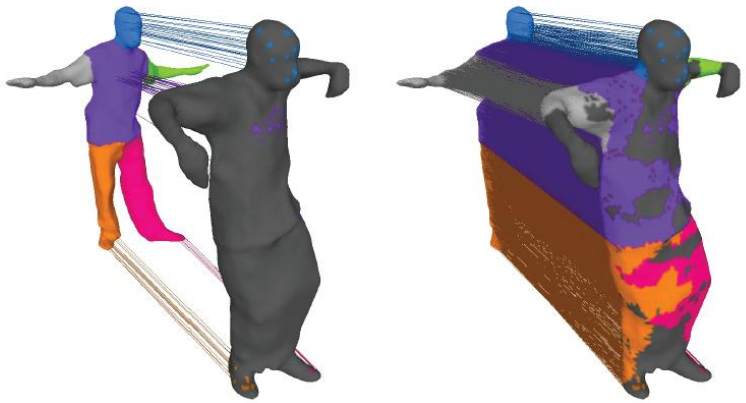
Introduction:

Motivation

- Dense matching [Zeng CVPR 2010]

(a) Sparse matching (b) Dense matching (a) Sparse matching (b) Dense matching

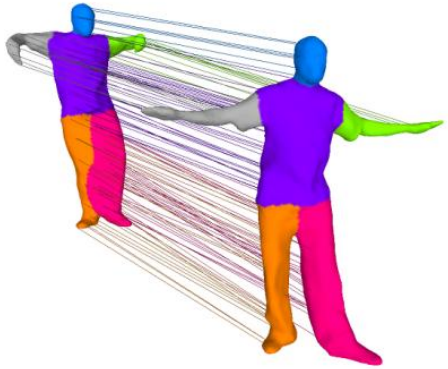
- Motion tracking [Tung CVPR 2011]



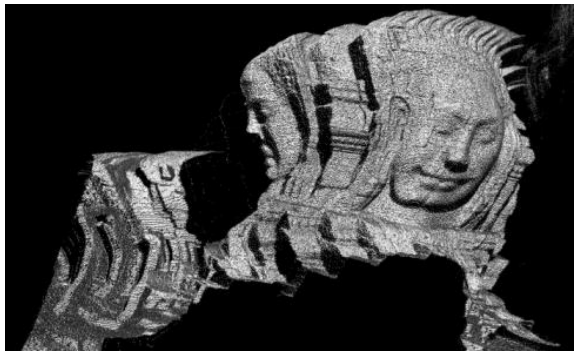
Introduction:

Recent trend

- In recent years, there is demand on sparse matching of deformed objects.



Moving object



Moving camera

- Computational efficiency is also demanded for real time processing

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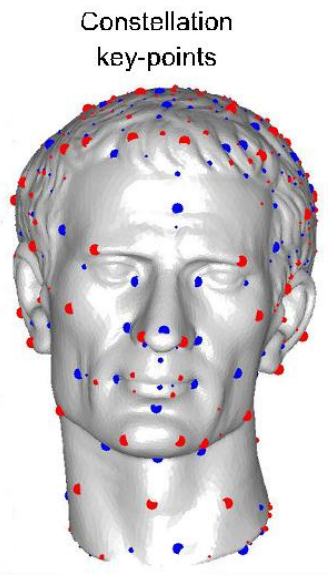
Our contribution

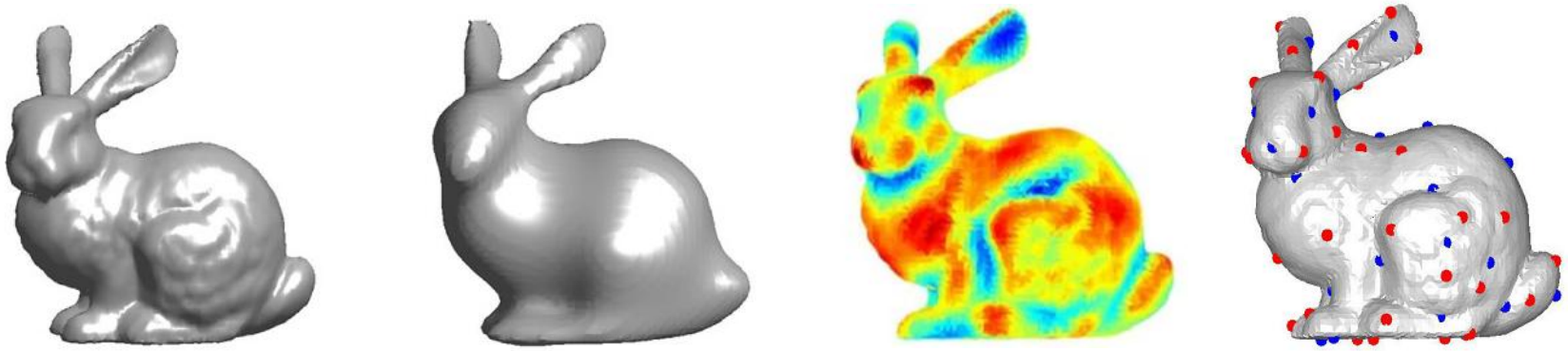
- Apply algebraic surface fitting to sparse 3D shape matching
- The proposed detector is robust on deformation
- Fast



Key-point detection:

Methodology

- Step 1: algebraic surface fitting
- Step 2: point deviation measurement
- Step 3: key point selection



Step 1 Step 2 Step 3

Algebraic surface fitting

- 3-D implicit polynomial (IP)

$$f_n(\boldsymbol{x}) = \sum_{0 \le i,j,k, i+j+k \le n} a_{ijk} x^i y^j z^k = 0$$

- 3-D shape induced by the polynomial

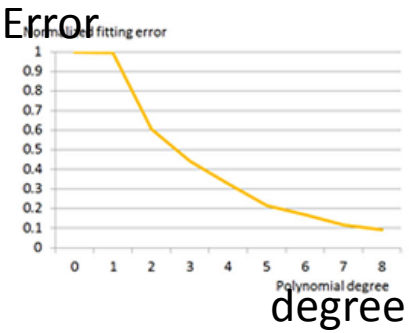
$$\tilde{\Gamma}_0 = \{\boldsymbol{x} = (x, y, z) | f(\boldsymbol{x}) = 0\}$$

Origin object

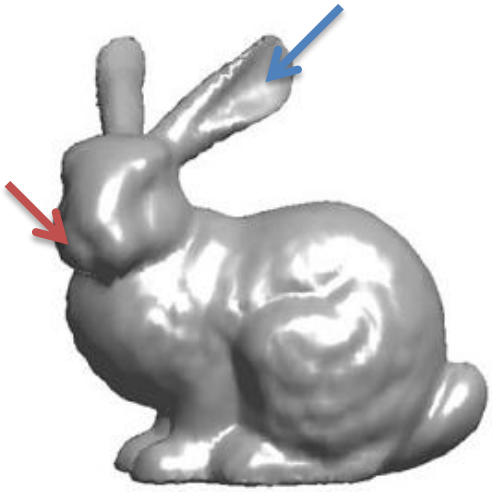
4-degree

6-degree

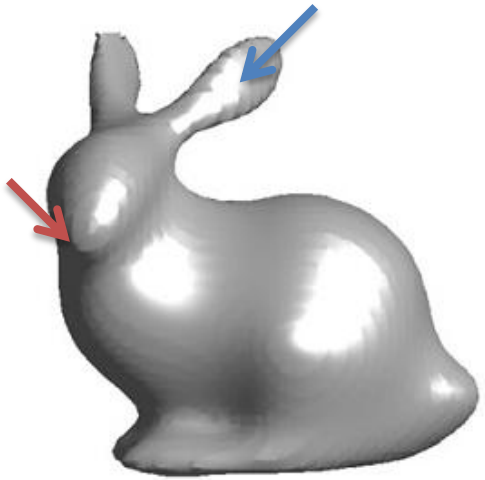
10-degree



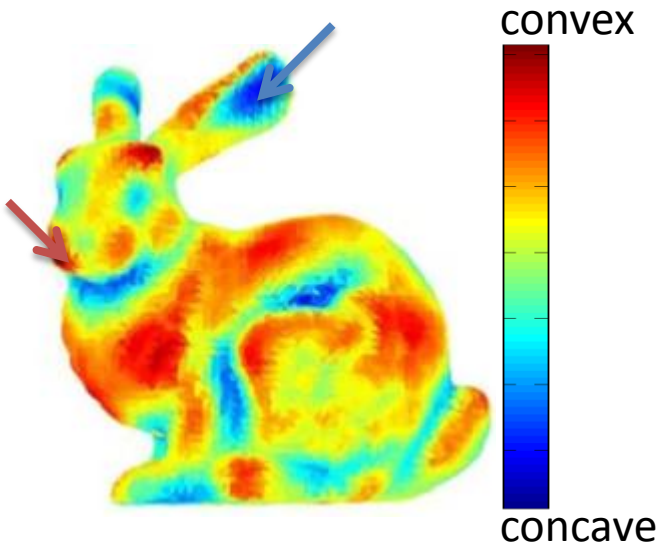
Algebraic distance of point deviation



Origin object



10-degree fitting $f(\boldsymbol{x}) = 0$



Color map of $f(\boldsymbol{x})$ on original object

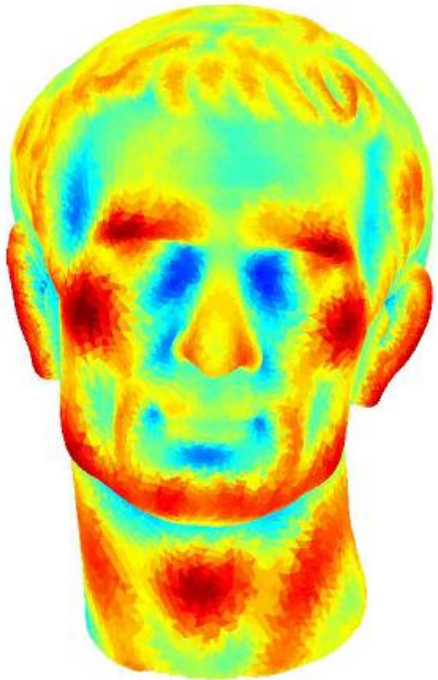
Key-point detection:

Key-point selection

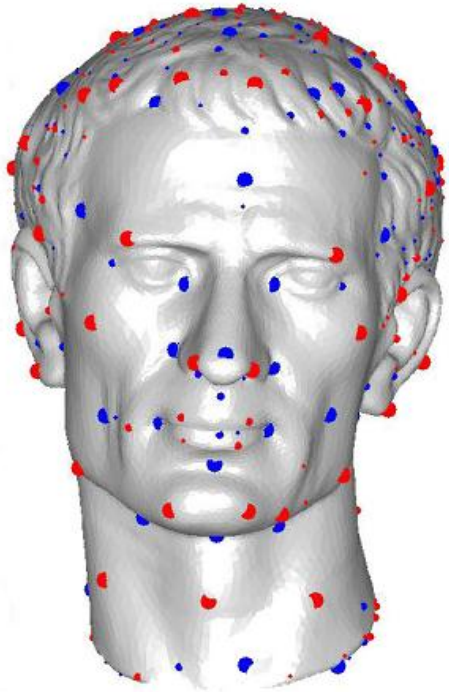
- Select local minimums (blue) and local maximums (red) according to the color map.

Original model

Color map of point deviation



Stand alone key-points



Key-point detection:

Mathematical support

- Theorem (local algebraic distance):
  - Given $3D$ shape Γ_0 consists of point set $\{x\}$ and its n-degree polynomial from 3L-addaptive-ASF $\tilde{f}(\cdot)$ along with the induced smooth approximation $\widetilde{\Gamma_0}$. For each point x, its polynomial value $\tilde{f}(x)$ is a locally signed algebraic distance of how far it is deviated from $\widetilde{\Gamma_0}$.

- Lemma 1 (monotonicity):
  - By 3L ASF, a locally monotonic space is generated around the 3D surface $\widetilde{\Gamma_0}$.

- Lemma 2 (inclusion):
  - The points on 3D surface Γ_0 are guaranteed to be located inside the locally monotonic space Ω with a very high probability

- Please refer to paper for details.

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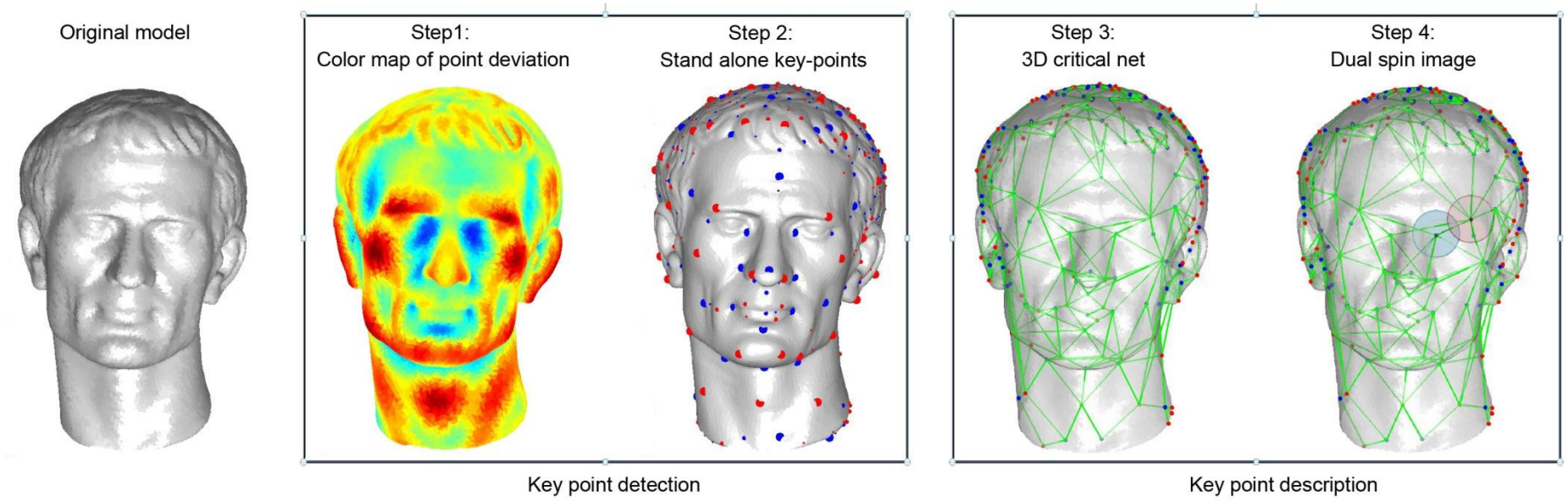
Critical net based shape descriptor

3D critical net

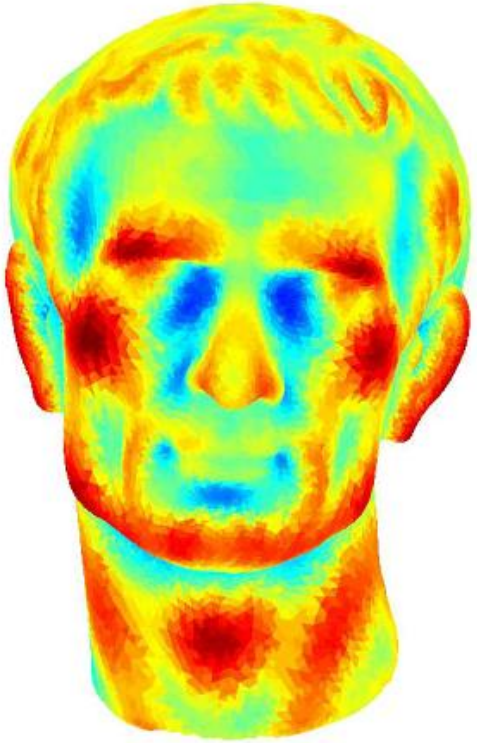
- Standalone key points would be more useful if a structure is given.



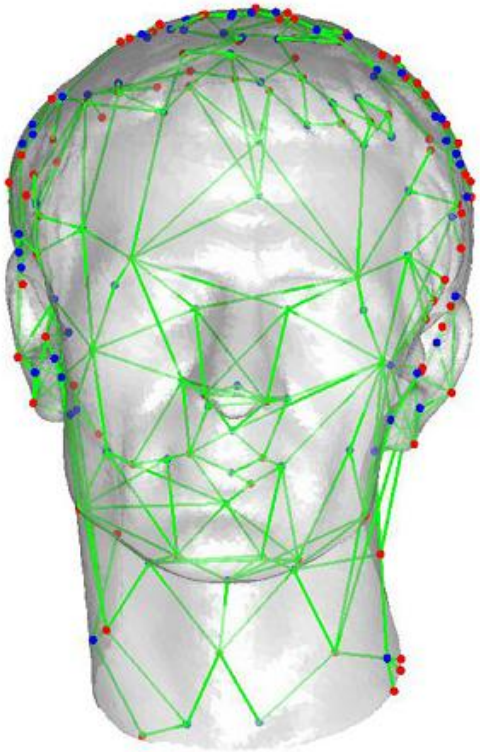
Critical net based shape descriptor

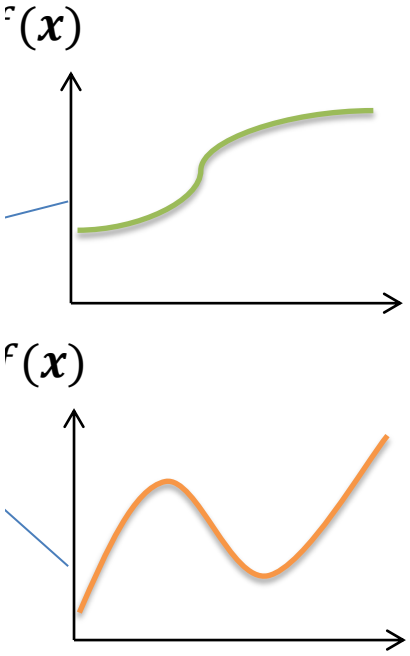
Generate 3D critical net

Color map of point deviation



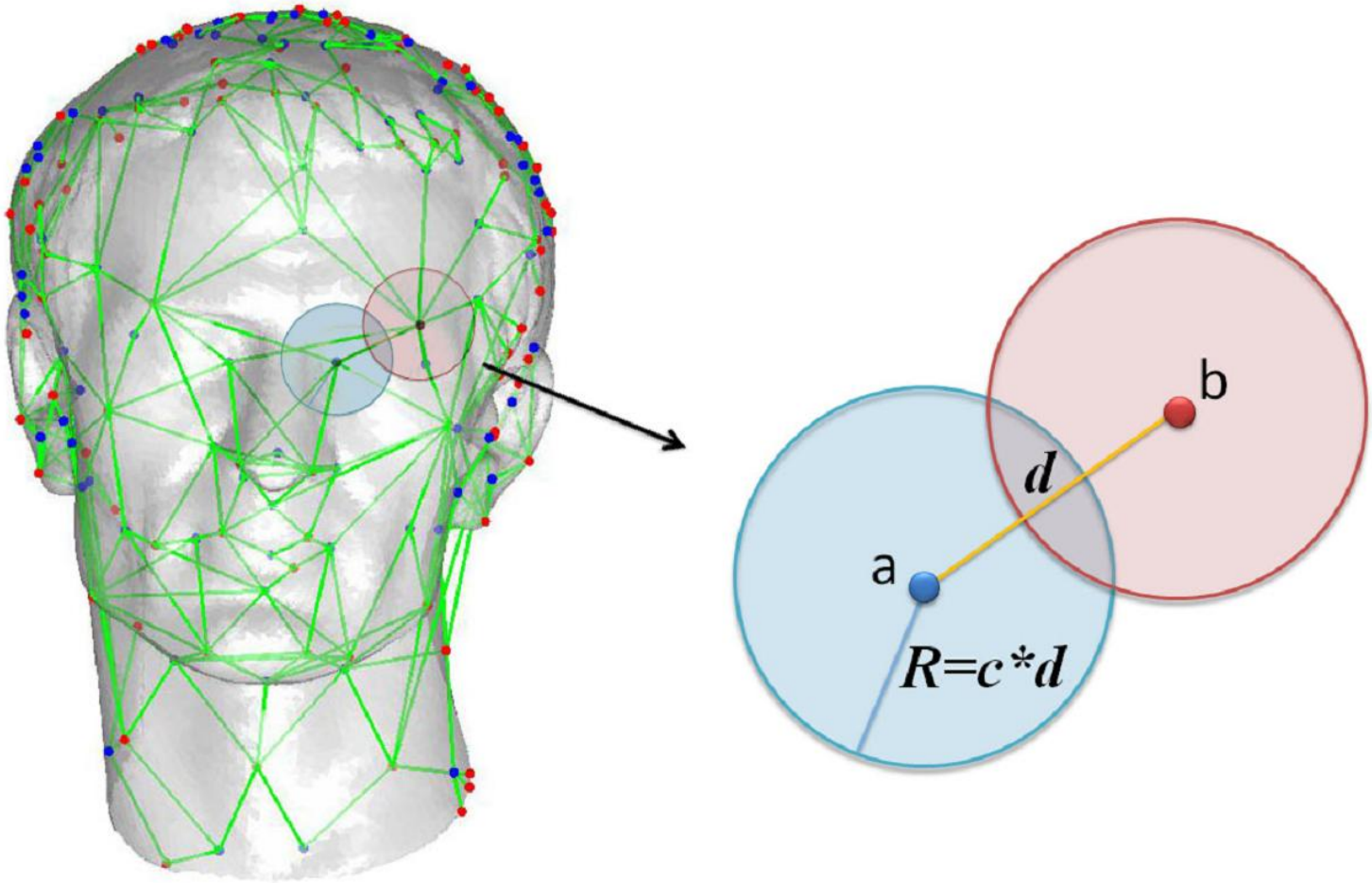
3D critical net





Critical net based shape descriptor

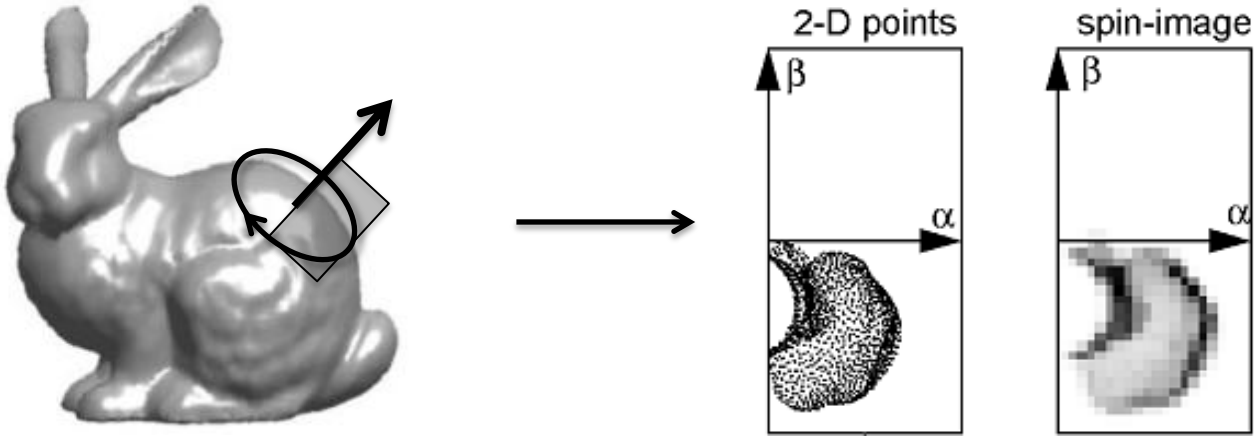
Dual Spin Image



Critical net based shape descriptor

Dual spin image

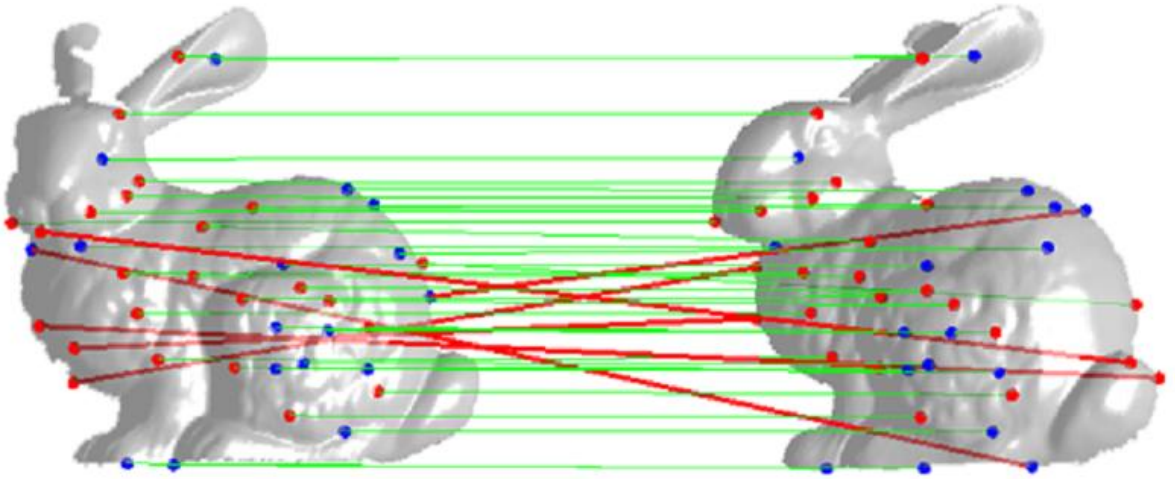
- Spin Image
- [A. E. Johnson PAMI (1999)]



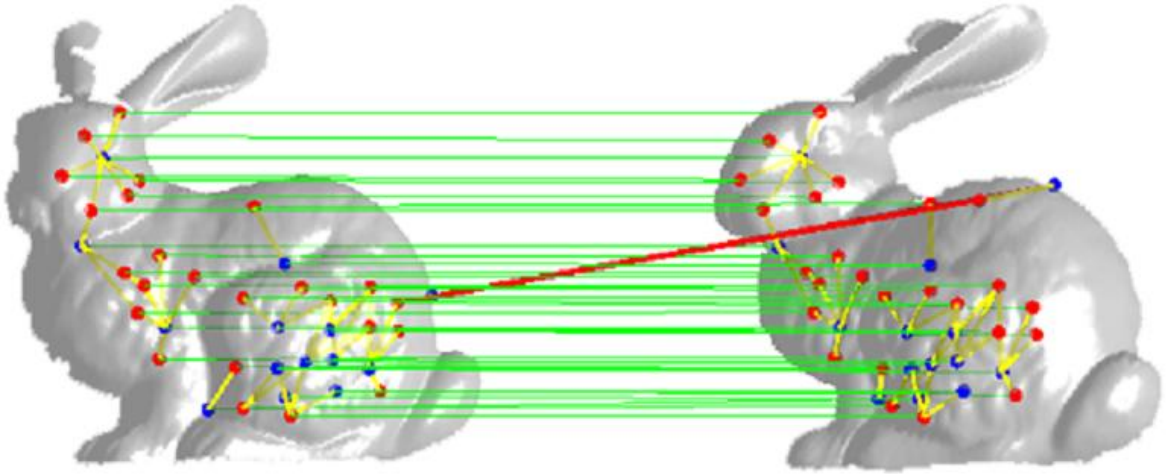
Critical net based shape descriptor

Matching

Spin Image



Dual Spin Image



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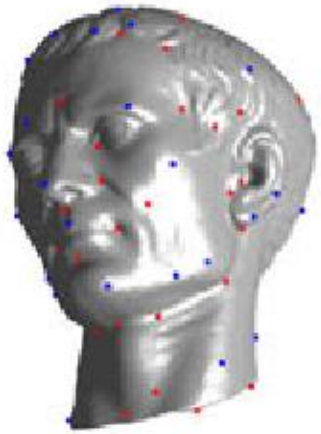
Experimental results

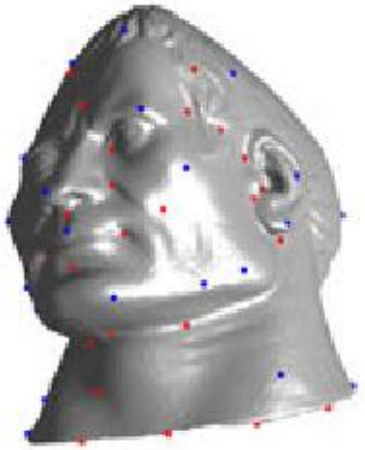
Repeatability of the detector

origin shape



KP1

deformed shape

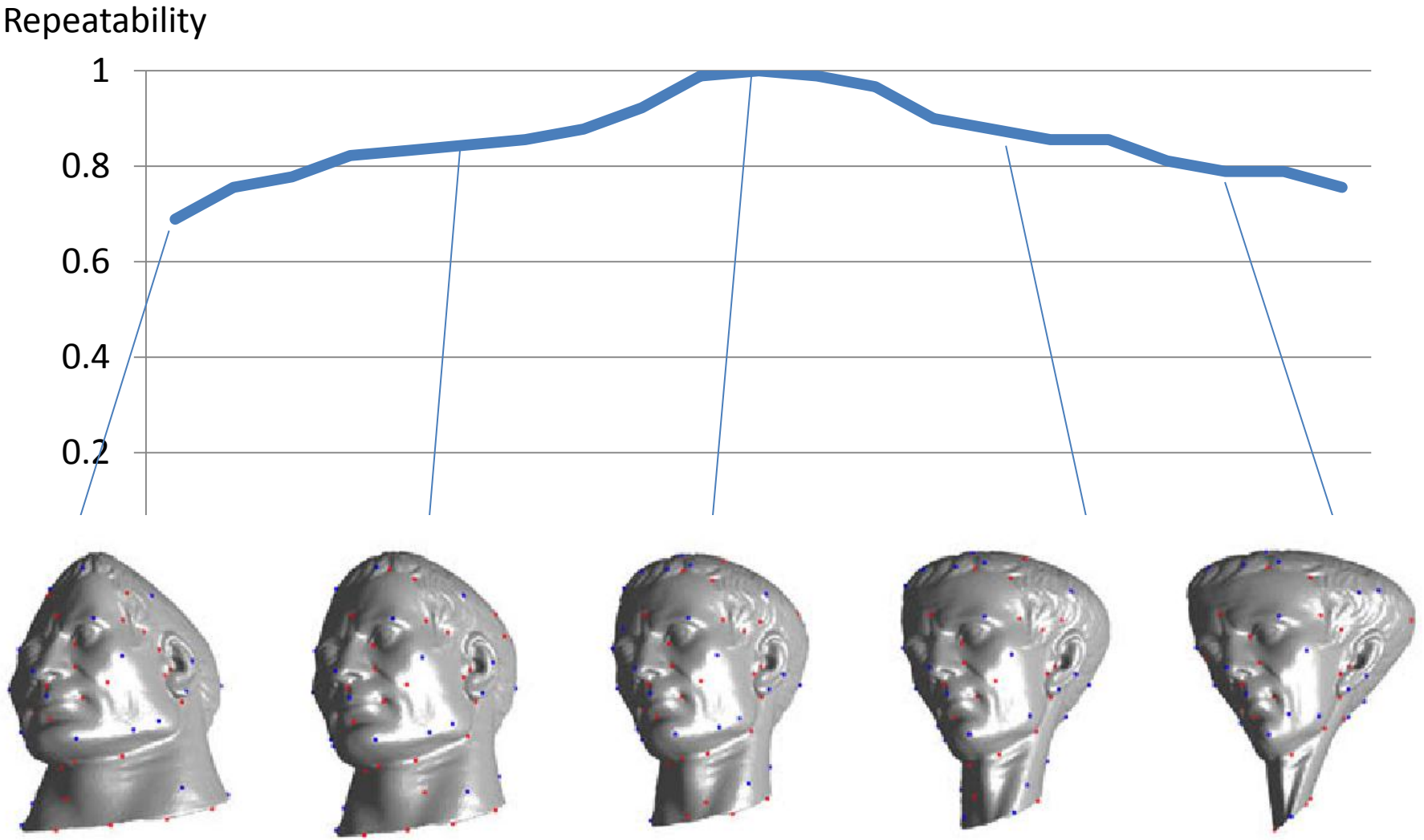


KP2

$$repeatability = \frac{repeatable \quad points}{\min(points \quad in \quad \{KP1\}, \{KP2\})}$$

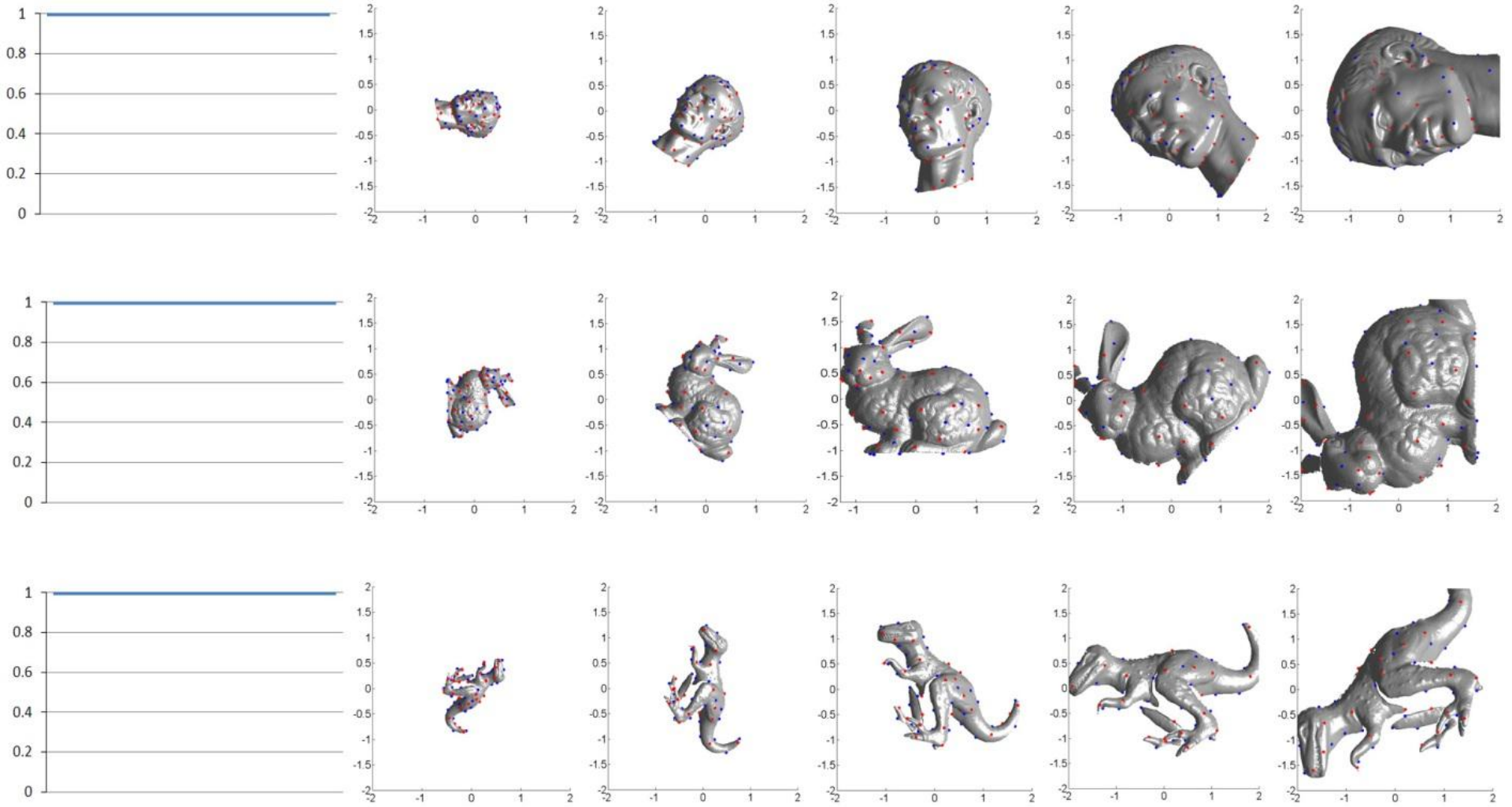
Experimental results

Repeatability of the detector



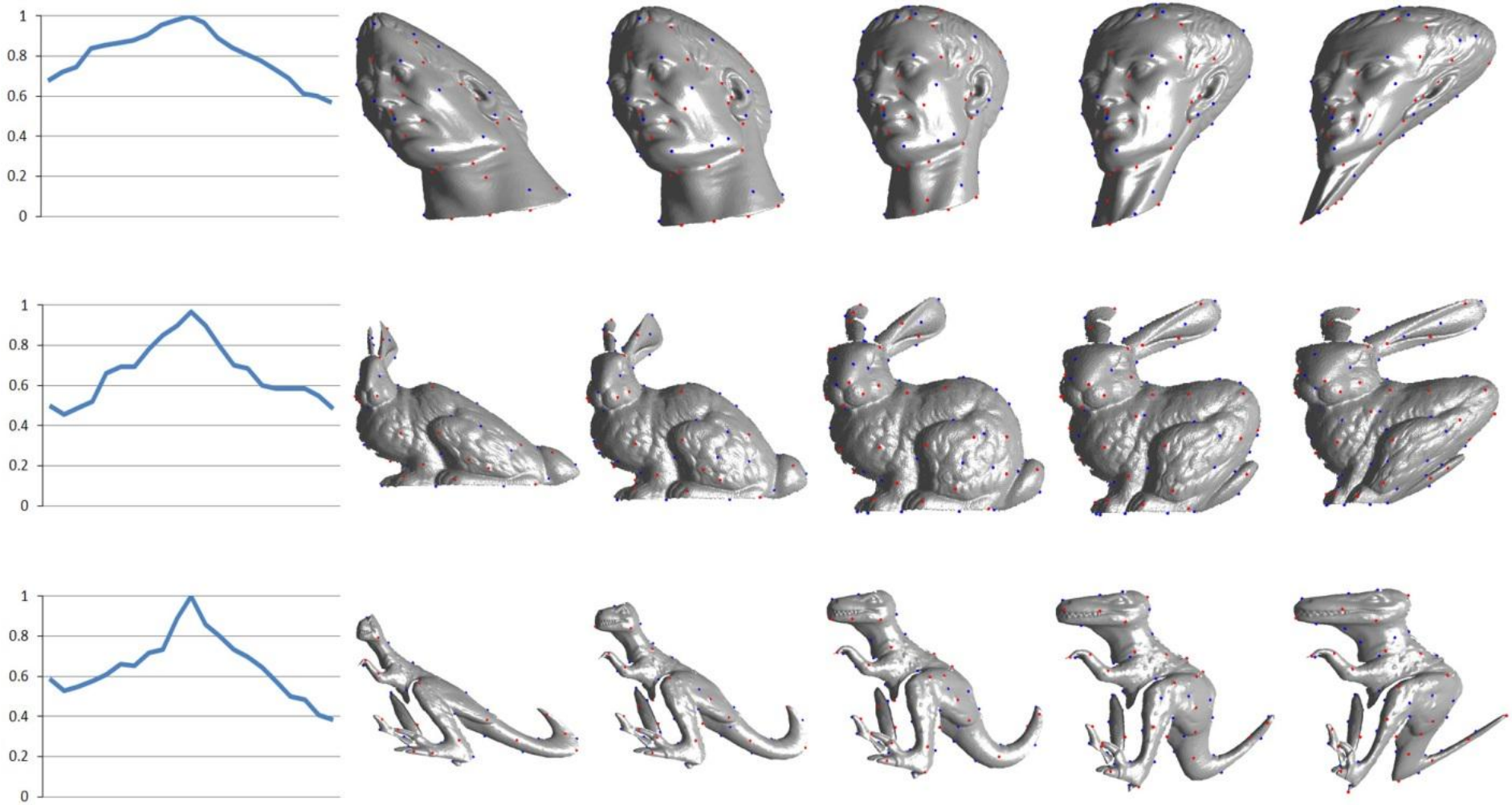
Experimental results: Repeatability of the detector

Invariance to rotation and scaling



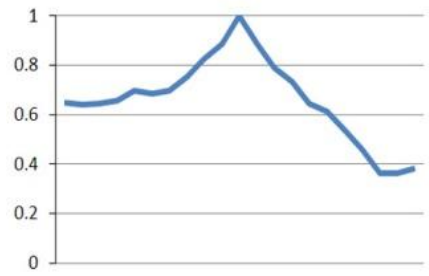
Experimental results: Repeatability of the detector

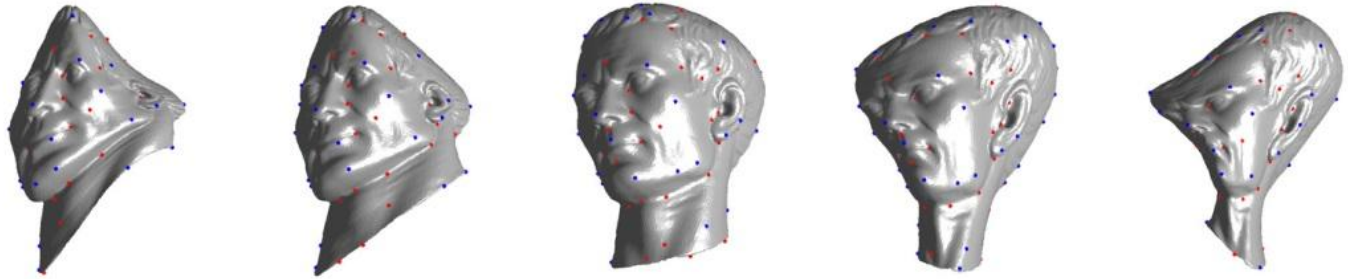
Affine deformation

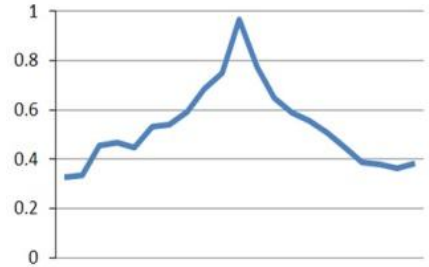


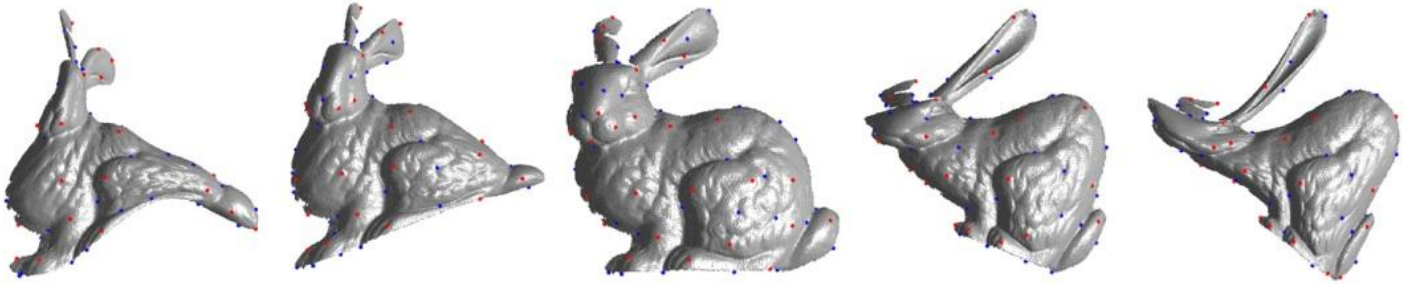
Experimental results: Repeatability of the detector

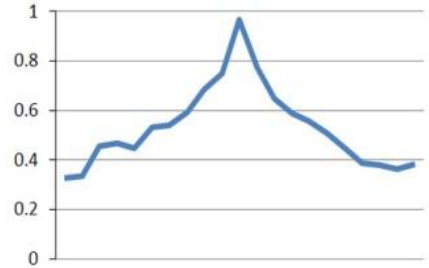
Non-linear deformation

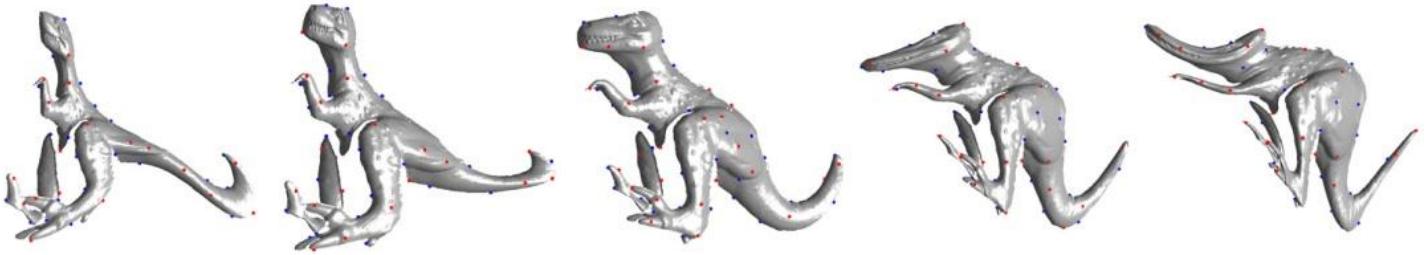






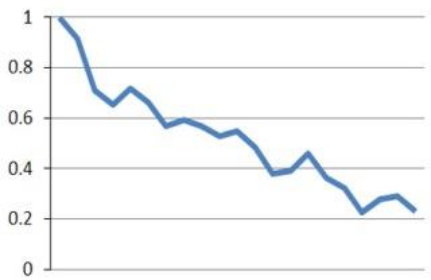


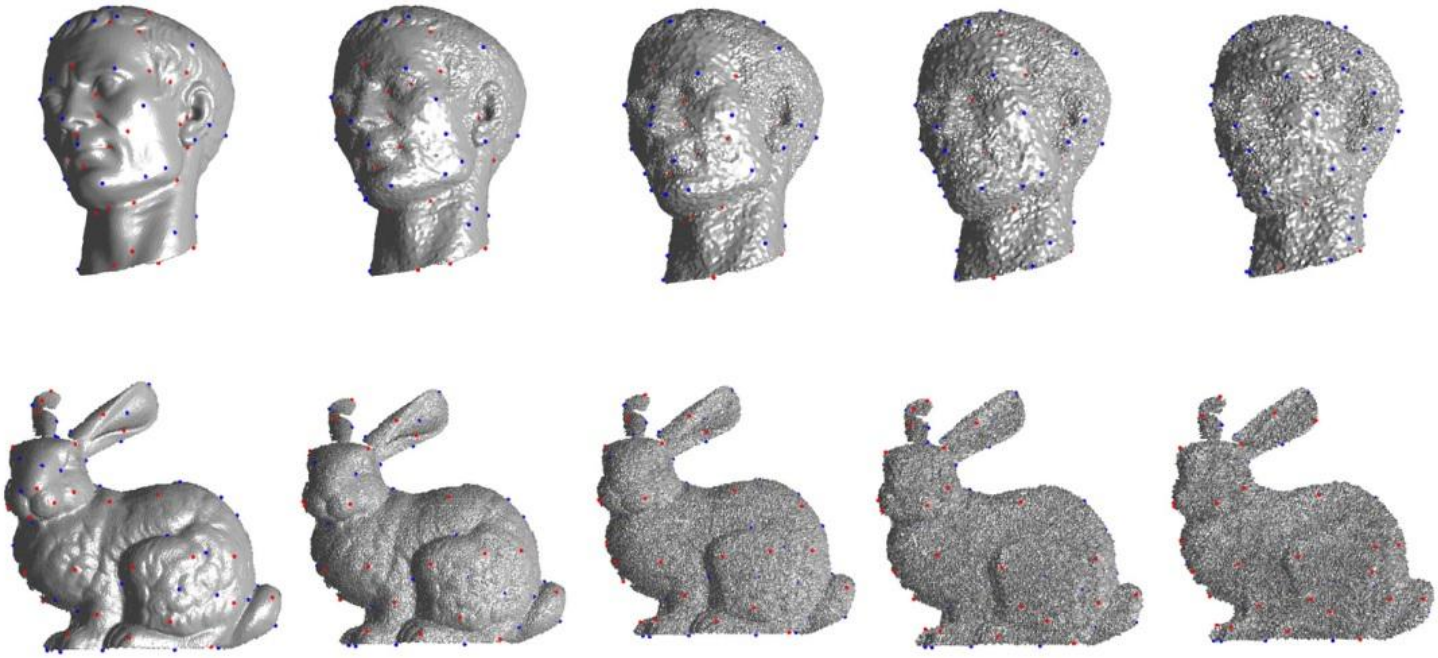


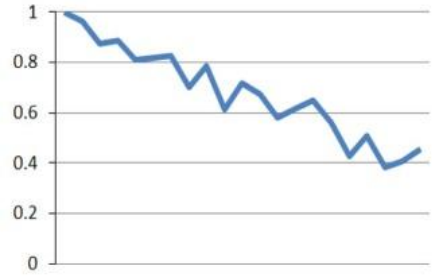


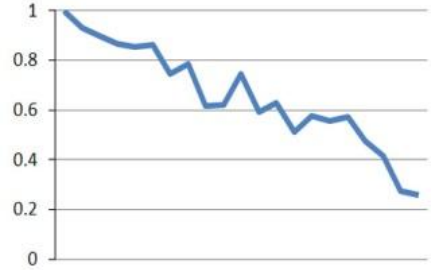
Experimental results: Repeatability of the detector

Gaussian noise





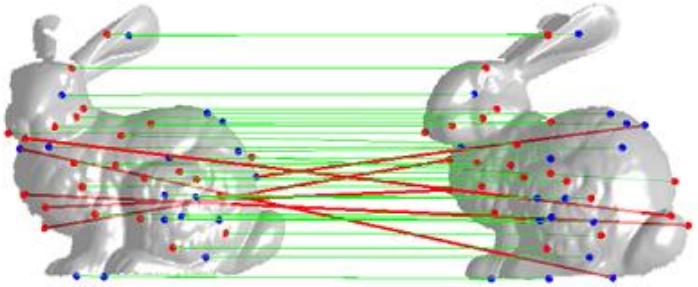




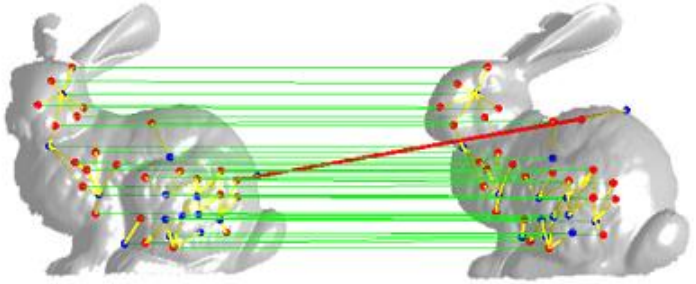
Experimental results

Matching accuracy

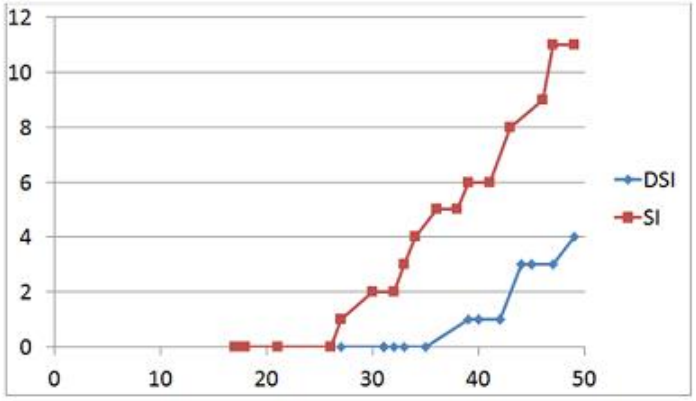
Spin Image



Dual Spin image



Wrong matches



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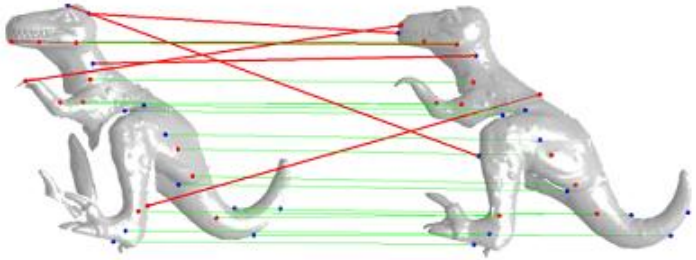

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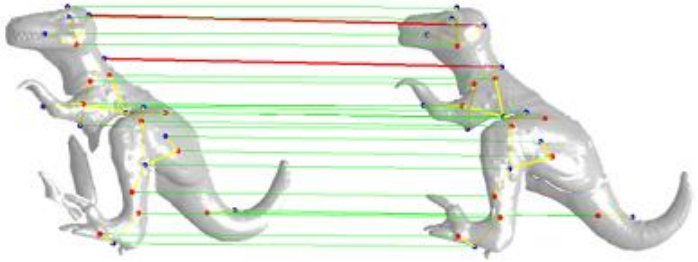
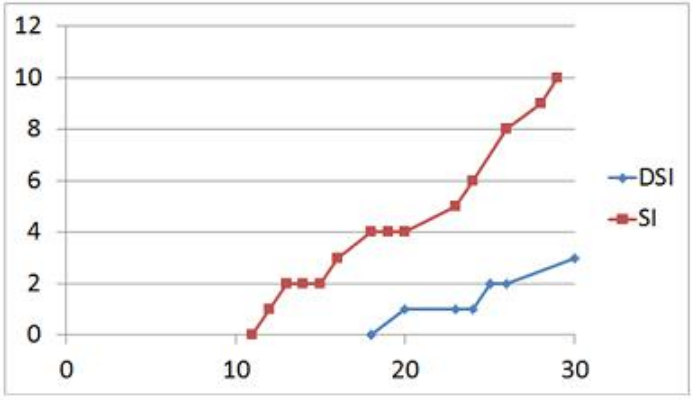


Wrong matches



Matched points

Experimental results

Computational efficiency

- Test on Core 2 Notebook 2.1G, 3G memory
- Matlab 2009b, no parallelization

Model Name	Points	Time (s)
FaceYO	14000	3.16
eros	26000	4.78
Bayon Face	30000	4.62
Bunny	40000	5.46
Brain	73000	7.37

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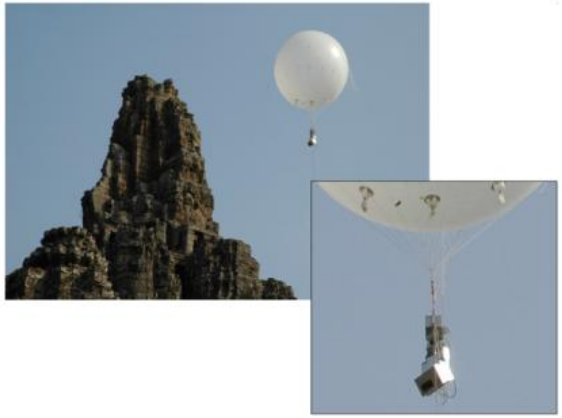
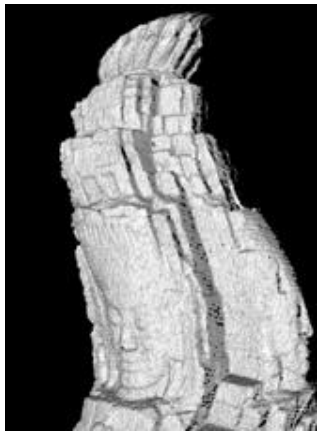
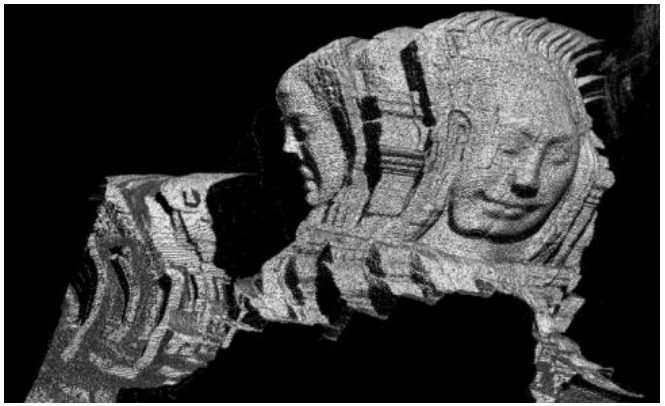
Application

Digital Bayon Archiving Project [Ikeuchi Lab]

- Flying laser range sensor





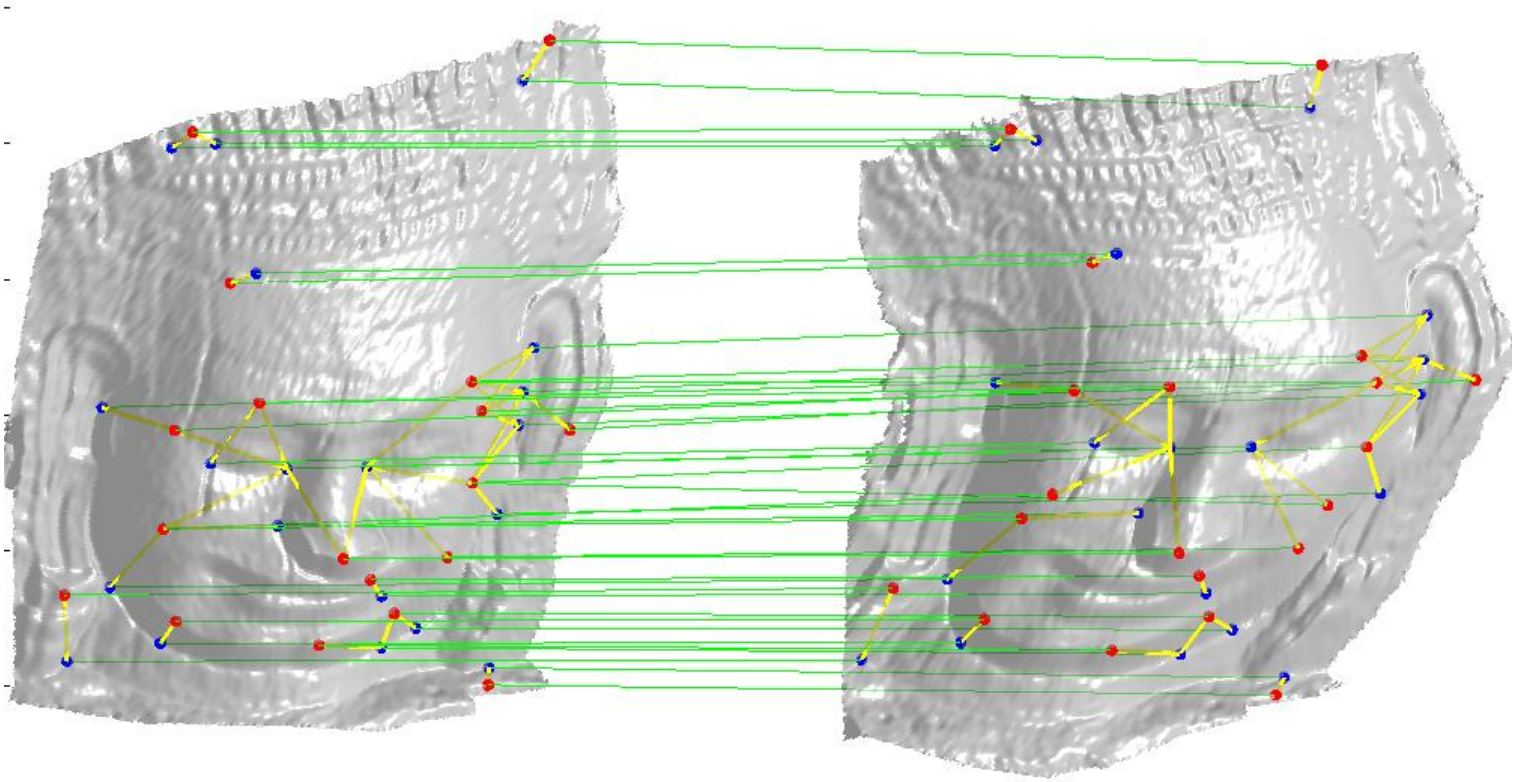


Application

Flying laser range sensor

Ground truth

FLRS data



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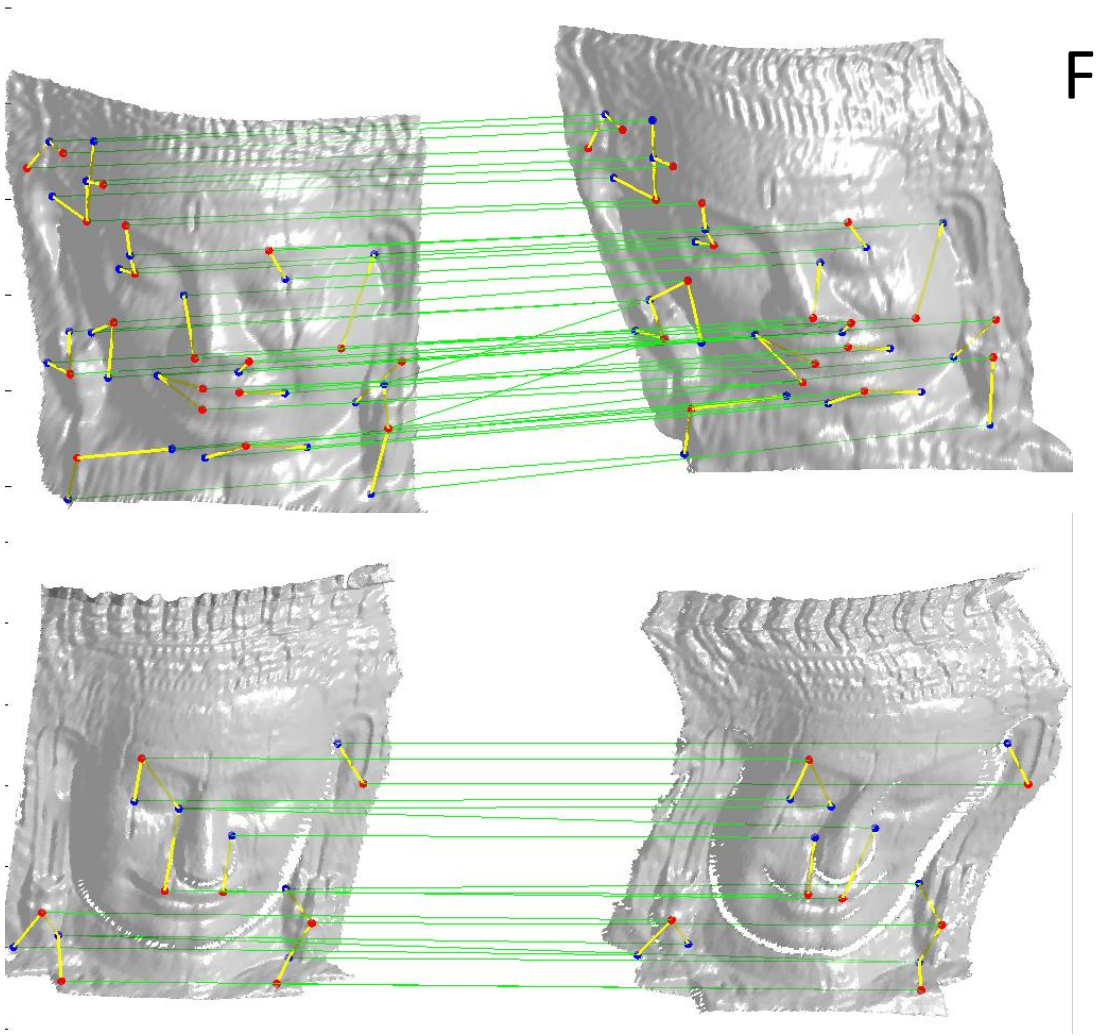
Flying laser range sensor

Ground truth



FLRS data

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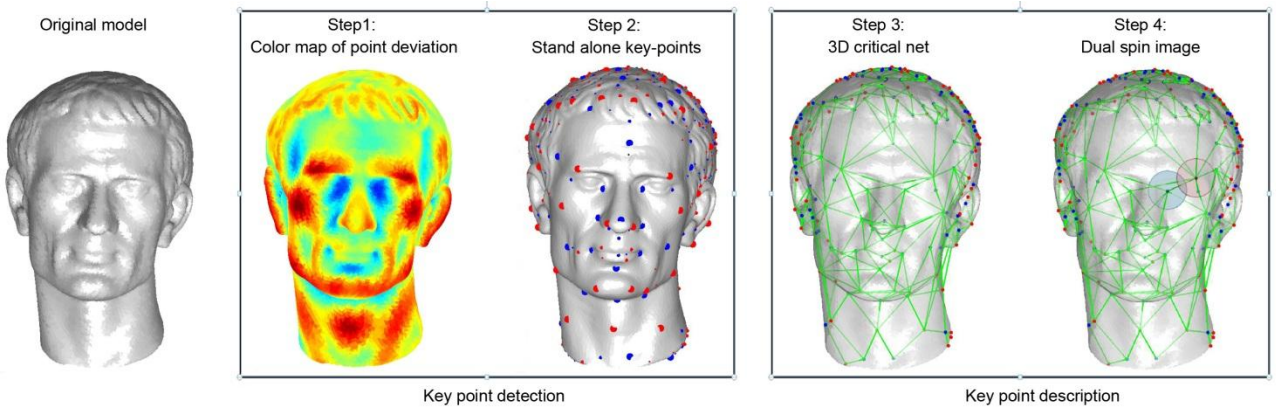
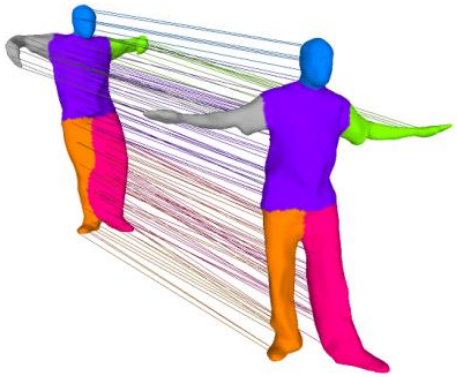
Conclusion



- Provided an original local feature based 3D free form surface matching method.
- The algebraic surface fitting based detector is robust and fast
- Provide algorithms to compute 3D critical net and the scale invariant dual spin image
- Application on FLRS is provided

Future works

- Applying the method on motion data correspondence
- Applying the method on SLAM (simultaneous localization and mapping)



Thank you for your attention!