Processing and Analysis of 2.5D Models

Monday, January 15, 2018

Focus of this thesis

2.5D/3D face landmarks localization

- **Potential application of landmarking:**
  - Face alignment, registration, reconstruction, face recognition, expressions recognition.

3D face recognition using non-rigid mapping techniques

- **Potential application:**
  - Designing of illumination and rotation independent face recognition systems.

Outline

- **3D facial points localization**
  - **Overview of the related work**
  - **Our main contribution**
    - **Noiseless HK-classification for precise and rotation invariant main facial landmarks localization**
  - **Evaluation**

3D facial points localization

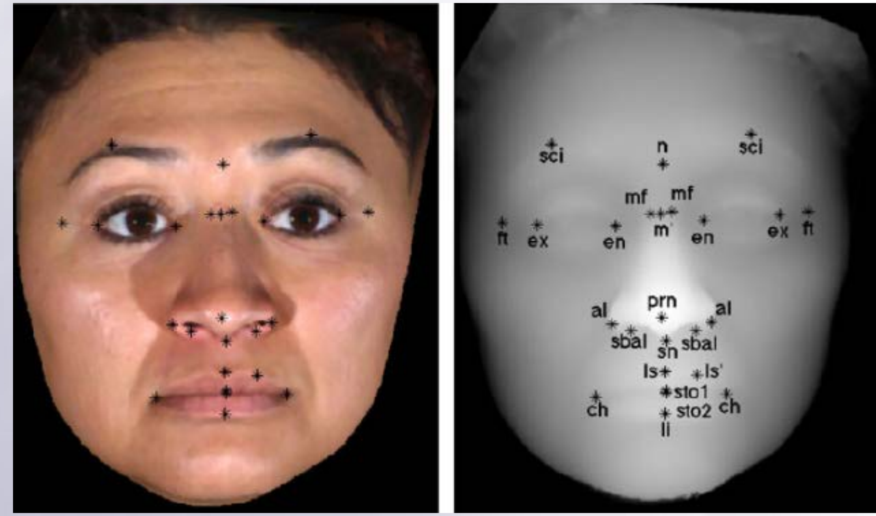
3D face landmarking: the problems and motivations

Face landmarks?

- **Anthropometric points having consistent reproducibility even in adverse conditions such as facial expressions, rotations, occlusions.**
- **Nose tip, eye corners, mouth corners, etc.**

Why landmarks?

- **Many potential applications:**
  - **face recognition,**
  - **face reconstruction,**
  - **face registration,**
  - **facial expressions recognition,**
  - **reference points for parameterization,**
  - **face localization,**
  - **face pose estimation … .**

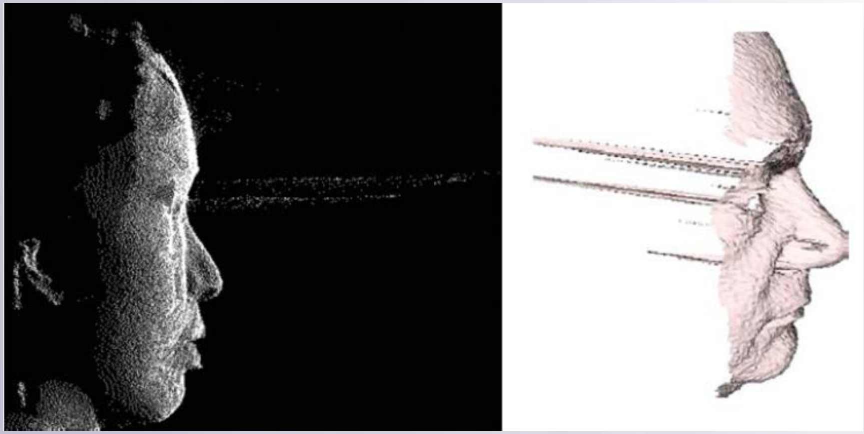


Why landmarks in 3D?

- **To better deal with difficulties of face pose and lighting conditions unsolved in the 2D modality.**

3D face landmarking: challenges

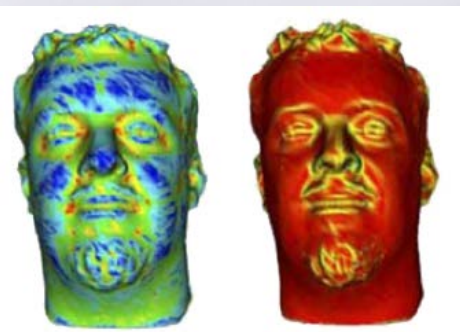
- Facial surface deformations by facial expressions,
- Partial facial occlusions,
- Self-occlusions,
- Noise,
- Face rotations,
- Model's resolution,
- Landmarks precision,
- Partial models.



State of the art: Different approaches

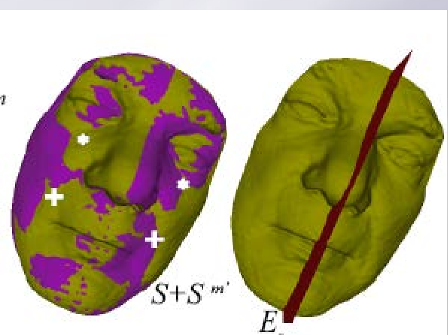
Curvatures analysis

- Moreno et al. 2003, Colombo et al. 2006, Chang et al. 2006, Sun & Yin 2008



Shape Index and Curvedness analysis

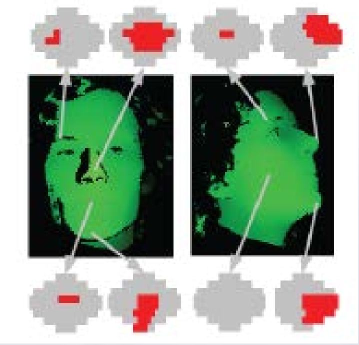
- Colbry et al. 2005, Lu et al. 2006, Nair & Cavallaro 2009,



Symmetry plane localization and slices analysis

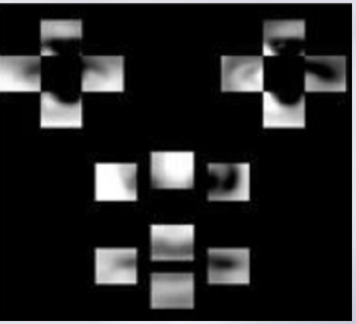
- Mian et al. 2005, Mian et al. 2006, Mian et al. 2007, Faltemier et al. 2008b, Tang et al. 2008, Wang et al. 2008, Wang et al. 2009

State of the art: Different approaches



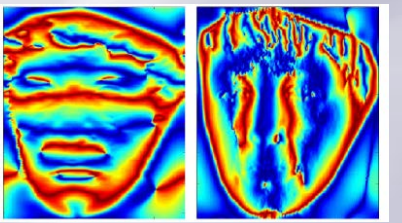
Point signatures, local features

- Conde et al. 2005, Xu et al. 2006, Pears 2008



Shape and Appearance Models

- Dibeklioglu et al. 2008, Zhao et al. 2009b, Nair & Cavallaro 2009

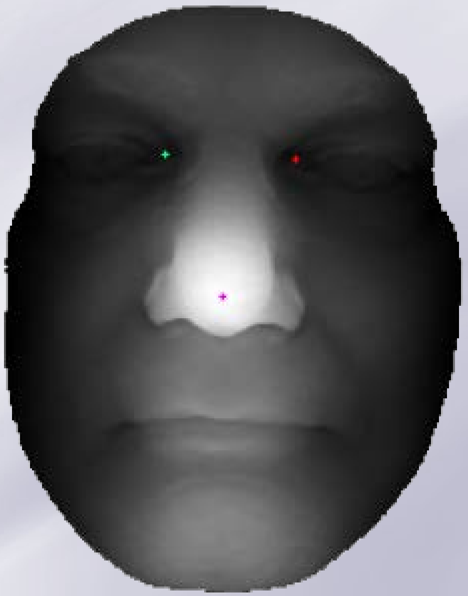


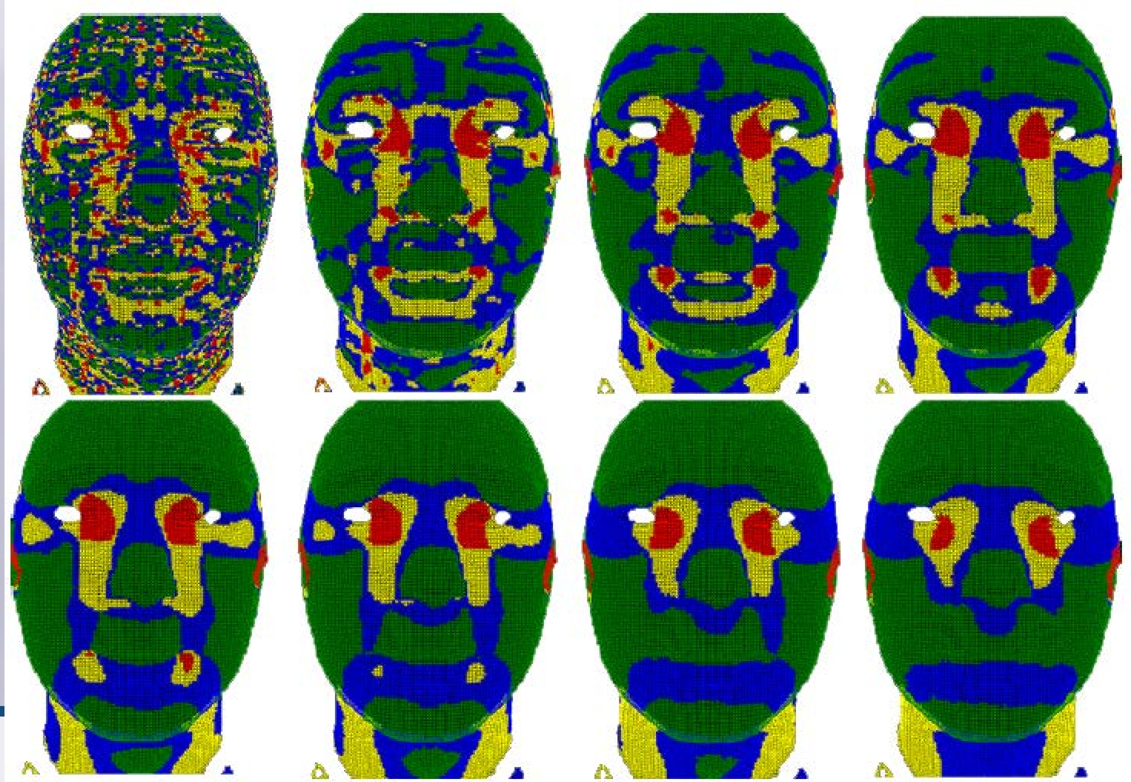
Multi-decision

- Mian et al. 2007, D'Hose et al. 2007, Nair & Cavallaro 2009

Our approach

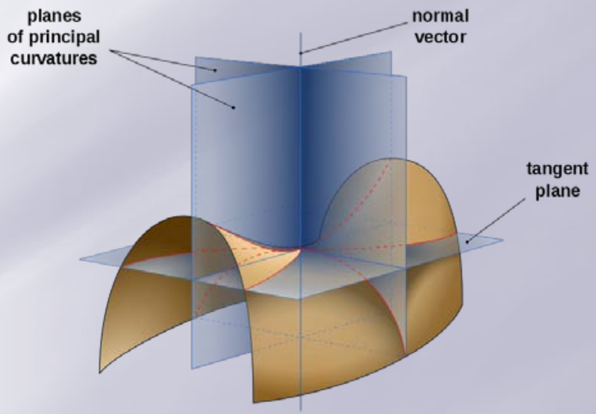
- Embed noise reduction into the curvatures calculation method to achieve:
  - precise,
  - resolution and
  - rotation invariant main facial anthropometric points.

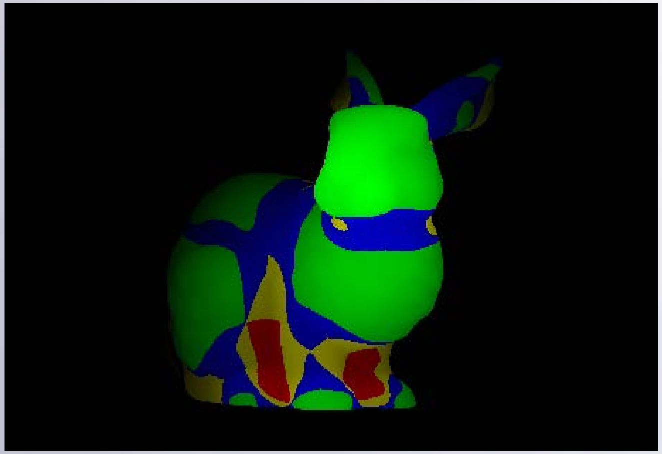




Why curvatures?

- Since the input of 3D facial algorithms are 3D models, the natural way to retrieve facial anthropometric points is to analyze facial surface
- The most popular way to analyze a 3D surface is by using a method called **HK-classification**
- The **HK-classification** in many cases is the first step to reduce the number of candidate vertexes for the anthropometric points





Source: Stuttgart Range Image Database

How to calculate Mean and Gaussian curvature?

- **Gaussian and Mean curvature** (Victor A. Toponogov, **"Differential Geometry of Curves and Surfaces",** 2006 Birkhauser Boston):

$$K = \frac{LN - M^2}{EG - F^2}, \qquad H = \frac{EN + GL - 2FM}{2(EG - F^2)}$$

where E,F,G are coefficients of the first fundamental form of surface, L,M,N are coefficients of the second fundamental form.

- **Since we consider surface as a function:**

$$z = f(x, y)$$

Curvature – how to calculate ?

- **If the surface is given as a f(x,y)** (Victor A. Toponogov, **"Differential geometry of curves and surfaces",** 2006 Birkhauser Boston**):**

$$L = \frac{f_{xx}}{\sqrt{1+f_x^2+f_y^2}}, M = \frac{f_{xy}}{\sqrt{1+f_x^2+f_y^2}}, N = \frac{f_{yy}}{\sqrt{1+f_x^2+f_y^2}},$$

$$E = 1+f_x^2, F = f_x f_y, G = 1+f_y^2, EG - F^2 = 1+f_x^2+f_y^2,$$

Where fx, fy, fxy, fxx, fyy, are the first and second derivatives of function in point (x,y)

Curvature

- Since we have only discrete representation of the surface a bi-quadratic polynomial approximation of the surface in each point needs to be estimated:

$$z = f(x, y) = A + Bx + Cy + Dx^2 + Exy + Fy^2.$$

First and second derivatives

- **First and second derivative from biquadratic polynomial approximation:**

$$\frac{\partial z}{\partial x} = f_x = B + 2Dx + Ey,$$

$$\frac{\partial z}{\partial y} = f_y = C + Ex + 2Fy,$$

$$\frac{\partial^2 z}{\partial xy} = f_{xy} = E, \ \frac{\partial^2 z}{\partial y^2} = f_{yy} = 2F, \ \frac{\partial^2 z}{\partial x^2} = f_{xx} = 2D.$$

Multilinear Regression algorithm

- **Biquadratic polynomial approximation of the surface can be estimated by Multilinear Regression algorithm.**

  In Multilinear Regression, we assume that the dependent data, z, depends linearly on several variables e.g. x, y.

- **The goal of Multilinear Regression is to minimize the sum:**

$$Error = \sum_{i=1}^{N} \left(a_1 x + a_2 y + b - f(x, y) \right)^2$$

Where N is the number of samples

Multilinear Regression algorithm

- **We can rewrite the system as matrix A, W and Y:**

$$AW = Y,$$

Where:

$$A = \begin{pmatrix} x_{11} & x_{21} & 1 \\ x_{12} & x_{22} & 1 \\ \dots & \dots & \dots \\ x_{1N} & x_{2N} & 1 \end{pmatrix}, W = \begin{pmatrix} a_1 \\ a_2 \\ b \end{pmatrix}, Y = \begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_N \end{pmatrix}.$$

Multilinear Regression algorithm

- **To obtain equation coefficients, a solution for a linear models needs to be found using Multilinear Regression**

$$W = (A^t A)^{-1} A^t Y,$$

- **If $(A^tA)^{-1}$ does not exist it means that the system has no solution**

Curvatures

$$H(x,y)=\frac{\left(1+f_y^2\right)f_{xx}-2f_xf_yf_{xy}+\left(1+f_x^2\right)f_{yy}}{2\left(1+f_x^2+f_y^2\right)^{\frac{2}{3}}}$$

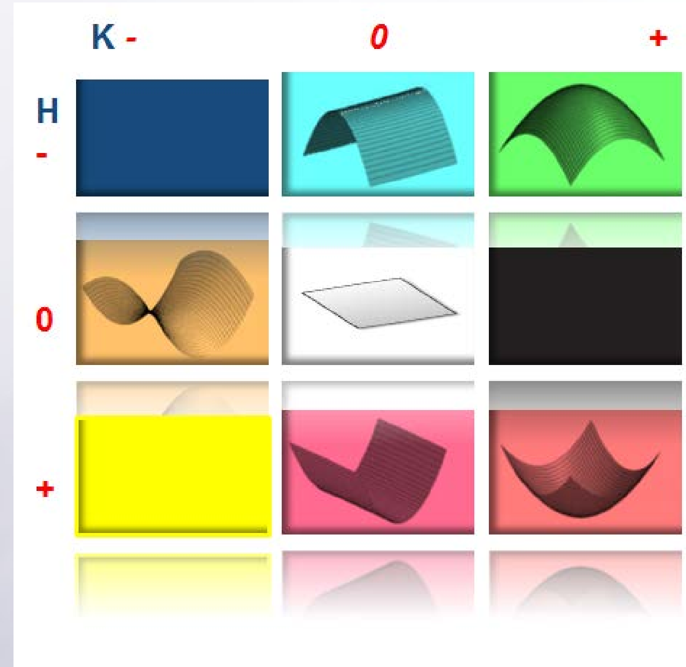
$$K(x,y)=\frac{f_{xx}f_{yy}-f_{xy}^2}{\left(1+f_x^2+f_y^2\right)^2}$$

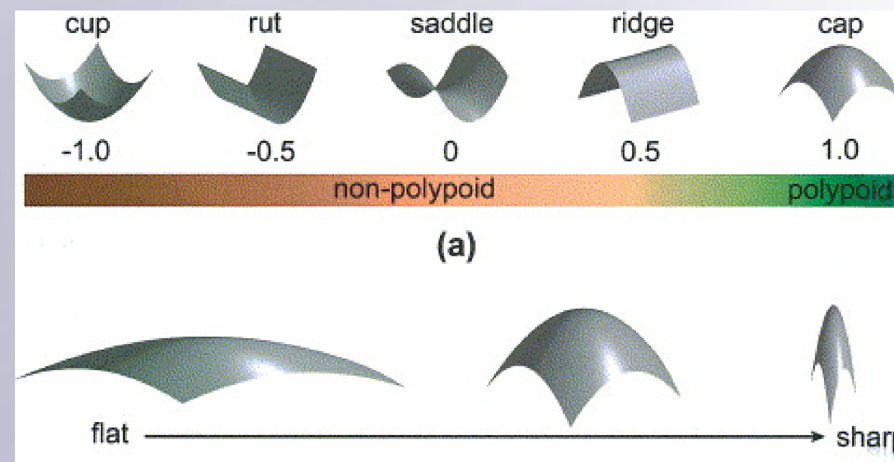
$$k_1(p)=H(p)+\sqrt{H^2(p)-K(p)}$$

$$k_2(p)=H(p)-\sqrt{H^2(p)-K(p)}$$

$$SI(p)=\frac{1}{2}-\frac{1}{\pi}\arctan\left(\frac{k_1(p)+k_2(p)}{k_1(p)-k_2(p)}\right)$$

$$Curvdness(v)=\frac{\sqrt{k_1^2(v)+k_2^2(v)}}{2}$$



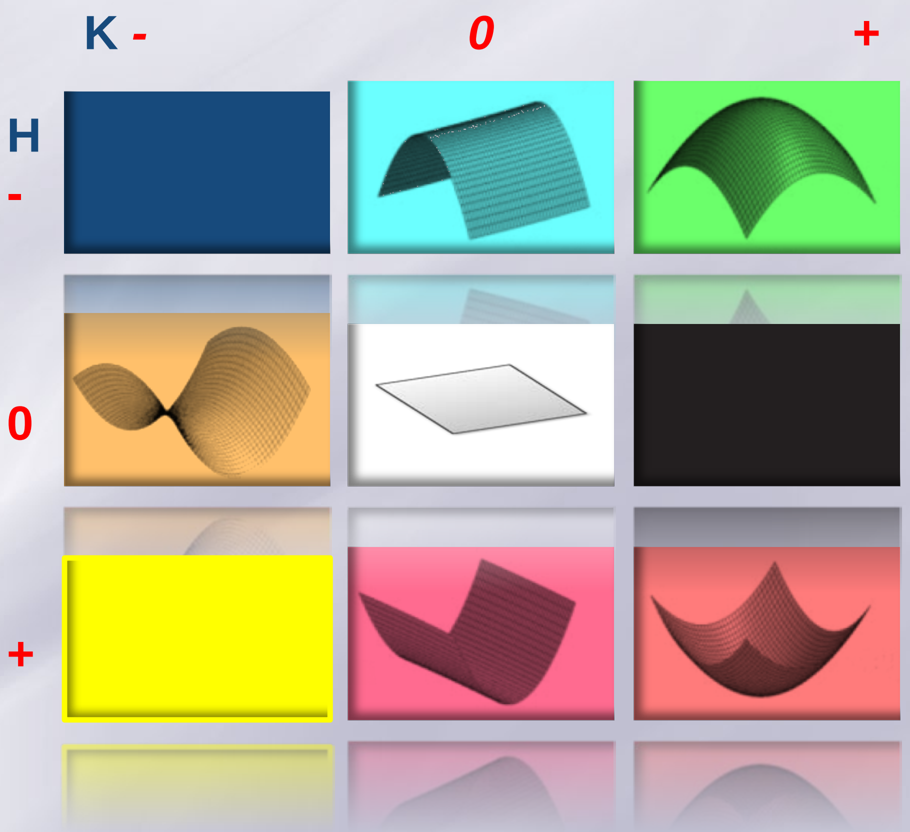


(a)

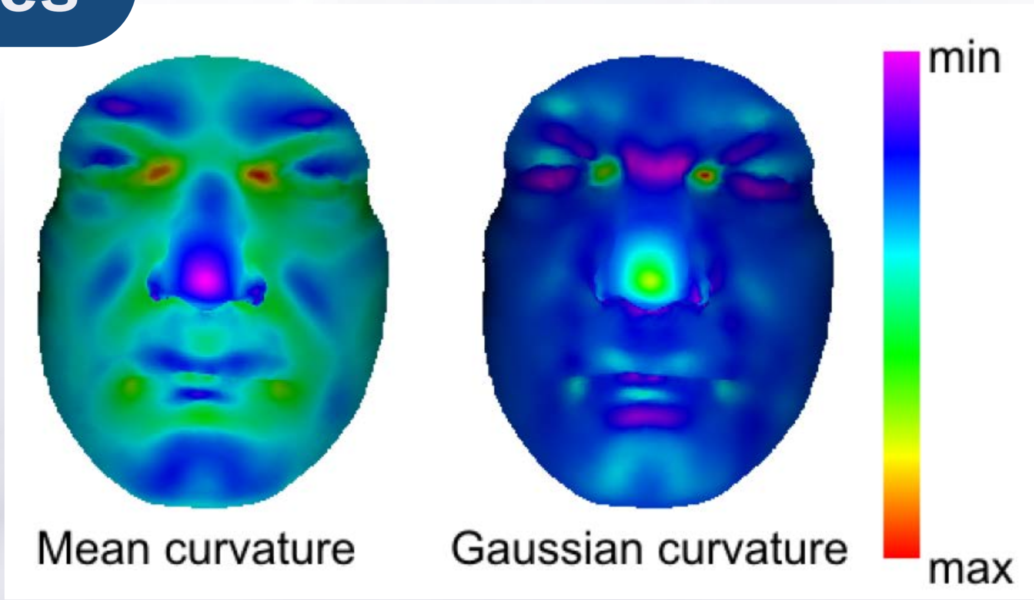
(b)

HK-Classification

The HK-classification is one of the differential geometry tools, used to partition 2.5D data into regions of homogeneous shapes, called homogeneous surface patches based on the signs of Mean (H) and Gaussian (K) curvatures.



Curvatures



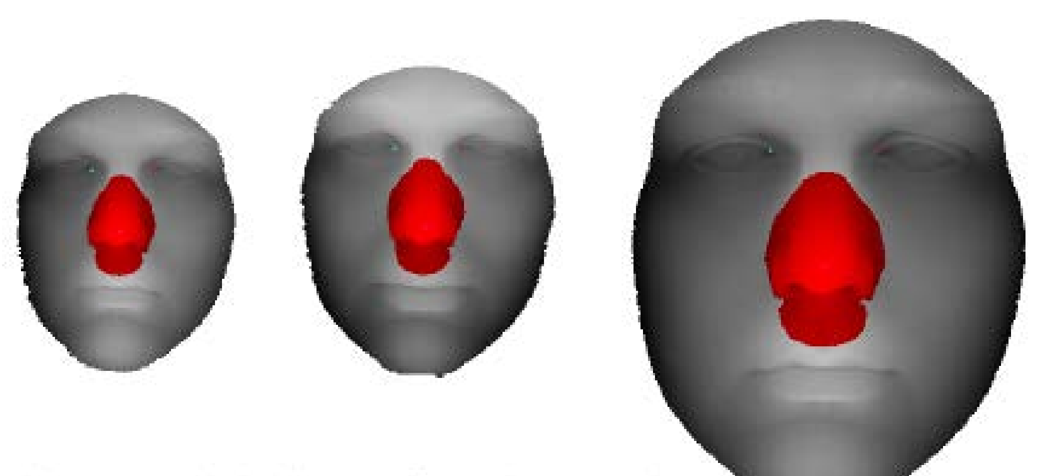
$$H(x,y) = \frac{(1+f_y^2)f_{xx} - 2f_x f_y f_{xy} + (1+f_x^2)f_{yy}}{2(1+f_x^2+f_y^2)^{\frac{3}{2}}},$$

$$K(x,y) = \frac{f_{xx}f_{yy} - f_{xy}^2}{(1+f_x^2+f_y^2)^2}$$

Modification of the curvatures calculation method

- The presented method is exposed to surface noise but also to resolution changes: direct local point's neighborhood as well as the function derivatives are both **sensitive to noise and resolution changes**.

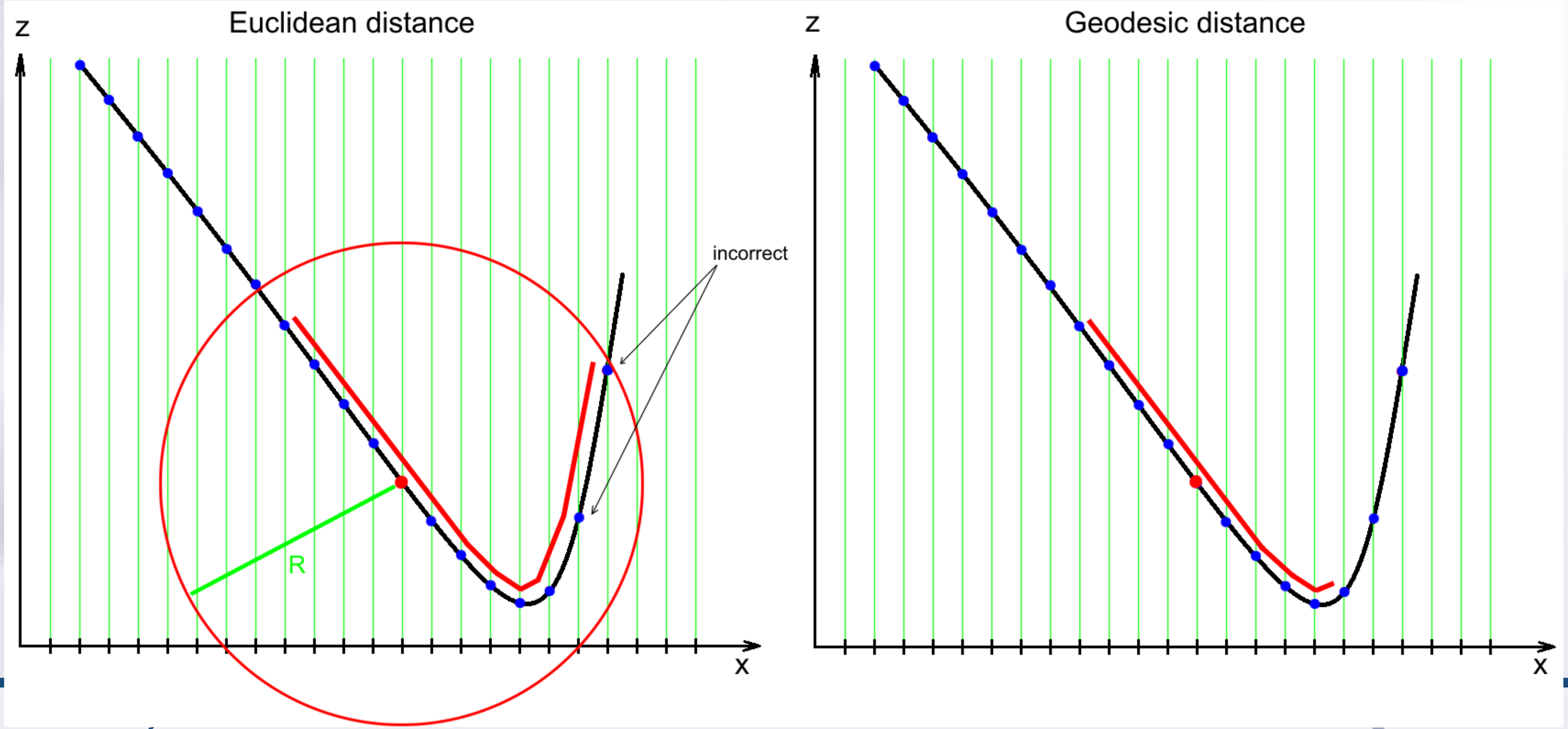
- One of the properties of 3D models is a real distance between vertices, which is expressed in [mm].
- The distance stays approximately constant between certain points under rigid deformations of a face as well as resolution changes.



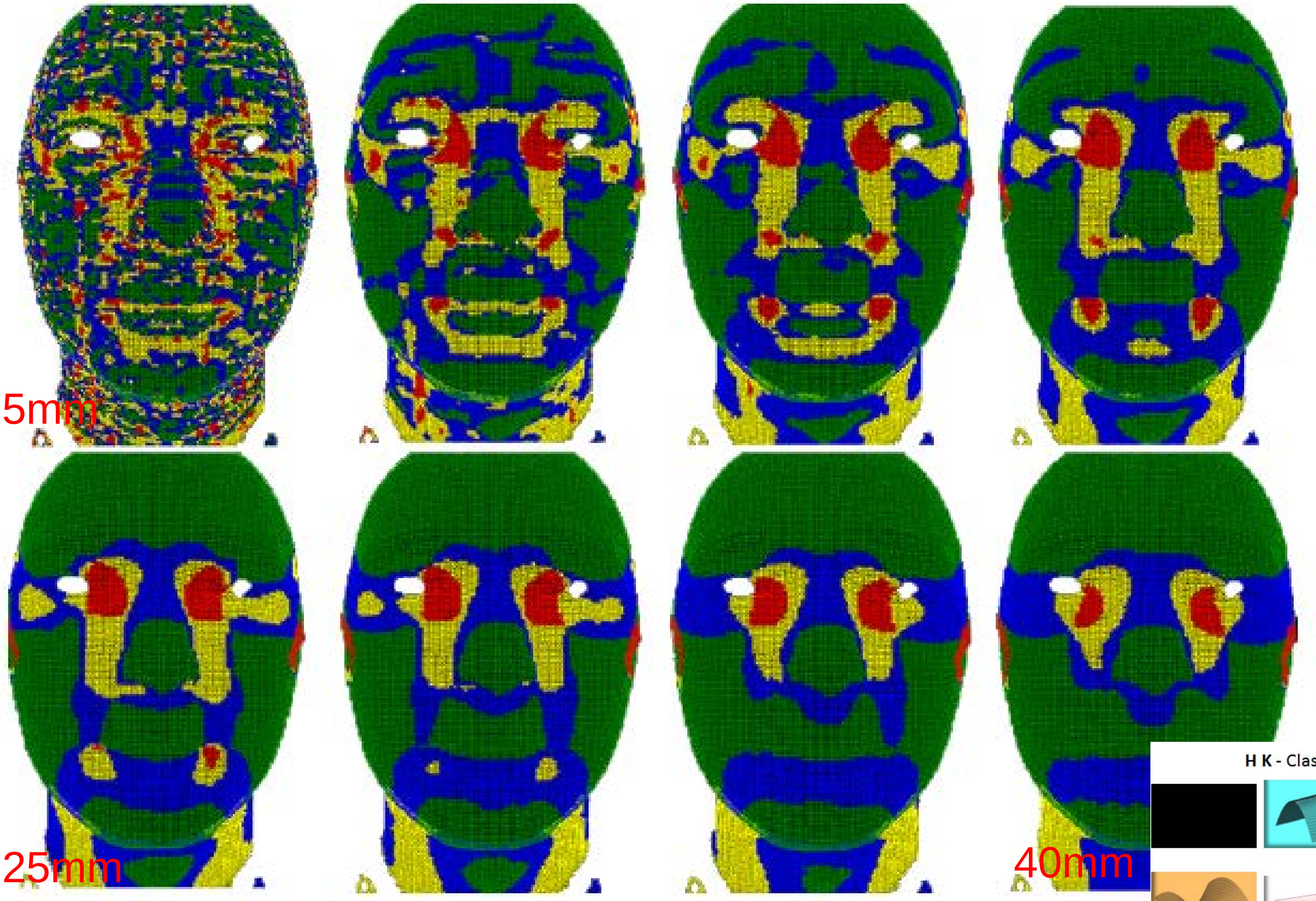
40mm geodesic distance from the nose tip

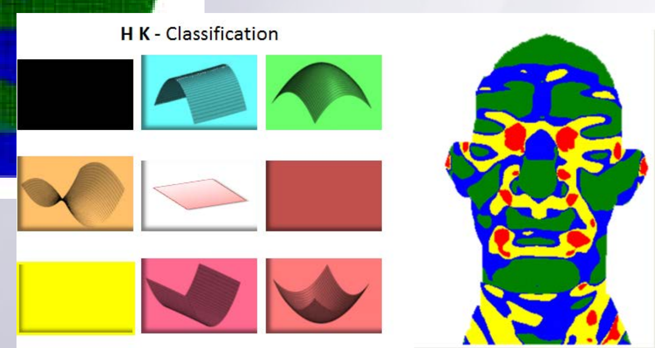
Modification of the curvatures calculation method

- To achieve smooth curvatures decomposition, insensitive to noise and resolution changes, we propose to use **geodesic distance** expressed in [mm] for the **definition of a neighborhood** in the Multilinear Regression algorithm.



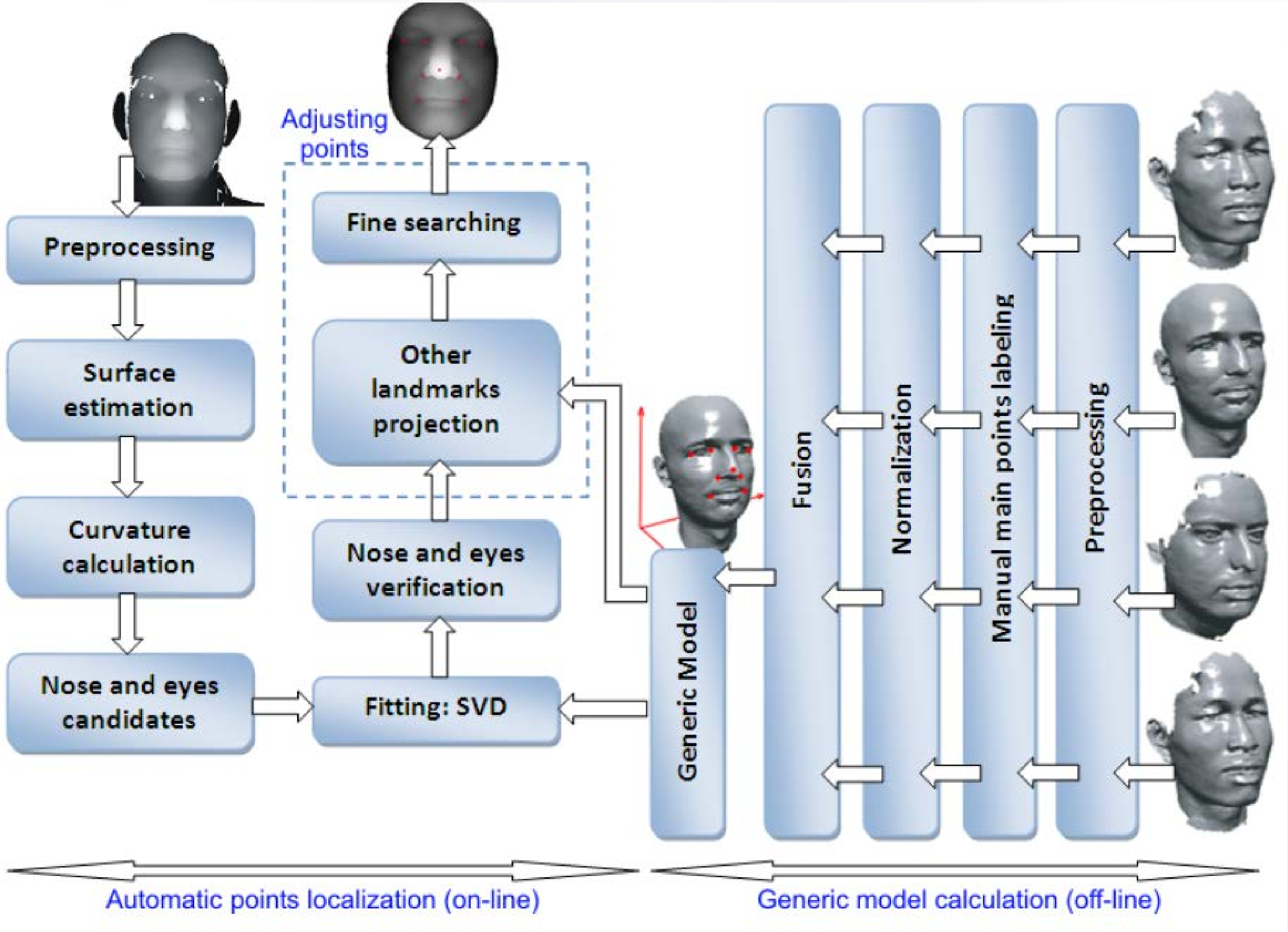
Noise reduction by controlling neighborhood size





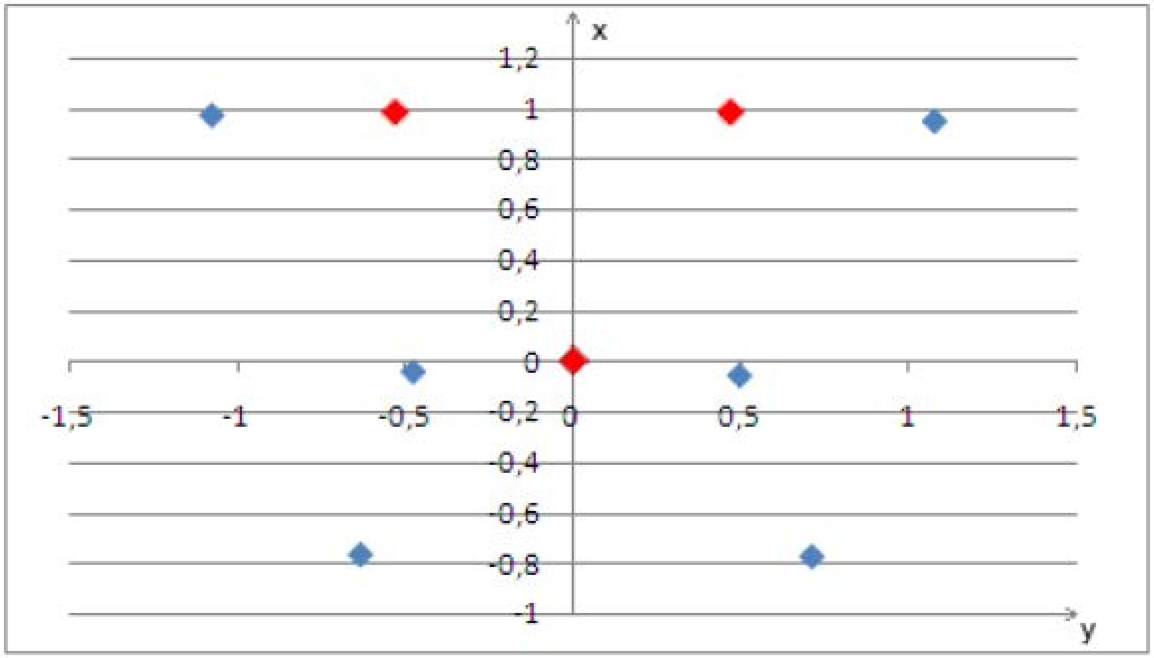
Possible use of noiseless curvatures

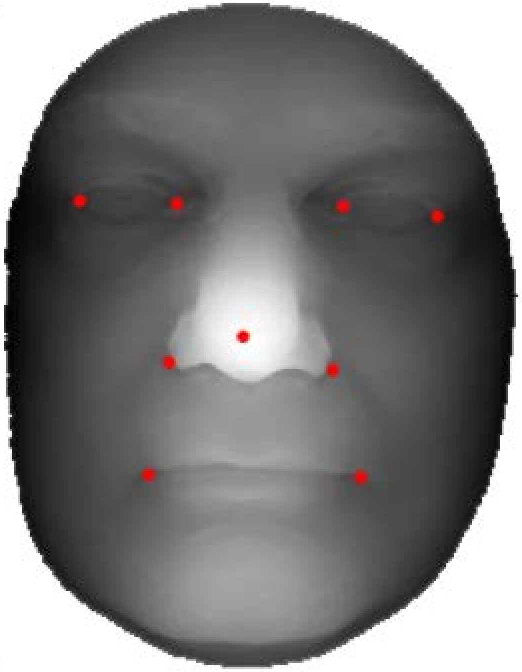
The overview of the approach



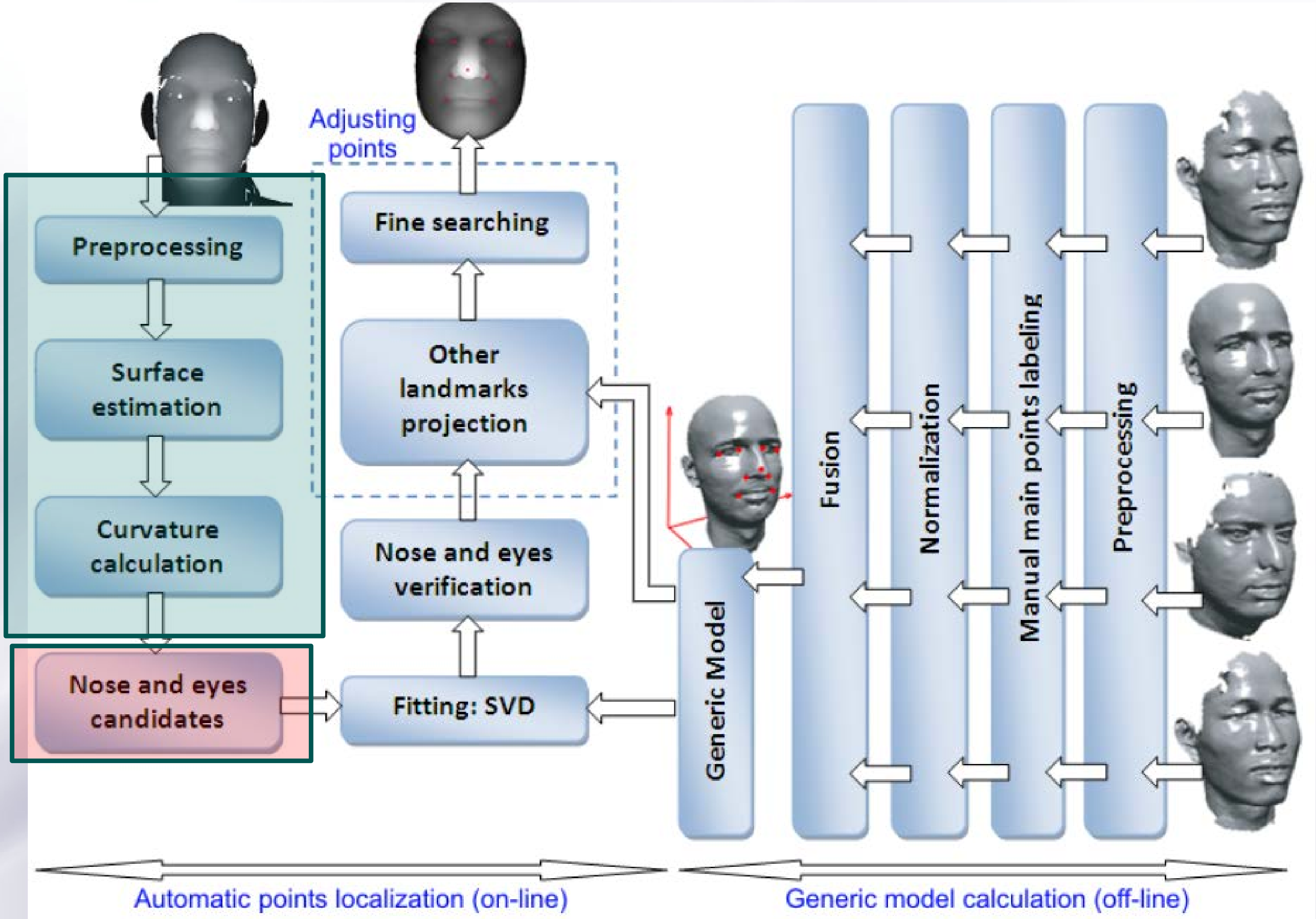
Generic face model

- **Mean facial points positions based on 40 models from the IV2 data set**



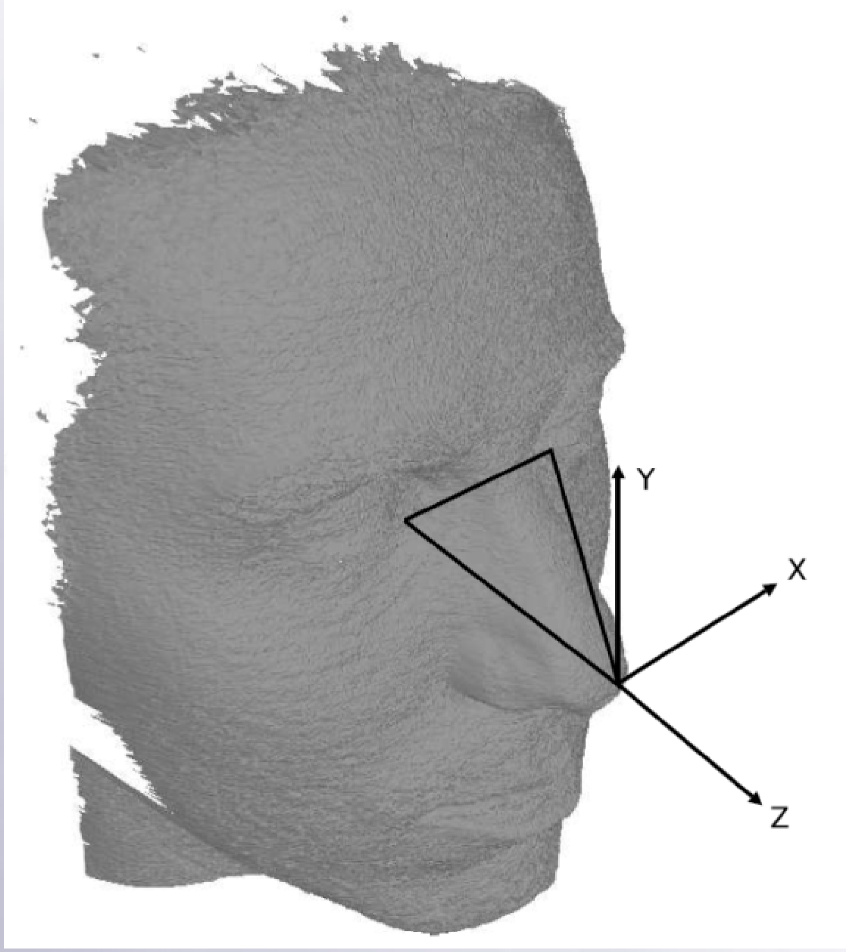


The overview of the approach



Main points localization

- **Most marked out points in the curvature space are:**
  - **the nose tip,**
  - **Inner corners of the eyes (upper corners of the nose).**



Colombo et al. 2006

HK-Classification and thresholds

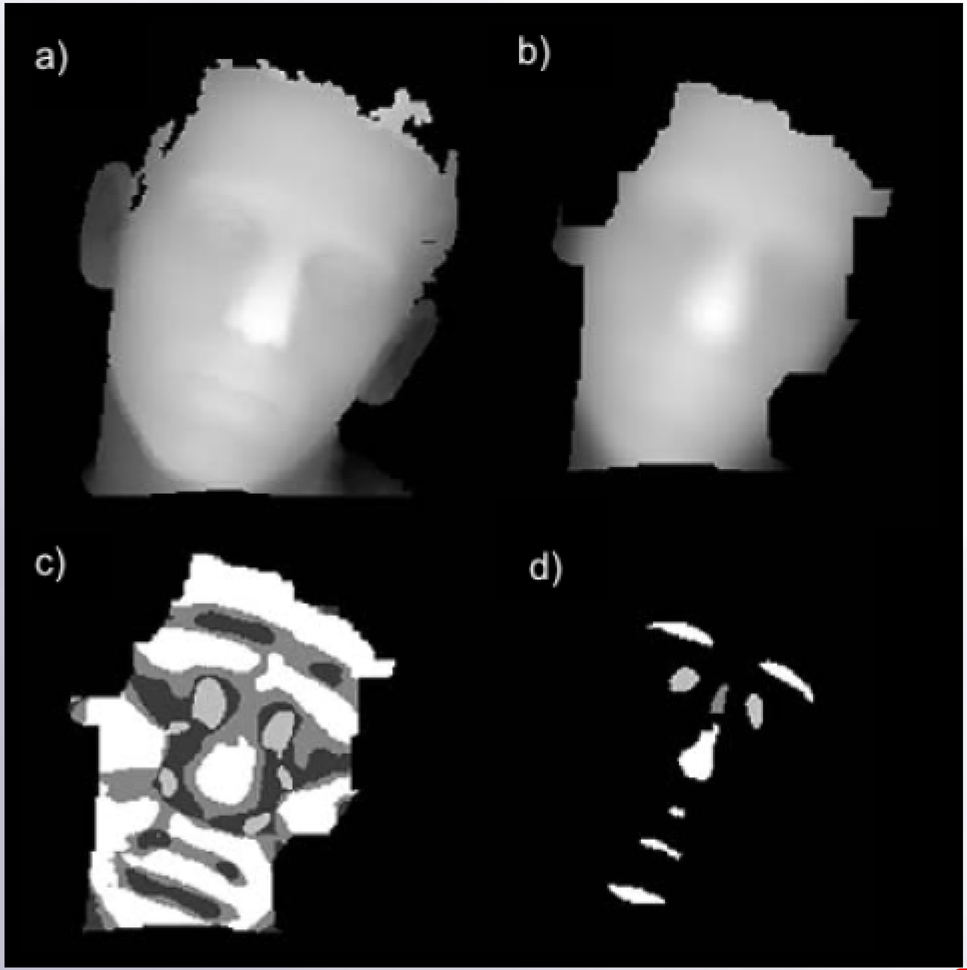
Previously

Surface approximation with 25mm in the used neighborhood

Fine details still preserved

- **Gaussian and Mean curvatures**

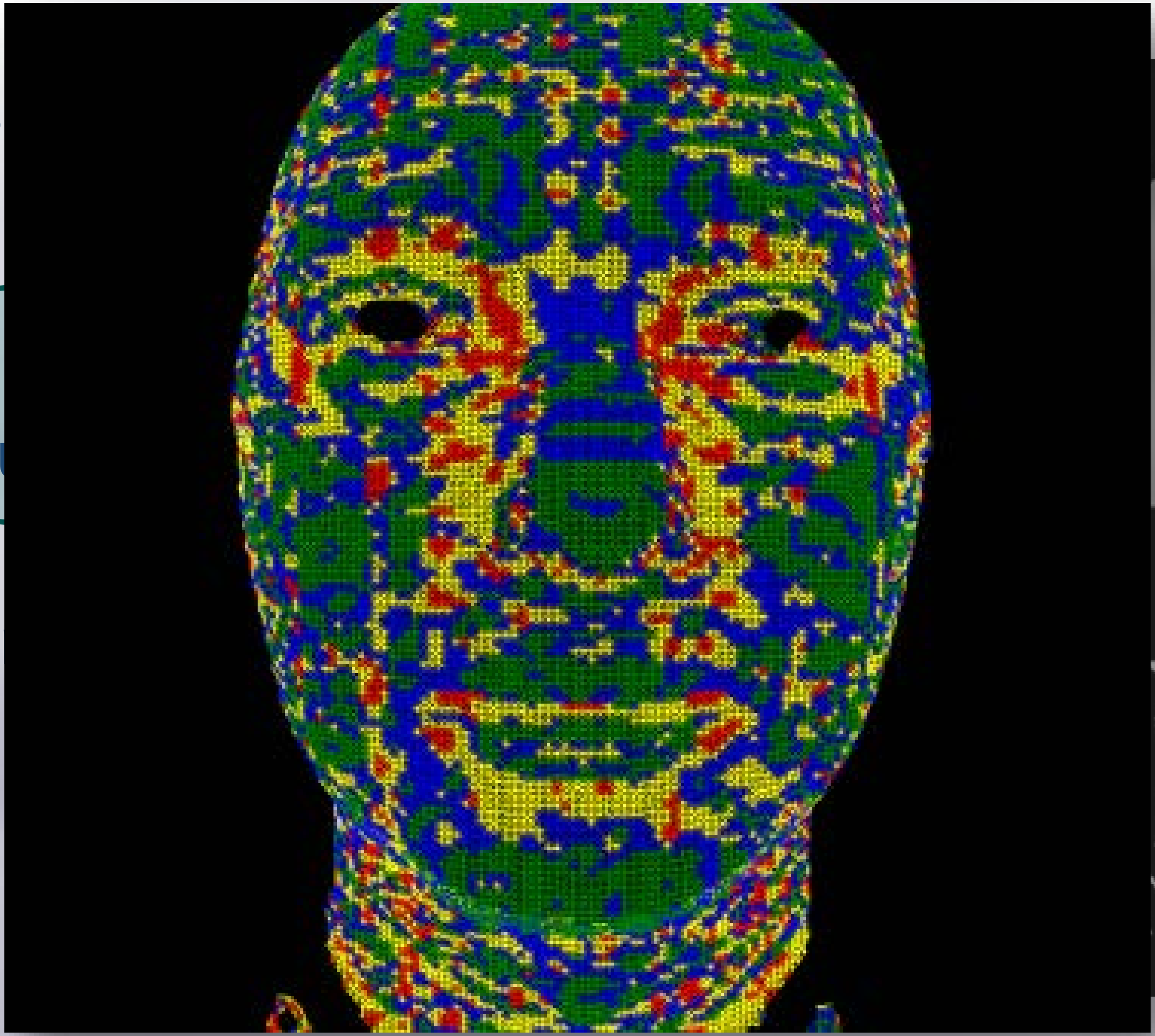
- **Applying thresholds**
  Why?

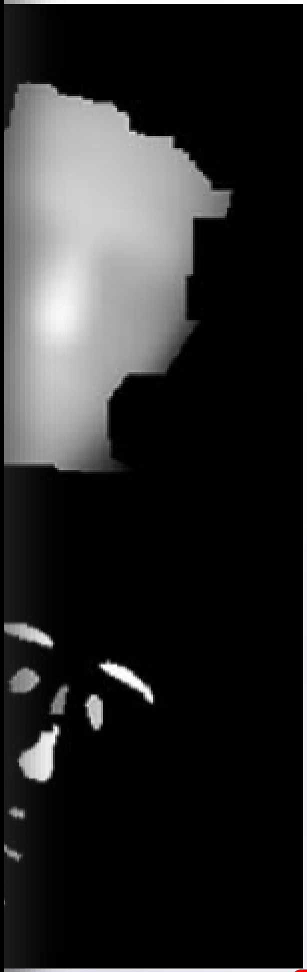


Colombo et al. 2006

HK-Classification and thresholds

- **Face s**
  Why?
- **Gauss**
  curvat
- **Applyi**
  Why?





HK-Classification and thresholds

- Face s
  Why?
- Gauss
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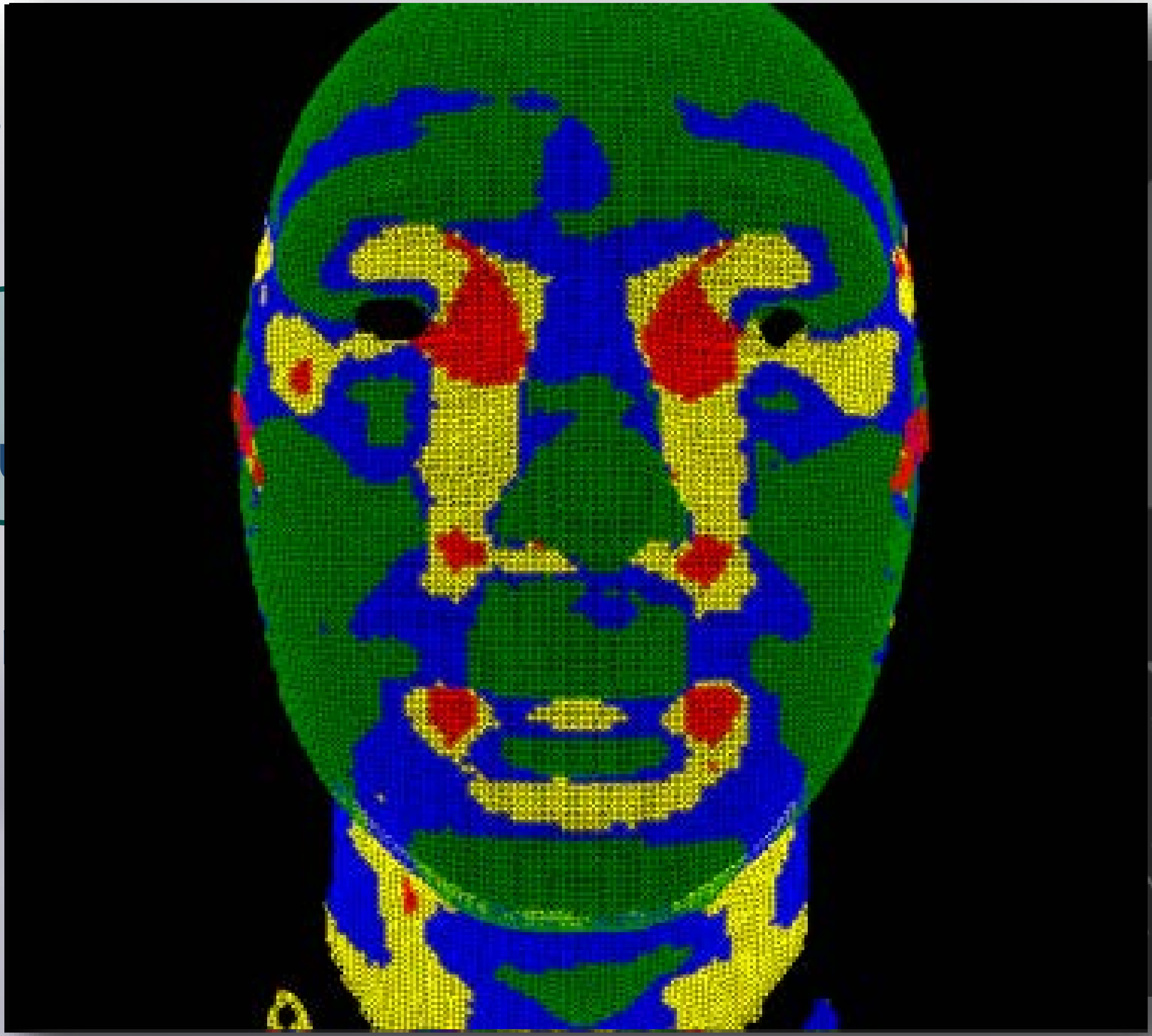
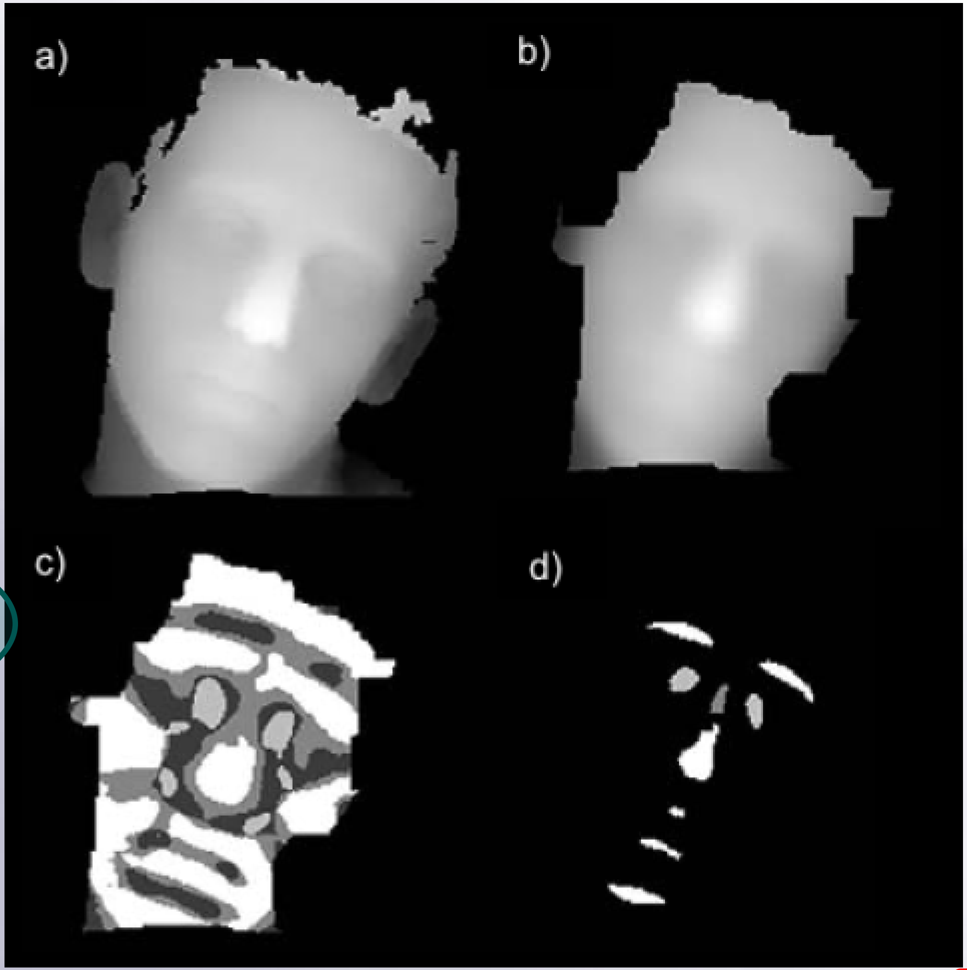
  Why?

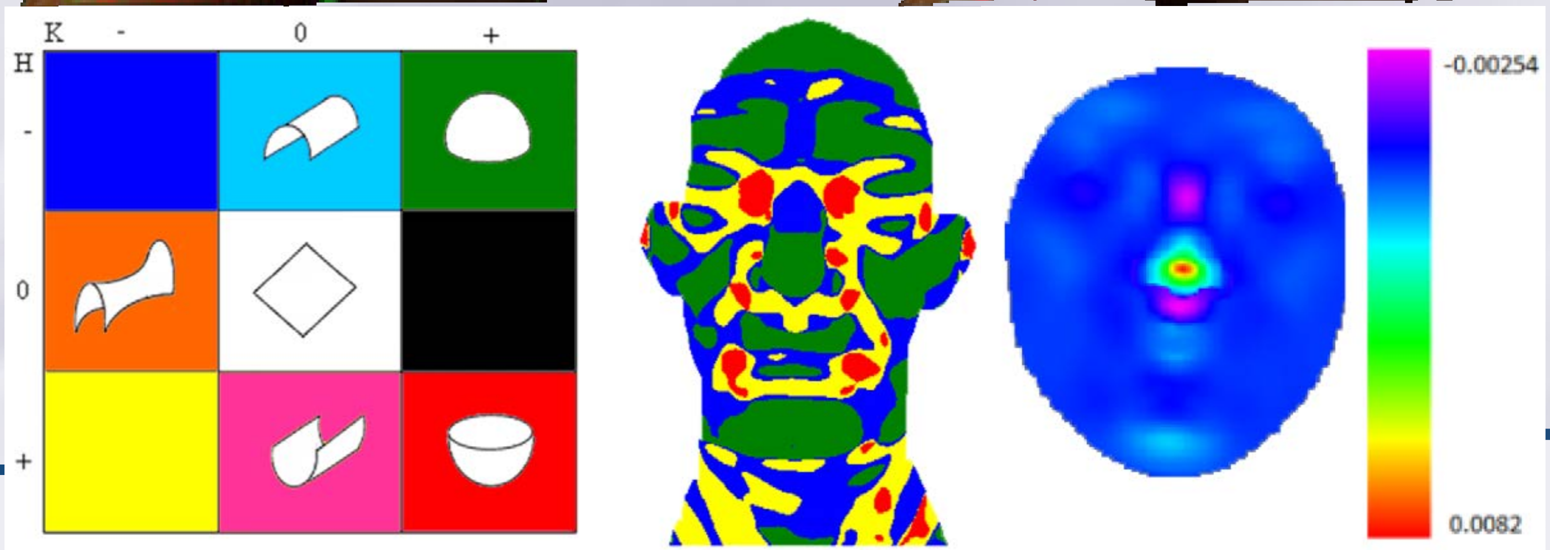


HK-Classification and thresholds

- **Face smoothing**
  Why?
- **Gaussian and Mean curvatures**
- **Applying thresholds**
  Why?



Reduce number of regions



Eyes:
K>0.00005
H>0

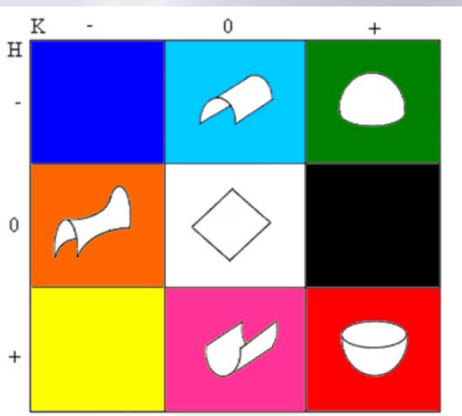
Nose Tip:
K>0.001
H<0

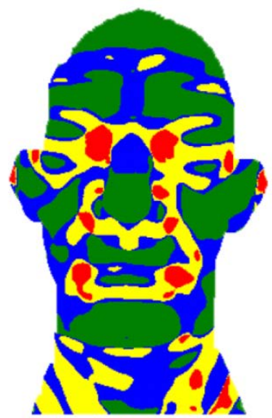
Reduced number of regions

- **Less point candidates,**
- **Faster computation,**
- **Loose regions of interest.**

Rejection Classifier presented later

K>0.00001 K>0.0001 K>0.001 K>0.01





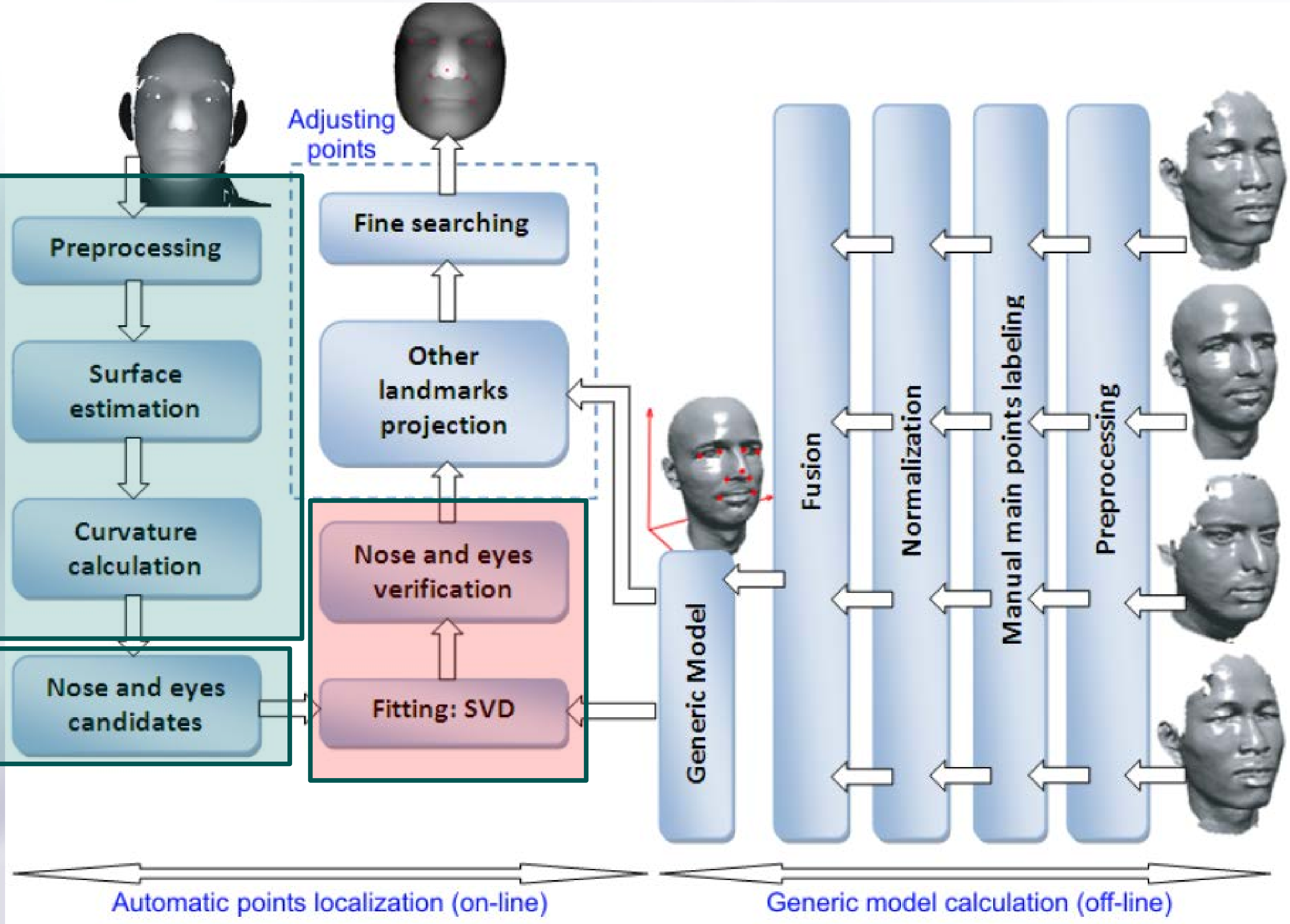
Humans precision

- To relate the results to humans' ability to manually localize facial landmarks ten people were asked to manually label the previously defined anchor points using **10 randomly selected 2.5D models from 10 subjects from the FRGC dataset.**

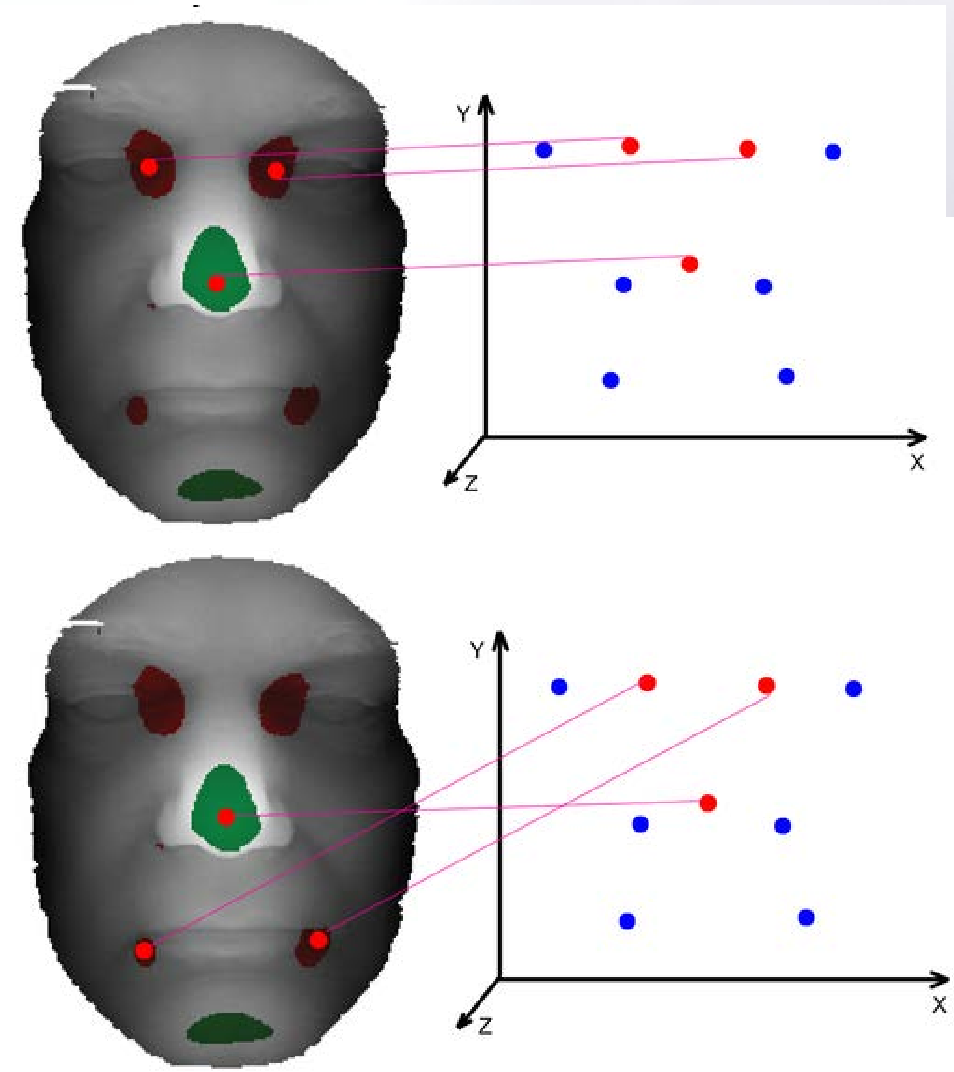
Anchor point	Mean error	Standard deviation
Left Eye Left Corner	2.9531	1.4849
Left Eye Right Corner	2.4194	1.0597
Left Eye Upper Eyelid	2.0387	1.3744
Left Eye Bottom Eyelid	1.9424	0.8507
Right Eye Left Corner	2.0473	1.077
Right Eye Right Corner	2.7559	1.5802
Right Eye Upper Eyelid	2.108	1.6449
Right Eye Bottom Eyelid	1.8362	0.8105
Left Corner of Nose	3.8023	1.9839
Nose Tip	1.9014	1.0474
Right Corner of Nose	4.4974	2.1489
Left Corner of Lips	1.9804	1.1045
Right Corner of Lips	1.9891	1.1905
Upper Lip	3.0414	1.5292
Bottom Lip	2.0628	1.3052

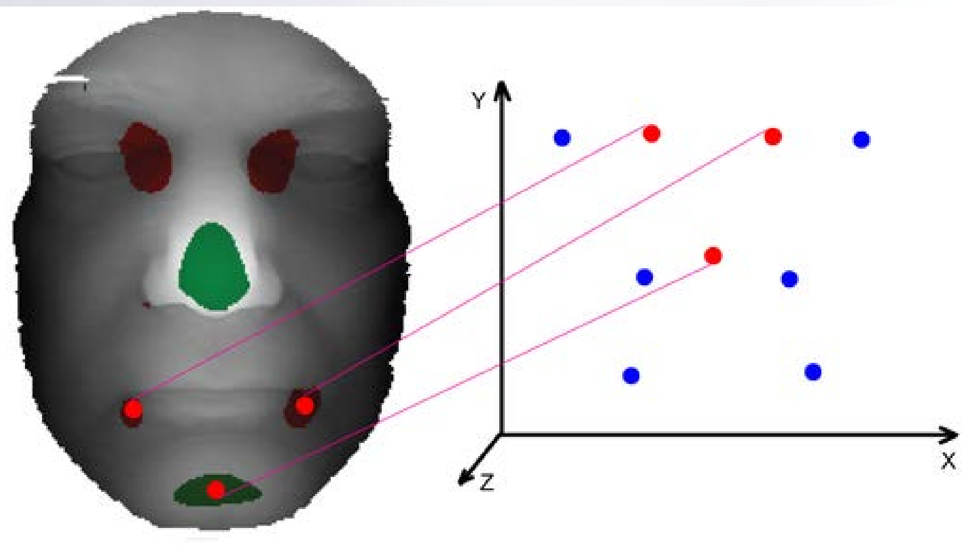
This experiment shows that each feature is not located accurately at the same place, therefore an anchor point on a 3D face model **should be considered more as a region than an exact point**.

The overview of the approach



The main points validation





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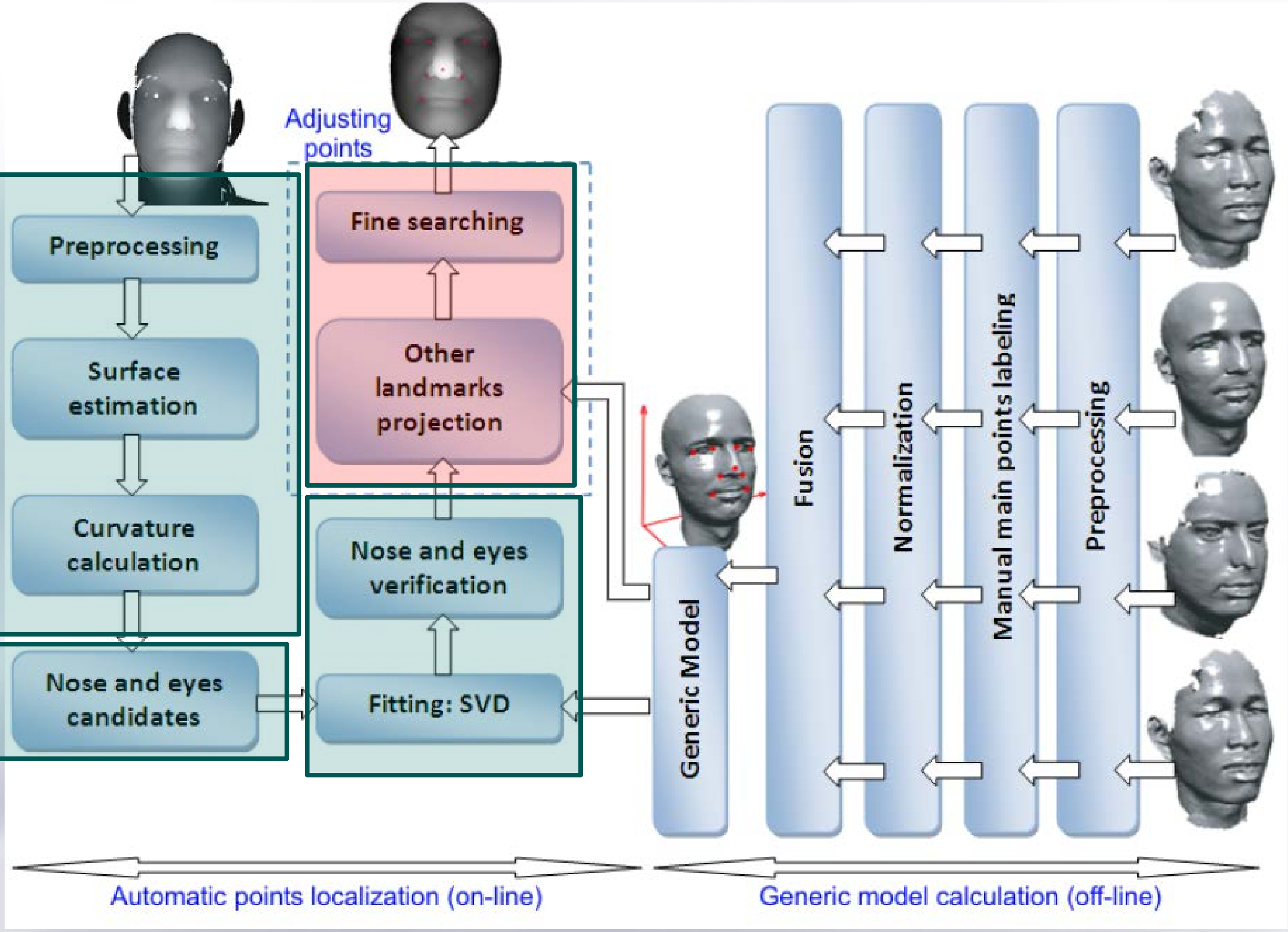
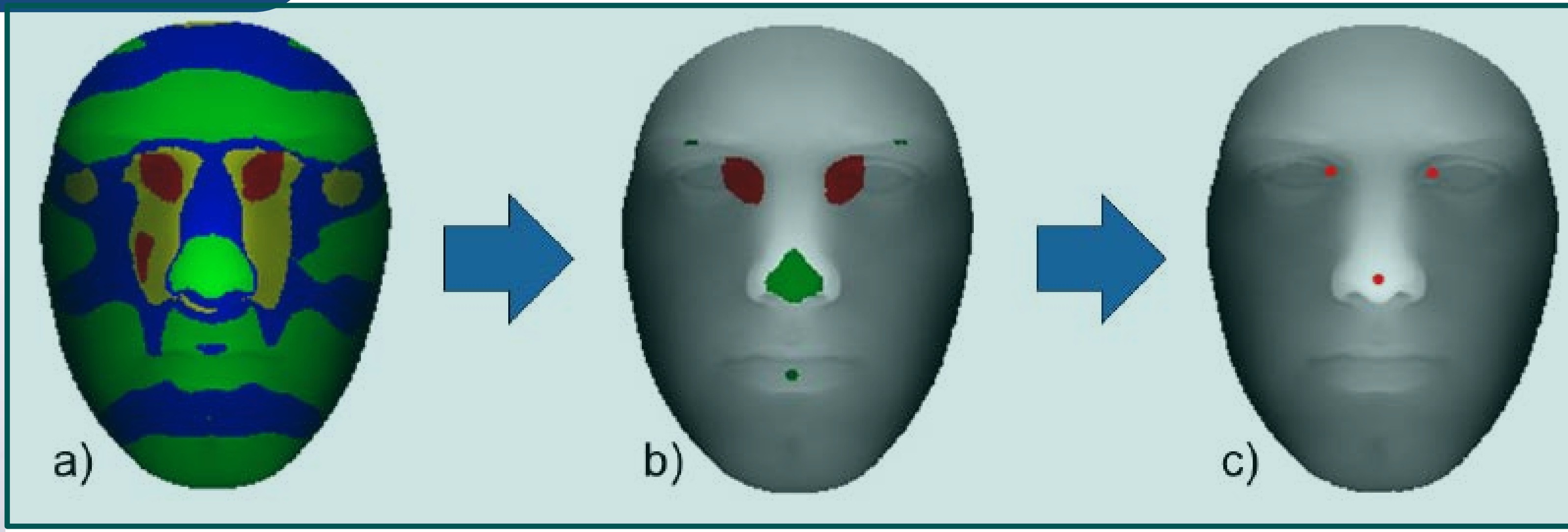
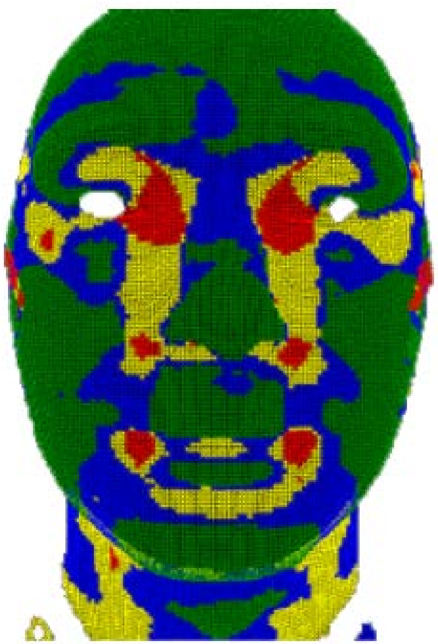
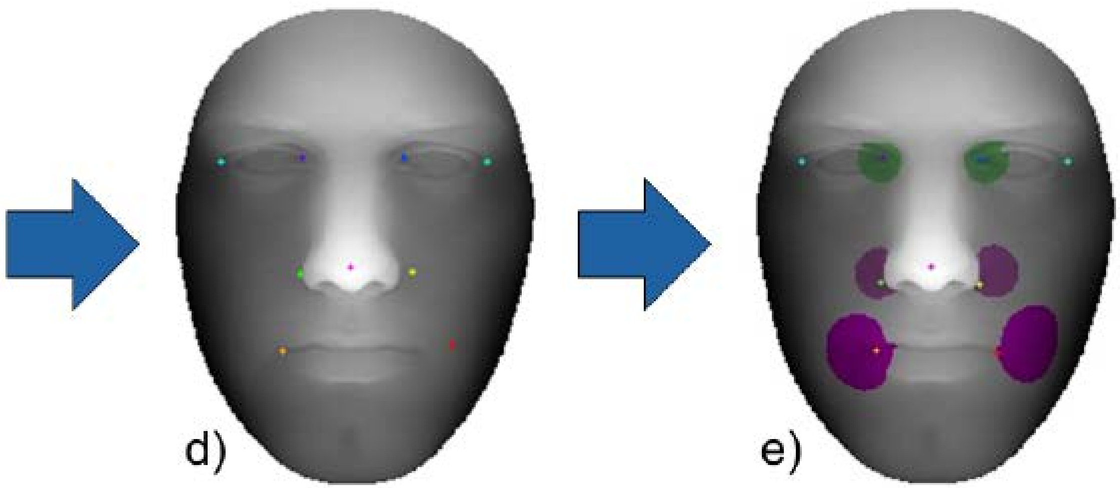
The overview of the approach



Fine analysis

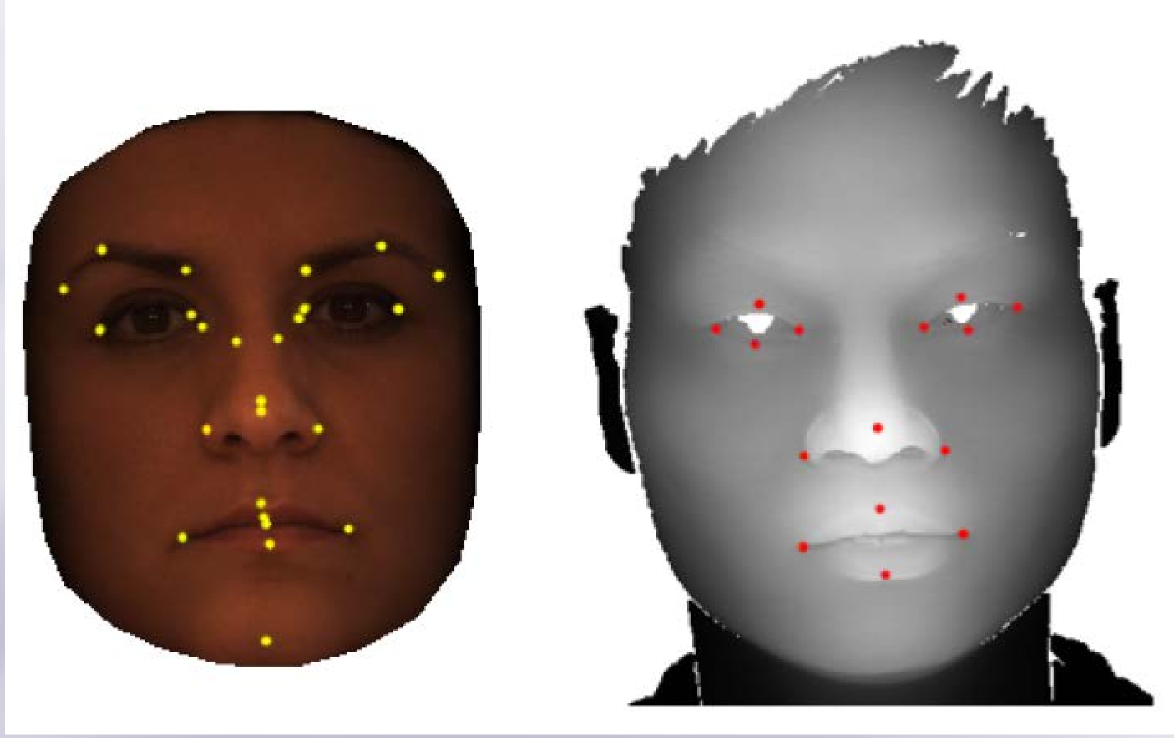






Experimental results

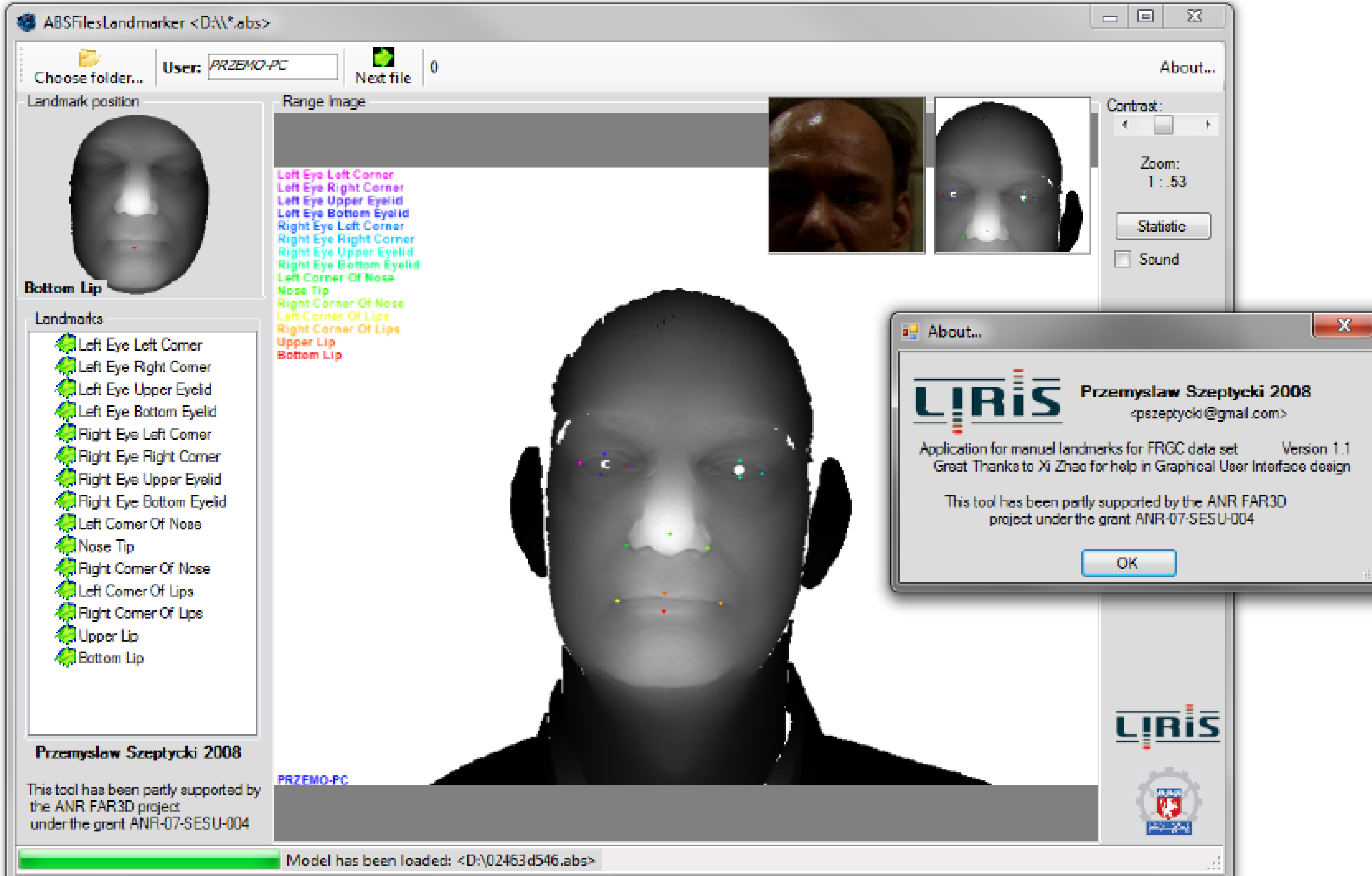
- In our experiment, we made use of the FRGC ver. 1.0 and ver. 2.0 datasets as well as the Bosphorus dataset.



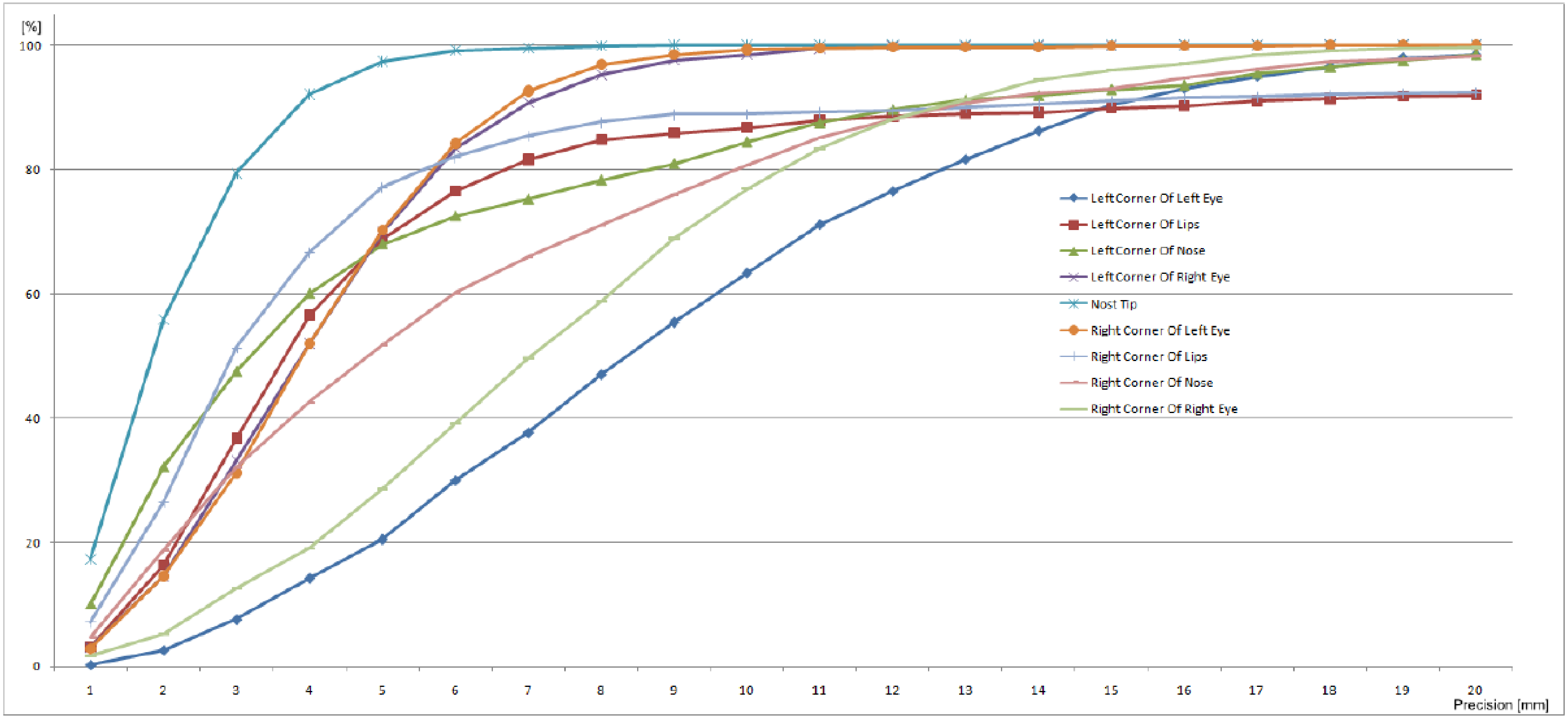
Generated random rotations:

yaw (from -90 to 90 degrees),
pitch (from -45 to 4 5degrees)
roll (from -30 to 30 degrees)

Manual landmarking project

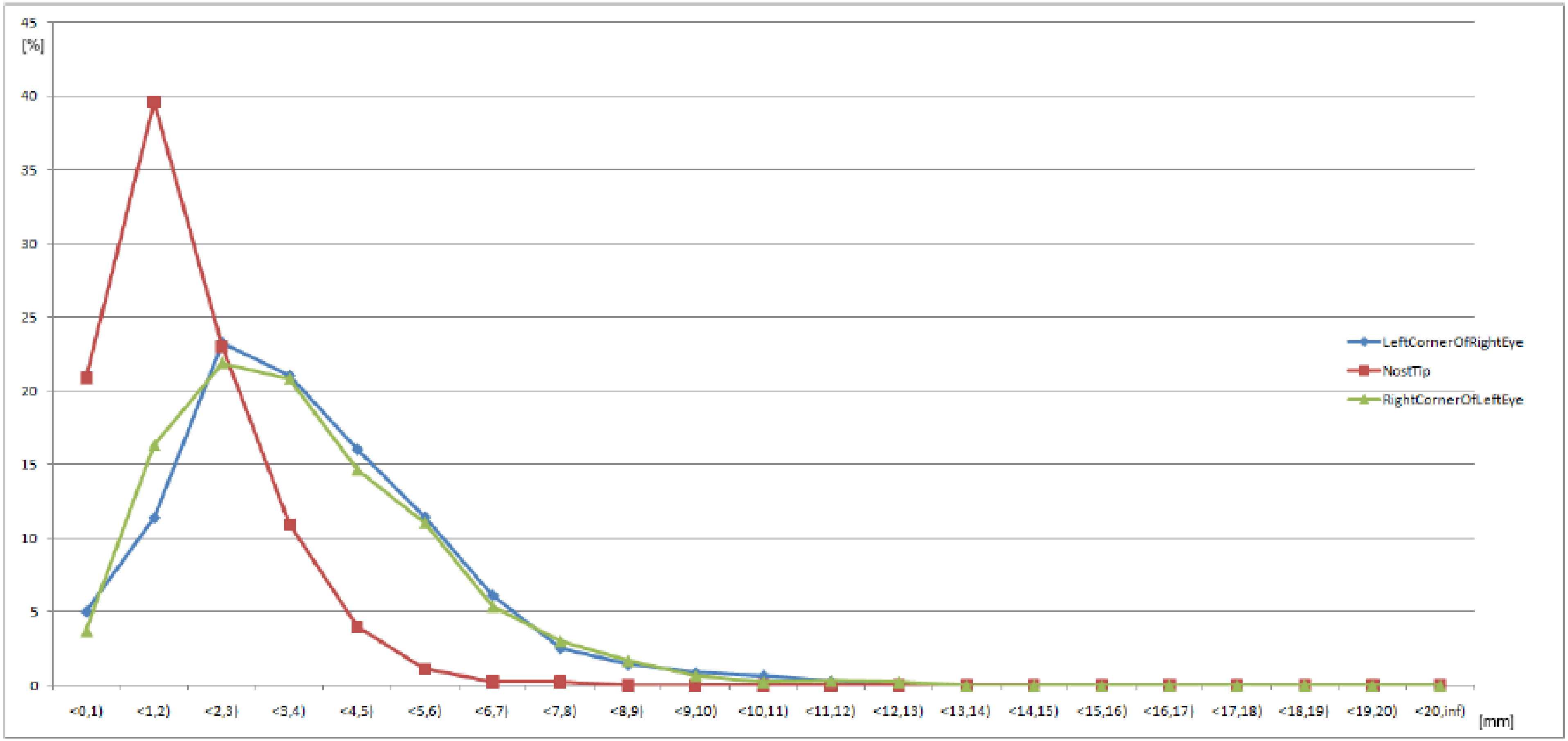


Experimental results



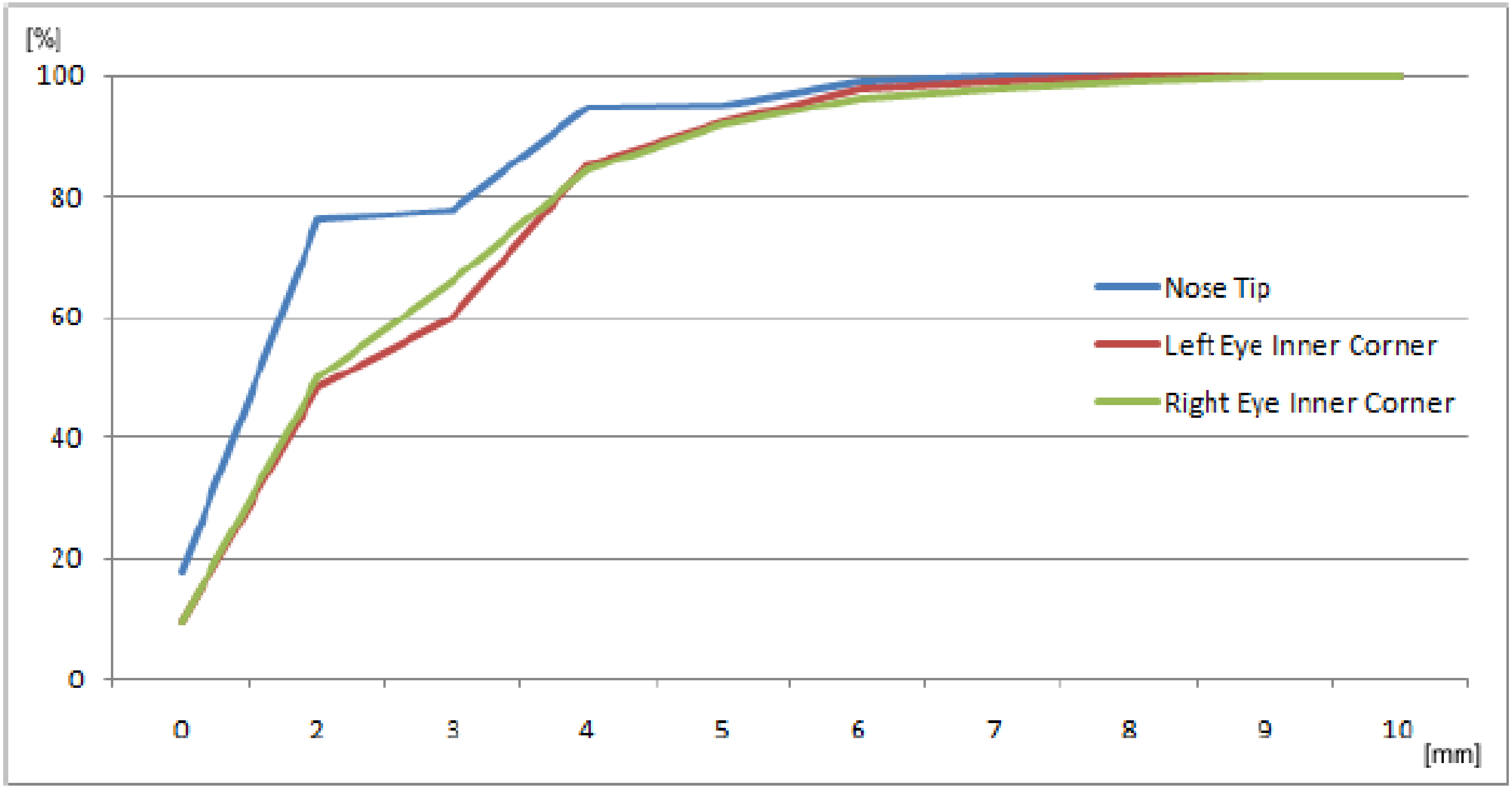
FRGC (1618 models)

Experimental results



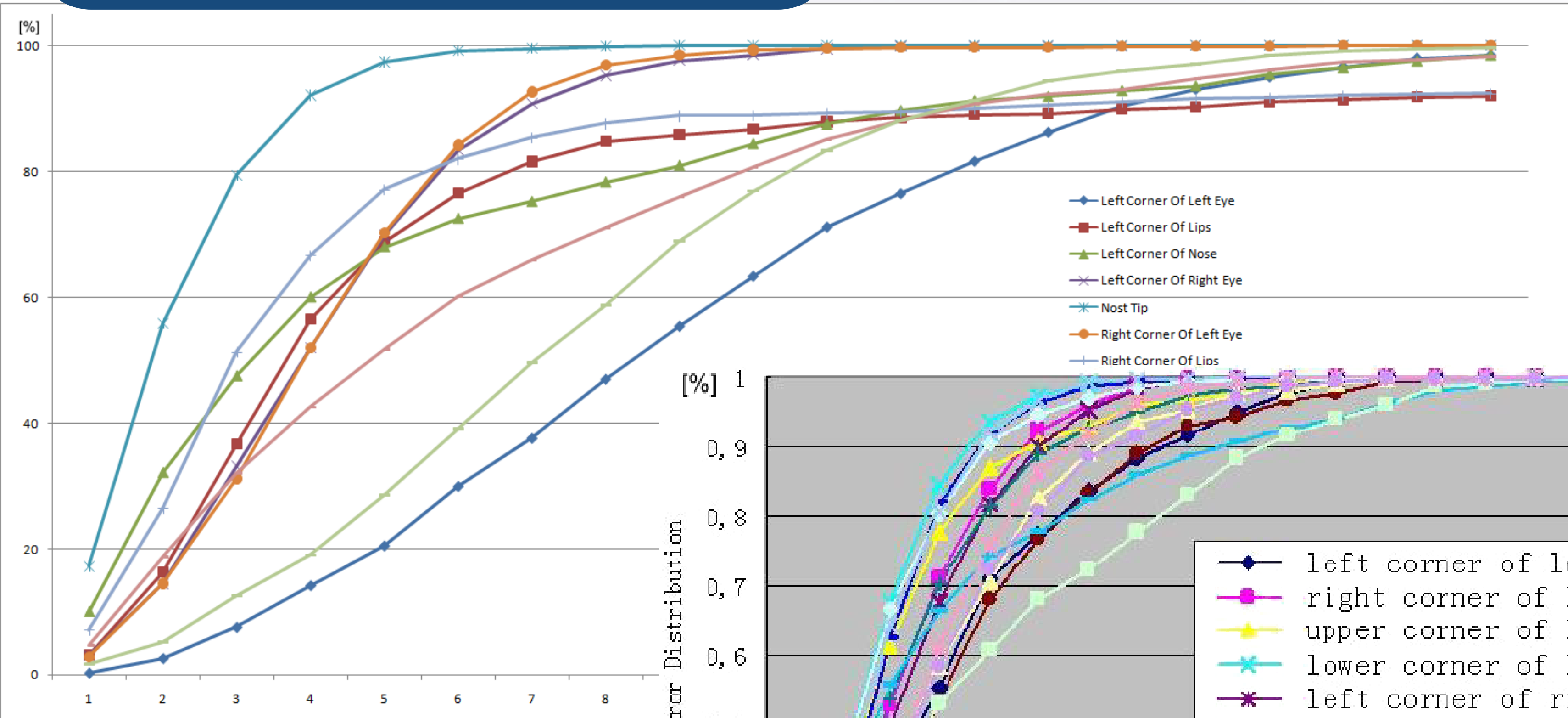
Landmarks frequency for the 3 main points on the FRGC dataset

Experimental results



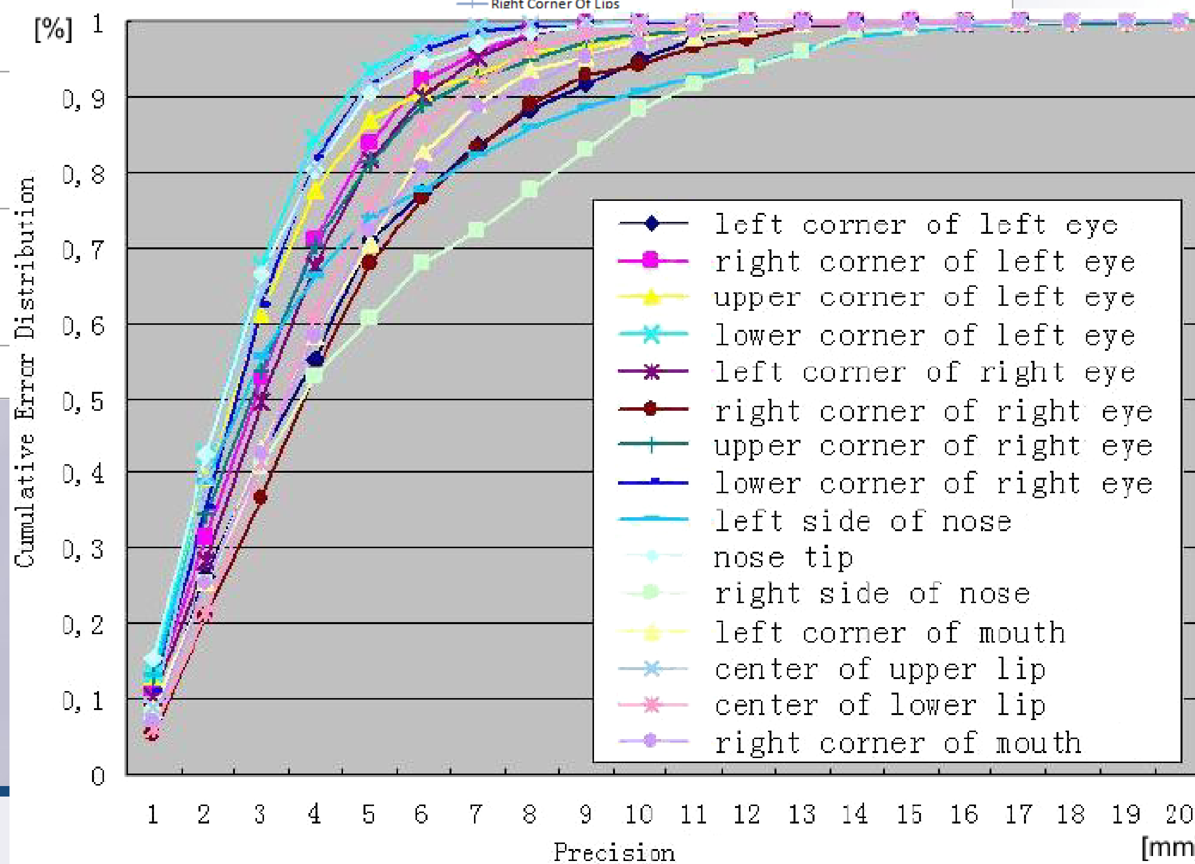
Bosphorus DB (frontal models of the first 46 subjects)

Comparison to SFAM



Our method

SFAM



Conclusion on landmarks localization

- The proposed modification in the curvatures calculation method
  - allows to achieve smooth curvatures decomposition without need of smoothing out the input models,
  - curvatures are stable across different models resolutions,
  - allows to localize precisely main facial features points,
  - helps to control smoothness of the curvatures,
  - fine details are still preserved.

- Points on the expression part cannot be precisely localized by curvatures analysis.
- Fast points candidates classifier, based on curvatures, can be created.

- Curvatures analysis.

Processing application

- **Publicly available**
- http://www.pszeptycki.com/tool.html