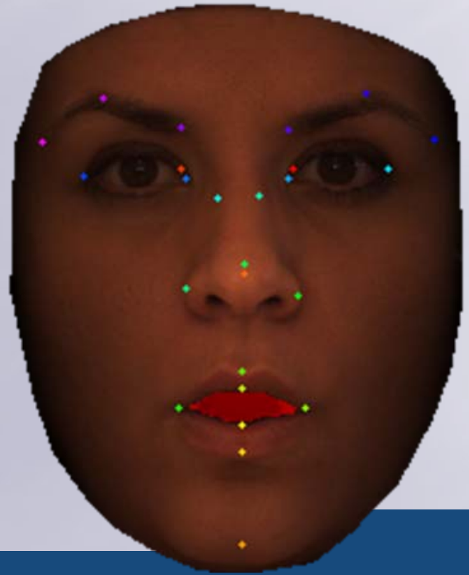
3D face preprocessing based on detection of high curvature edges for harmonic maps alignment



Przemyslaw Szeptycki,
Prof. Dimitris Samaras,
Prof. David Gu,
Dr Mohsen Ardabilian,
Prof. Liming Chen

LIRIS
CNRS Centre National de la Recherche Scientifique UMR 5205
Stony Brook University
École Centrale Lyon

11/02/2011 16:13

Agenda

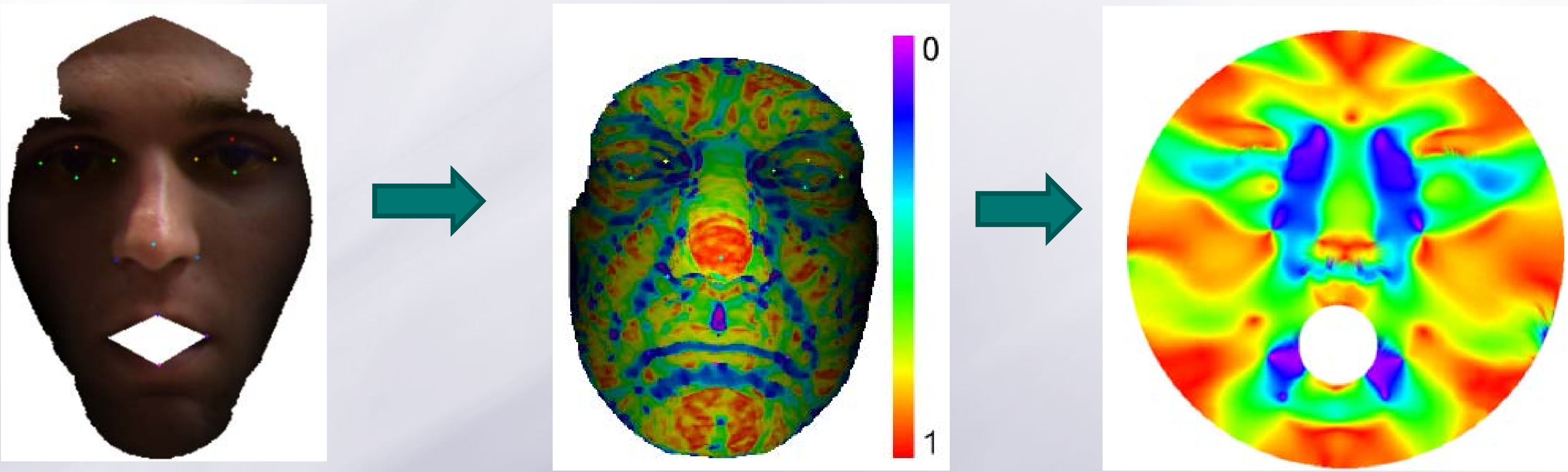
- Why preprocessing 3D faces?
- Facial surfaces are near-isometric under expressions?
- Making facial surfaces near-isometric under facial expressions:
  - Detecting open mouth on 3D facial models?
  - Modifying the geodesic distance
- Experimental results of open mouth detection,
- Conclusion.

Why preprocessing 3D face models?

- They are noisy…
- To gain any information about them,
- To process only interesting parts,
- Applying geometric tools for 3D face analysis
  - conformal mapping
- Previously
  - "*Conformal mapping-based 3D face recognition*", P. Szeptycki, M. Ardabilian, L. Chen, W. Zeng, D. Gu, D. Samaras, 3D PVT 2010
  - "*Partial face biometry using shape decomposition on 2D conformal maps of faces*", P. Szeptycki, M. Ardabilian, L. Chen, W. Zeng, D. Gu, D. Samaras, ICPR 2010

Previously

- *"Conformal mapping-based 3D face recognition" 3D PVT*



(2D)^{2}PCA for recognition

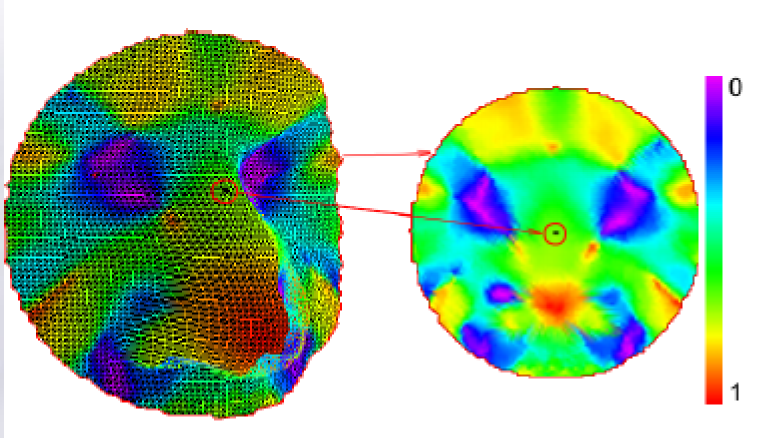
	I	II	III
ShapeIndex	86.43%	97.65%	69.38%
Mean Curv.	86.84%	94.29%	75.51%
Curvadness	86.23%	96.30%	70.91%
Kakadiaris 2007 PAMI[6]	97%	-	-
Wang 2006 CVPR[9]	95.7%	-	-

I - Neutral vs. All
II - Neutral vs. Neutral
III - Neutral vs. Expression

Rank-1 recognition rate on 62 subjects from FRGCv2.0 data set

Previously

- "Partial face biometry using shape decomposition on 2D conformal maps of faces"



(2D)^{2}PCA for recognition

	I	II	III
$(2D)^2$PCA			
ShapeIndex 25mm	72.85%	81.65%	65.71%
ShapeIndex 20mm	75.34%	82.1%	69.46%
ShapeIndex 15mm	77.1%	82.78%	72.15%
ShapeIndex 10mm	76.14%	84.5%	68.86%
Mean Curv. 15mm	67.09%	72.8%	62.12%
Nearest Neighbor			
L_1			
ShapeIndex 25mm	74.77%	82.27%	68.26%
ShapeIndex 20mm	75.26%	82.09%	69.31%
ShapeIndex 15mm	**79.18%**	84.5%	74.55%
ShapeIndex 10mm	77.42%	85.19%	70.65%
L_2			
ShapeIndex 15mm	75.74%	82.96%	69.46%
1 Loop ICP	70.21%	-	-

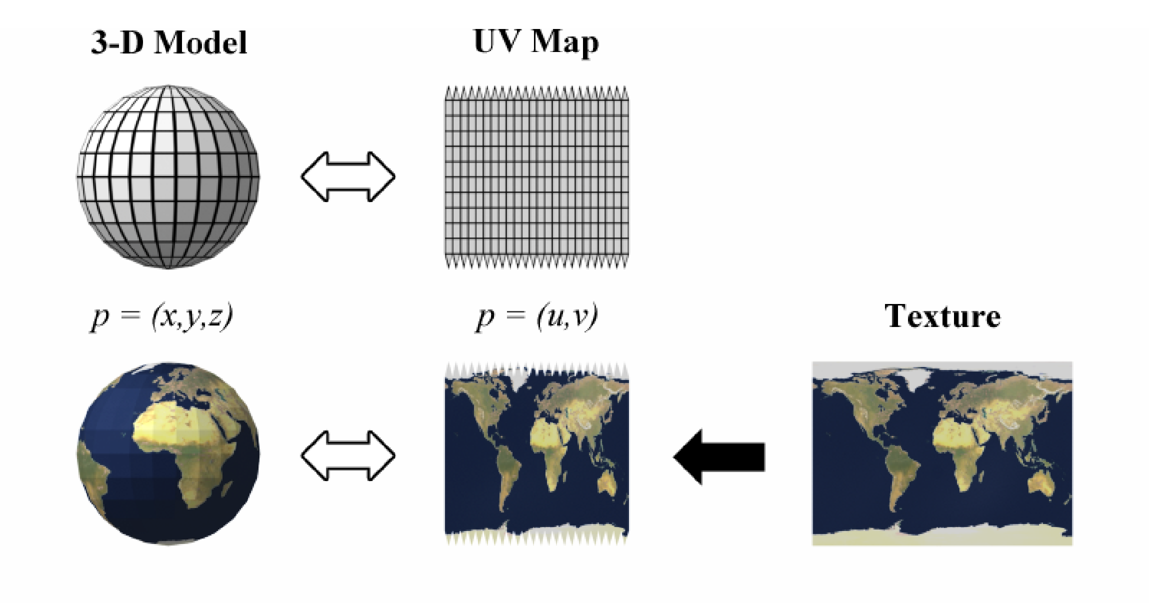
I - Neutral vs. All
II - Neutral vs. Neutral
III - Neutral vs. Expression

Summary

- Mapping 3D data to a 2D domain has following advantages:
  - Will allow all previously developed 2D recognition techniques for 3D face recognition,
  - Reduces amount of data to process,
  - Still has all advantages of 3D face recognition (direct correspondence between model and map)
  - Has potential to deal with facial expressions (non rigid mapping)

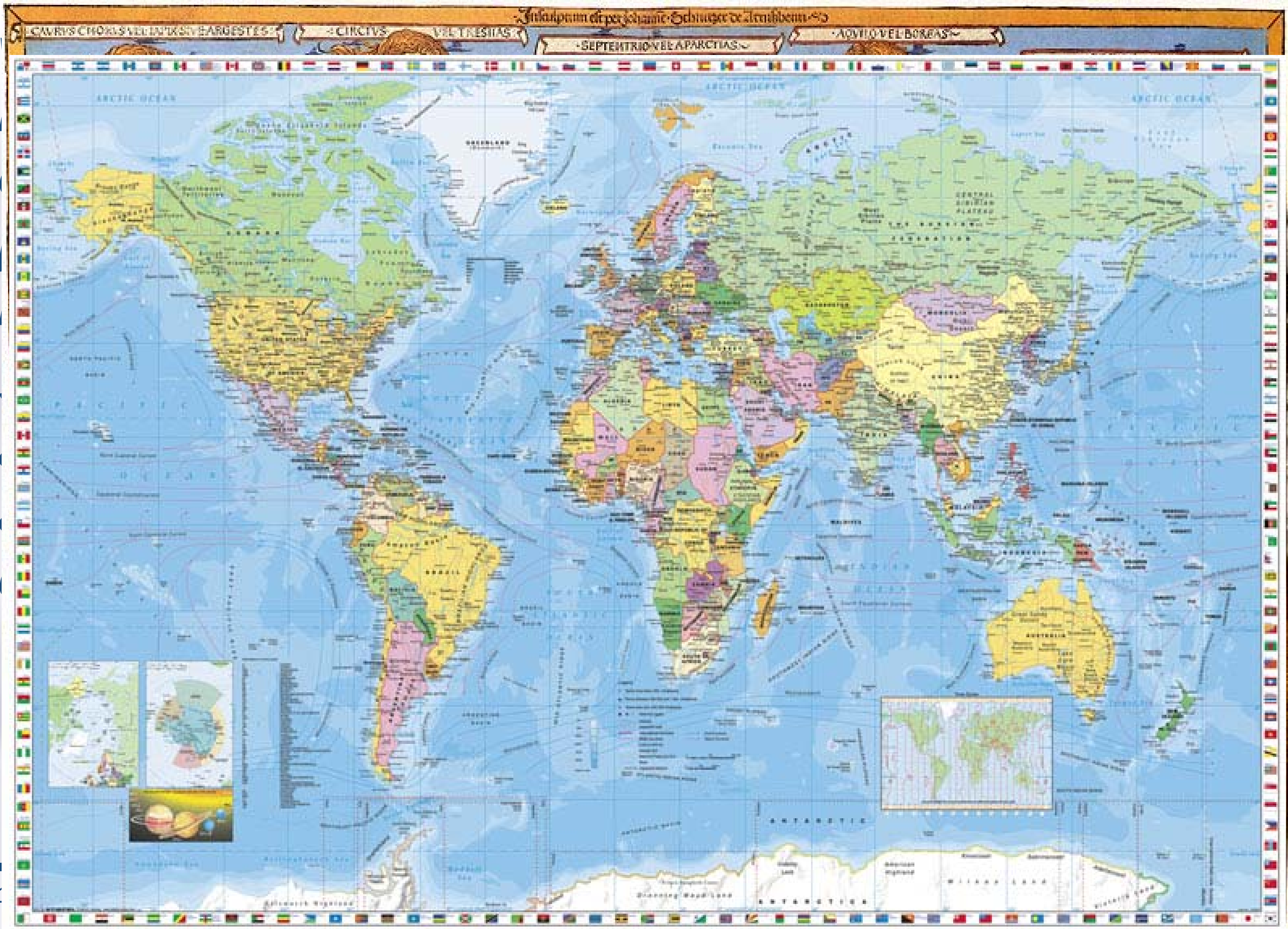
Mapping

- A parameterization of a surface can be viewed as a one-to-one mapping from the surface to a suitable domain (a plane).
- Parameterizations have many applications in various fields of science, but the main driving force in the development of the first parameterization methods was the application to texture mapping.



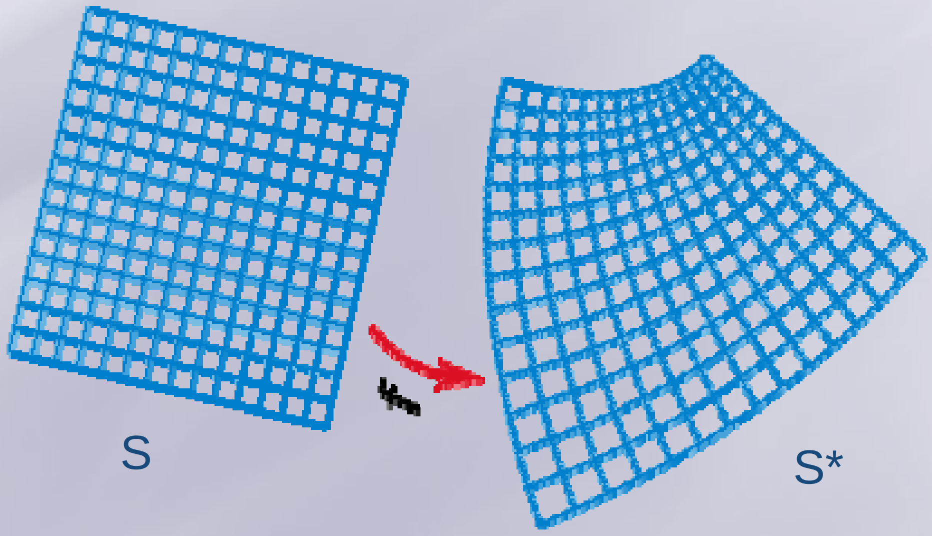
Historical Background

- The Greek astronomer *Claudius Ptolemy* (90-168 A.D.)



Conformal mapping

- Parameterizations almost always introduce distortion
- Conformal – angle preserving
- A mapping from S to S* is conformal or angle-preserving if the angle of intersection of every pair of intersecting arcs on S* is the same as that of the corresponding pre-images on S at the corresponding point.



Harmonic Maps

- Harmonic maps are quasi-conformal maps which can be computed by minimizing a harmonic energy.
- Although harmonic maps are easy to compute, they require satisfaction of the boundary condition. If the boundary condition is given, the solution exists and is unique.

Why we should use Harmonic maps?

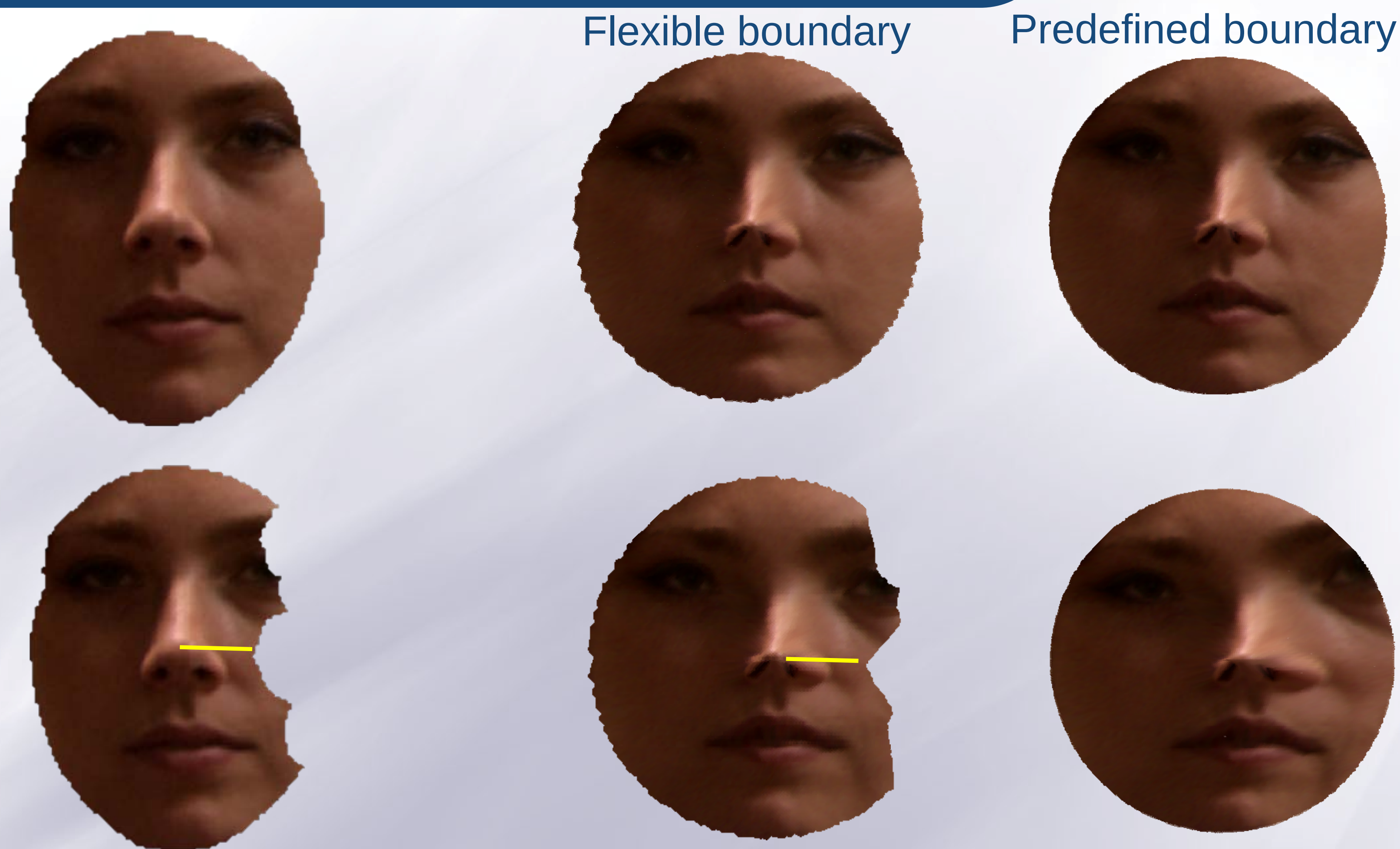
- Maps are stable and insensitive to resolution,
- Can integrate geometric and appearance information,
- Model non-rigid deformations,
- Have advantage being fast and correctly aligned maps can give accurate correspondence between surfaces,
- 3D shape matching problem can be simplified to 2D, which is a better understood problem.

- Therefore, highly accurate and efficient 3D shape matching algorithm can be achieved.

Conditions

- **Harmonic maps require:**
  - **Unchanged boundary condition**
    - **Achieved by:**
      - *Consistent cropping*
  - **Unchanged surface topology**
    - **Achieved by:**
      - *Open mouth detection and removal*
  - **Proper triangulation (sparse system stability)**
    - **Can be corrected by re-triangulation.**

Flexible boundary of HM



Flexible boundary of HM

Flexible boundary

Predefined boundary

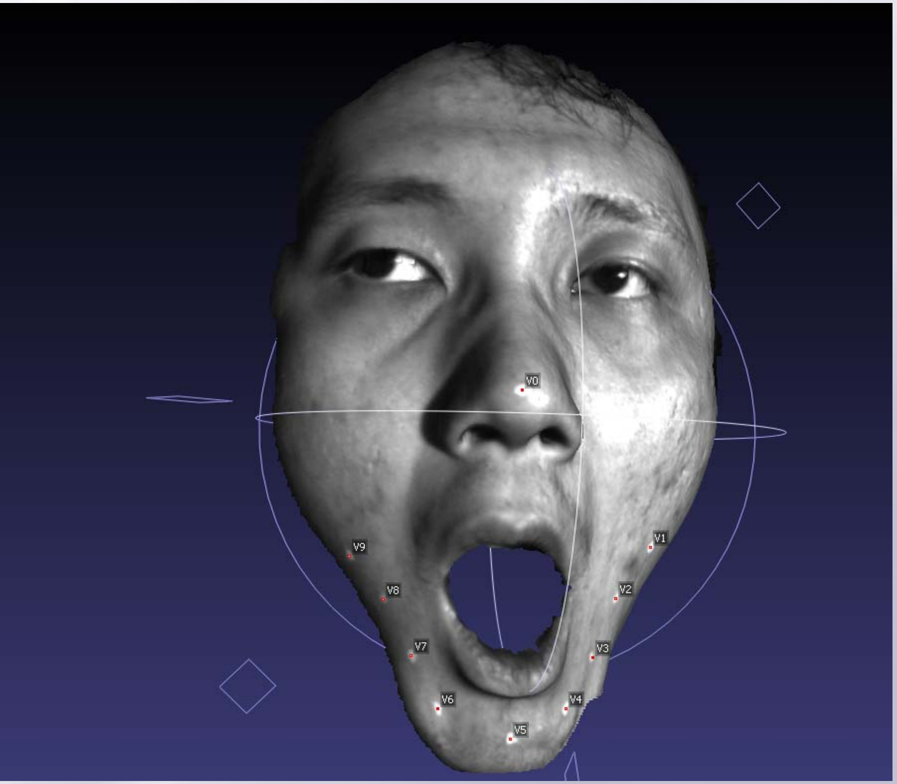
How to create comparable Harmonic maps?

- *Conditions*
  - Flexible harmonic map boundary
    - Deals with missing data
  - Consistent boundary
    - Remove all protruded parts…
  - Preserving surface topology
    - Detect open mouth …

Under facial expressions,

FACIAL SURFACES ARE NEAR-ISOMETRIC ?

Facial expressions

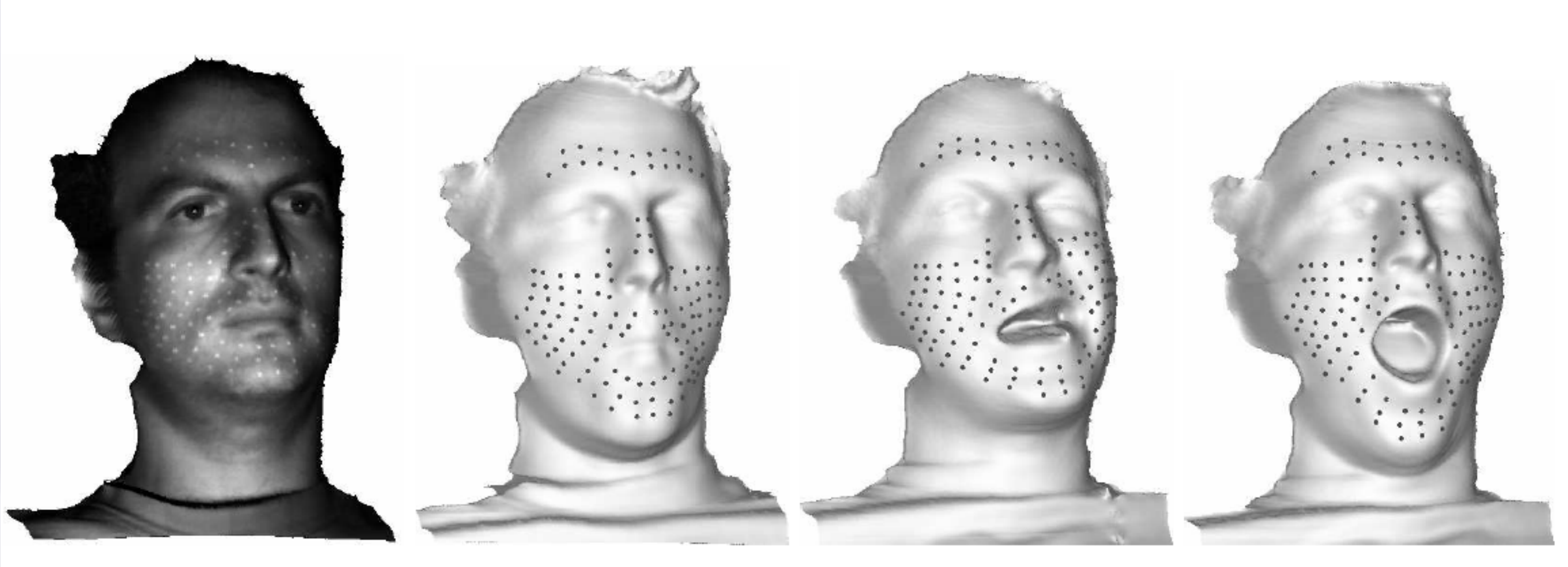


Is it the same?

Subproject

Near-isometric facial expressions

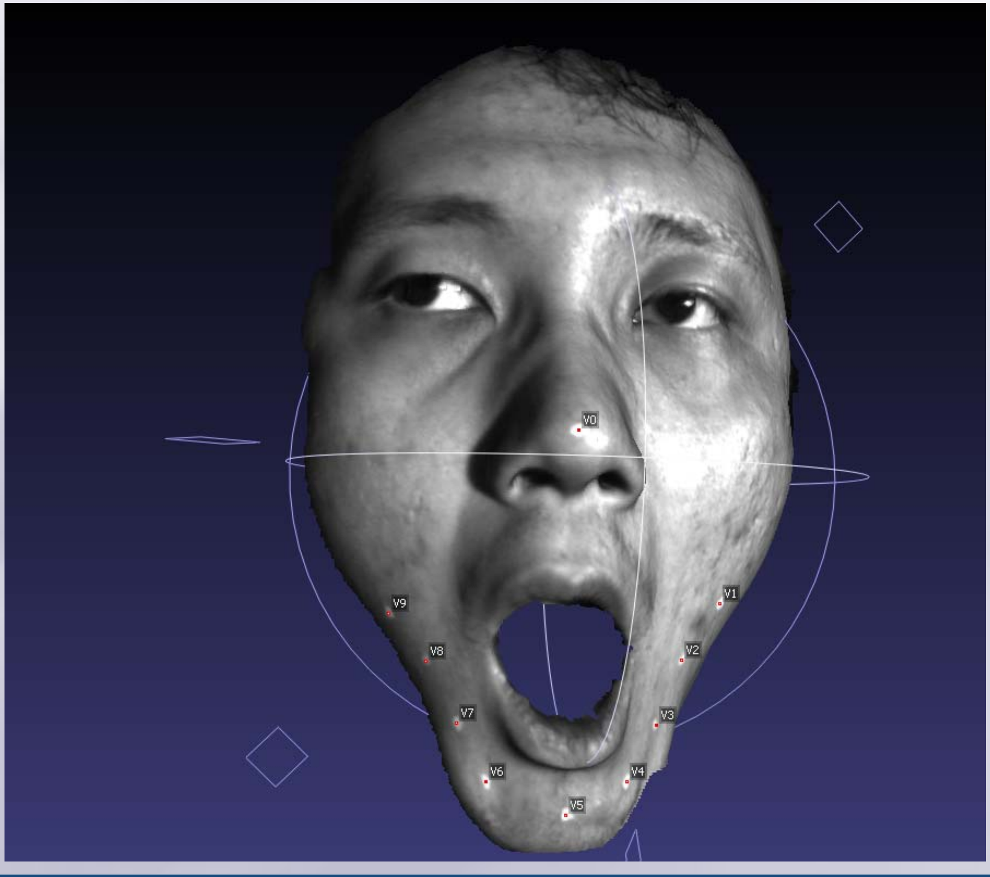
- Isometric means distance-preserving
- Bronstein et al.
  - “Expression invariant representation of faces” presented a facial expression invariant model based on the assumption that the face expression can be modeled as near-isometric.



„Expression invariant representation of faces”

Is it true this assumption ?

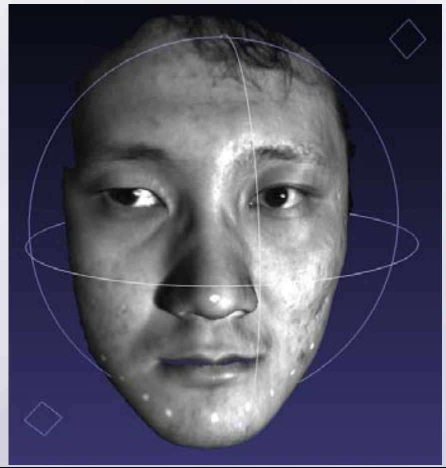
- Our validation
  - a face was physically marked with 10 points covering the lower part of the face, which is most involved during large expressions.

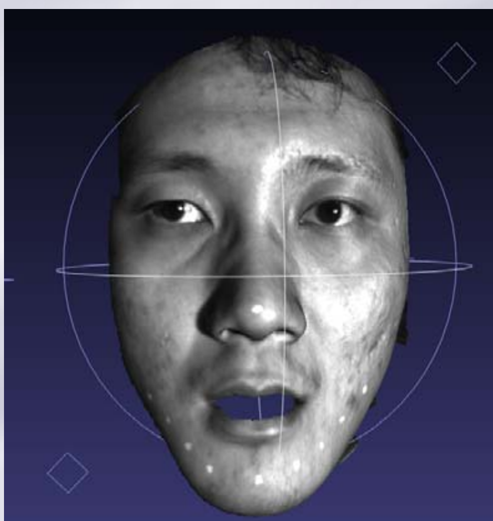


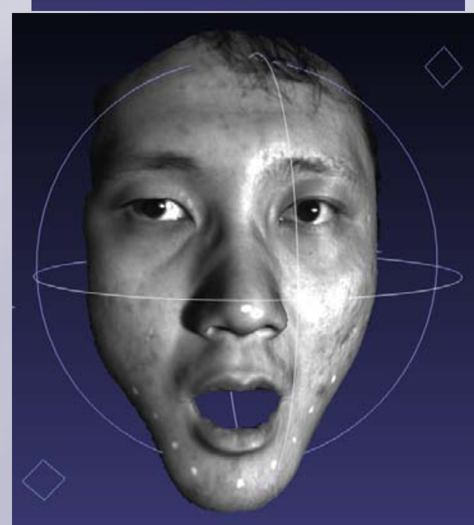

V0
V1
V2
V3
V4
V5
V6
V7
V8
V9

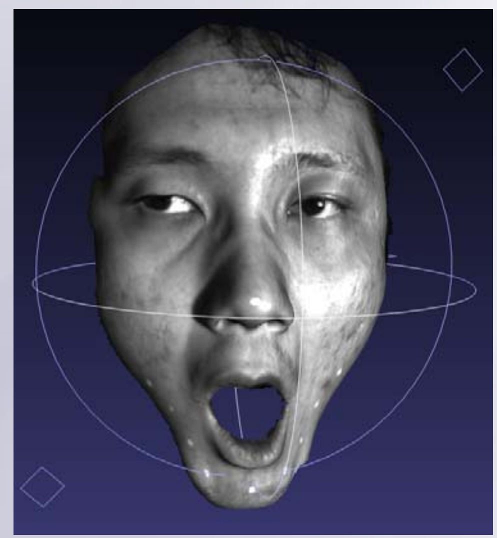
Our validation

- A subject was asked to introduce four expressions:







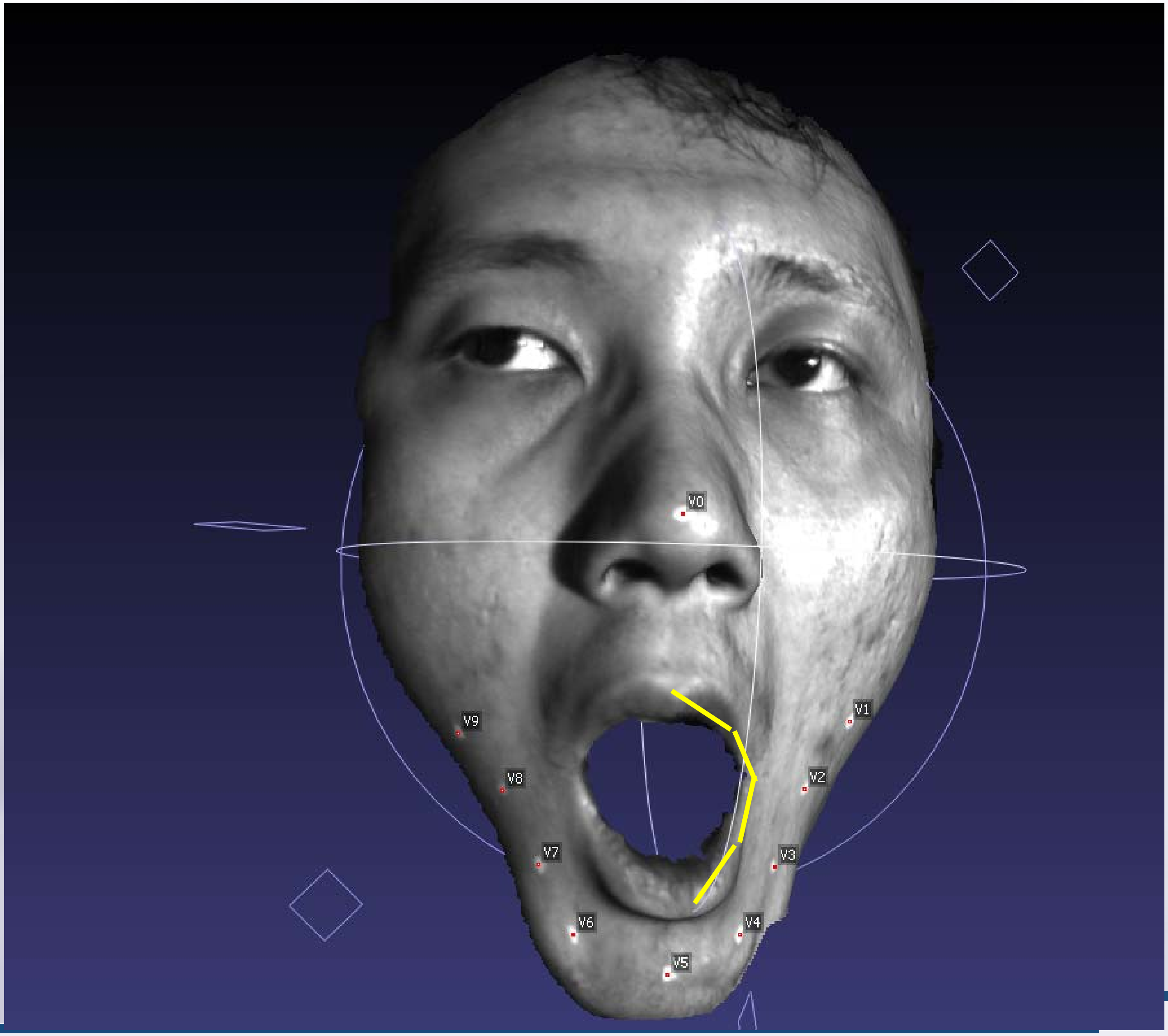


3 levels of mouth opening

Our validation

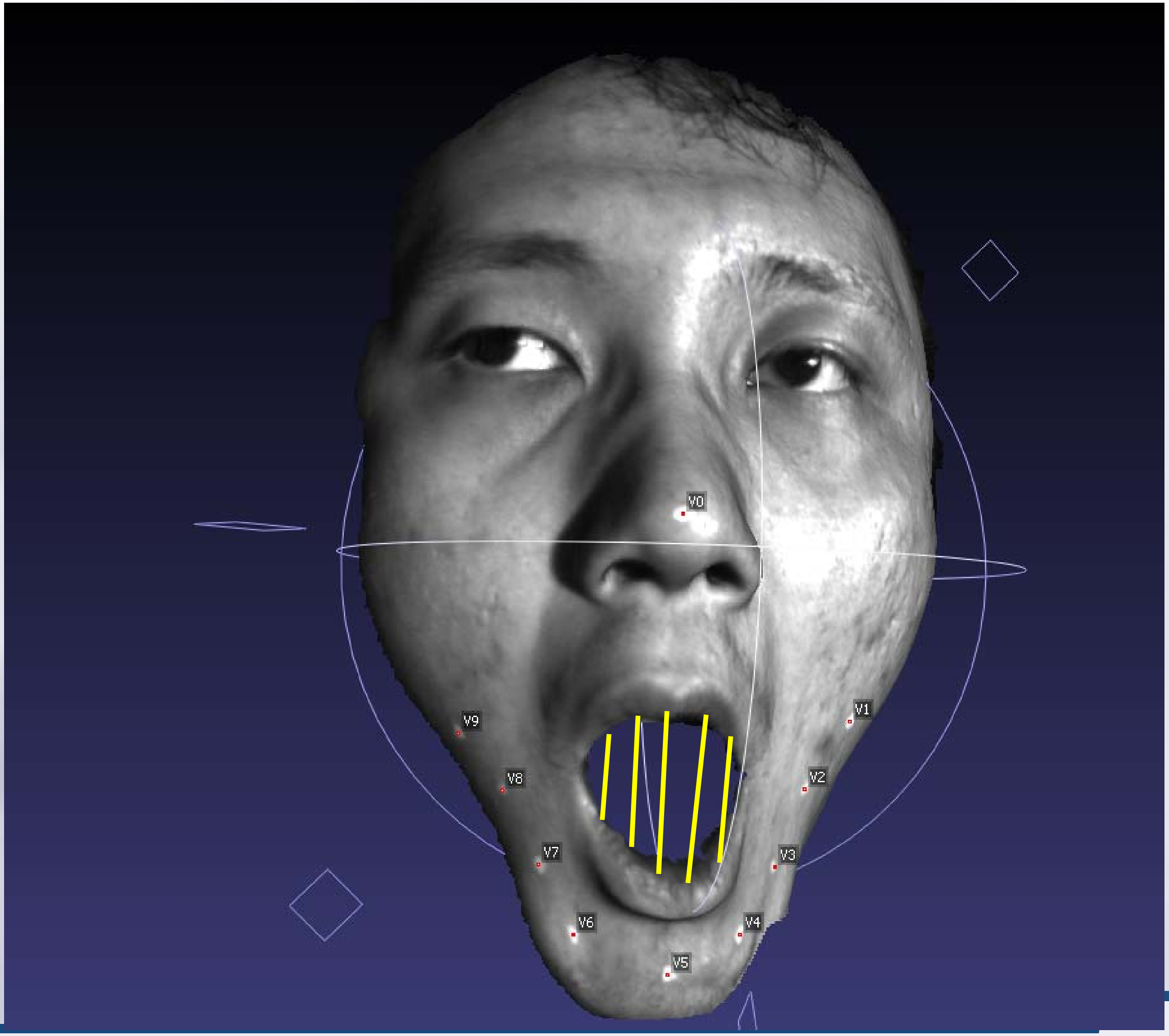
- All expressions were registered using the same 3D scanner.
- For each 3D facial model the mouth part was removed to preserve surface topology.
- Each manual point was selected for all expressions giving nine traceable points and the nose tip.
- Afterwards the geodesic, **modified geodesic**, as well as Euclidean distances were calculated between the nose tip and all the traceable points to verify if the isometric or near-isometric assumption holds.

Measuring Geodesic distances



using Dijkstra's algorithm

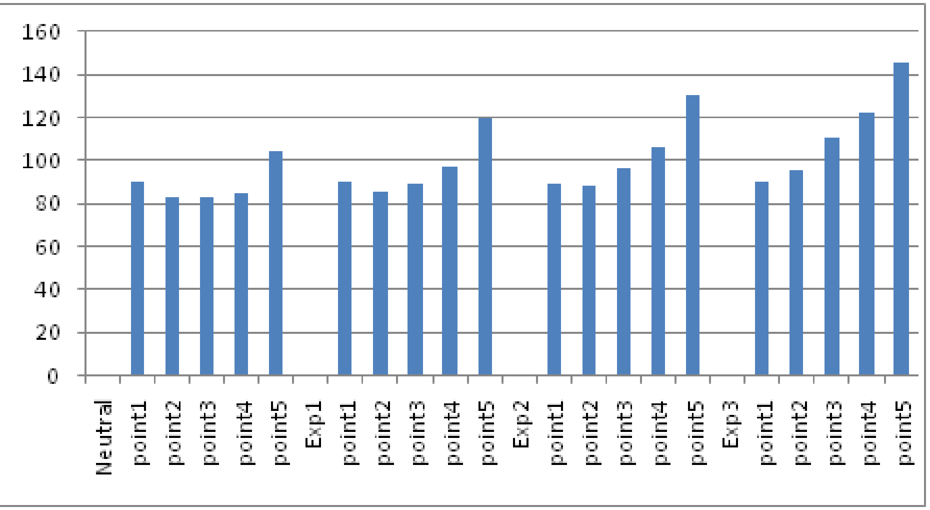
Modified geodesic distance



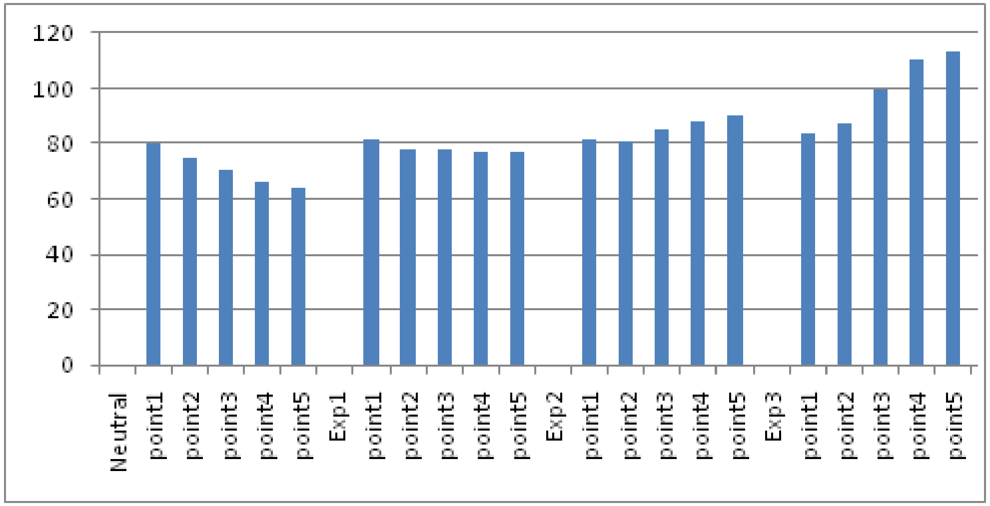
using Dijkstra's algorithm

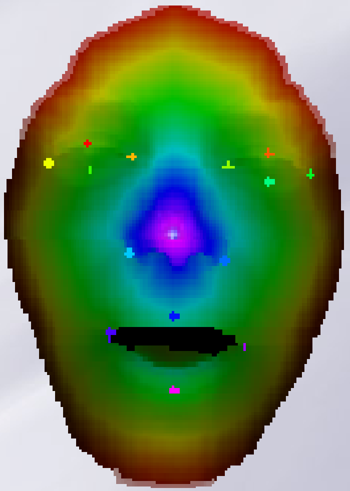
Results

Geodesic

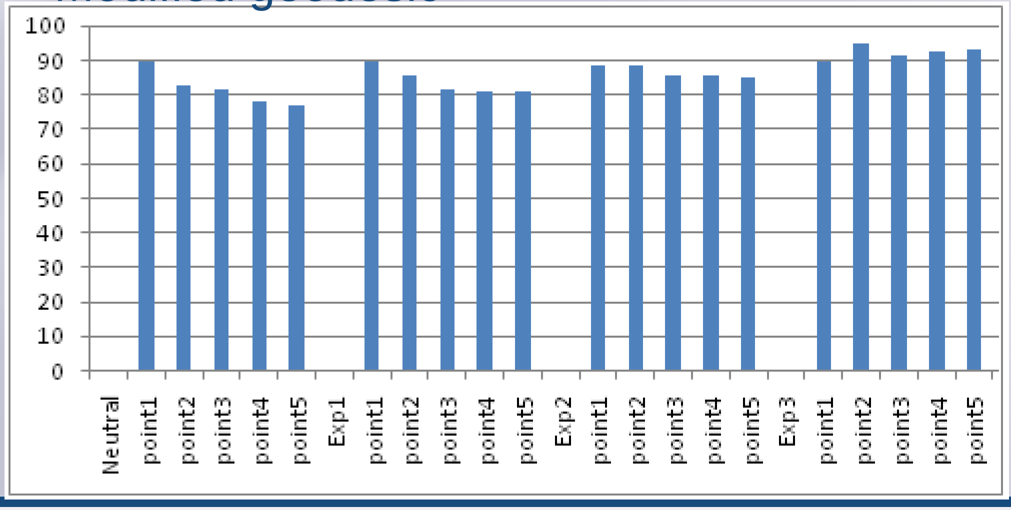


Euclidean



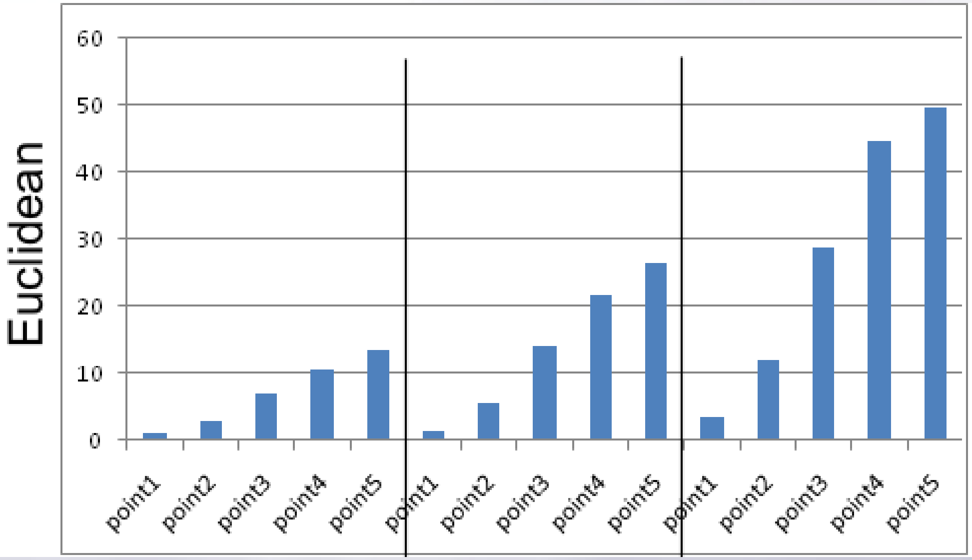


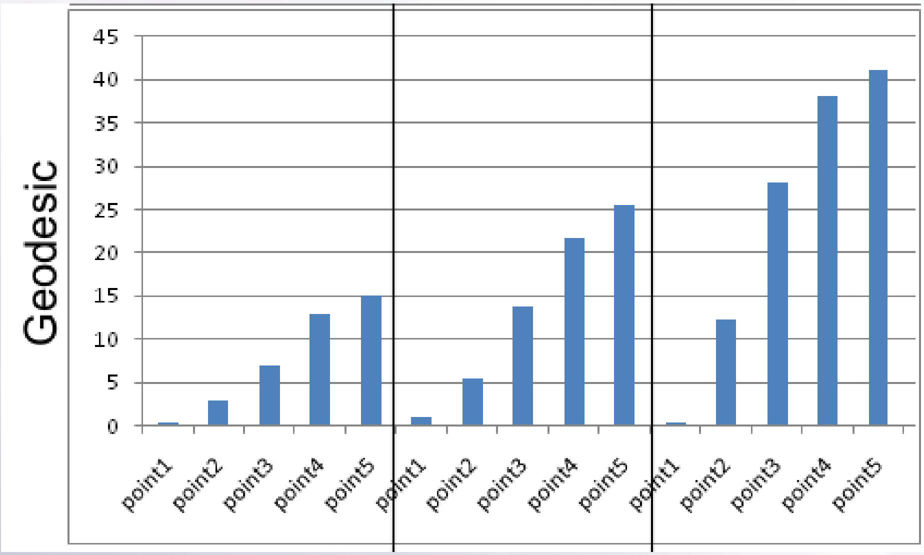
Modified geodesic

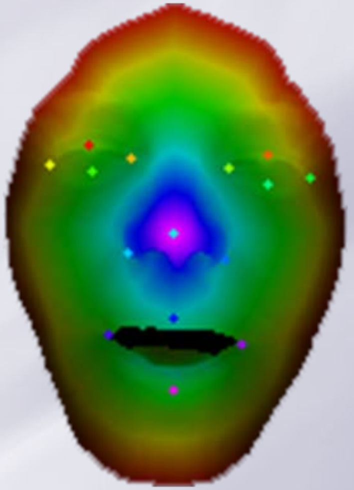


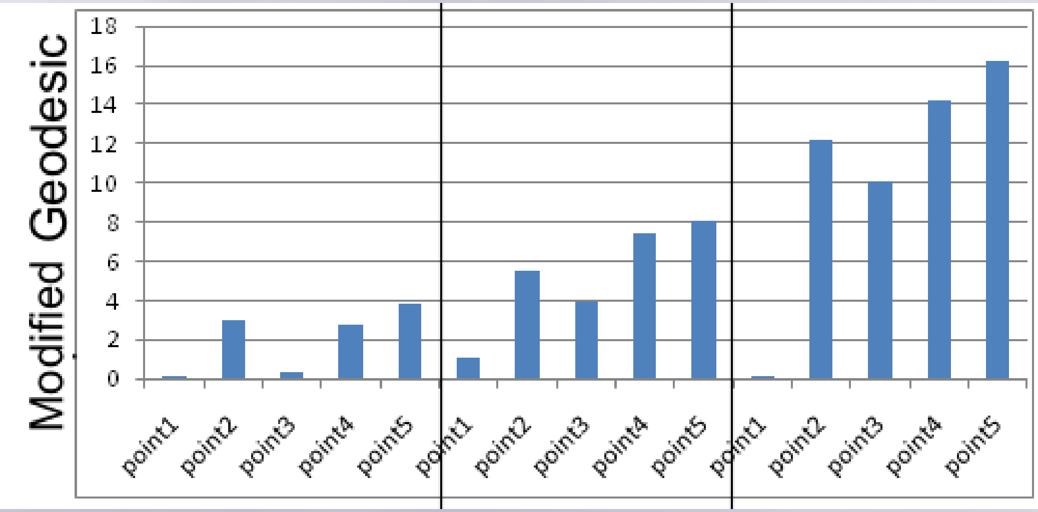
distances from the nose tip

Results – differences in distances

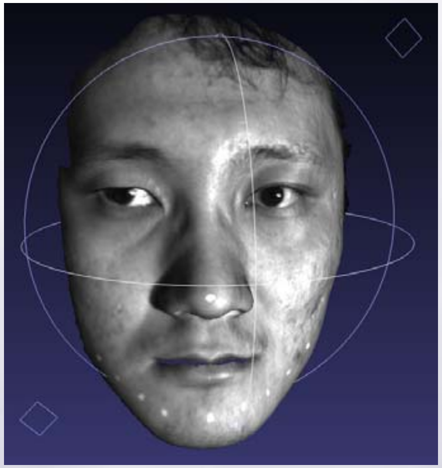


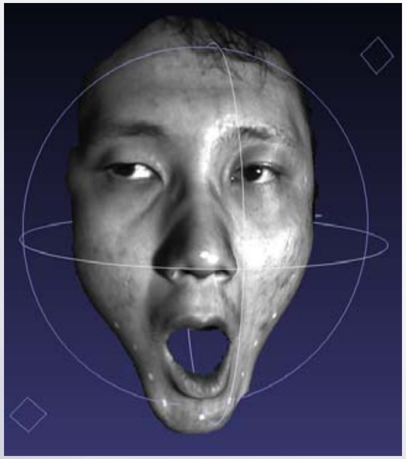




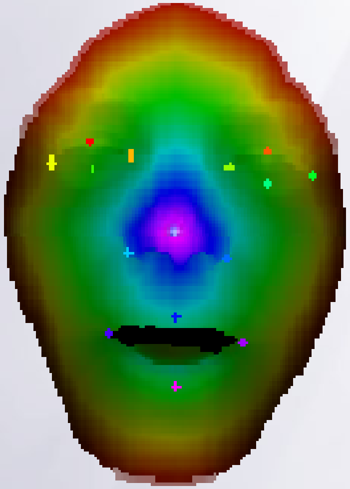


Results





- Differences between neutral expression and large mouth opening in point no 5.
  - Geodesic distance: 41.2 mm
  - Euclidean distance: 49.7 mm
  - **Modified Geodesic distance: 16.2 mm**

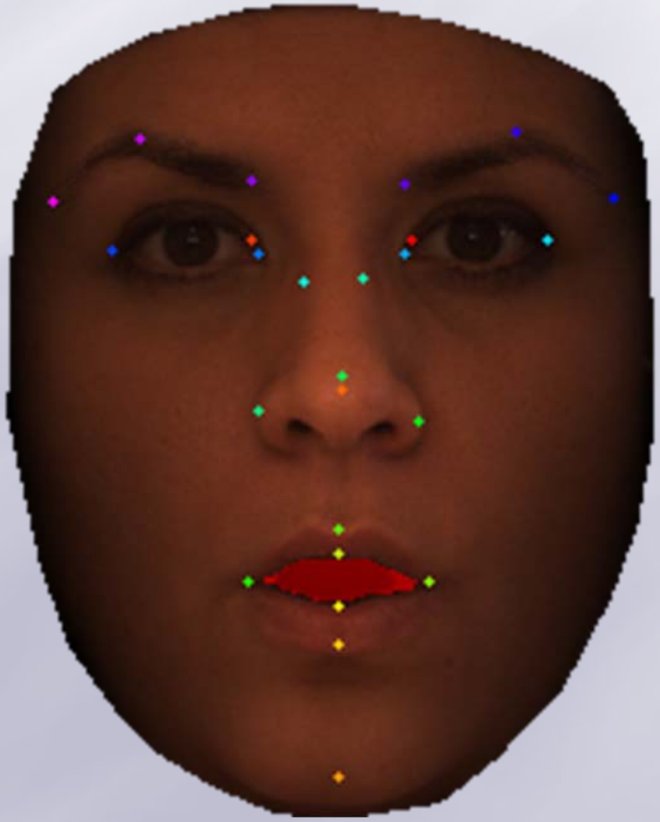


How to create comparable Harmonic maps?

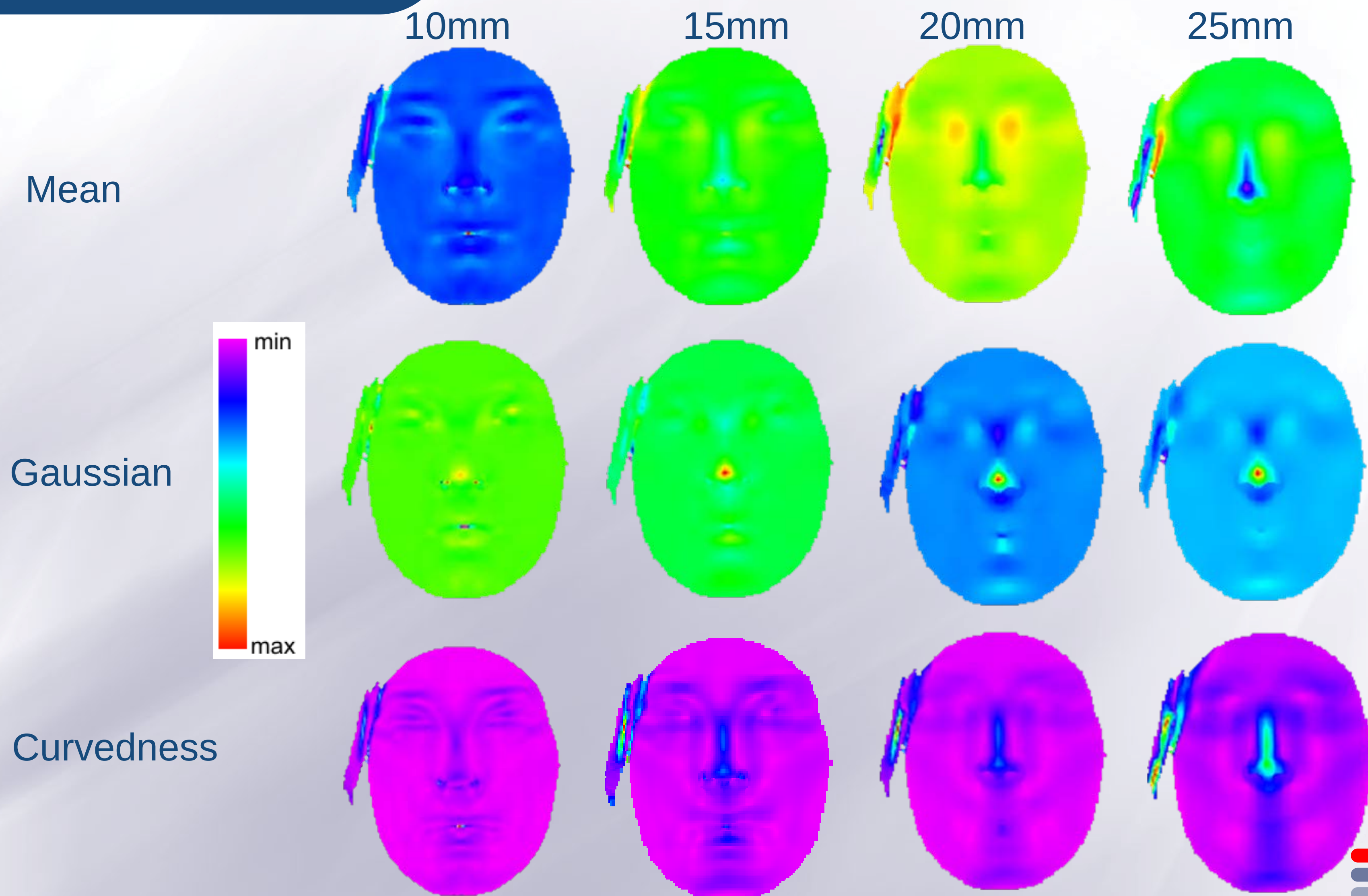
- *Flexible harmonic map boundary* ✓
  - Deals with missing data
- *Removal of all protruded parts*
  - Will help to achieve consistent boundary
- *Open mouth detection*
  - Consistent lower face boundary in case of large expressions
    - modified geodesic distance
  - Will help to preserve surface topology

How?

Open mouth detection

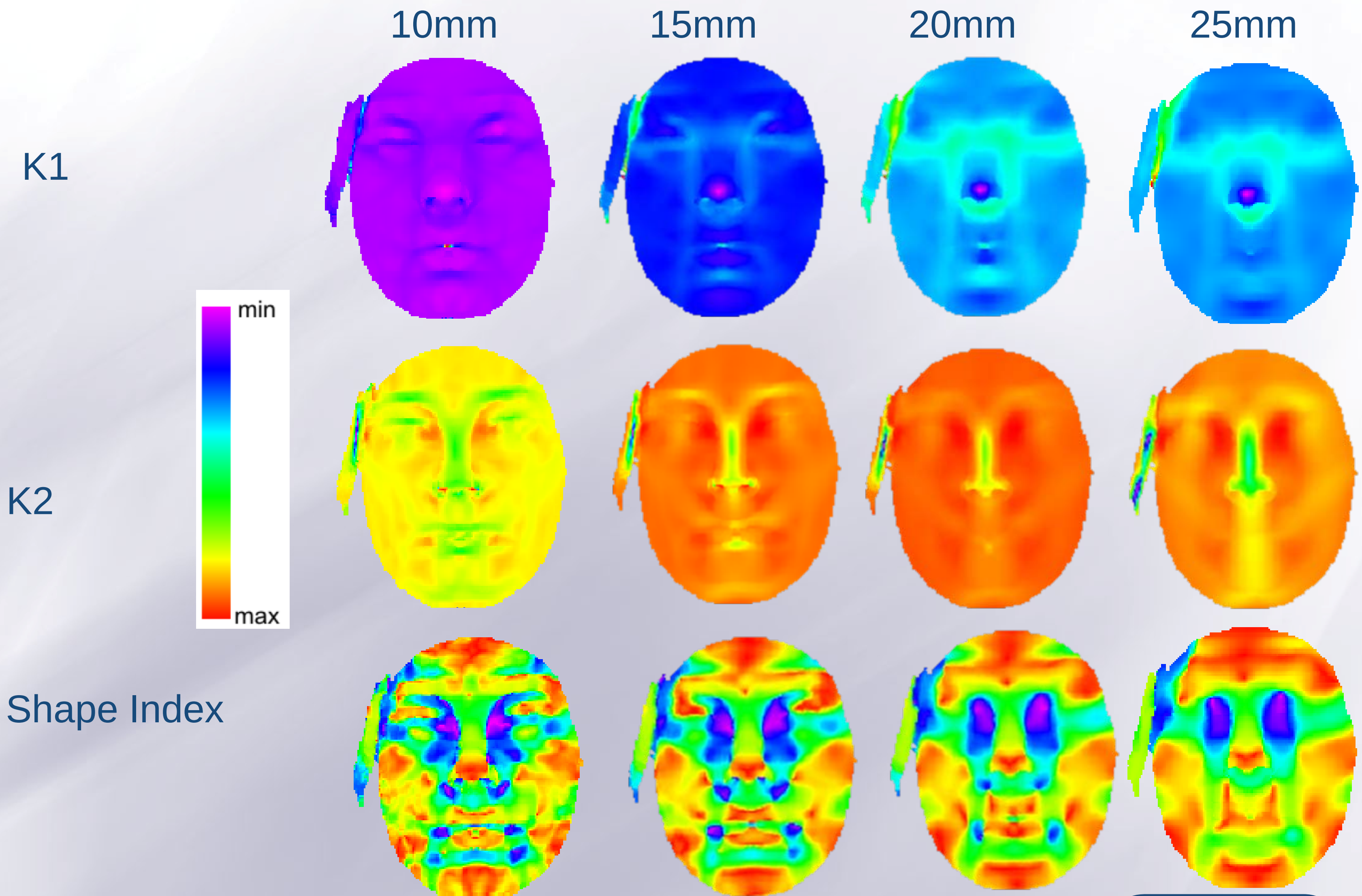


Curvatures



Under different resolution

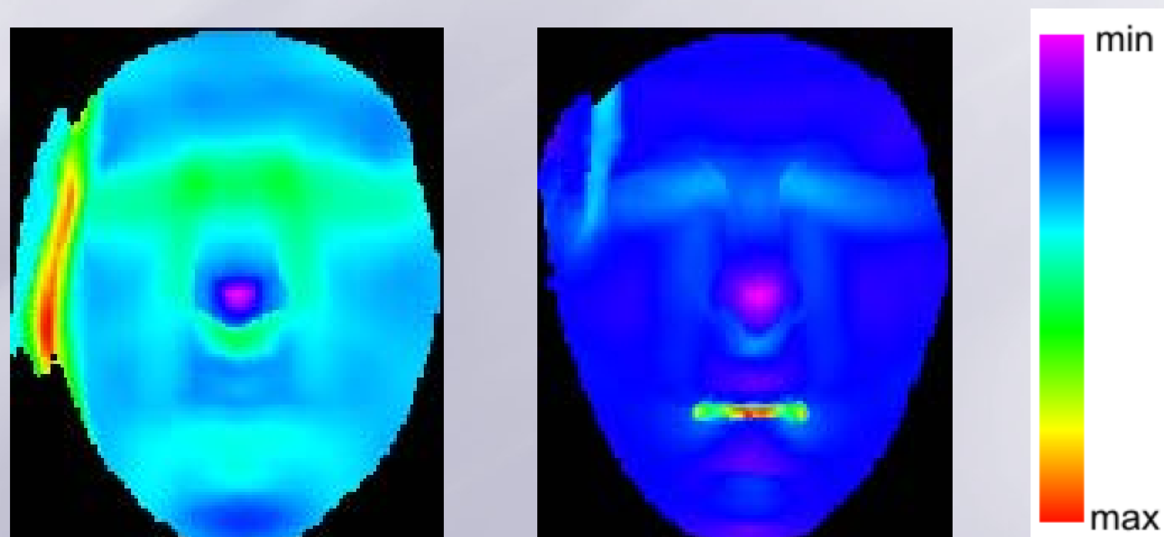
Curvatures



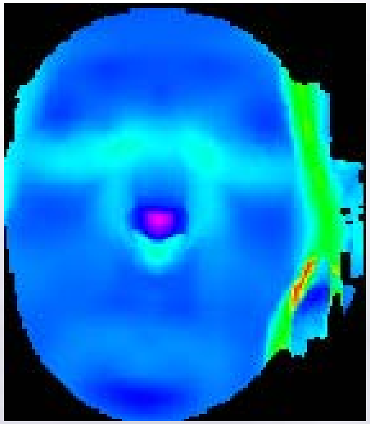
Under different resolution

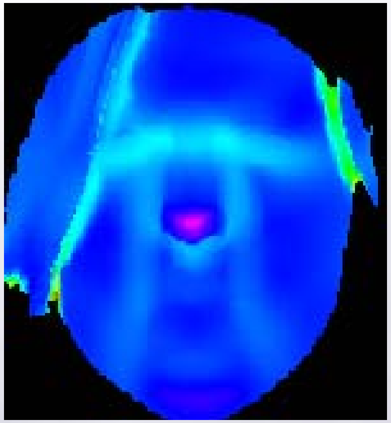
Observation

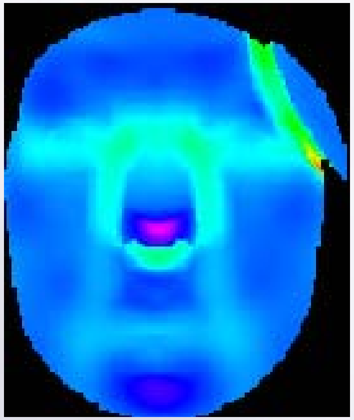
- An observation, of different curvatures decompositions over facial models leads to the conclusion: **that high principal curvature K1 forms edges between facial surface and protruded parts as well as between open lips.**

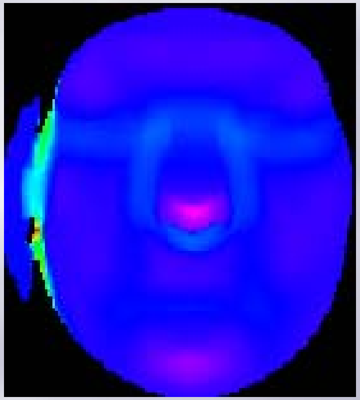


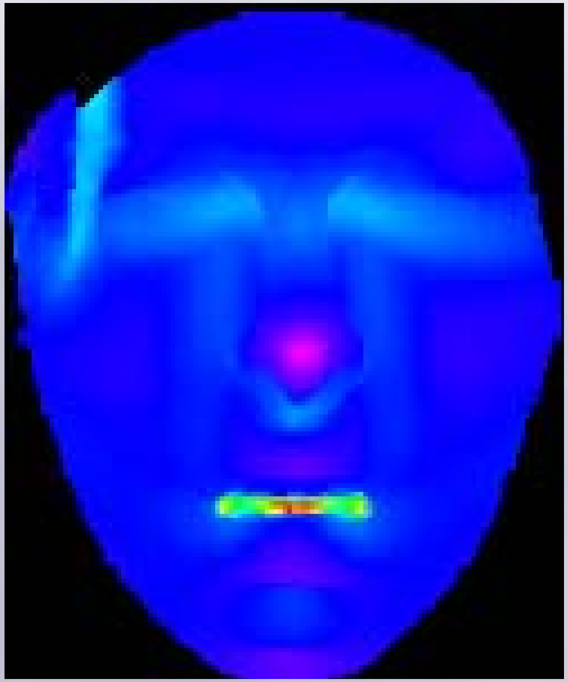
K1

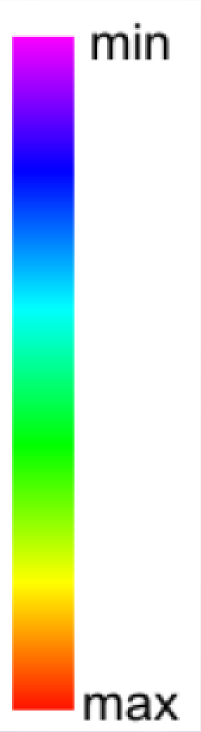






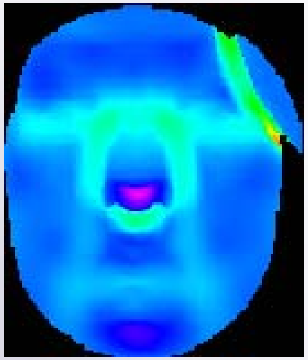


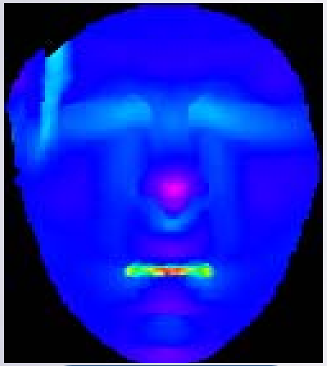




How to achieve consistent Harmonic maps?

- *Flexible harmonic map boundary* ✓
  - Deals with missing data
- *Removal of all protruded parts*
  - Remove all edges between protruded parts and facial surface
  - use modified geodesic distance for face cutting.
- *Open mouth detection*
  - Remove open mouth part
  - use modified geodesic distance for face cutting.



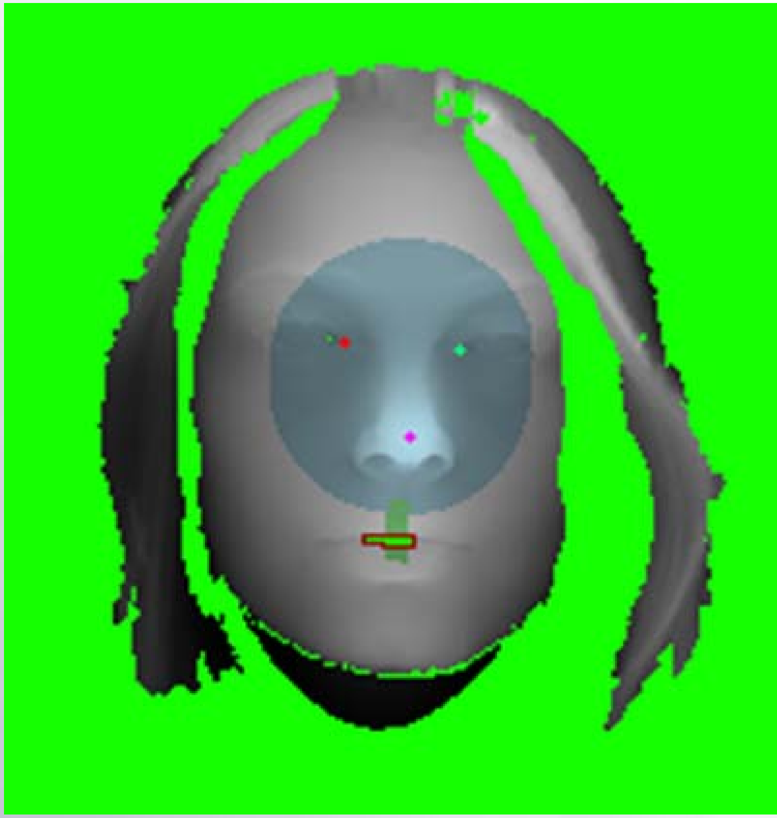


How to localize the high curvature region?

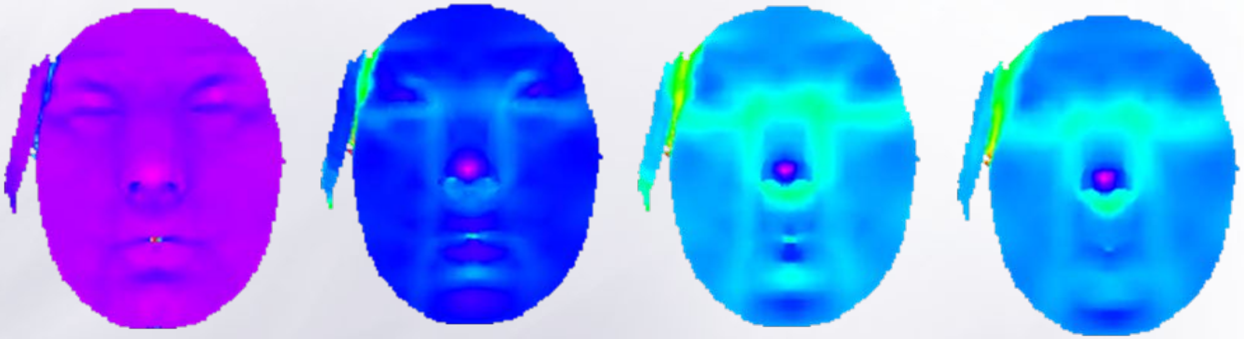
- **Verify a face for the maximum allowed curvature values and set the thresholds.**
  - Use rigid facial region (not influenced by expressions)
- **Remove all points, where curvature values of which are beyond the thresholds.**
  - Use thresholds on different curvature resolutions

Rigid facial region selection

- Localize a rigid facial part parameterized based on the three main facial points.
- The rigid region can be localized by selecting points where the sum of distances of which to the three main points is lower than the sum of distances between the three points increased by 15%.



Threshold



- K_1 curvature was calculated at different resolution using five neighborhood sizes between 10 and 40 mm.
  - $K_{1(10)}$, $K_{1(15)}$, $K_{1(20)}$, $K_{1(25)}$, $K_{1(40)}$
- Using rigid region, a threshold was defined for each curvature at the certain resolution.
  - $TK_{1(10)}$, $TK_{1(15)}$, $TK_{1(20)}$, $TK_{1(25)}$, $TK_{1(40)}$
  - The thresholds were defined as the maximum curvature values localized on the rigid facial part.

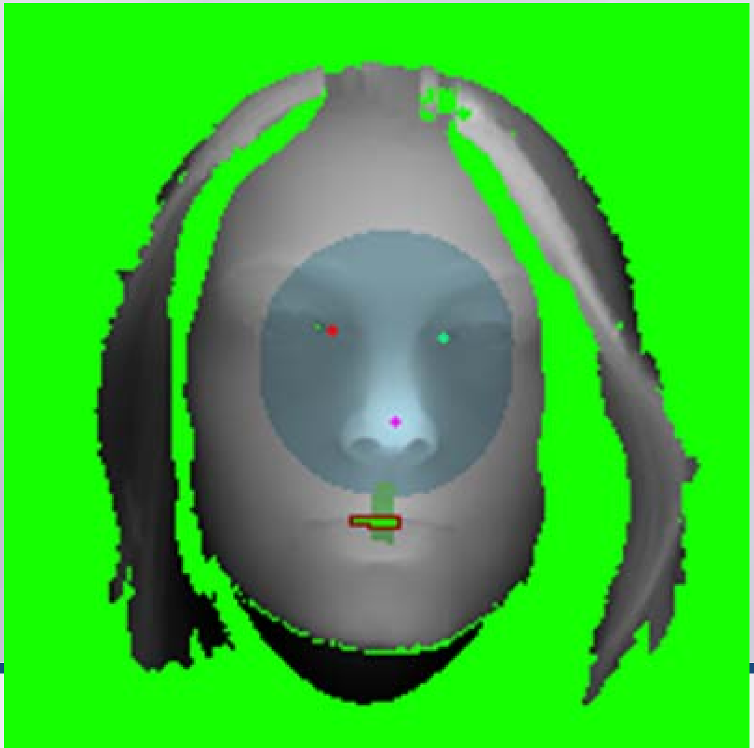
Abnormal curvatures

- All points on the model of which curvature values exceed the thresholds can be considered as abnormal face edges. Those region can be later processed and removed.

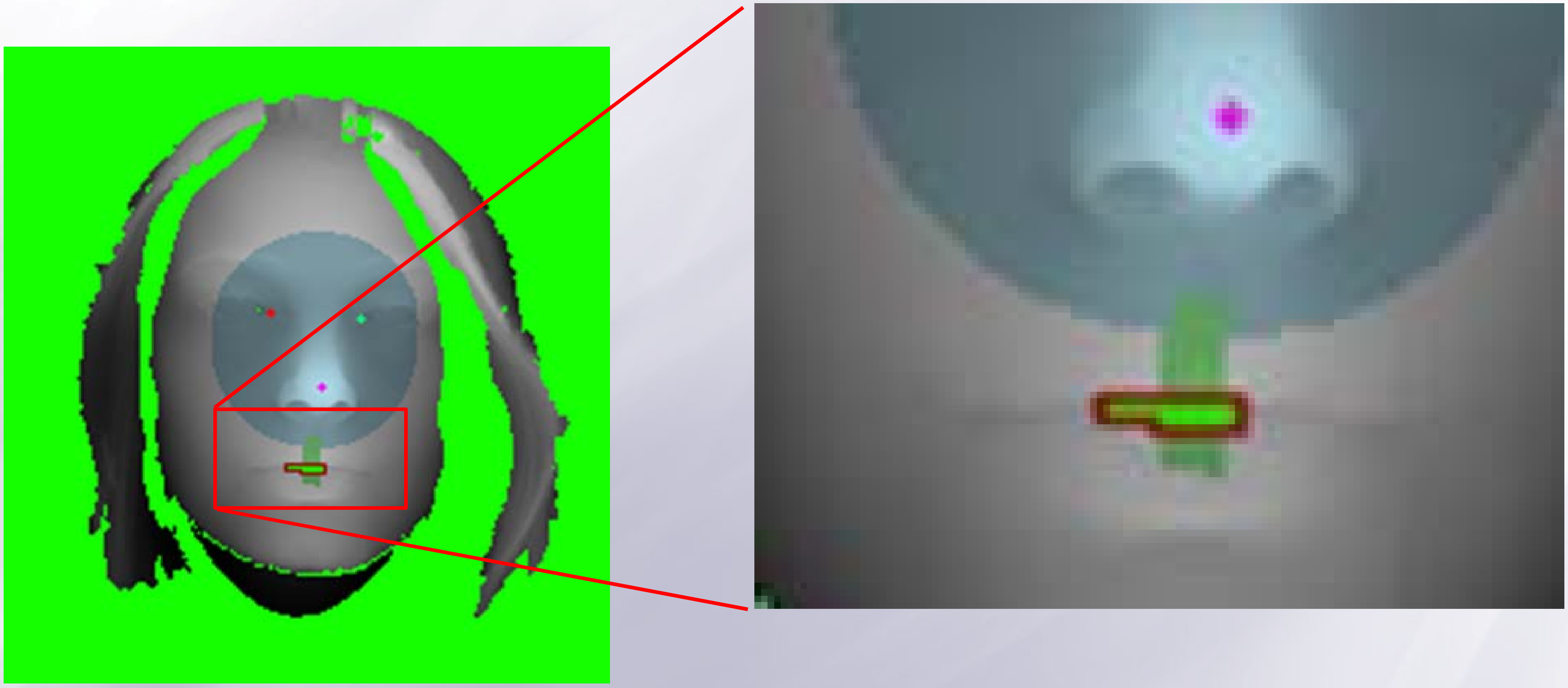
$$K_{1(10)} > TK_{1(10)} \text{ or}$$
$$K_{1(15)} > TK_{1(15)} \text{ or}$$
$$K_{1(20)} > TK_{1(20)} \text{ or}$$
$$K_{1(25)} > TK_{1(25)} \text{ or}$$
$$K_{1(40)} > TK_{1(40)}$$

Mouth detection

- The high curvature regions belong to the open mouth as well as appear on the side of facial surface, on cloths or hair parts.
- To detect those corresponding to the mouth part, the mouth position needs to be known.



Mouth position

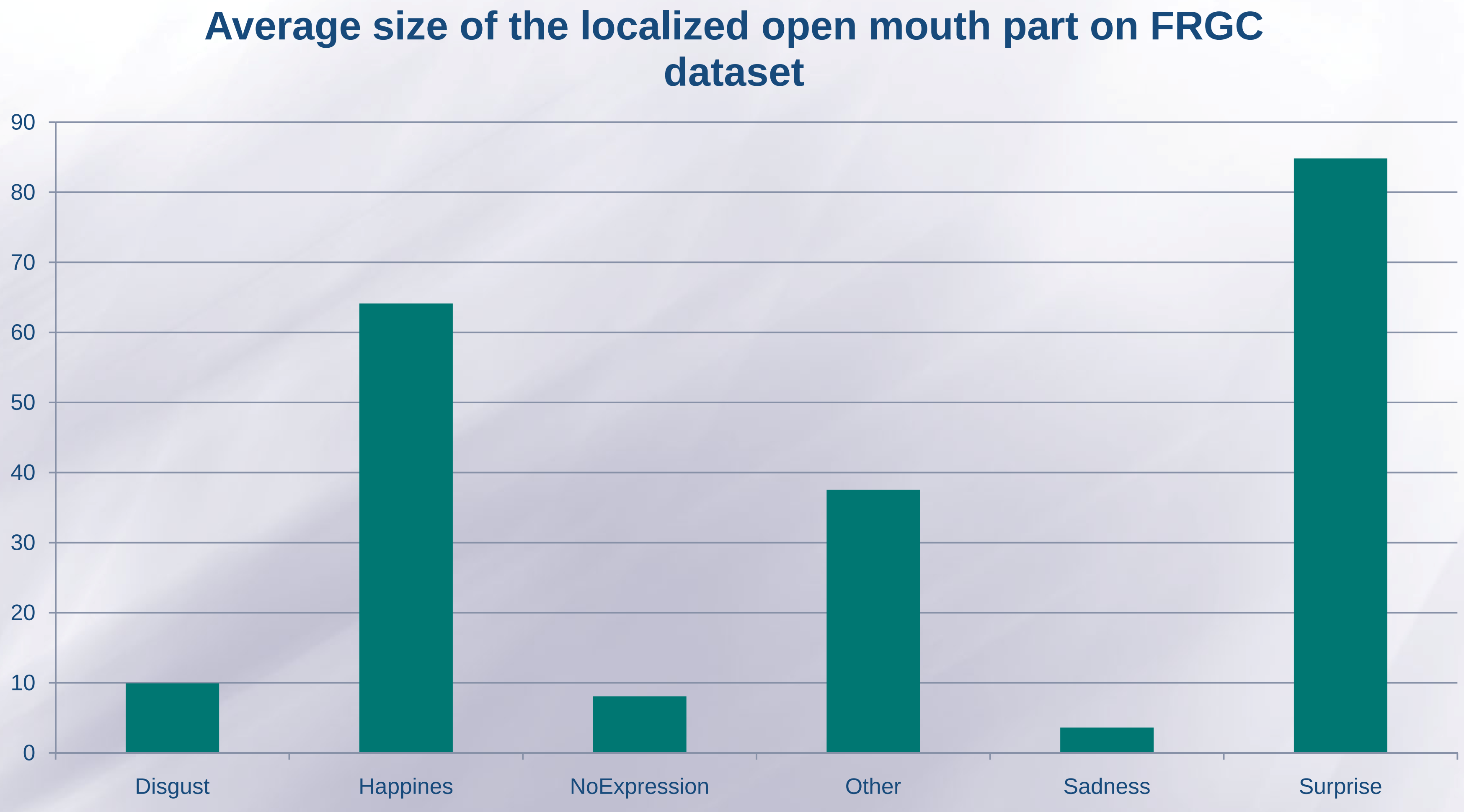


Mean Euclidean distance from the nose tip to the upper lip, using FRGC data set is 30mm +- 10mm

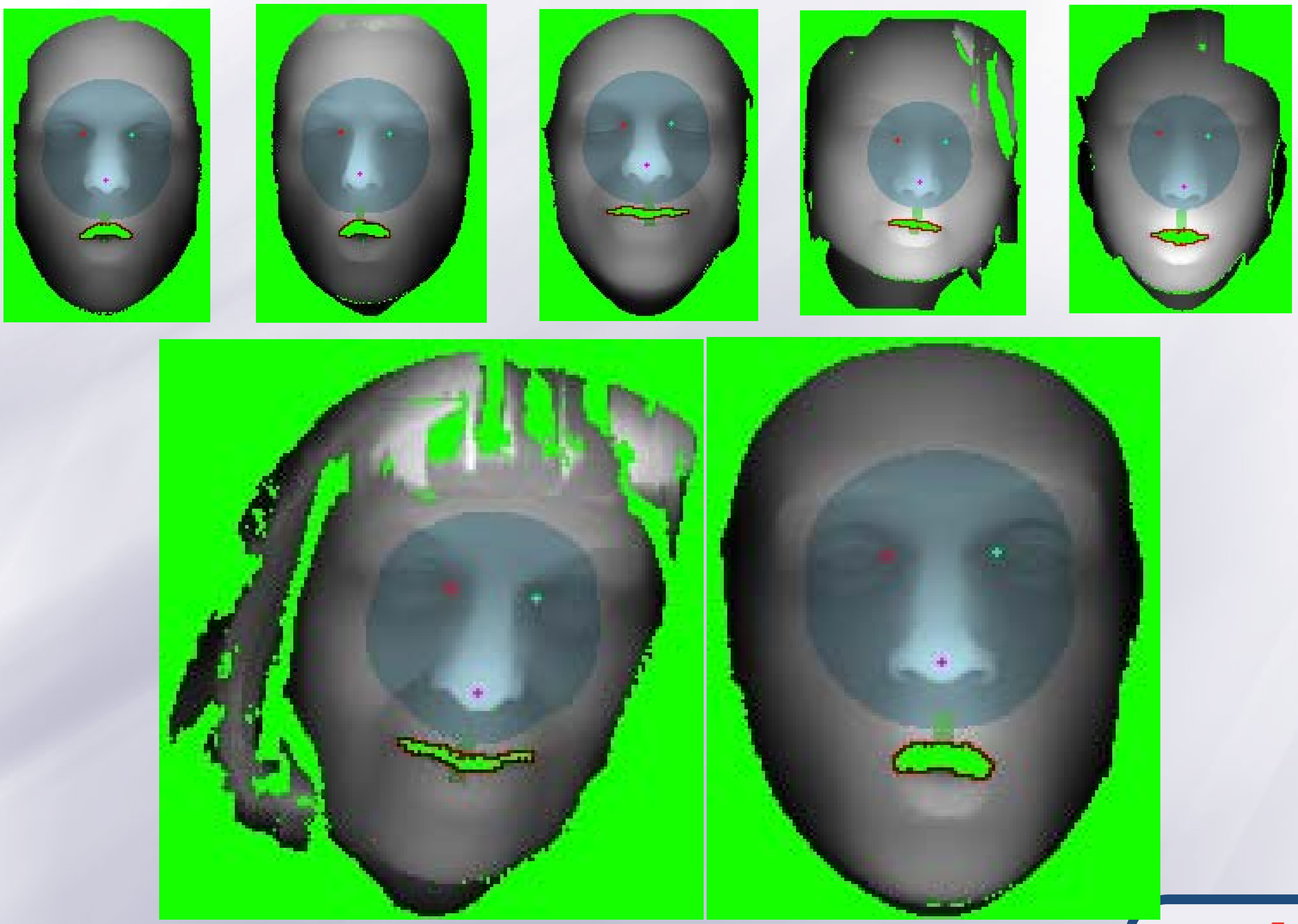
Experiments

- **Data sets**
  - **FRGC v2 data set - noisy models**
  - **Bosphorpus - large facial expressions**

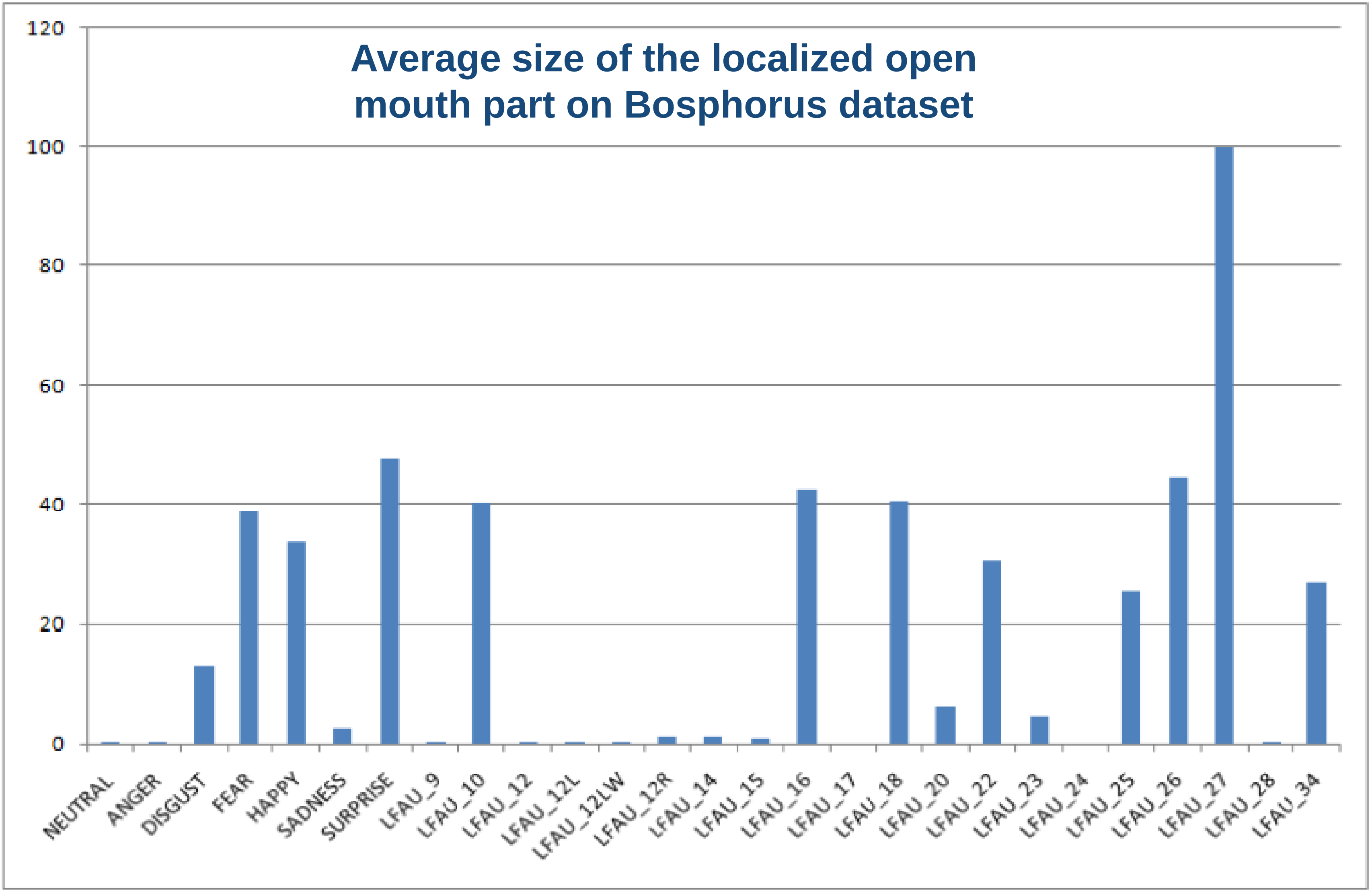
Mouth localization



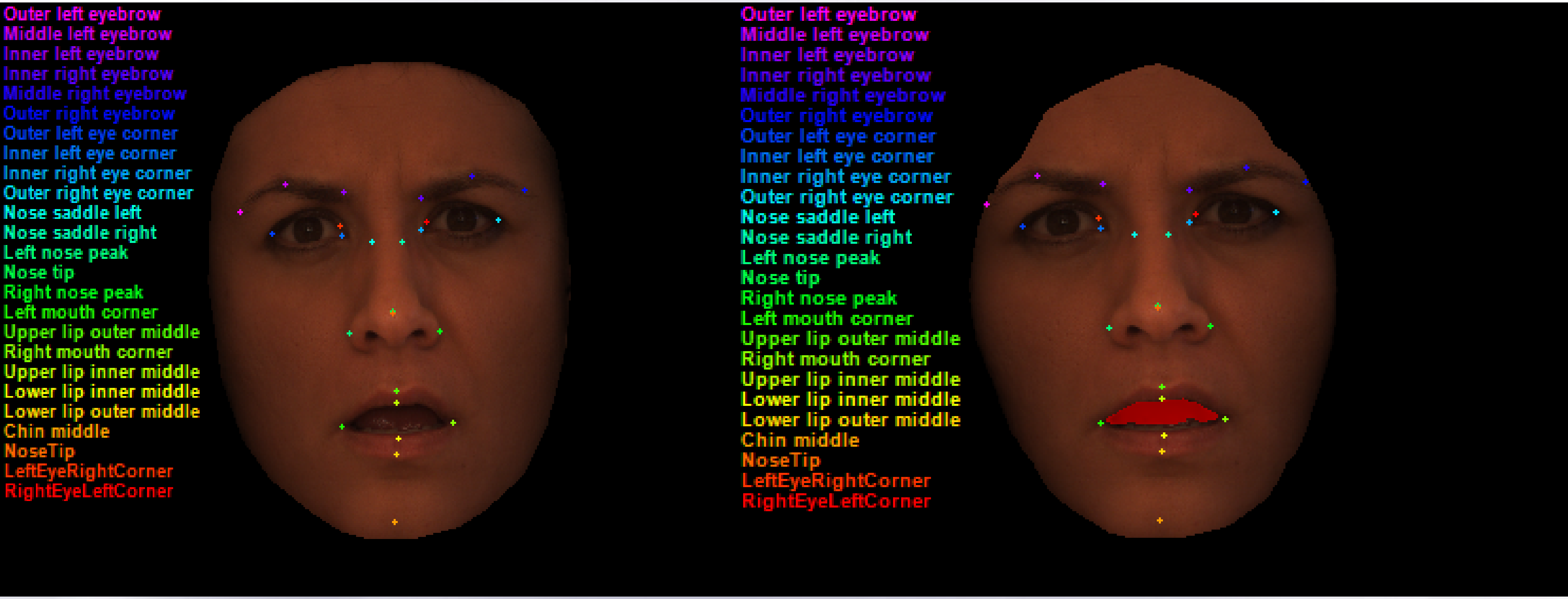
Examples (FRGC)



Bosphorus


Average size of the localized open mouth part on Bosphorus dataset
120
100
80
60
40
20
0
NEUTRAL
ANGER
DISGUST
FEAR
HAPPY
SADNESS
SURPRISE
LFAU_9
LFAU_10
LFAU_12
LFAU_12L
LFAU_12LW
LFAU_12R
LFAU_14
LFAU_15
LFAU_16
LFAU_17
LFAU_18
LFAU_20
LFAU_22
LFAU_23
LFAU_24
LFAU_25
LFAU_26
LFAU_27
LFAU_28
LFAU_34

Bosphorus



Outer left eyebrow
Middle left eyebrow
Inner left eyebrow
Inner right eyebrow
Middle right eyebrow
Outer right eyebrow
Outer left eye corner
Inner left eye corner
Inner right eye corner
Outer right eye corner
Nose saddle left
Nose saddle right
Left nose peak
Nose tip
Right nose peak
Left mouth corner
Upper lip outer middle
Right mouth corner
Upper lip inner middle
Lower lip inner middle
Lower lip outer middle
Chin middle
NoseTip
LeftEyeRightCorner
RightEyeLeftCorner
Outer left eyebrow
Middle left eyebrow
Inner left eyebrow
Inner right eyebrow
Middle right eyebrow
Outer right eyebrow
Outer left eye corner
Inner left eye corner
Inner right eye corner
Outer right eye corner
Nose saddle left
Nose saddle right
Left nose peak
Nose tip
Right nose peak
Left mouth corner
Upper lip outer middle
Right mouth corner
Upper lip inner middle
Lower lip inner middle
Lower lip outer middle
Chin middle
NoseTip
LeftEyeRightCorner
RightEyeLeftCorner

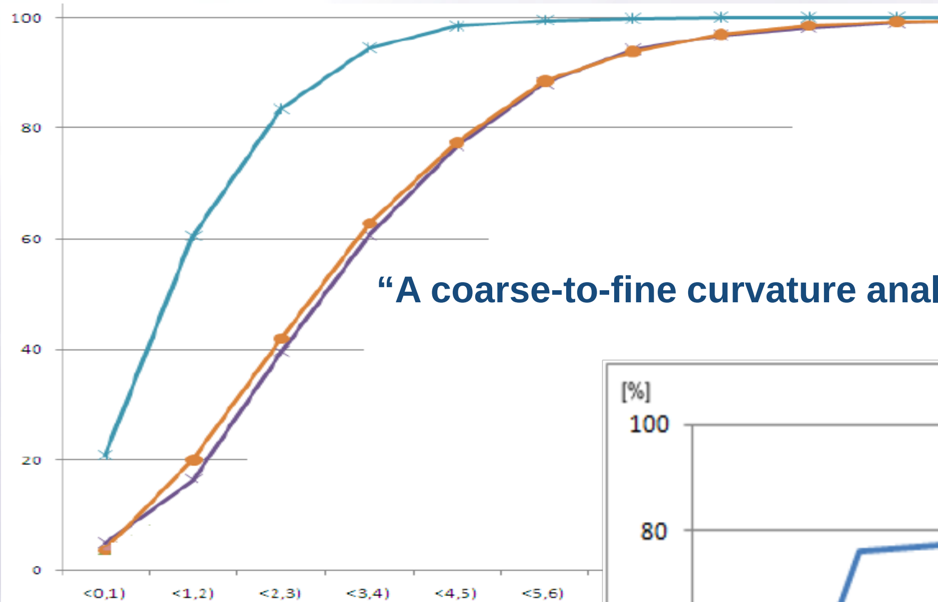
Cropping FRGC

Proposed method
Modified Geodesic
95mm

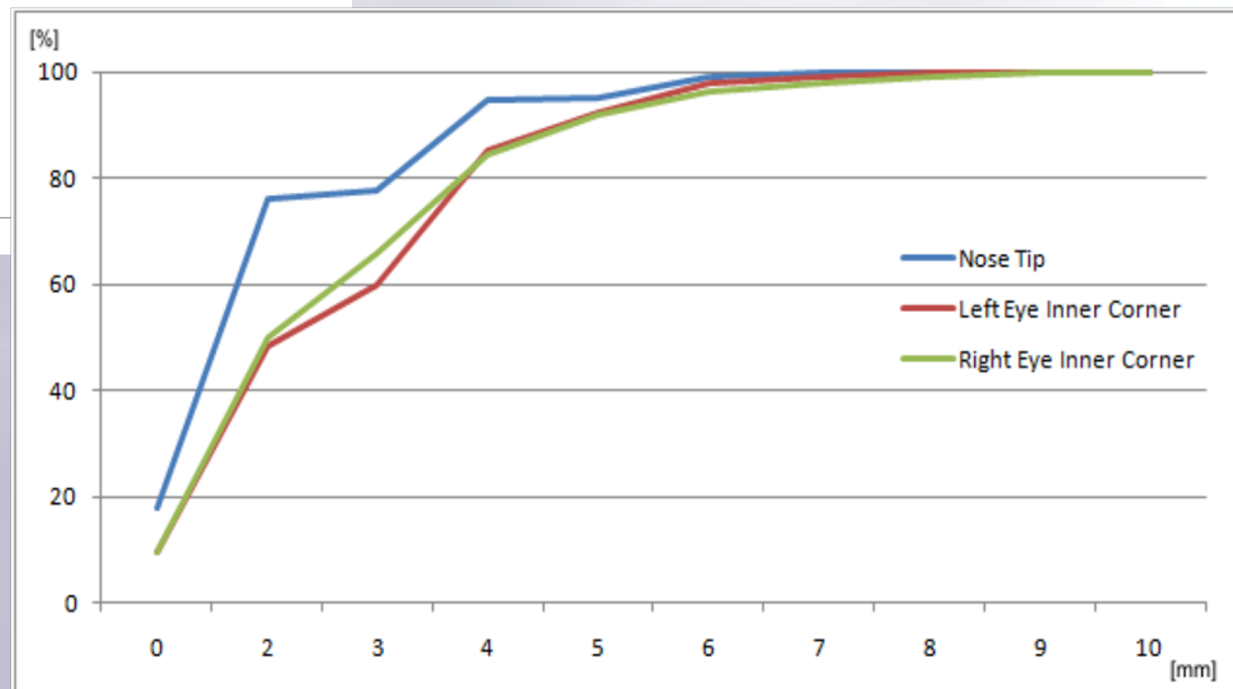
Sphere 90mm

Landmarks precision

“A coarse-to-fine curvature analysis-based rotation invariant 3D face landmarking”

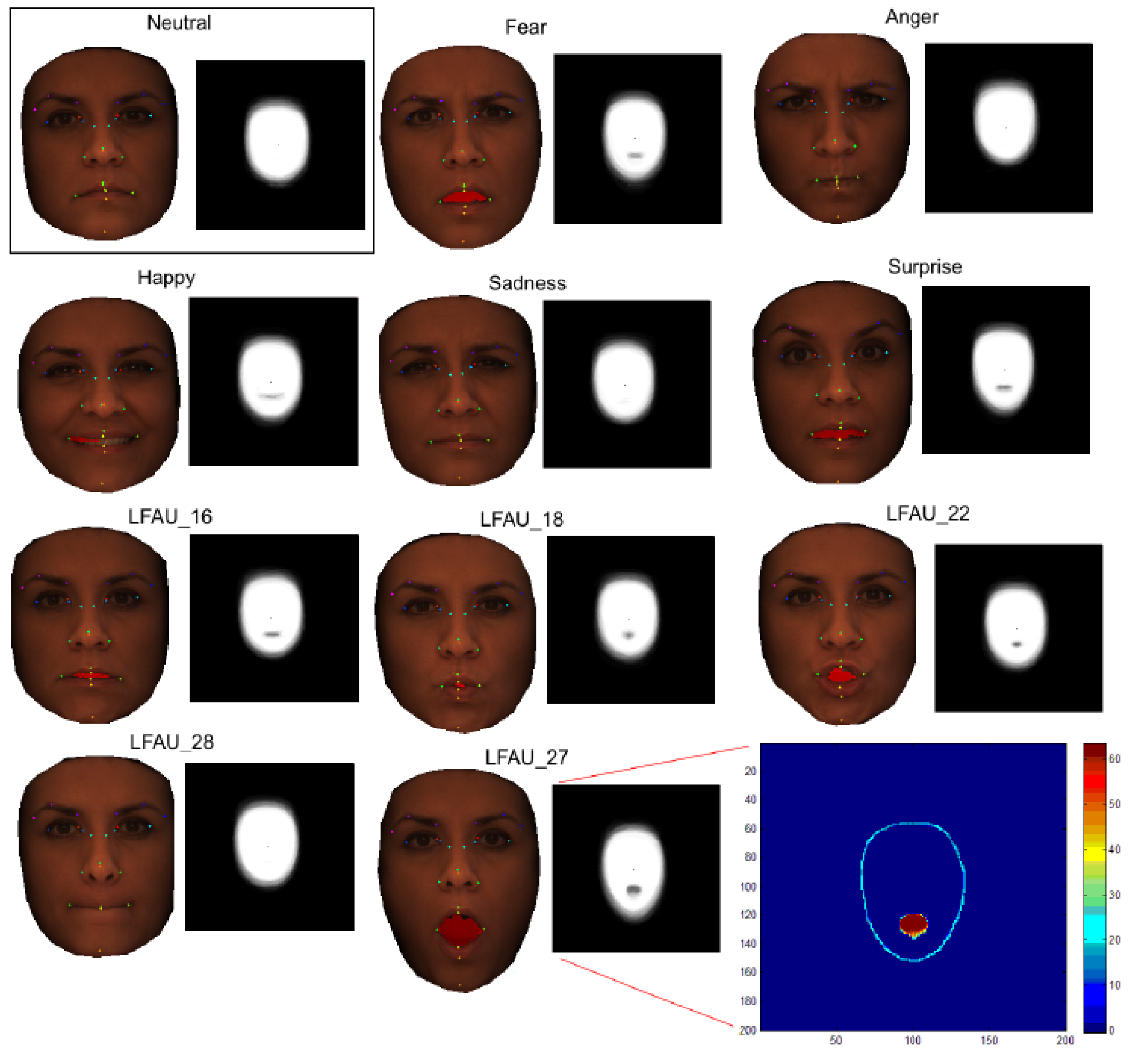


FRGC

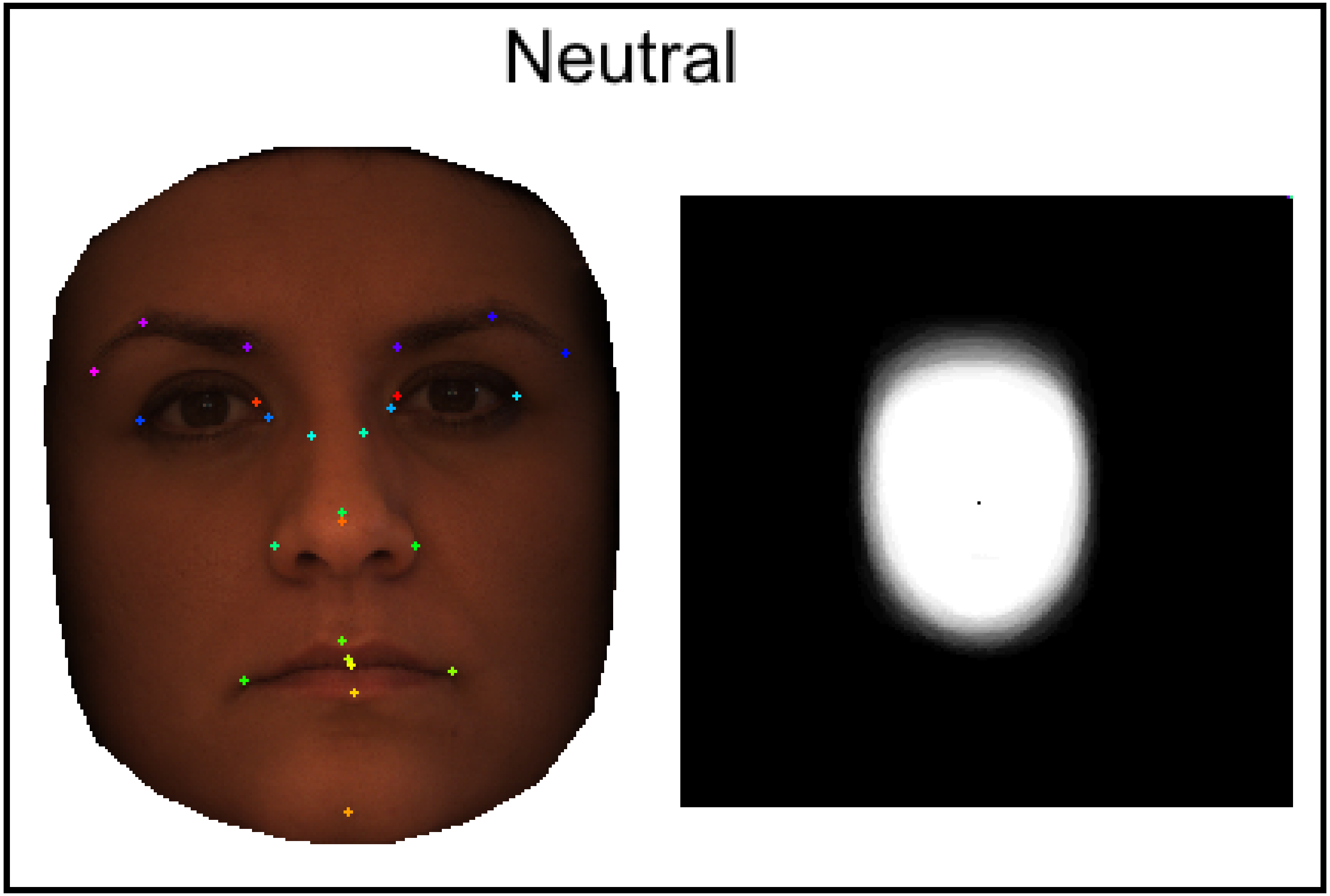


Bosphorus

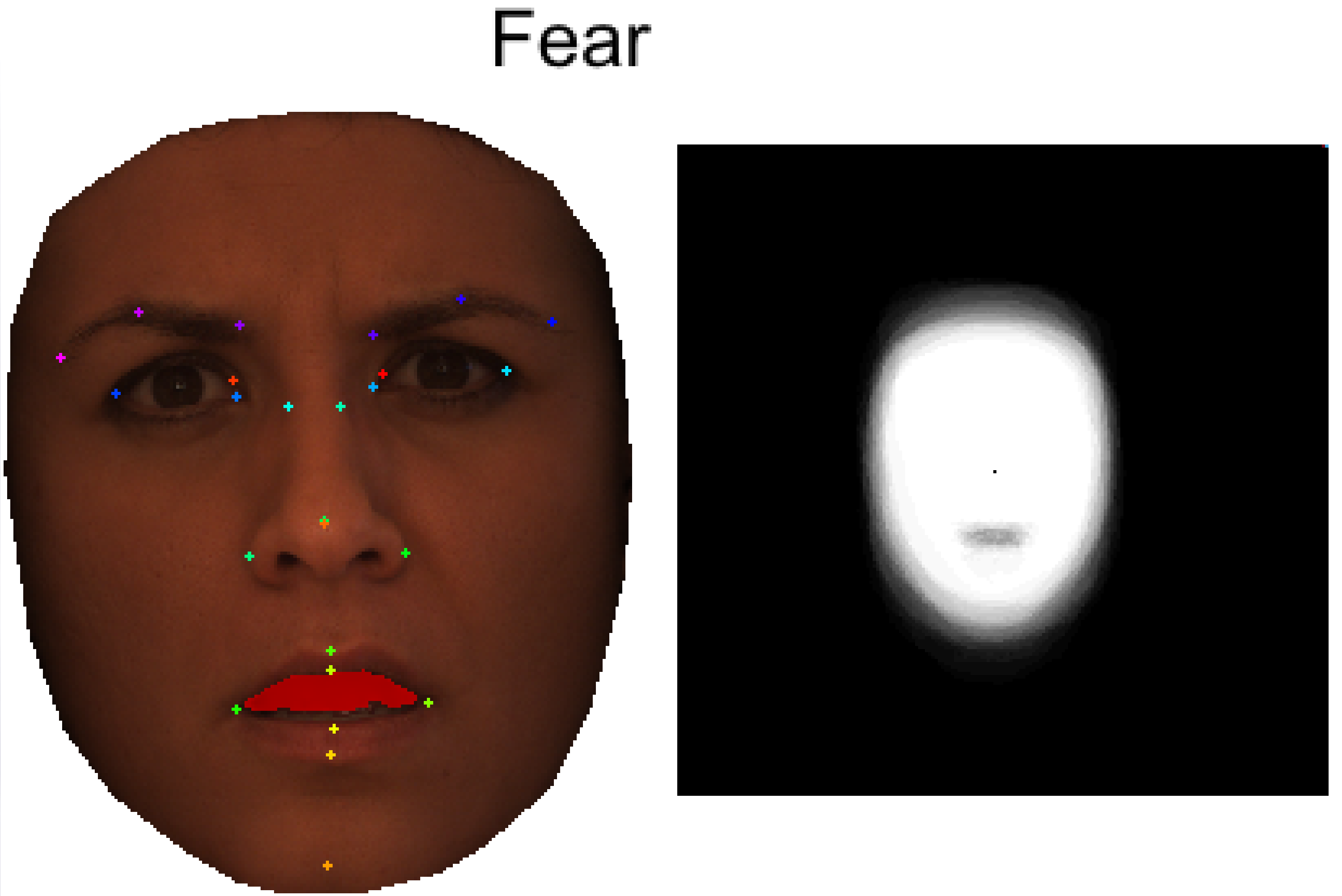
Open mouth frequency



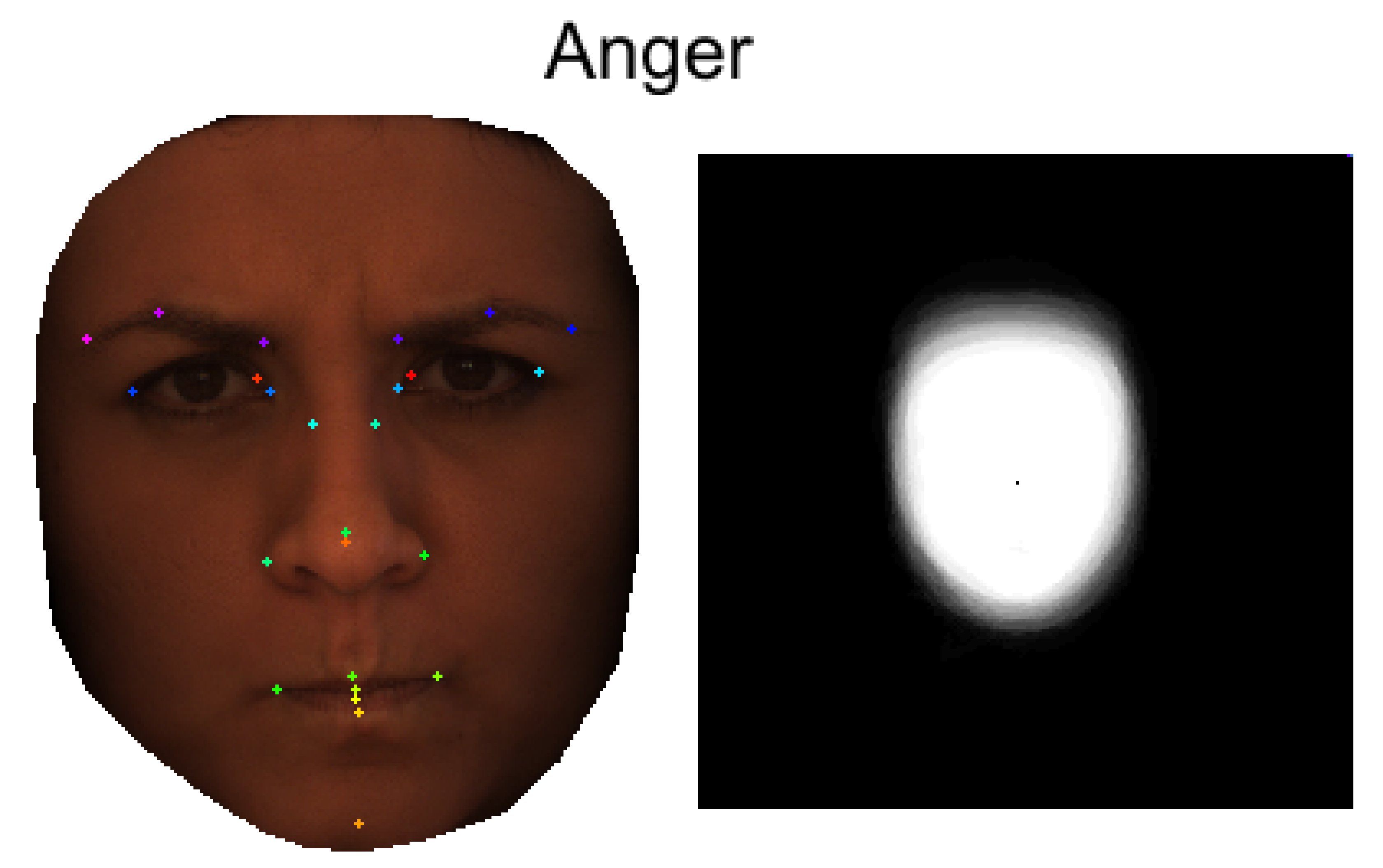
Neutral



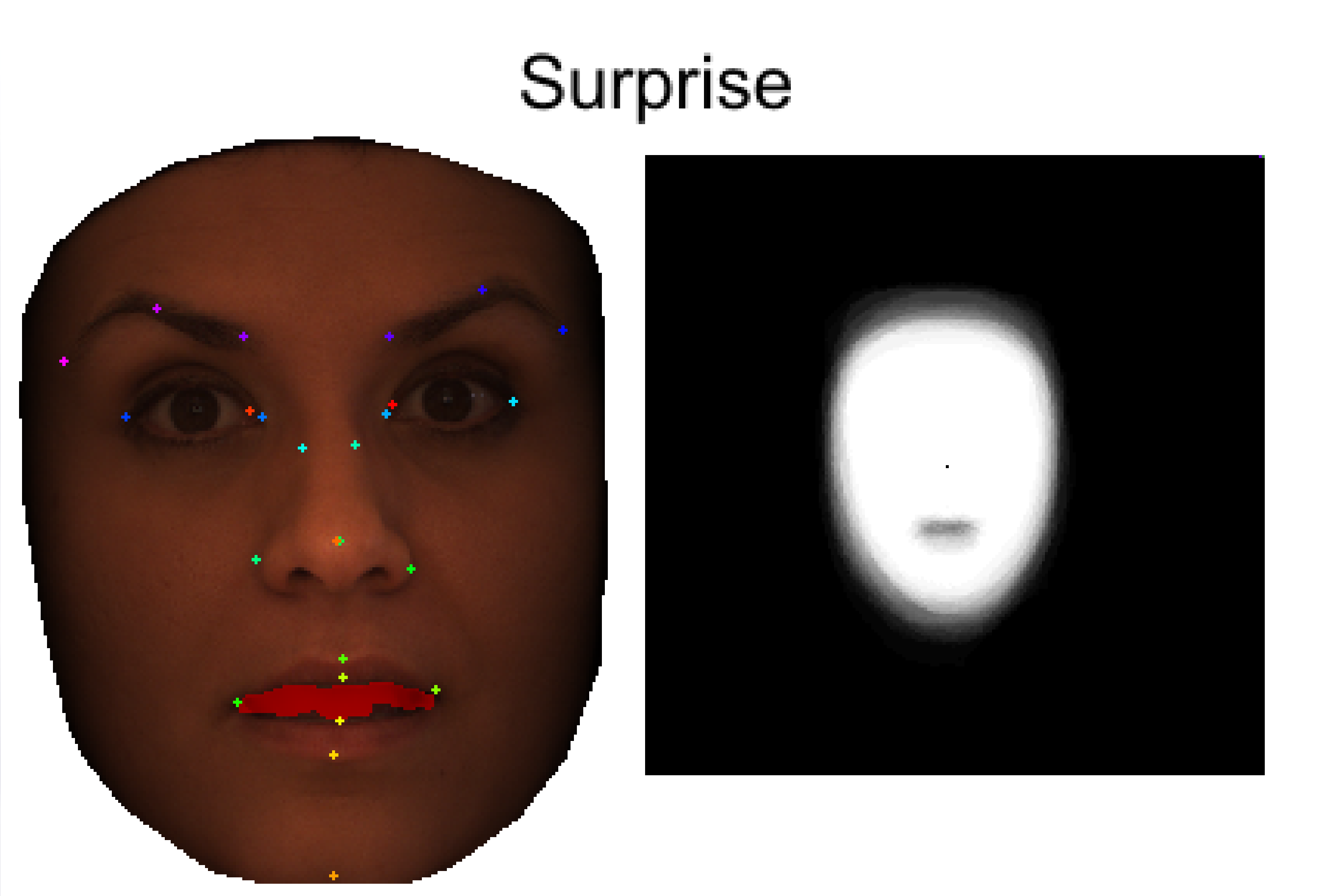
Fear



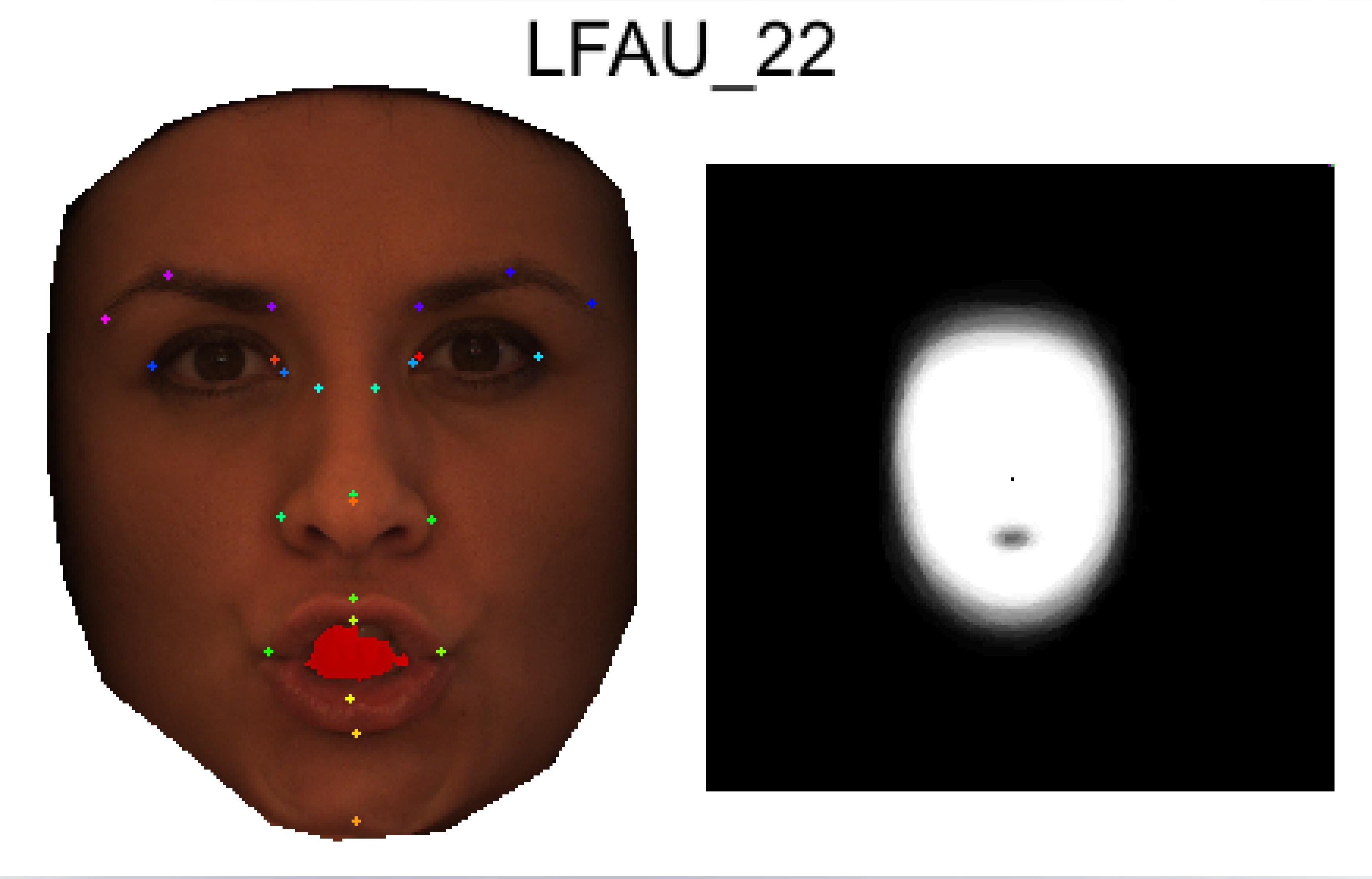
Anger



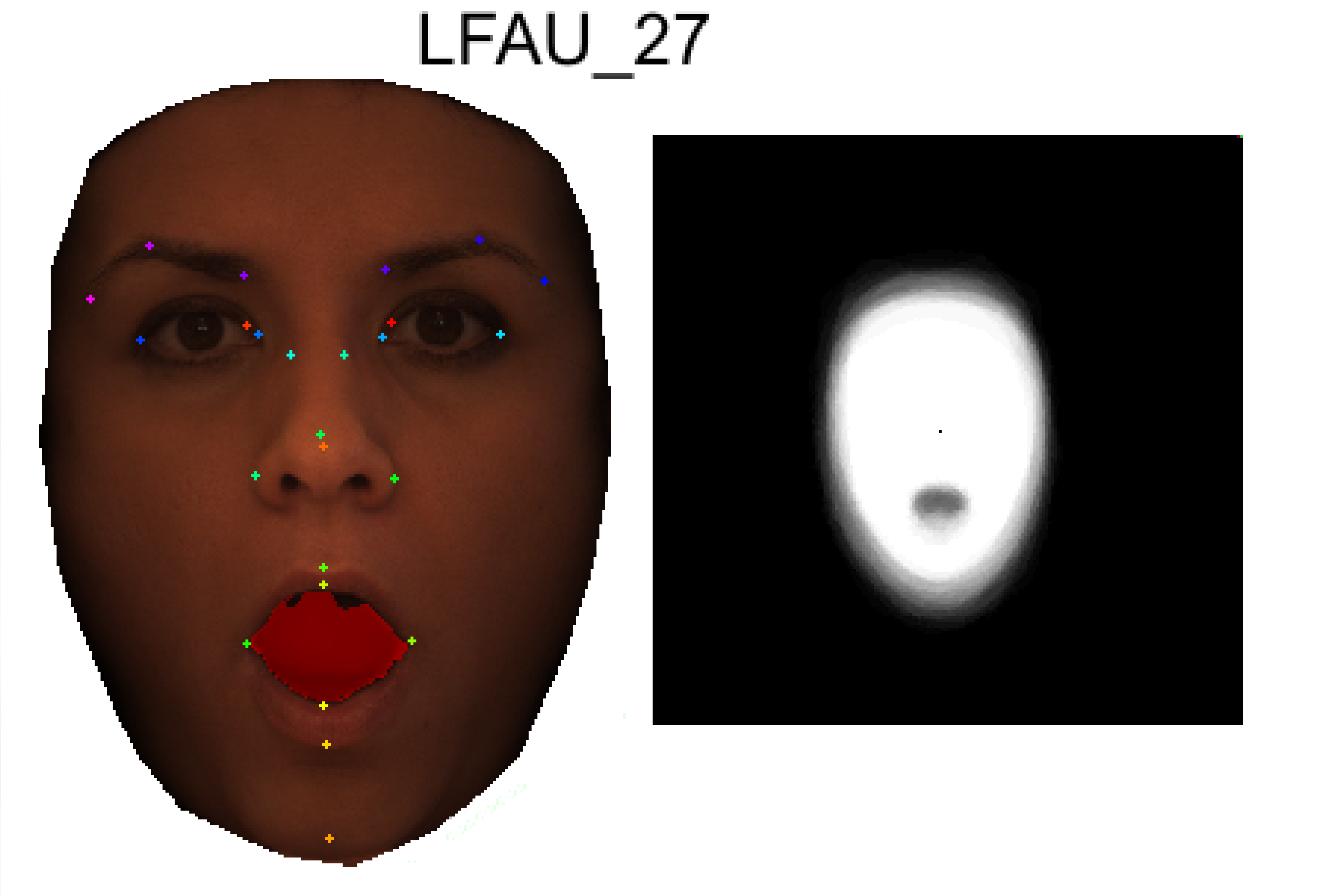
Surprise



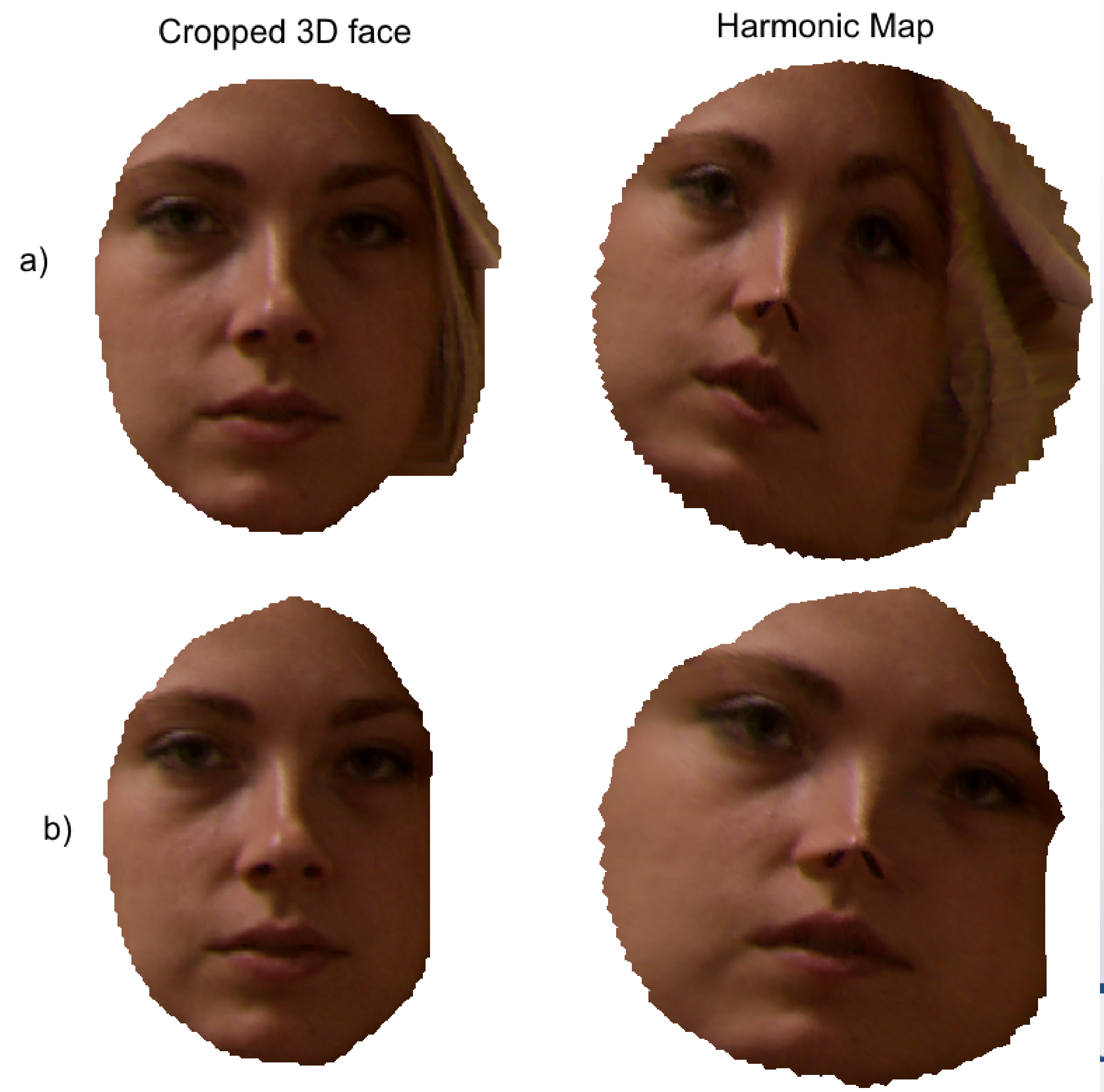
LFAU_22



LFAU_27



Harmonic maps



Conclusion

- Direct application of geometric tools for the purpose of 3D face analysis is infeasible
  - data are noisy
  - data are discrete
  - data are not consistent because of hair, facial expressions, mouth opening, etc.

- Pre-processing is a necessary step!

Future work

- Process whole FRGC data set to achieve consistently cropped models,
- Move the cropped models to 2D domain by harmonic mapping,
- Perform recognition using differential geometry properties decomposed on 2D images.

Thank You

CECIAS APELIOTES
ASIA
MARE INDICUM
MARE INDICUM
MARE
PRASODUM