Analysis of Human Face Shape Abnormalities Using Machine Learning

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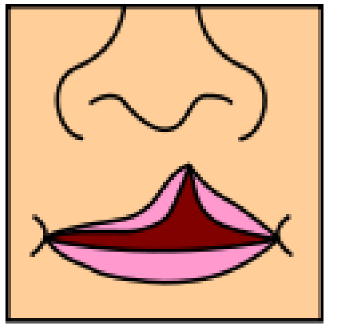
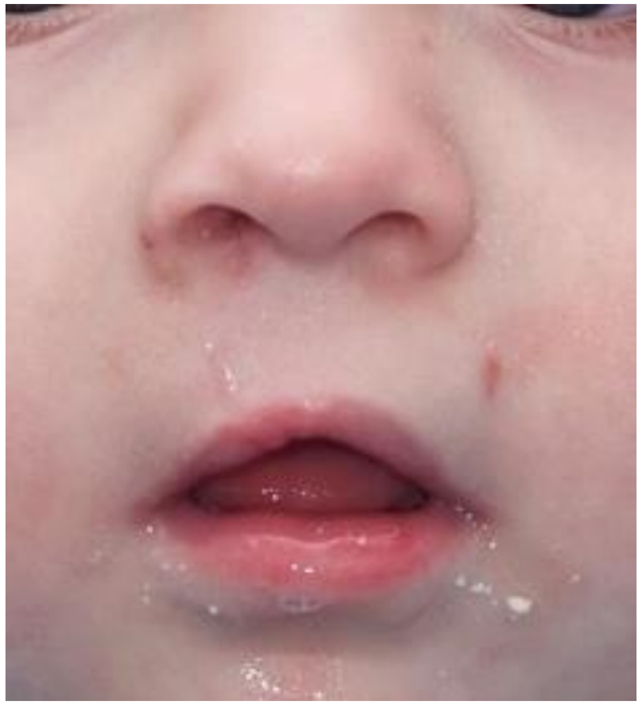
Motivation

- Cleft lip and/or palate
  - 1 in 700-1000 children born with cleft
- No “gold standard”
- Relatively new area



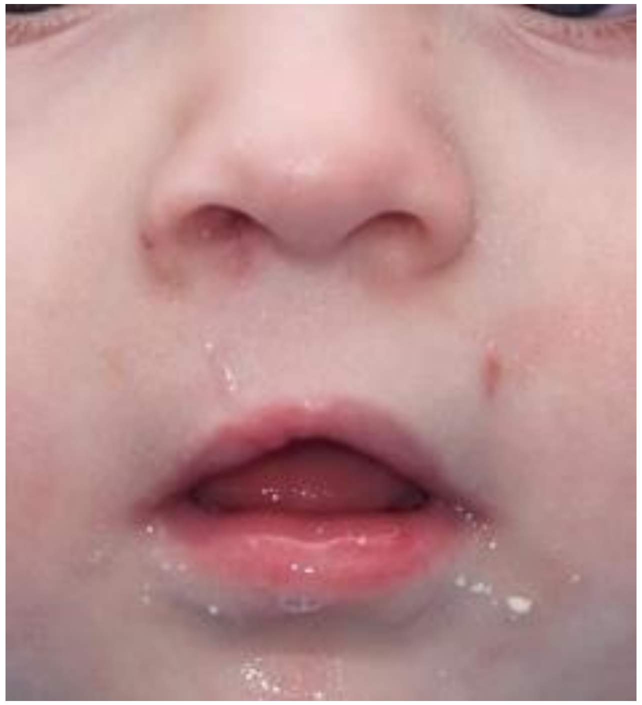
Plastic Surgery: Subjective outcomes

VS



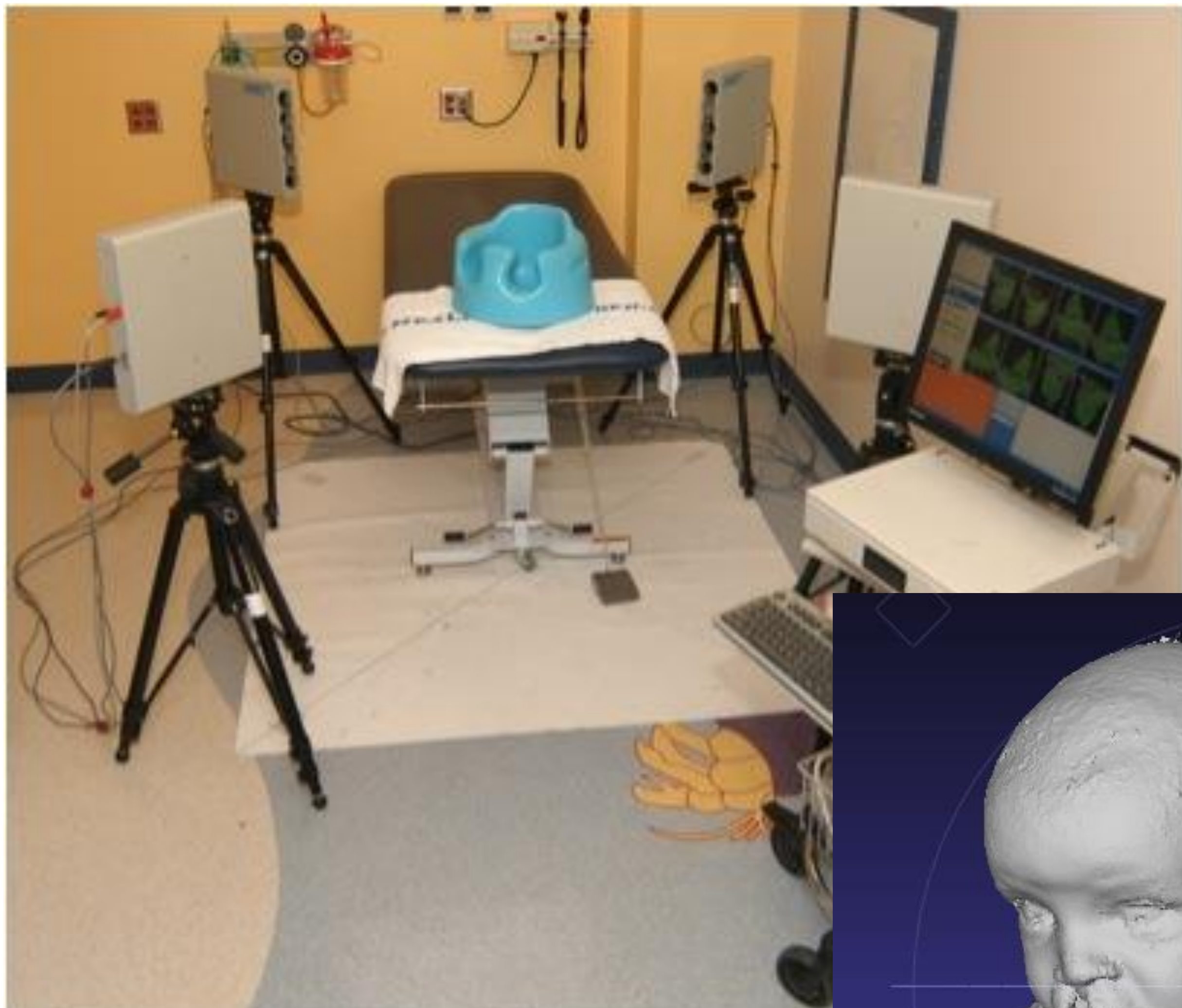
Plastic Surgery: Subjective outcomes

VS



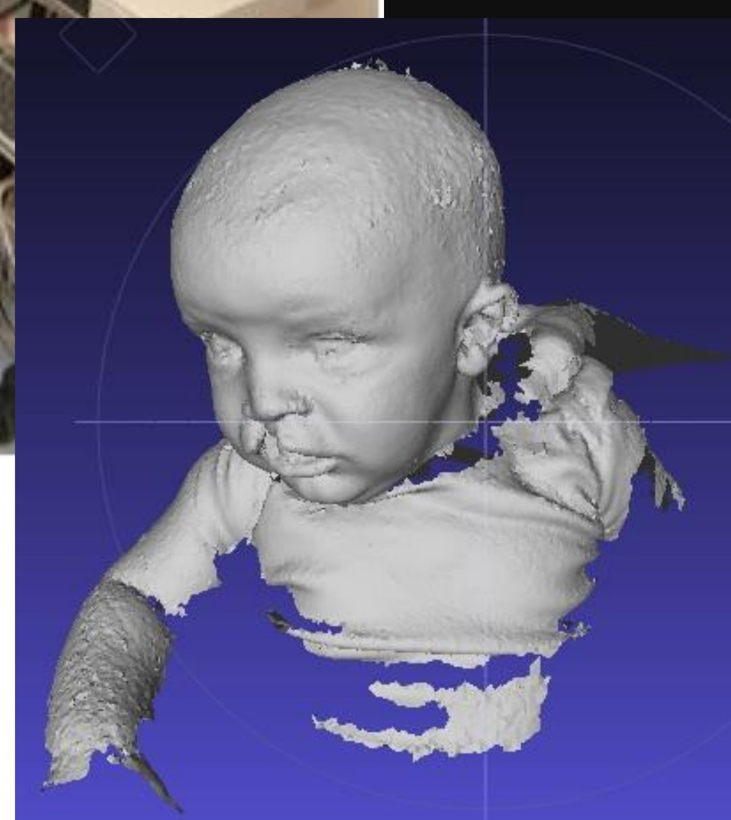
Anthropometric Calculators

3dMD System and Data Format



3dMD system

Texture map



3D mesh

Previous Use of 3d Images

Raw image from 3dMD

Crop the face out and normalize by hand

Label all the landmarks

Calculate the distance between landmarks

Automated Face Extraction and Normalization

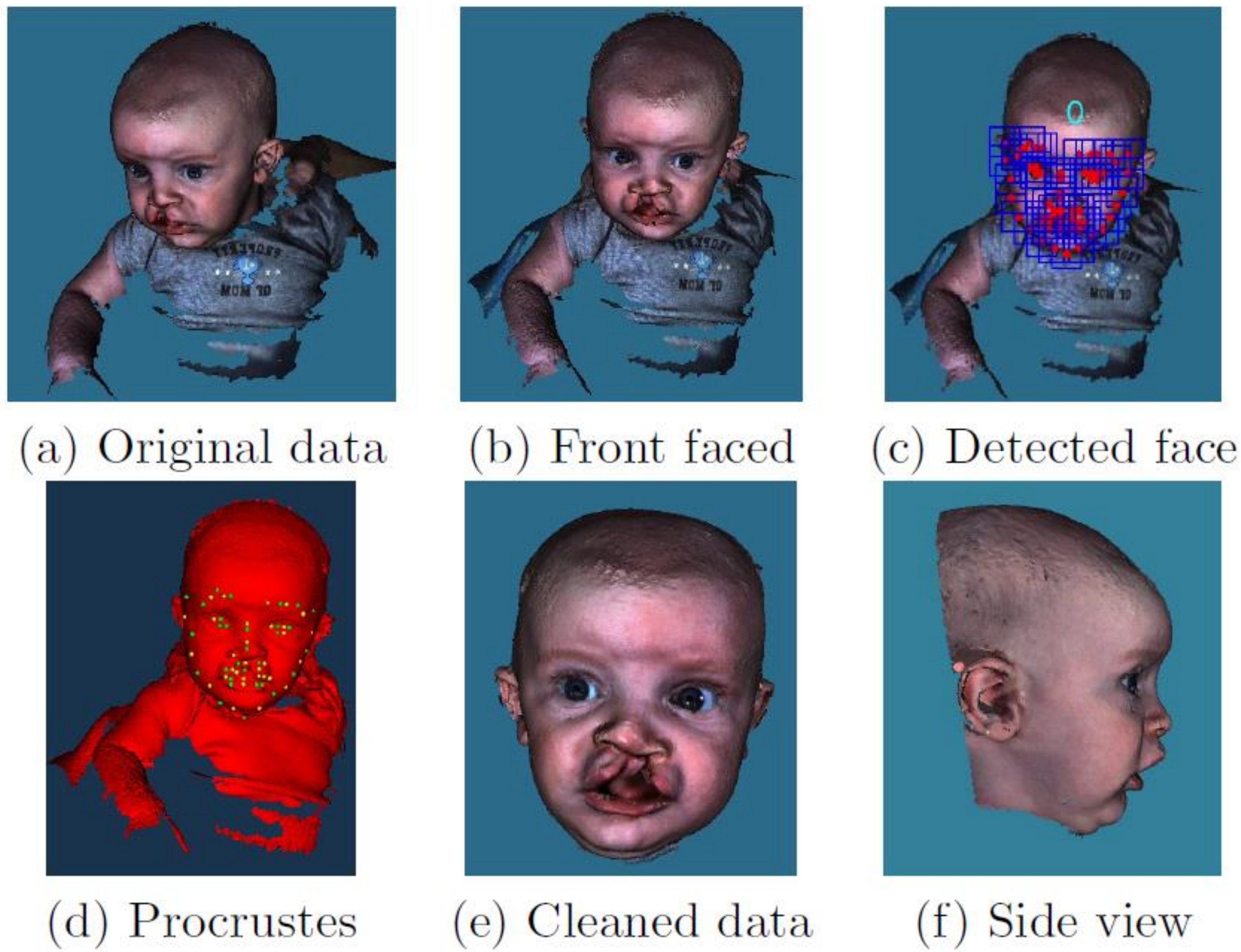
- Problem statement: given raw data by 3dMD system, crop out the face, front part of skull, and ears based on medical experts’ requirement

Input

Output

Automated Face Extraction and Normalization

- Steps:



(a) Original data (b) Front faced (c) Detected face

(d) Procrustes (e) Cleaned data (f) Side view

J. Wu, R. Tse, L. Shapiro, "Automated Face Extraction and Normalization of 3D Mesh Data", submitted to Proceedings of the 2014 IEEE Engineering in Medicine and Biology Annual Conference, 2014.

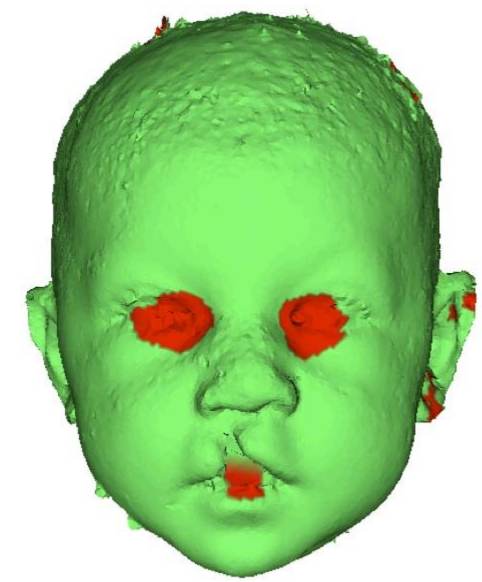
Automated Face Extraction and Normalization

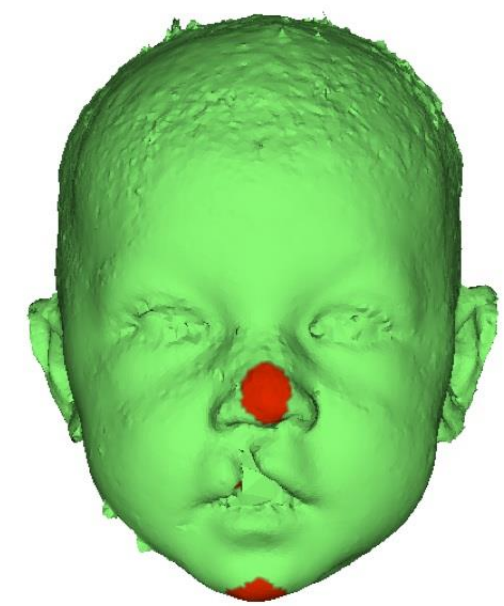
- Step1(a): detect landmark-related regions

Low level
- Shape index
- Curvedness
- Besl-Jain value

Histogram
- Multi-scale histogram
- For different radius

Classify
- SVM
- Predicted score





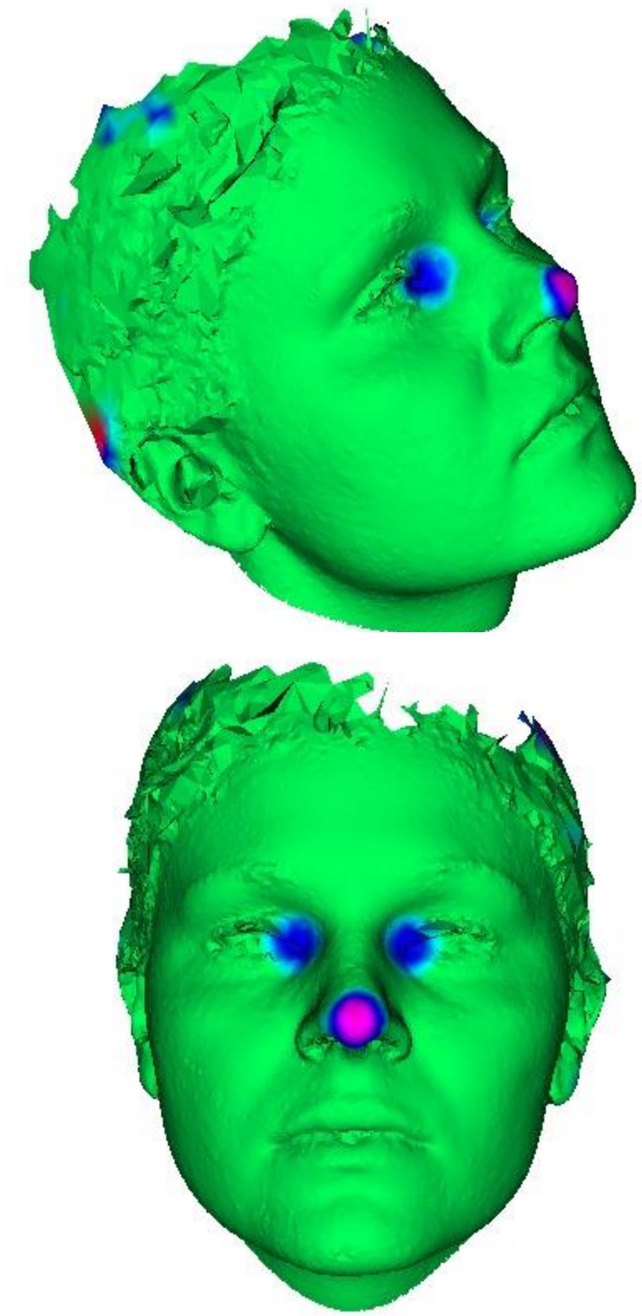
Automated Face Extraction and Normalization

- Step1(b): rotate to frontal position

Eye/nose regions
- Remove small regions

Triangle determine
- Geometric information
- Determine eye-nose-eye triangle

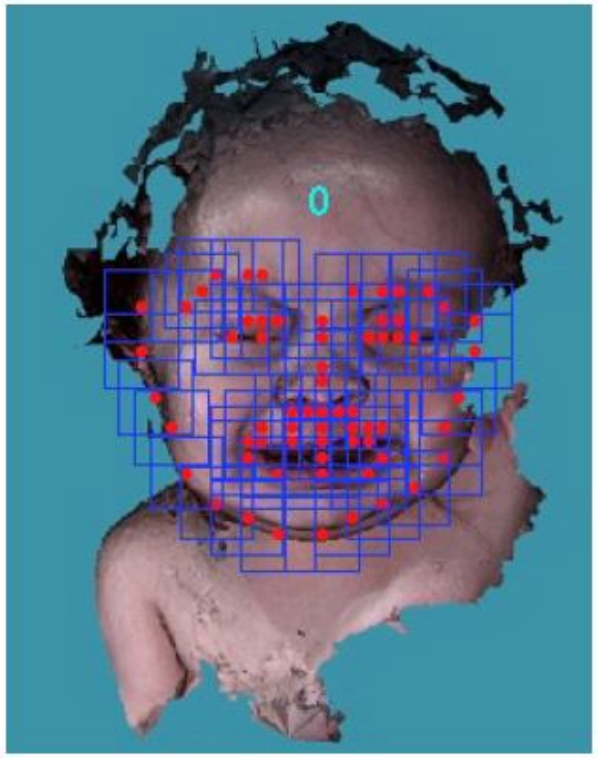
Rotate
- Frontal position



Automated Face Extraction and Normalization

- Step2: face detection

(a) Face detection on the original data

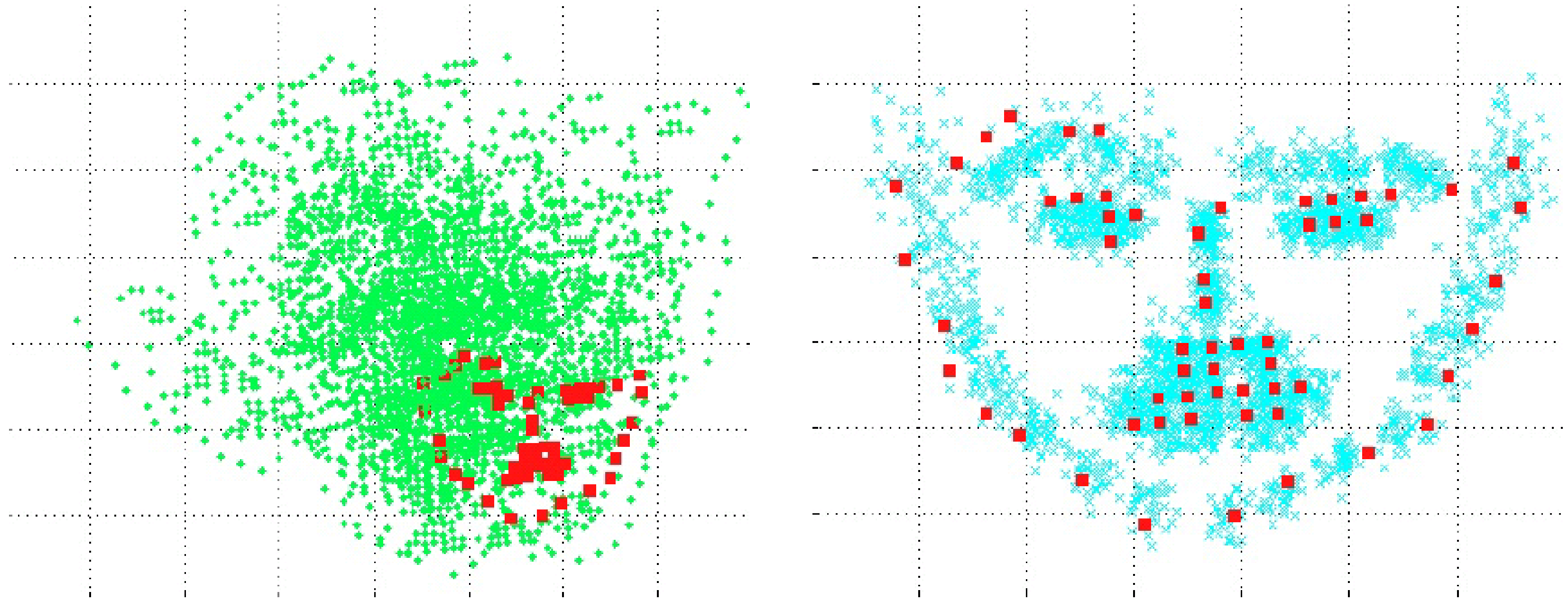


(b) Face detection on the screenshot

X. Zhu and D. Ramanan: Face detection, pose estimation, and landmark localization in the wild CVPR 2012

Automated Face Extraction and Normalization

- Step3: Pose normalization using the Procrustes analysis (PA)
- PA is performed by optimally translating, rotating and uniformly scaling the objects.



(a) Landmarks before PA (b) Landmarks after PA

Automated Face Extraction and Normalization

- Steps4: final cleanup

Standard bounding box

- Keep forehead
- Front part of the skull

Cleanup underneath the chin

- Surface normal
- Color information (hue value)

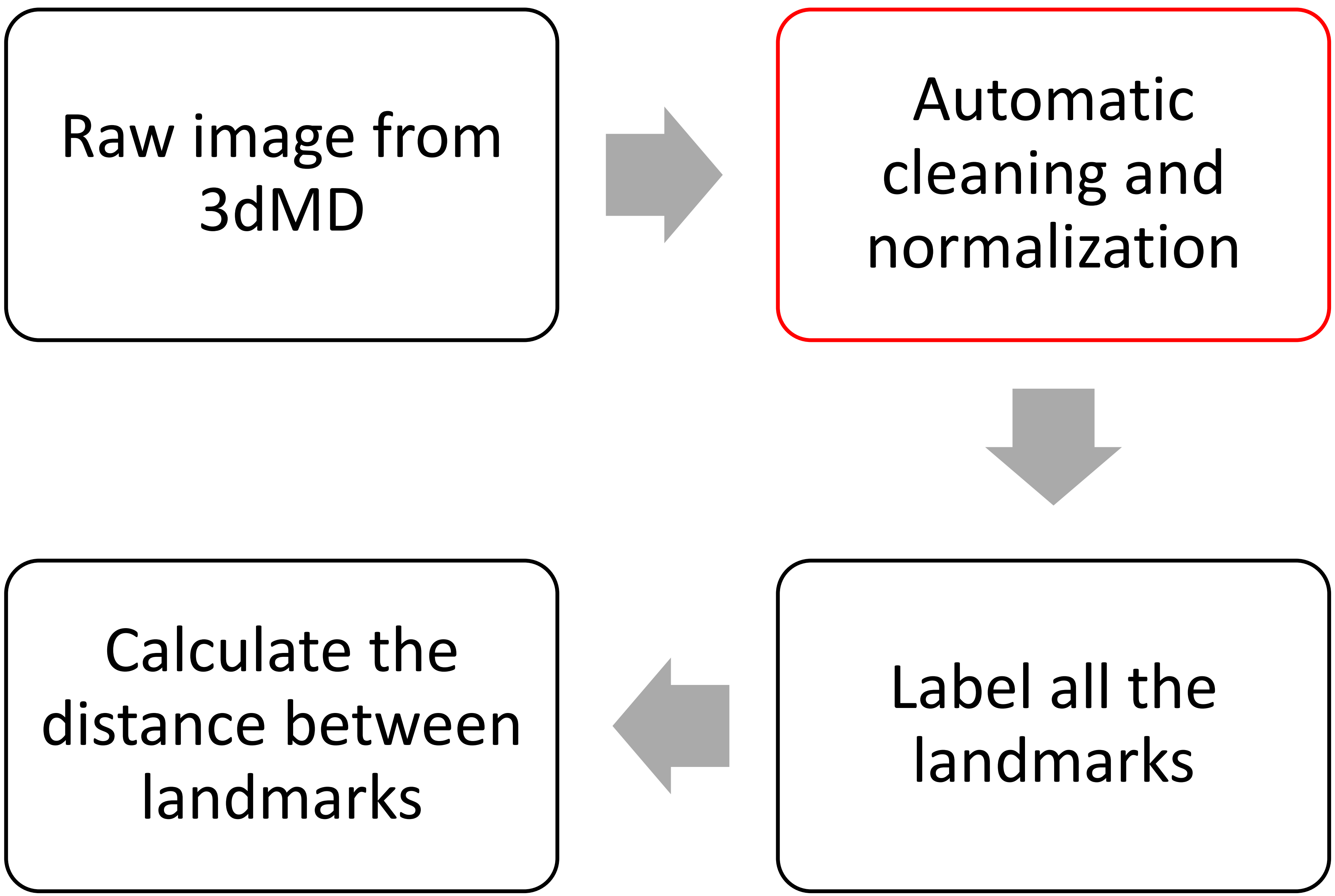
Scale back

Automated Face Extraction and Normalization

- Experiment results

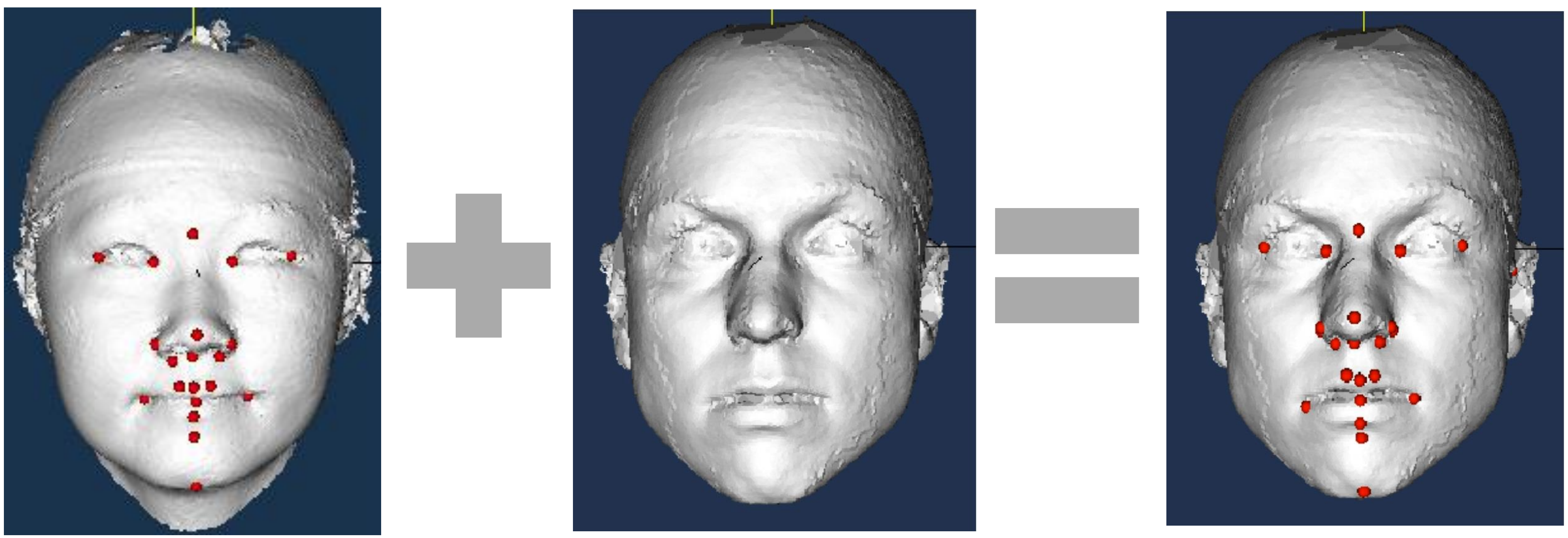
Accuracy for each step in the progress			
Dataset	Control	Unrepaired cleft	Repaired cleft
# of instances	21	64	35
Eye-nose detection	21 (100%)	60 (94%)	34 (97%)
Face detection	21 (100%)	64 (100%)	35 (100%)
Ear and forehead	21 (100%)	64 (100%)	35 (100%)
No clothes left	21 (100%)	60 (94%)	32 (91%)

System Progress



Automatic Landmark Location

- Problem statement: given a template with manually labeled landmarks and a target data, transfer the labeled landmarks to the target data



Template Target Target with transferred landmarks

S. Liang, J. Wu, S. Weinberg, L. Shapiro, “Detection of Landmarks on 3D Human Face Data Via Deformable Transformation”, in Proceedings of the 2013 IEEE Engineering in Medicine and Biology Annual Conference, 2013.

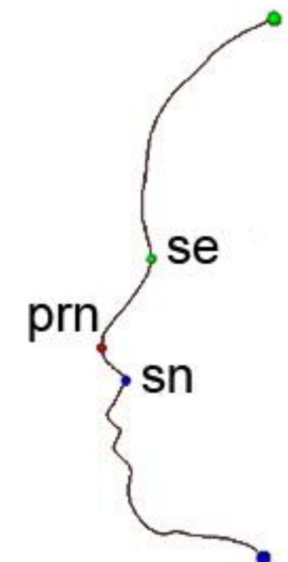
Automatic Landmark Location

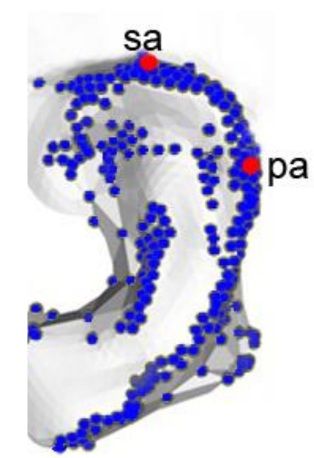
- Method: initial key points using geometric information, followed by a deformable registration

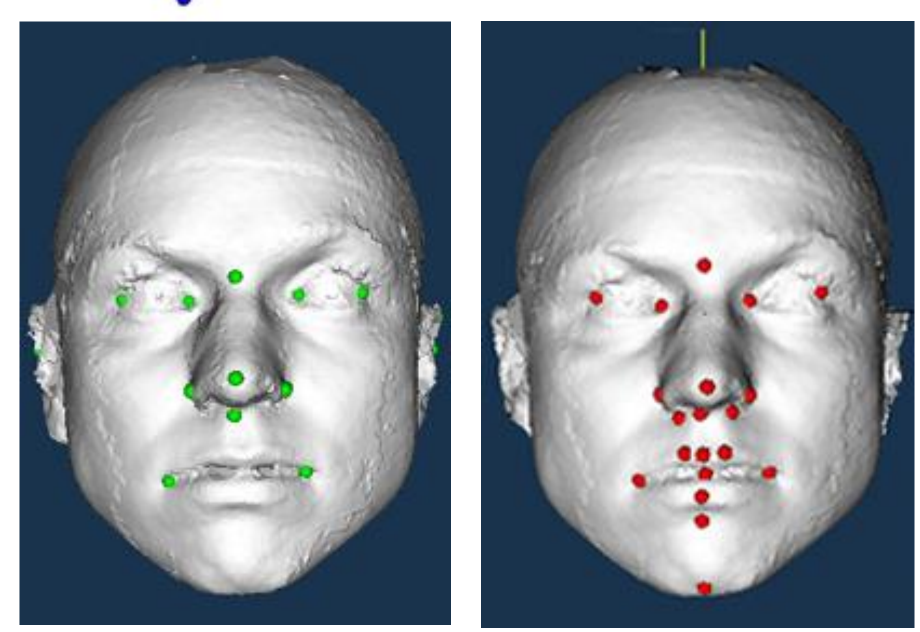
Initial key points
- Geometric information

Deformable registration
- Minimize an energy function

Transfer landmarks







Automatic Landmark Location

- Dataset: 994 normal (aged 3 – 40)
- Experiment results:

Average distances (mm) and the standard deviation of our method and methods in the literature						
Landmark name	Our method	Yu	Nair	Lu	Colbry	Perakis
Nose tip	1.7±1.1	2.2±6.8	8.8	8.3±19.4	4.1±5.1	4.9±2.4
Right mouth corner	3.1±2.1	------------	------------	6.0±16.9	6.9±8.6	5.6±4.3
Left mouth corner	3.1±1.6	------------	------------	6.2±17.9	6.7±9.3	6.4±4.3
chin	5.2±3.5	------------	------------	------------	11.0±7.6	6.0±4.3
Right eye inner corner	3.4±4.1	4.7±9.8	12.1	9.3±17.2	5.5±4.9	5.1±2.5
Left eye inner corner	3.8±4.5	5.6±16.1	11.9	8.2±17.2	6.3±5.0	5.5±2.6
Right eye out corner	3.1±5.6	------------	20.5	9.5±17.1	------------	5.8±3.4
Left eye out corner	5.0±5.9	------------	19.4	10.3±18.1	------------	5.7±3.5

System Progress

Raw image from 3dMD

Automatic cleaning and normalization

Automatic landmark location

~~Calculate the distance between landmarks~~

Children with Cleft
Before and After Surgery

Before surgery

After surgery

Find the Mid-facial Reference Plane

Human-based

- The direct method
- The m-lmk method

Computer-based

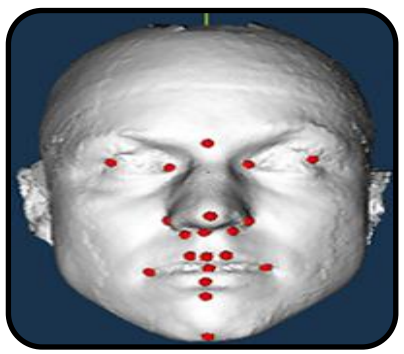
- The learning method
- The a-lmk method
- The mirror method

- Survey the medical experts
- Performance on predicting

Computer-based Methods

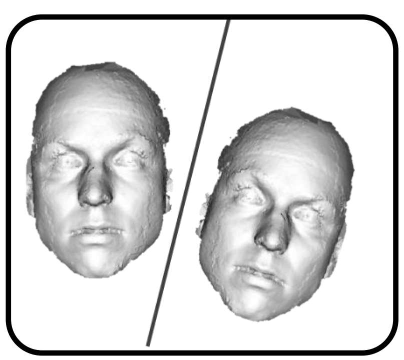
The learning method

From learned landmark related regions



The a-lmk method

From automatic landmarks



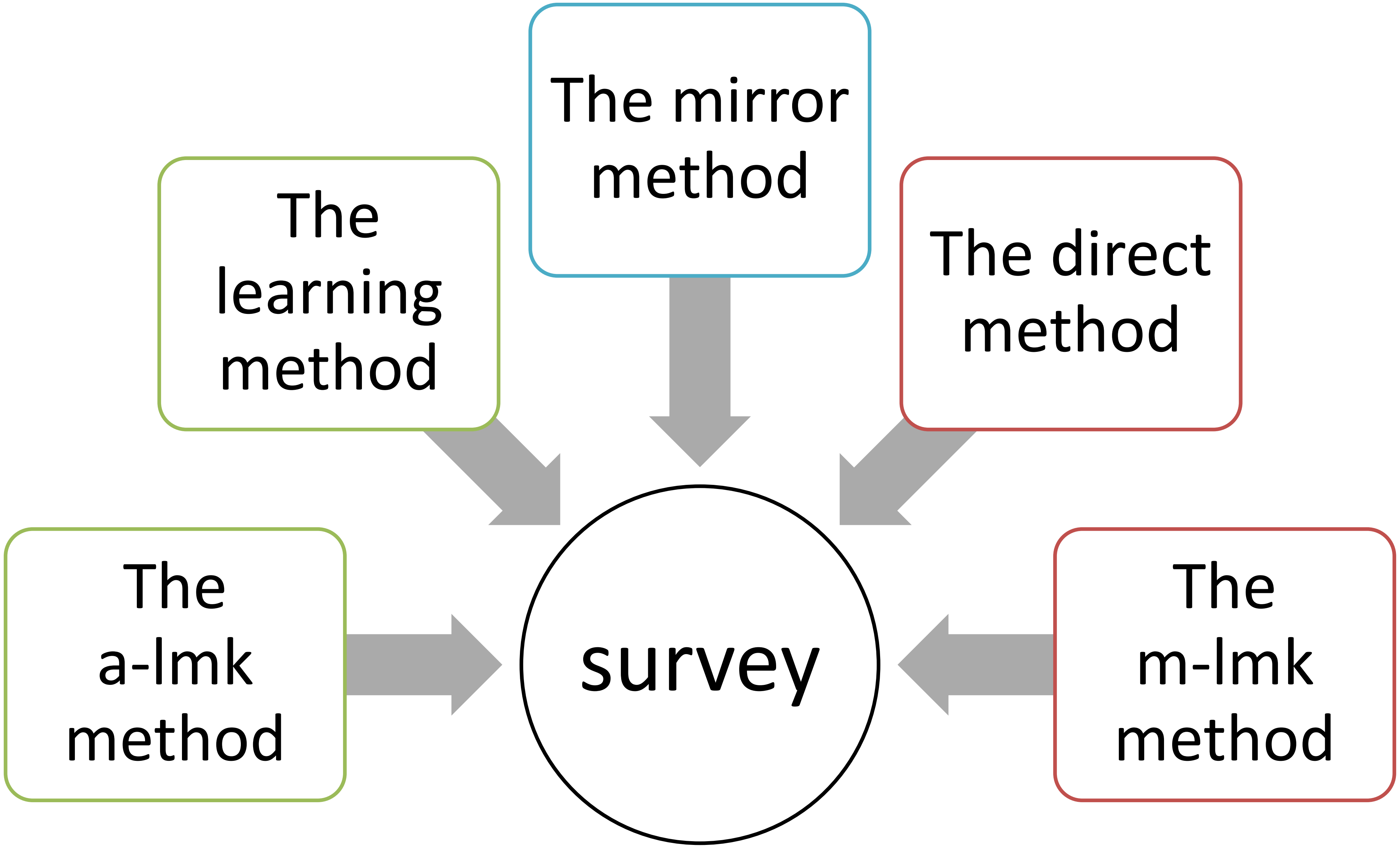
The mirror method

From literature

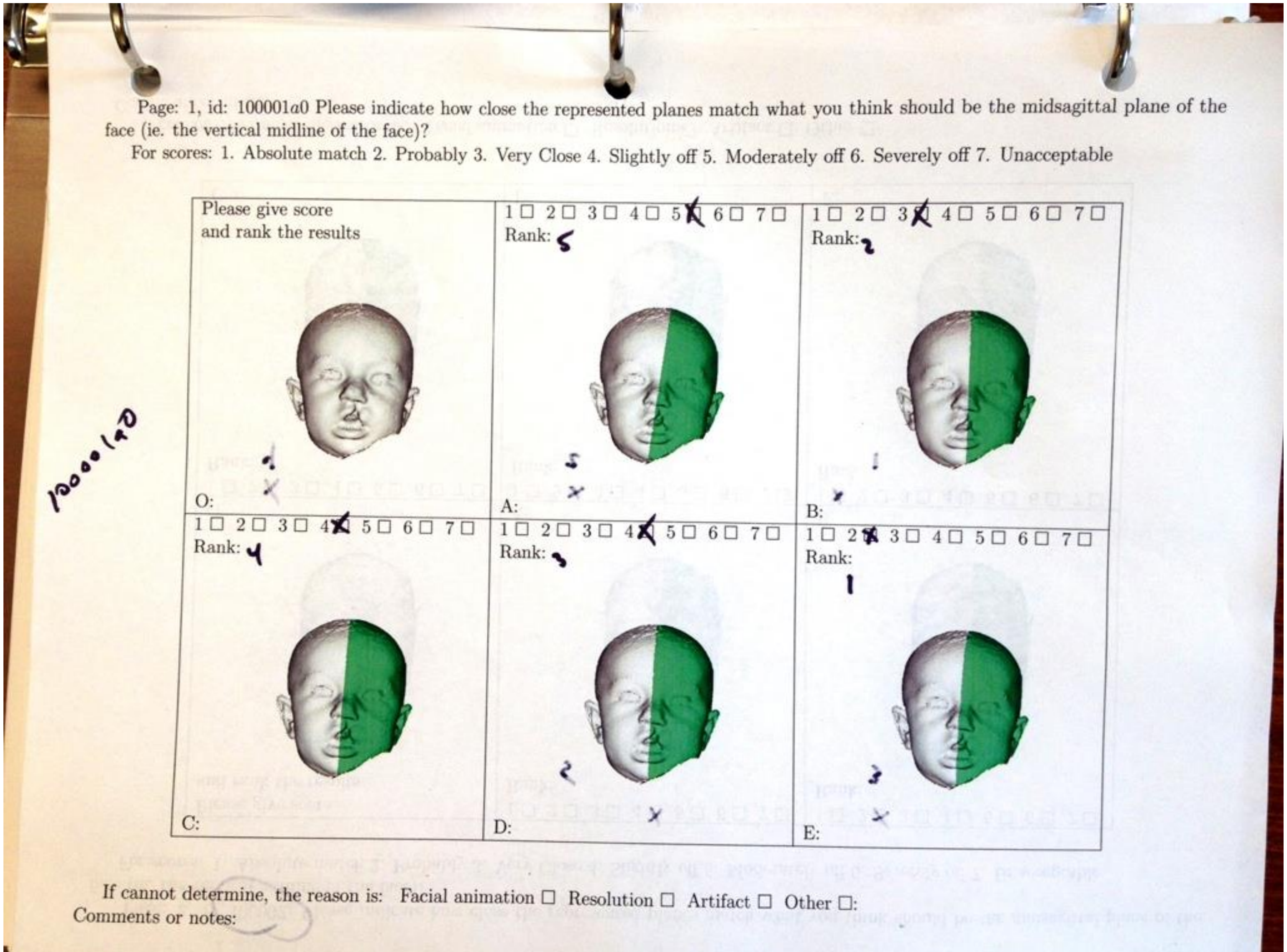
J. Wu, R. Tse, C. Heike, L. Shapiro, “Learning to Compute the Plane of Symmetry for Human Faces”, ACM Conference on Bioinformatics, Computational Biology and Biomedicine 2011, August 2011.

Survey Setup

- Six medical experts, 50 data (35 unilateral cleft, 10 bilateral cleft, 5 control)



Survey Form



100001a0

Page: 1, id: 100001a0 Please indicate how close the represented planes match what you think should be the midsagittal plane of the face (ie. the vertical midline of the face)?

For scores: 1. Absolute match 2. Probably 3. Very Close 4. Slightly off 5. Moderately off 6. Severely off 7. Unacceptable

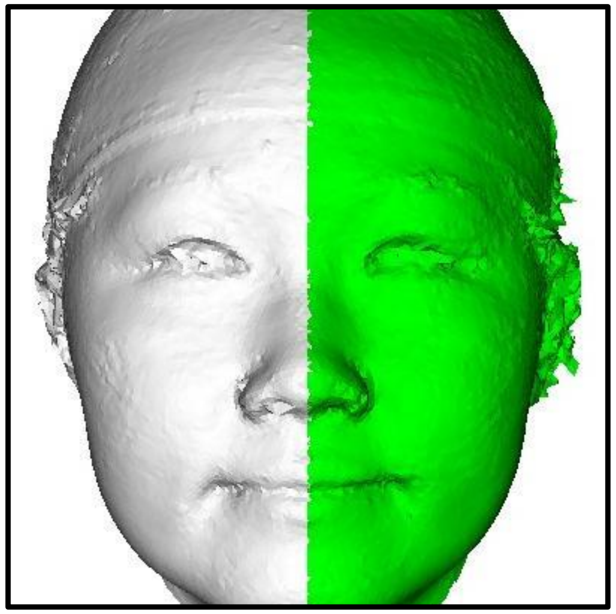
Please give score and rank the results O:	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☒ 6 ☐ 7 ☐ Rank: 5 A:	1 ☐ 2 ☐ 3 ☒ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Rank: 2 B:
1 ☐ 2 ☐ 3 ☐ 4 ☒ 5 ☐ 6 ☐ 7 ☐ Rank: 4 C:	1 ☐ 2 ☐ 3 ☐ 4 ☒ 5 ☐ 6 ☐ 7 ☐ Rank: 3 D:	1 ☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ Rank: 1 E:

If cannot determine, the reason is: Facial animation ☐ Resolution ☐ Artifact ☐ Other ☐:

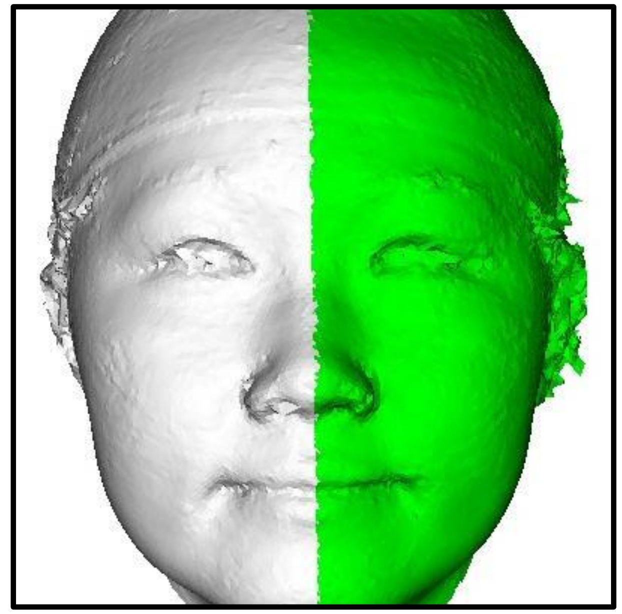
Comments or notes:

Survey Scale Example

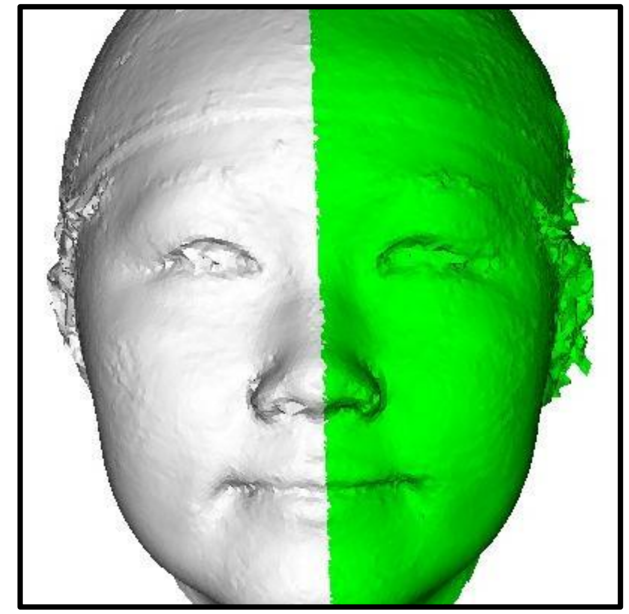
1 (absolute match)



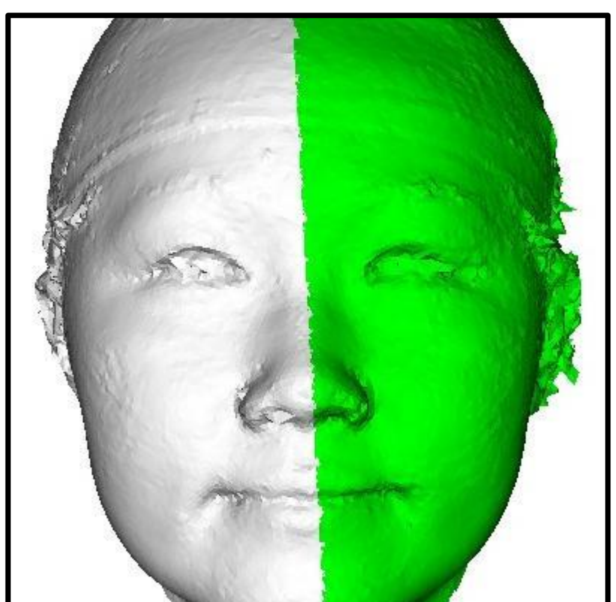
2 (probably)



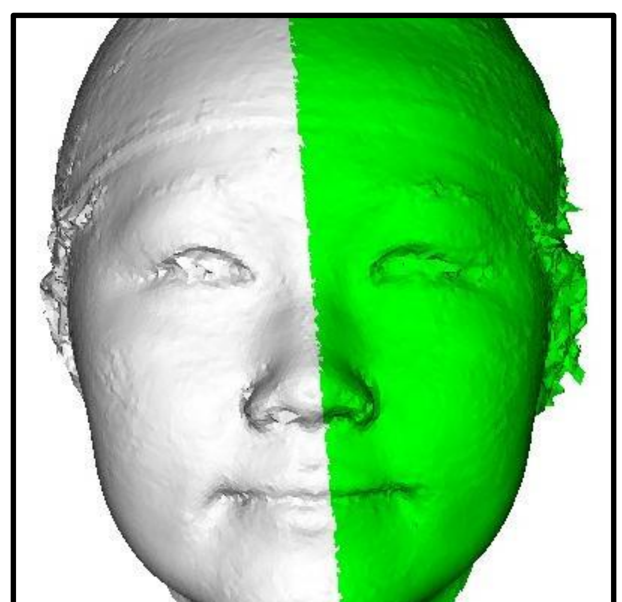
3 (very close)



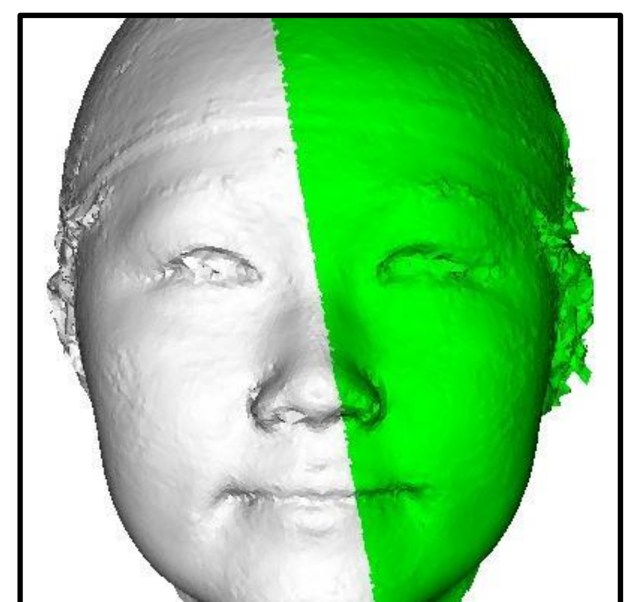
4 (slightly off)



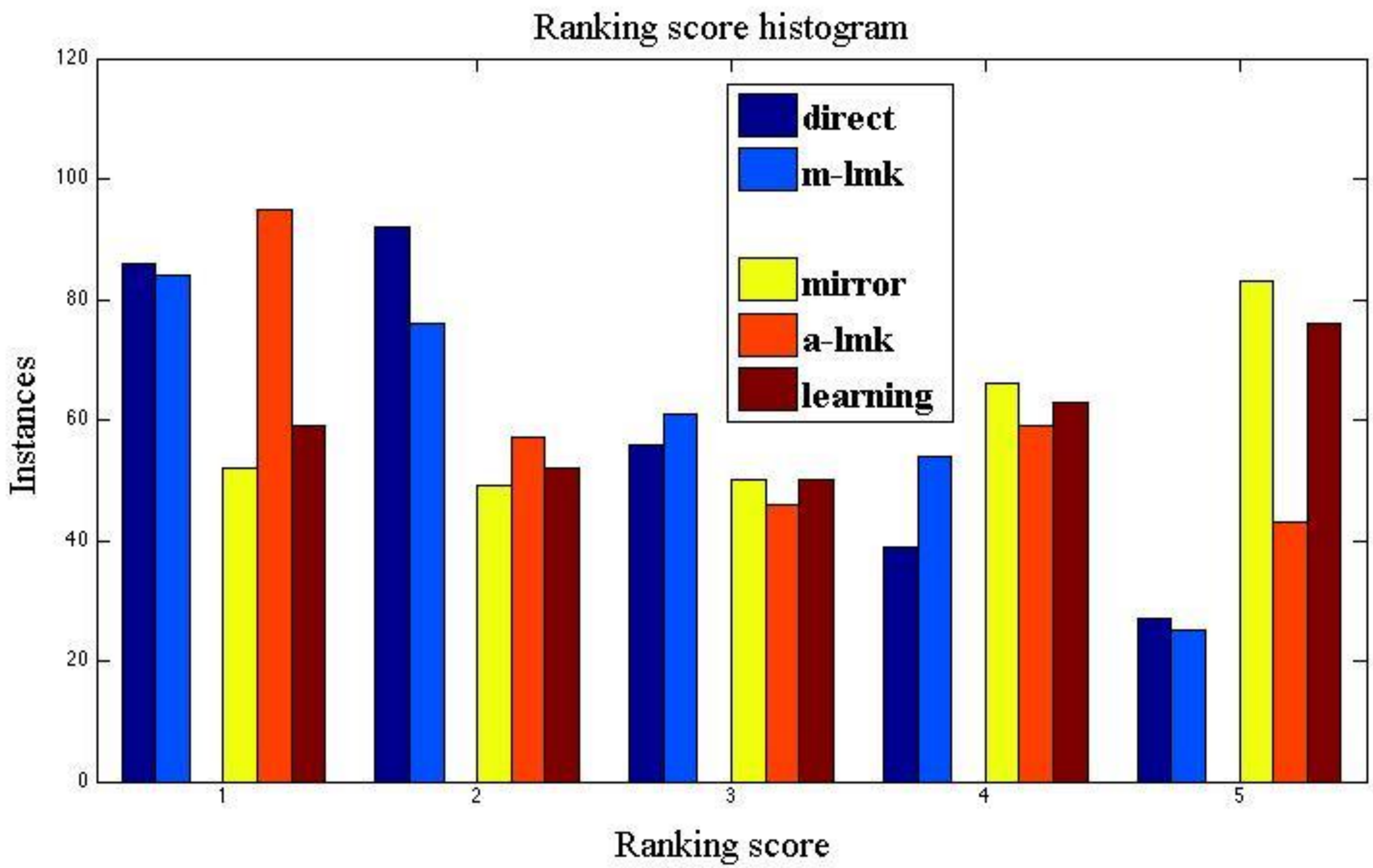
5 (moderately off)



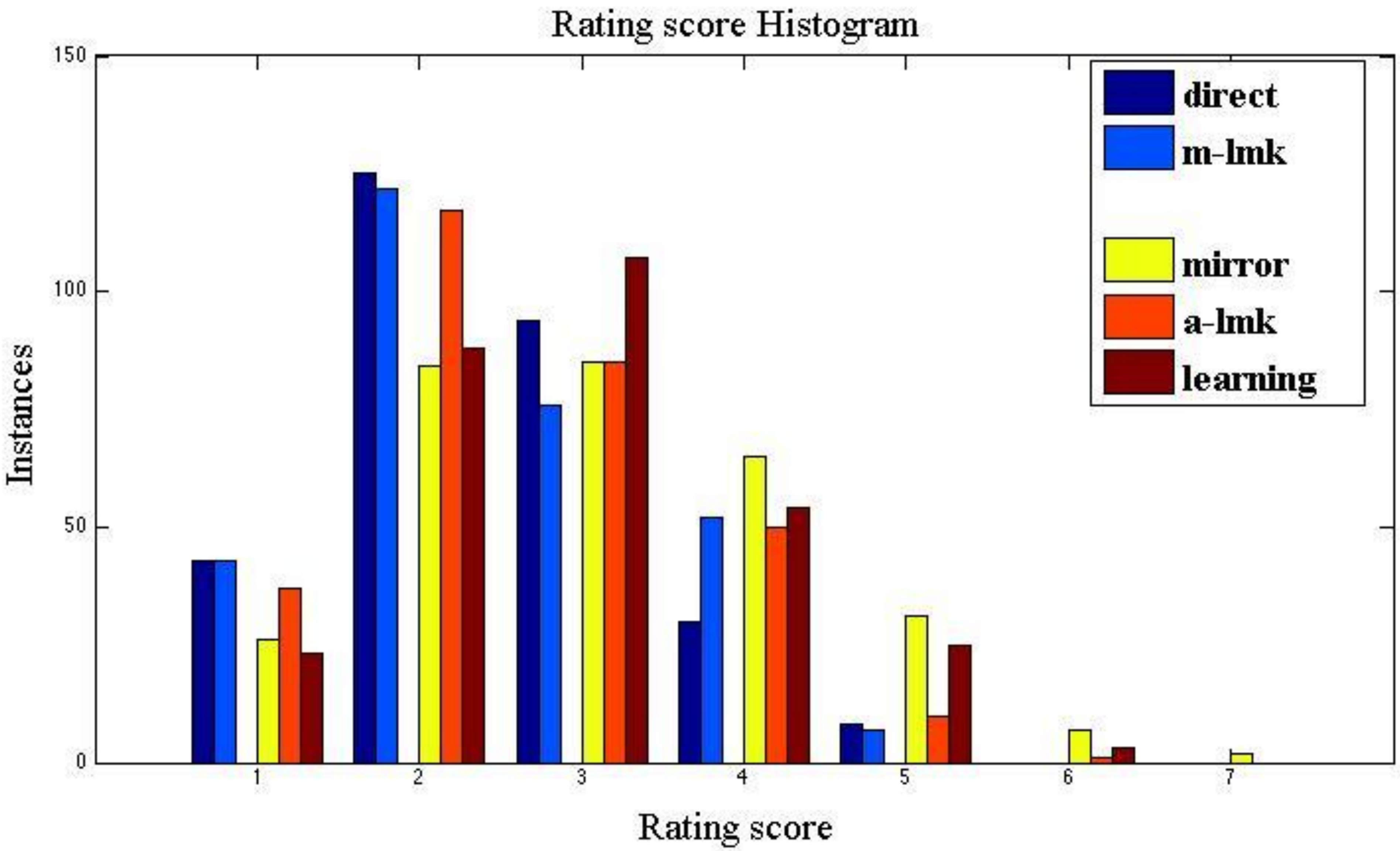
6 (severely off)



The average ranking score for all methods					
Method	direct	m-lmk	mirror	a-lmk	learning
All (50)	2.43	2.54	3.27	2.66	3.15

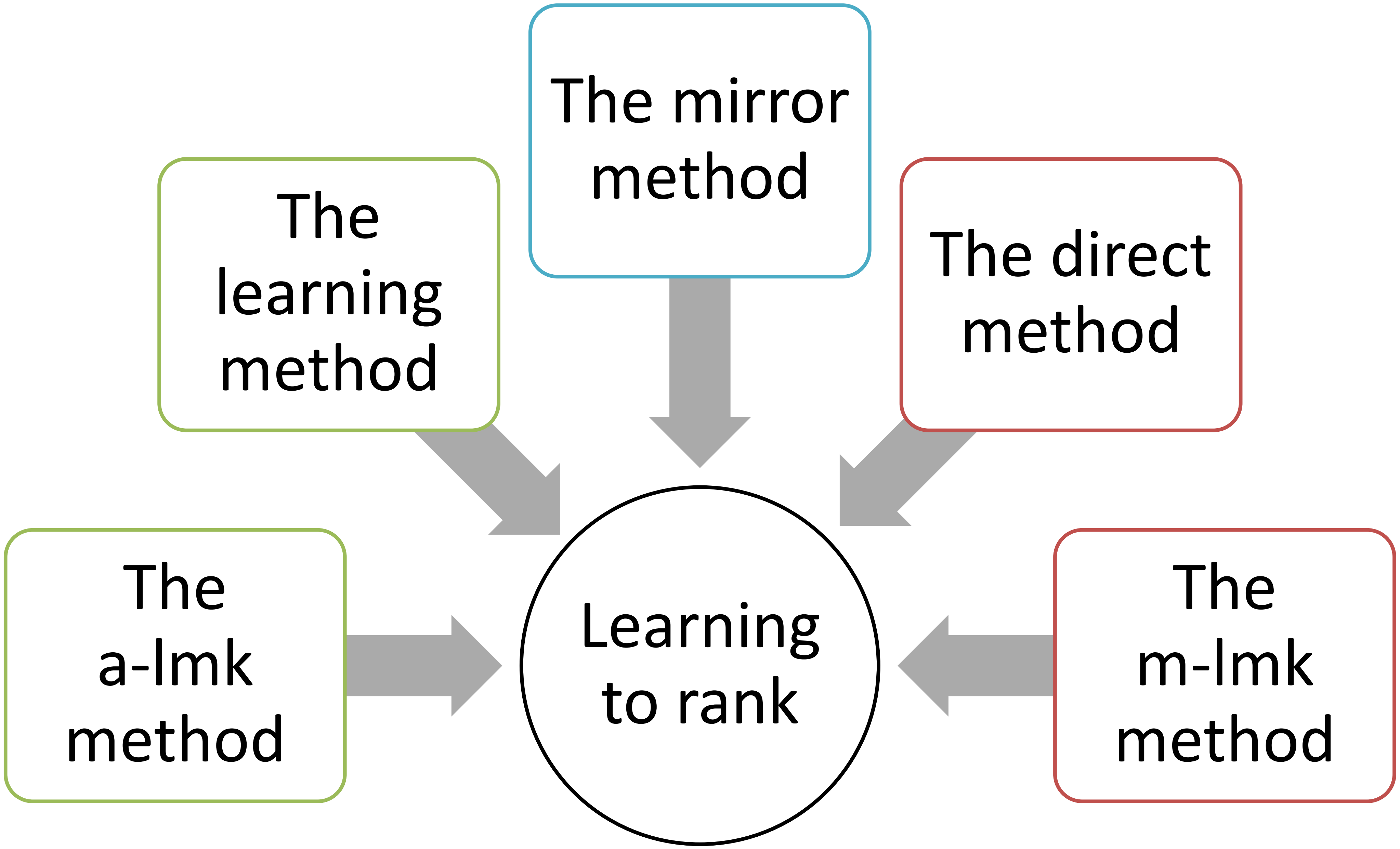


The average rating score for all methods					
Method	direct	m-lmk	mirror	a-lmk	learning
All (50)	2.45	2.53	3.07	2.61	2.93



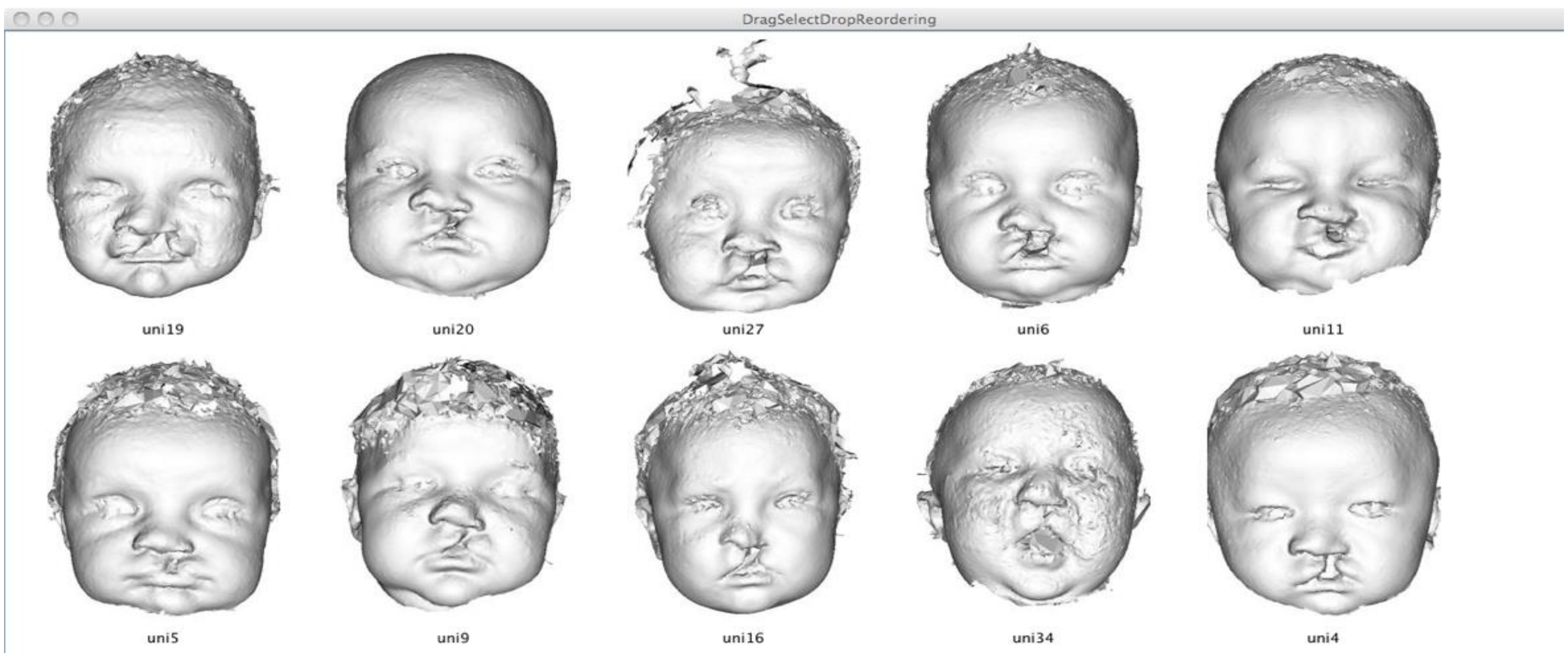
Learning to Rank

- Performance on predicting



Learning to Rank

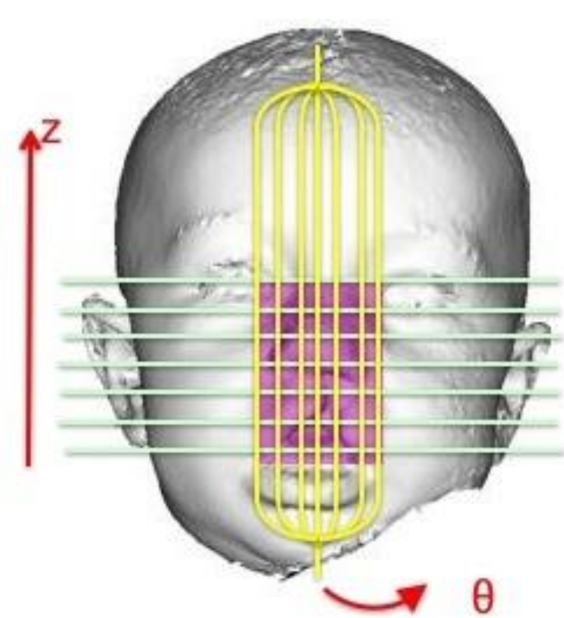
- Problem statement: given a list of manually ranked cleft image, learn how to rank based on the severity

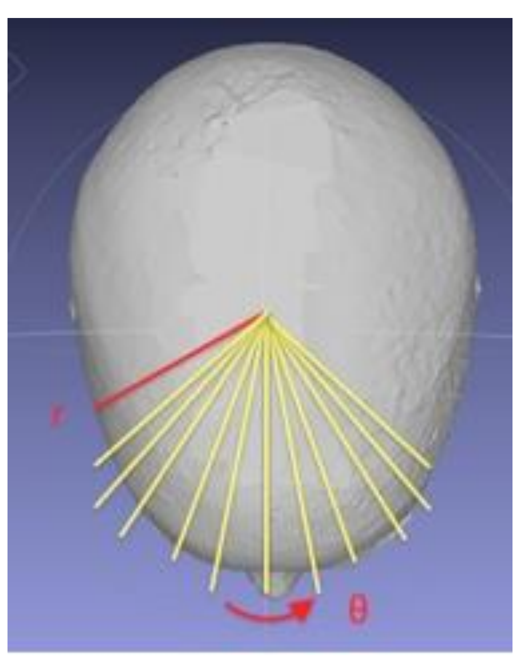


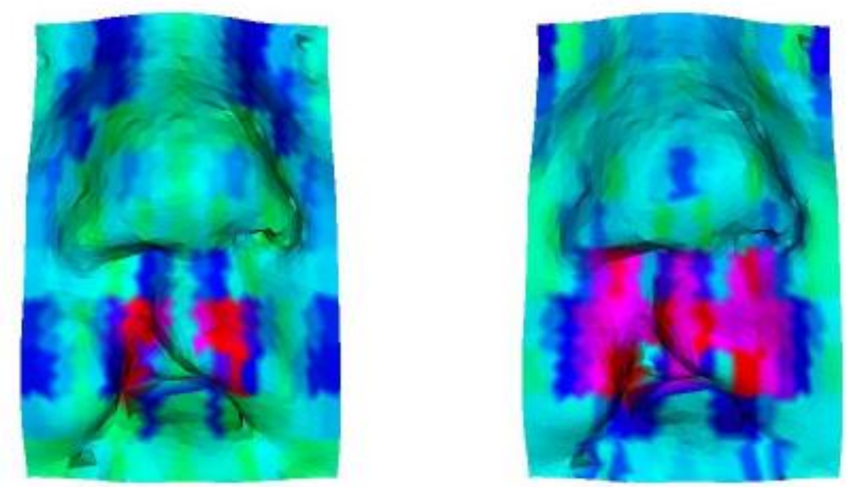
J. Wu, R. Tse, L. Shapiro, “Learning to Rank the Severity of Unrepaired Cleft Lip Nasal Deformity on 3D Mesh Data”, in International Conference in Patten Recognition, 2014.

Learning to Rank

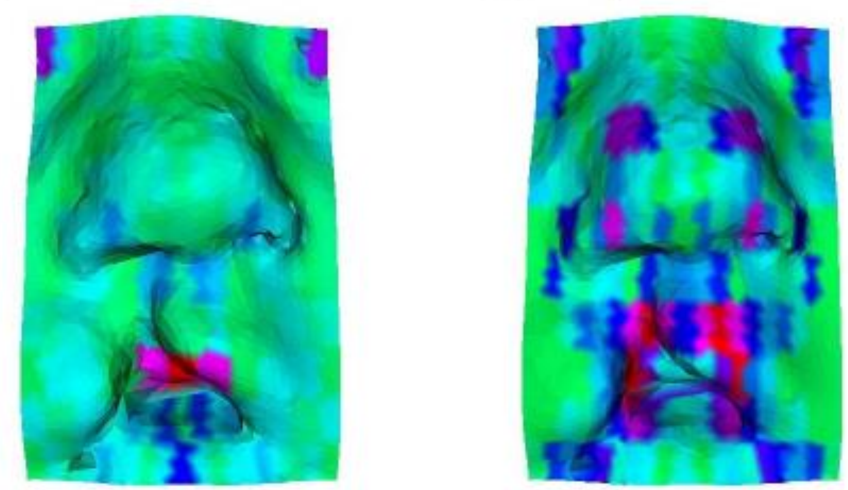
- Features







(a) Radius difference (b) Angle difference



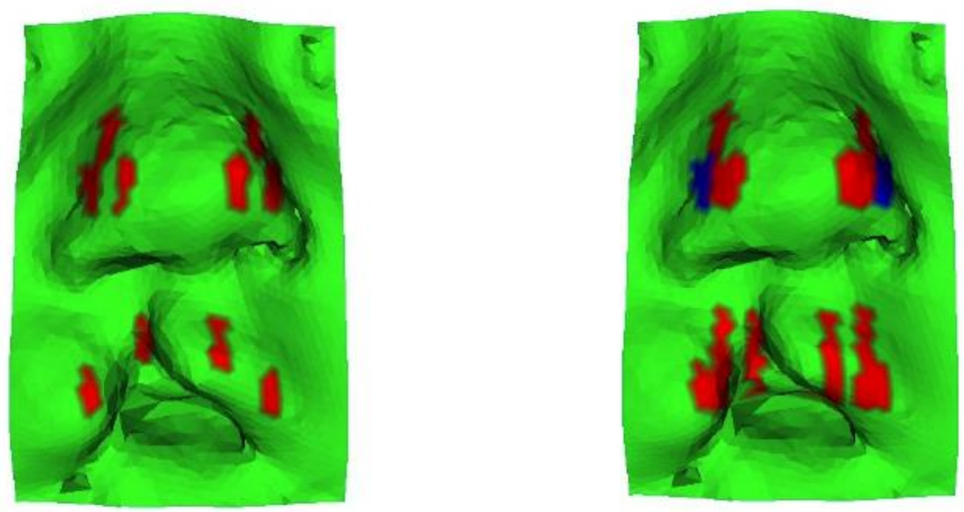
(c) Curvature difference (d) Edge difference

Learning to Rank

- Evaluation
  - The Spearman correlation coefficient ρ

Ranking correlations for all features(feature length 400, CV4).				
Method	Linear R	SVM R	RankNet	RankBoost
mirror	0.66	0.64	0.51	0.68
a-lmk	0.60	0.60	0.51	0.77
learning	0.57	0.59	0.67	0.75
m-lmk	0.56	0.55	0.63	0.64
direct	0.52	0.52	0.63	0.77

Learning to Rank

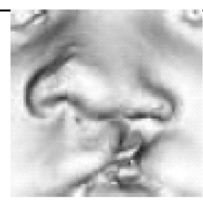
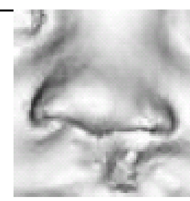
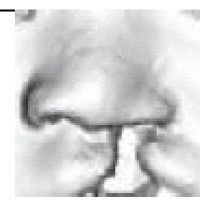
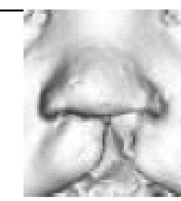


(a) Top 5 selected grids (b) Top 10 selected grids

Ranking correlations for selected features(feature length 5, CV4).				
Method	Linear R	SVM R	RankNet	RankBoost
mirror	0.73	0.73	0.72	0.68
a-lmk	0.79	0.78	0.81	0.71
learning	0.79	0.81	0.84	0.75
m-lmk	0.80	0.81	0.83	0.77
direct	0.80	0.81	0.83	0.75

Learning to Rank

- Sample results

expert's order	1	2	3	4	5	6	7	8	9	10
images										
learning	1	3	2	4	5	6	8	9	7	10
a-lmk	1	2	3	5	6	4	8	7	9	10
mirror	1	2	4	8	5	6	9	3	7	10
m-lmk	1	2	3	4	5	6	9	7	10	8
plane	1	2	3	5	4	6	7	9	10	8

System Progress

Raw image from 3dMD → Automatic cleaning and normalization → Automatic landmark location → The mid-facial reference plane → Learning to rank based on severity

Quantifying the Asymmetry and the Nasal Deformity

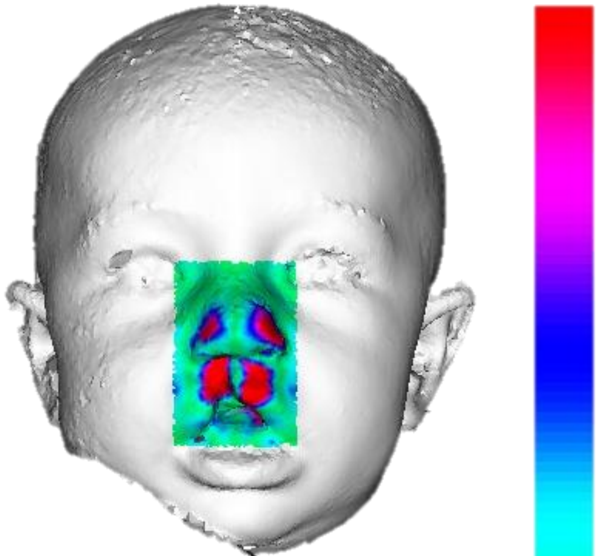
Asymmetry descriptors

- Grid-based radius difference (RDa)
- Grid-based angle difference (ADa)
- Point-based difference (PDa)

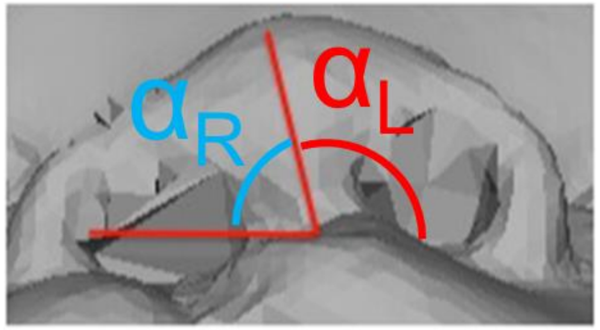
Nasal deformity descriptors

- The angle of columella (α)
- The distance from nose tip to the mid-facial reference plane (dp)
- The Angle Between the Plane of the Nose and the Mid-facial Reference Plane (β)

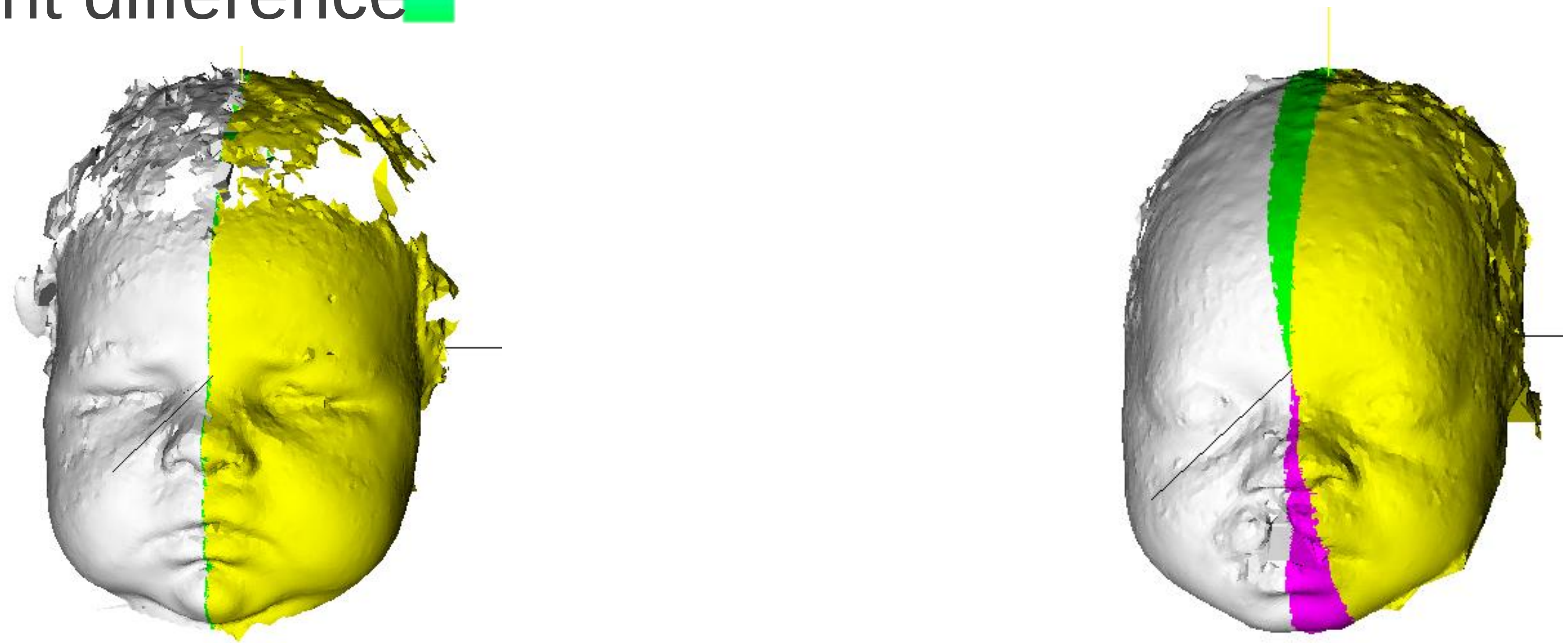
Quantifying the Asymmetry and the Nasal Deformity



Point difference

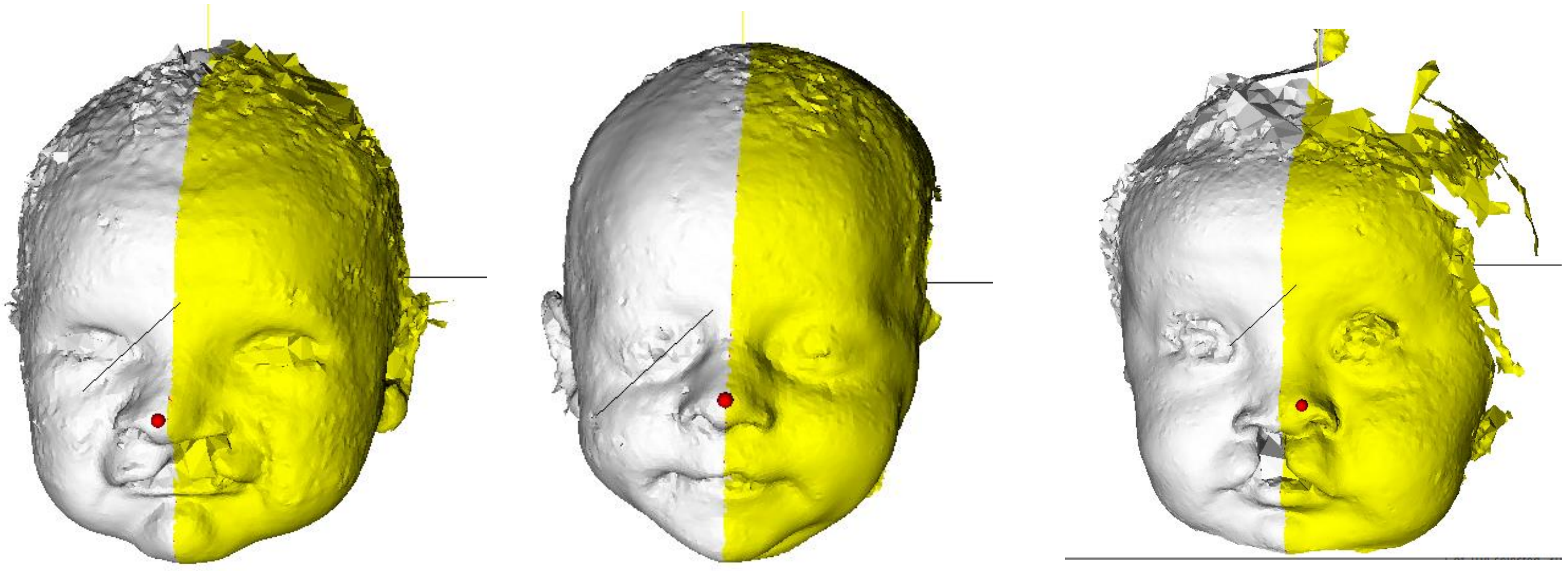


The angle of columella (α)



The Angle Between the Plane of the Nose and the Mid-facial Reference Plane (β)

Quantifying the Asymmetry and the Nasal Deformity



The distance from nose tip to the mid-facial reference plane (dp)

Average Score Before and After Surgery

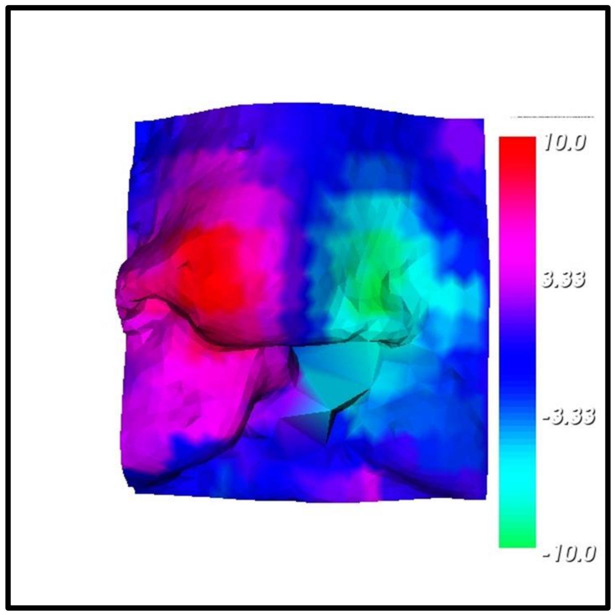
- Dataset: 35 unilateral cleft before and after surgery

Comparing three asymmetry scores before and after surgery			
Score	RDa	ADa	PDa
Before surgery	2.04	0.39	4.33
After surgery	1.07	0.26	1.67
Decrease	48%	33%	61%

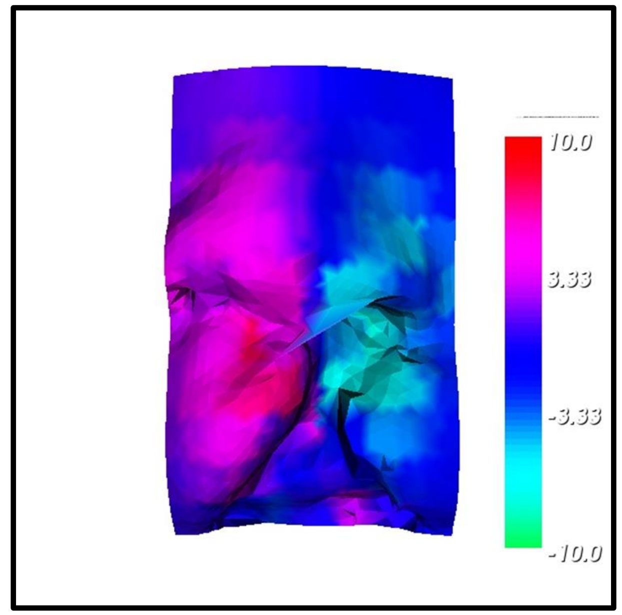
Comparing three nose deformity scores before and after surgery			
Score	$\|\alpha\|$	$\|dp\|$	β
Before surgery	0.043	3.29	0.19
After surgery	0.001	1.38	0.11
Decrease	80%	58%	44%

Radius Difference Before and After Surgery

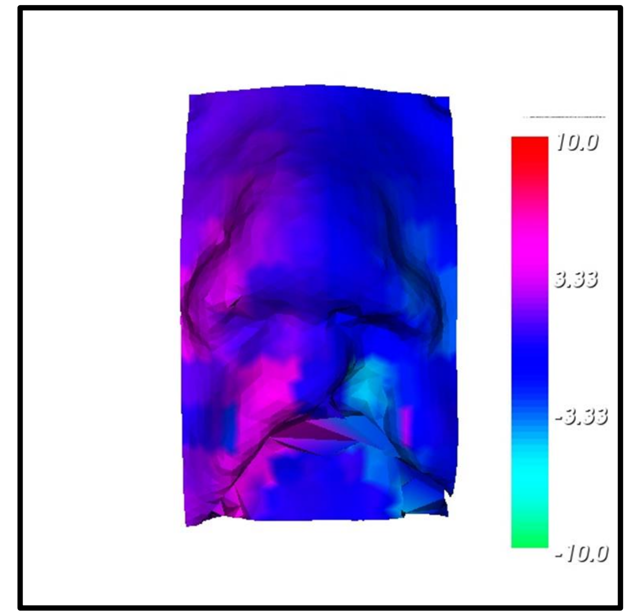
3.28



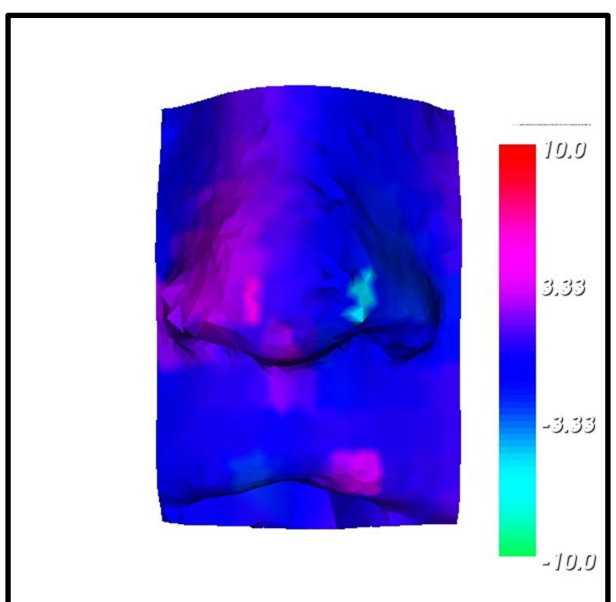
2.72



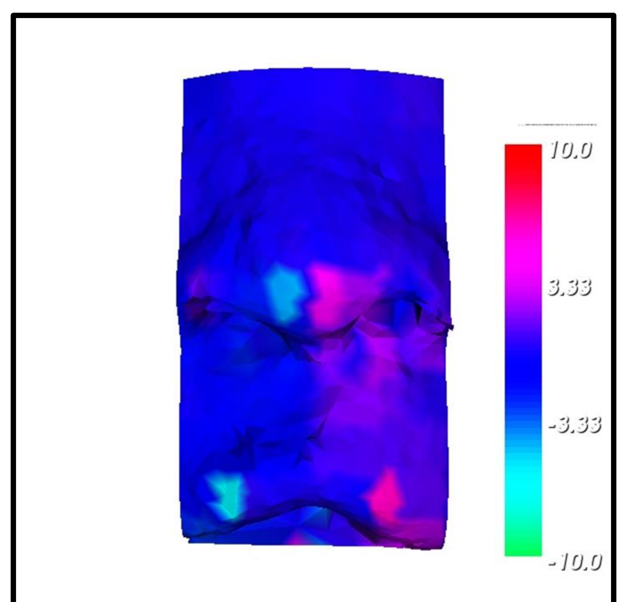
1.64



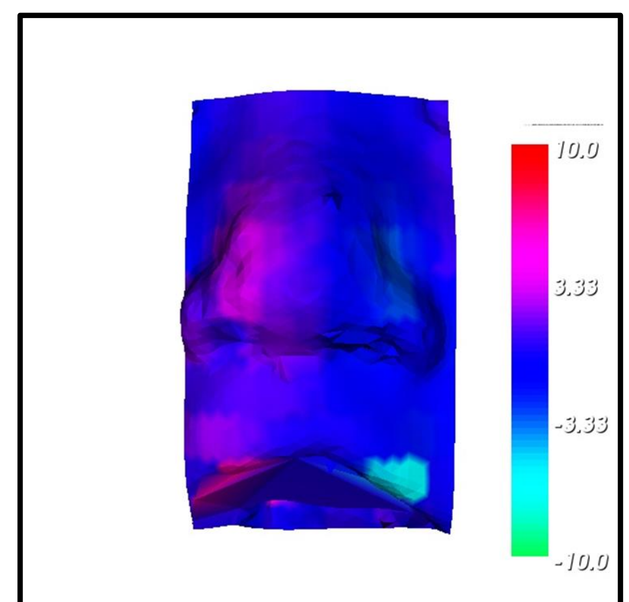
1.03



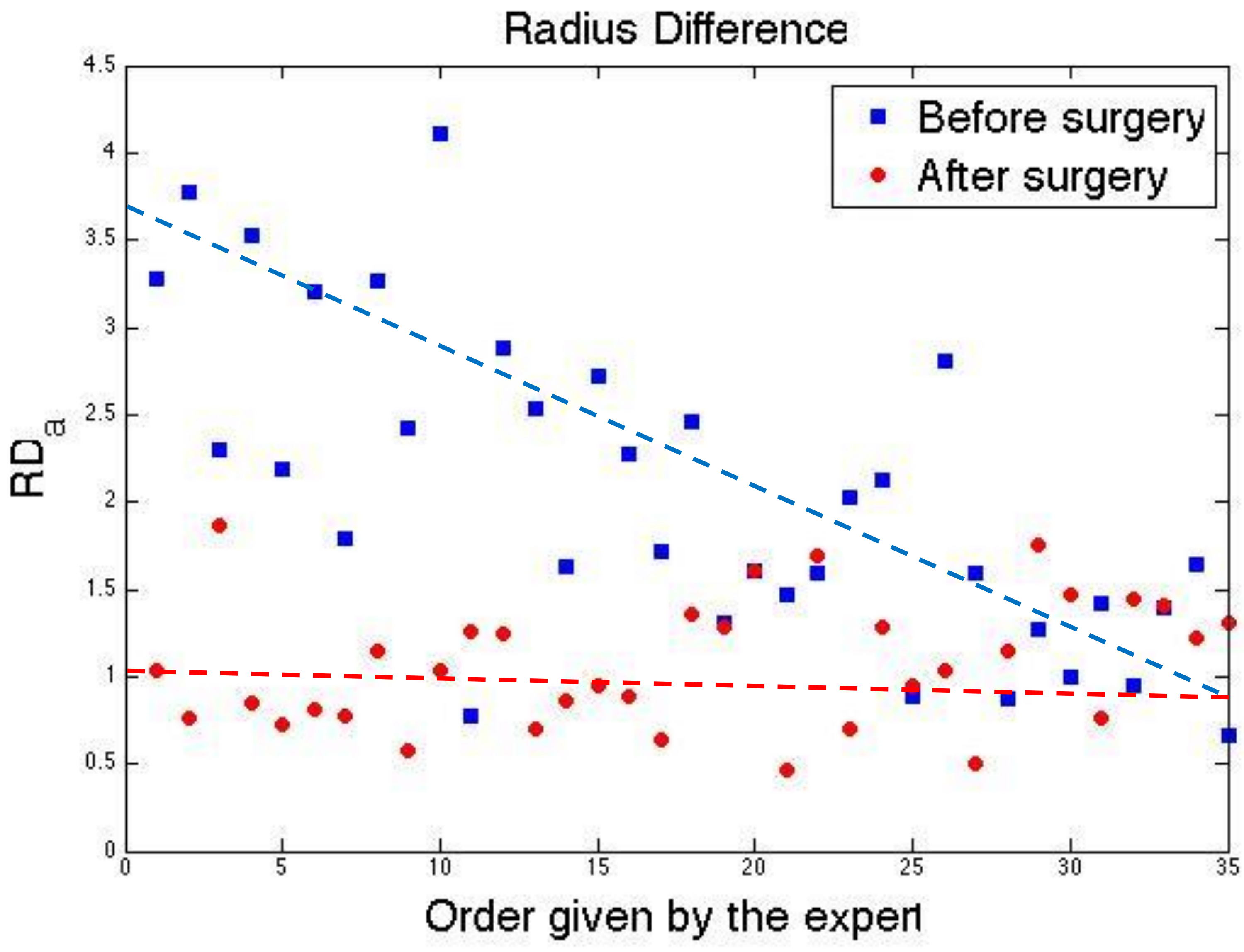
0.95



1.22



Quantifying the Asymmetry and the Nasal Deformity



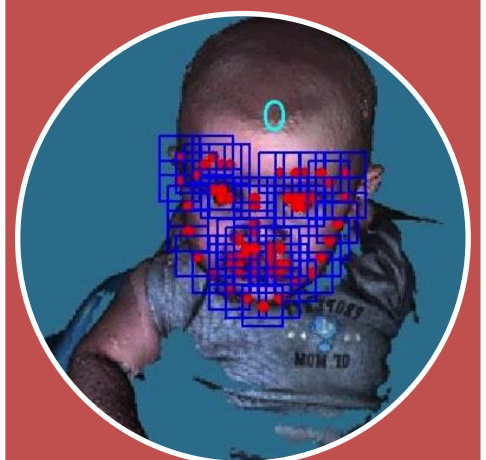
Quantifying the Asymmetry and the Nasal Deformity

- Correlation coefficient of descriptors with ranks given by medical expert based on the severity of cleft before surgery

Correlation coefficient of asymmetry descriptor with experts ranking			
Score	RDa	ADa	PDa
Before surgery	0.71	0.70	0.72
After surgery	0.27	0.02	0.19
Improvement	0.70	0.61	0.70

Correlation coefficient of nose deformity descriptor with experts ranking			
Score	$\lvert\alpha\rvert$	$\lvert dp\rvert$	β
Before surgery	0.29	0.76	0.72
After surgery	0.05	0.35	0.04
Improvement	0.30	0.76	0.64

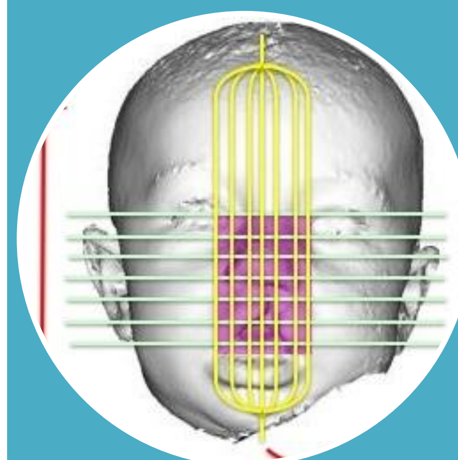
Contributions



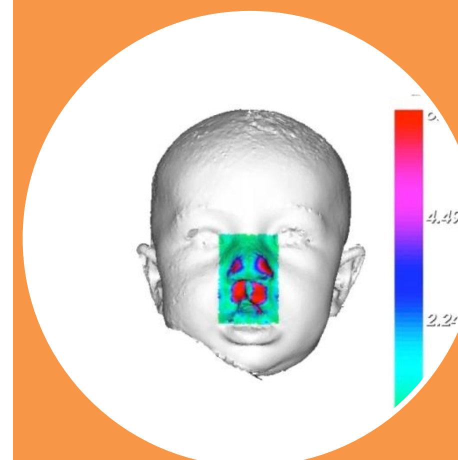
Crop and normalization

Landmark location

Mid-facial reference plane



Rank based on severity



Quantification

A whole system

Thank you!

Questions?