3D Craniofacial Image Analysis and Retrieval

3D mesh object → 3D Shape Analysis → intermediate representation → Classification or Quantification

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* This talk draws on the research of Indriyati Atmosukarto (Ph.D. 2010) and Jia Wu.
Deformational Plagiocephaly

- Flattening of head caused by pressure
- Delayed neurocognitive development
- Assessment is subjective and inconsistent
- Need *objective* and *repeatable* severity quantification method
22q11.2 Deletion Syndrome (22q11.2DS)

• Caused by genetic deletion
• Cardiac anomalies, learning disabilities
• Multiple subtle physical manifestations
• Assessment is subjective
Cleft Lip and Palate

- 1:1000 newborns
- Wide spectrum of deformities
- Varying degrees of symmetry
- Objective assessment of severity and outcome is lacking
Objective

• Investigate new methodologies for representing 3D craniofacial shapes

• Use these representations for
  – Classification of abnormality
  – Quantification of abnormality and particular symptoms
  – Retrieval of images from a database that are similar to a given image
Deformational Plagiocephaly (Manual) Measurements

- **Anthropometric landmark**
  - Physical measurements using calipers

- **Template matching**

- **Landmark photographs**

  - Cranial Index (CI)
  - Oblique Cranial Length Ratio (OCLR)

Kelly et al. 1999

www.cranialtech.com

Hutchison et al. 2005
22q11.2DS (Manual) Measurements

- Anthropometric landmark
- 2D template landmark + PCA
  - Boehringer et al.
  - Gabor wavelet + PCA to analyze 10 facial dysmorphologies

- 3D mean landmark + PCA
  - Hutton et al.
  - Align to average face + PCA
Computing the Plane of Symmetry

• **Mirror method**

Benz et al. 2002

1. hypothesize plane location
2. construct the mirror image
3. overlay mirror image on face
4. find closest corresponding points
5. use corresponding points to better estimate the plane
6. repeat (2-5) till convergence
Data Collection

3dMD multi-camera stereo system

Reconstructed 3D mesh
Global 2D Azimuth-Elevation Angle Histogram

Indriyati Atmosukarto

• 3D Shape Quantification for Deformational Plagiocephaly

• Classification of 22q11.2DS

• Future retrieval of “similar” normal heads
3D Shape Quantification for Deformational Plagiocephaly

• Discretize azimuth elevation angles into 2D histogram

• **Hypothesis**: flat parts on head will create high-valued bins
Shape Severity Scores for Posterior Plagiocephaly

- Left Posterior Flatness Score (LPFS)
- Right Posterior Flatness Score (RPFS)
- Asymmetry Score (AS) = RPFS - LPFS
- Absolute Asymmetry Score (AAS)
Classification of Posterior Plagio

Absolute Asymmetry Score (AAS) vs Oblique Cranial Length Ratio (OCLR)
Classification of Posterior Plagio

Absolute Asymmetry Score (AAS) vs Oblique Cranial Length Ratio (OCLR)

#misclassified controls: OCLR 8, AAS 2
Classification of Deformational Plagiocephaly

- Treat 2D histogram as feature vector
- Classify five plagiocephaly conditions

<table>
<thead>
<tr>
<th>Posterior plagiocephaly</th>
<th>Brachycephaly</th>
<th>Forehead asymmetry</th>
<th>Ear asymmetry</th>
<th>Overall severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.793</td>
<td>0.868</td>
<td>0.674</td>
<td>0.603</td>
<td>0.766</td>
</tr>
</tbody>
</table>
Classification of 22q11.2DS

- Treat 2D histogram as feature vector

<table>
<thead>
<tr>
<th></th>
<th>8×8</th>
<th>16×16</th>
<th>24×24</th>
<th>32 × 32</th>
<th>Experts’ median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole 2D hist</td>
<td>0.651</td>
<td>0.569</td>
<td><strong>0.79</strong></td>
<td>0.684</td>
<td>0.68</td>
</tr>
</tbody>
</table>
## Classification of 22q11.2DS Facial Features

<table>
<thead>
<tr>
<th></th>
<th>8×8</th>
<th>16×16</th>
<th>24×24</th>
<th>32×32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midface Hypoplasia</td>
<td>0.639</td>
<td>0.744</td>
<td>0.697</td>
<td>0.651</td>
</tr>
<tr>
<td>Tubular Nose</td>
<td>0.709</td>
<td>0.593</td>
<td>0.581</td>
<td>0.663</td>
</tr>
<tr>
<td>Bulbous Nasal Tip</td>
<td>0.593</td>
<td>0.581</td>
<td>0.581</td>
<td>0.639</td>
</tr>
<tr>
<td>Prominent Nasal Root</td>
<td>0.547</td>
<td>0.639</td>
<td>0.616</td>
<td>0.658</td>
</tr>
<tr>
<td>Small Nasal Alae</td>
<td>0.561</td>
<td>0.675</td>
<td>0.571</td>
<td>0.560</td>
</tr>
<tr>
<td>Retrusive Chin</td>
<td>0.526</td>
<td>0.674</td>
<td>0.560</td>
<td>0.546</td>
</tr>
<tr>
<td>Open Mouth</td>
<td>0.875</td>
<td>0.799</td>
<td>0.844</td>
<td>0.683</td>
</tr>
<tr>
<td>Small Mouth</td>
<td>0.671</td>
<td>0.526</td>
<td>0.752</td>
<td>0.585</td>
</tr>
<tr>
<td>Downturned Mouth</td>
<td>0.613</td>
<td>0.539</td>
<td>0.553</td>
<td>0.630</td>
</tr>
</tbody>
</table>
Learning 3D Shape Quantification

• Analyze 22q11.2DS and 9 associated facial features

• Goal: quantify different shape variations in different facial abnormalities
Learning 3D Shape Quantification - Facial Region Selection

• Focus on 3 facial areas
  – Midface, nose, mouth

• Regions selected manually
Learning 3D Shape Quantification - 2D Histogram Azimuth Elevation

• Using azimuth elevation angles of surface normal vectors of points in selected region
Learning 3D Shape Quantification - Feature Selection

- Determine most discriminative bins
- Use **Adaboost** learning
- Obtain positional information of important region on face
Learning 3D Shape Quantification - Feature Combination

• Use **Genetic Programming (GP)** to evolve mathematical expression

• Start with random population
  – Individuals are evaluated with fitness measure
  – Best individuals reproduce to form new population
Learning 3D Shape Quantification - Genetic Programming

• Individual:
  – Tree structure
  – Terminals e.g variables eg. 3, 5, x, y, …
  – Function set e.g +, -, *, …
  – Fitness measure e.g sum of square …

```
5*(x+y)
```
Learning 3D Shape Quantification - Feature Combination

• 22q11.2DS dataset
  – Assessed by craniofacial experts
  – Groundtruth is union of expert scores

• **Goal**: classify individual according to given facial abnormality
Learning 3D Shape Quantification - Feature Combination

- **Individual**
  - Terminal: selected histogram bins
  - Function set: +,-,*,min,max,sqrt,log,2x,5x,10x
  - Fitness measure: F1-measure

\[
F(\text{prec}, \text{rec}) = \frac{2 \times (\text{prec} \times \text{rec})}{\text{prec} + \text{rec}}
\]

\[
X_6 + X_7 + (\max(X_7, X_6) - \sin(X_8) + (X_6 + X_6))
\]
Learning 3D Shape Quantification - Experiment 1

- **Objective:** investigate function sets
  - Combo1 = {+, -, *, min, max}
  - Combo2 = {+, -, *, min, max, sqrt, log2, log10}
  - Combo3 = {+, -, *, min, max, 2x, 5x, 10x, 20x, 50x, 100x}
  - Combo4 = {+, -, *, min, max, sqrt, log2, log10, 2x, 5x, 10x, 20x, 50x, 100x}
Learning 3D Shape Quantification - Experiment 1

• Best F-measure out of 10 runs

<table>
<thead>
<tr>
<th>Facial anomaly</th>
<th>Combo1</th>
<th>Combo2</th>
<th>Combo3</th>
<th>Combo4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midface Hypoplasia</td>
<td>0.8393</td>
<td>0.8364</td>
<td>0.8527</td>
<td>0.80</td>
</tr>
<tr>
<td>Tubular Nose</td>
<td>0.8571</td>
<td>0.875</td>
<td>0.8667</td>
<td>0.8813</td>
</tr>
<tr>
<td>Bulbous Nasal Tip</td>
<td>0.8545</td>
<td>0.8099</td>
<td>0.8103</td>
<td>0.7544</td>
</tr>
<tr>
<td>Prominent Nasal Root</td>
<td>0.8667</td>
<td>0.8430</td>
<td>0.8571</td>
<td>0.8335</td>
</tr>
<tr>
<td>Small Nasal Alae</td>
<td>0.8846</td>
<td>0.8454</td>
<td>0.8454</td>
<td>0.8571</td>
</tr>
<tr>
<td>Retrusive Chin</td>
<td>0.7952</td>
<td>0.8000</td>
<td>0.7342</td>
<td>0.7586</td>
</tr>
<tr>
<td>Open Mouth</td>
<td>0.9444</td>
<td>0.9714</td>
<td>0.9189</td>
<td>0.9189</td>
</tr>
<tr>
<td>Small Mouth</td>
<td>0.6849</td>
<td>0.7568</td>
<td>0.6829</td>
<td>0.7750</td>
</tr>
<tr>
<td>Downturned mouth</td>
<td>0.8000</td>
<td>0.7797</td>
<td>0.8000</td>
<td>0.8000</td>
</tr>
</tbody>
</table>
Tree structure for quantifying midface hypoplasia

\[((X7-X7) + (X6+(((X6+X6)-X7)+(X7-X2)))+X7))+(X9-5X9+X7+X7)\]

Xi are the selected histogram bins
Learning 3D Shape Quantification - Experiment 2

- **Objective**: compare local facial shape descriptors

<table>
<thead>
<tr>
<th>Facial abnormality</th>
<th>Region Histogram</th>
<th>Selected Bins</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midface hypoplasia</td>
<td>0.697</td>
<td>0.721</td>
<td>0.853</td>
</tr>
<tr>
<td>Tubular nose</td>
<td>0.701</td>
<td>0.776</td>
<td>0.881</td>
</tr>
<tr>
<td>Bulbous nasal tip</td>
<td>0.617</td>
<td>0.641</td>
<td>0.855</td>
</tr>
<tr>
<td>Prominent nasal root</td>
<td>0.704</td>
<td>0.748</td>
<td>0.867</td>
</tr>
<tr>
<td>Small nasal alae</td>
<td>0.733</td>
<td>0.801</td>
<td>0.885</td>
</tr>
<tr>
<td>Retrusive chin</td>
<td>0.658</td>
<td>0.713</td>
<td>0.800</td>
</tr>
<tr>
<td>Open mouth</td>
<td>0.875</td>
<td>0.889</td>
<td>0.971</td>
</tr>
<tr>
<td>Small mouth</td>
<td>0.694</td>
<td>0.725</td>
<td>0.775</td>
</tr>
<tr>
<td>Downturned mouth</td>
<td>0.506</td>
<td>0.613</td>
<td>0.800</td>
</tr>
</tbody>
</table>
Learning 3D Shape Quantification - Experiment 3

- **Objective:** predict 22q11.2DS

<table>
<thead>
<tr>
<th>Method</th>
<th>F-measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantification vector with SVM</td>
<td>0.709</td>
</tr>
<tr>
<td>Quantification vector with Adaboost</td>
<td>0.721</td>
</tr>
<tr>
<td>Quantification vector with GP</td>
<td>0.821</td>
</tr>
<tr>
<td>Global saliency map</td>
<td>0.764</td>
</tr>
<tr>
<td>Selected bins of global saliency map</td>
<td>0.9</td>
</tr>
<tr>
<td>Global 2D histogram</td>
<td>0.79</td>
</tr>
<tr>
<td>Selected bins of global 2D histogram</td>
<td>0.9</td>
</tr>
<tr>
<td>Selected bins of global saliency map with GP</td>
<td>0.96</td>
</tr>
<tr>
<td>Selected bins of global 2D histogram with GP</td>
<td>0.92</td>
</tr>
<tr>
<td>Expert’s median</td>
<td>0.68</td>
</tr>
</tbody>
</table>
Learning to Compute the Plane of Symmetry for Human Faces

Jia Wu

• Overview

- Train a classifier to identify regions about landmark points
- Train a second classifier to determine which of these regions are useful in computing the plane of symmetry
- Use these classifiers to select regions of a face and use their center points to compute the plane of symmetry
- The RANSAC algorithm fits the plane and discards outliers
Landmark by medical experts

Landmarks labeled by experts

Standard symmetry plane
10 kinds of landmarks.

– Nose: ac, prn, sn, se
– Eyes: en, ex
– Mouth: (li, ls), ch, sto, slab
Positive/negative samples

Training for en: the inner corners of the eyes

Training for prn: most protruded point of nasal tip
Features: Histograms of Gaussian Curvature and Curvedness with Different Neighborhood Sizes

Gaussian curvature

Curvedness (distance from origin in curvature plane)

Histograms of Gaussian curvatures of a positive sample and a negative sample
Interesting points prediction

Prediction of en: the inner corners of the eyes

Prediction of prn: most protruded point of nasal tip
Connected regions for en: each color means one region

Connected regions for prn: each color means one region
How to define “useful” symmetric regions

• A useful pair of regions should be symmetric to the standard symmetry plane
• A useful single region should have the center on the standard symmetry plane

useful regions for en  
useful regions for prn
Procedure for New data

Select possible landmark areas (from Landmark model)

Find and pair connected regions

Determine useful singles and useful pairs (from Symmetry model)

Get center and draw a plane using learned centers

interesting regions for prn

Predicted as useful single

Predicted as useful pair
Procedure for New Images

Centers of useful regions

Centers for constructing plane of symmetry are red.

Result: Plane of symmetry
Results on 22q11.2DS Data Set compared to Mirror Method
Results on Rotated Data Set

Compare symmetry plane to ground truth

Angle to ground truth

Rotation combination

Learning method

Mirror method

Compare symmetry plane to ground truth

Measure

Rotation combination

Learning method

Mirror method
Some Results on Cleft Subjects

Learning method

Mirror method
Some More Recent Results
Using Only En, Se, and Gn
Contributions

• **Representation** of craniofacial anatomy by azimuth elevation histograms and other local features.

• **Classification and quantification** of abnormal conditions using this representation.

• **New learning methodology** for finding the plane of symmetry of the face, even for cleft patients.
Future Directions

• A retrieval system is being designed that will use multiple different low-level features in different areas of the face to retrieve similar images from image databases.

• The asymmetry of the face will be studied more thoroughly and quantified.

• A series of new features will be designed to describe and quantify the degree of cleft lip and palate.
Acknowledgements

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- the **National Institute of Health** under grant number K23-DE017741
CranioGUI

- Purpose: all web-based graphical interface, no setup,
- allows people to try our modules with no overhead.