Facial soft tissue thicknesses prediction using anthropometric distances

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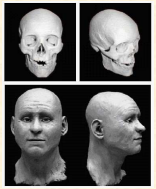
Facial Reconstruction

Facial Reconstruction is recreating the face of an unidentified individual from their skeletal remains.

- Forensic: determining the face of victims in the murders
- Archaeology: verifying the remains of historic figures.
- Anthropology: approximating the look of early hominid forms.



2 Dimensional reconstruction

- Requires a forensic artist who draws the picture
- Usually requires cooperation between artist and forensic anthropologist

3 Dimensional reconstruction

- Clay modeling approach.
- Landmark dowels are placed on the predefined landmarks on the skull
- The lengths of these dowels are the tissue depth at the dowel's landmark.
- Clay is then filled between the dowels to build up the tissue depth of the unknown person

Soft Tissue Thickness Prediction

- **The critical issue in any Facial Reconstruction is soft tissue thickness prediction**
- **All known facial reconstruction systems collect tissue depths at predefined landmarks of a population and use the average value in the reconstruction.**
- **There are some methods to collect tissue depths information**
  - Invasive technique: needle technique
  - Non-invasive techniques: ultrasound, MRI, CT

Our Method

- **We treat the soft tissue thickness prediction issue the missing data problem**
  - The tissue depths are the target
  - The skull shape is the input
- **One solution for the missing data problem is to**
  - Collect data of pairs of input and target
  - Apply machine learning techniques to obtain a model that best describes input-target relationship

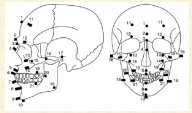
References

1. M. Hagan, H. Demuth, M. Beale. Neural Network Design. *PWS Publishing Company, Boston, Massachusetts*
2. http://www.huntsman.com/advanced_materials/Images/news/Skulls.jpg
   http://en.wikipedia.org/wiki/Forensic_facial_reconstruction
3. http://newsdesk.si.edu/images_full/images/museums/nmnh/written_in_bone/JAMESFORT-APVA-1046B-078.jpg
   http://library.thinkquest.org/04oct/00206/lo_pti_facial_reconstruction.htm
4. http://upload.wikimedia.org/wikipedia/en/4/4c/2D_Facial_Reconstruction_by_Karen_T._Taylor.jpg
   http://en.wikipedia.org/wiki/Forensic_facial_reconstruction

Data Description

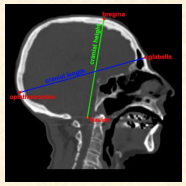
Target Data

- Soft tissue thicknesses at facial landmarks
- Facial features: distance between 2 pupils, nose height, and nose length.



Input Data

- Distances between facial landmarks. These distances must be measured from the skull itself. In the case of facial reconstruction, only these distances are known

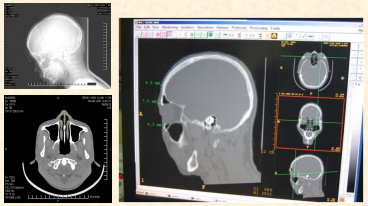


	Input (17 fields)			Target (38 fields)		
	Cranial height	Cranial width	...	Vertex thickness	Nose length	...
Data 1	137	140	...	6.5	46	...
Data 2	127	145	...	5.8	43	...
Data 3	132.4	145	...	5.8	46.9	...
...	...	...	...	...	...	...
Data98	129.4	139	...	4.1	42.7	...

These information can be measured from any discovered skull

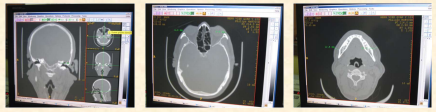
Need to predict these information

Data Collecting



Data is obtained using the Computed Tomography (CT) technique

- CT image is in high quality and the distances between facial landmarks can be measured visually.



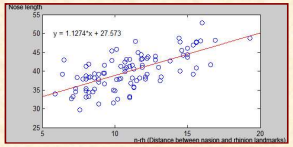
Collected data of 220 Vietnamese candidates

- 98 males, 122 females
- Age varies from 17 to 82
- Weight varies from 38kg to 75kg

Discovery of Relationships

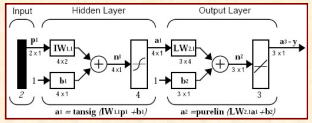
Applying Linear Regression

- Fitting a linear equation to the observed data
- Can only discover one to one relationships
- is applied for all pairs of input-target. For each target field, the pair with best performance (in term of MSE) is chosen



Neural network approach

- This structure can represent any functional relationship between inputs and outputs if the hidden layer has enough neurons [1]
  - two-layer feed forward network
  - tan-sigmoid transfer function in the hidden layer
  - linear transfer function in the output layer
- Every target field has its own neural network prediction model
  - In the training process, all the input fields are taken into account



Discovered One to One Linear Relationships

This is the results of applying the linear regression technique on the whole data sets

- In these equations, y is the output, and x is the input

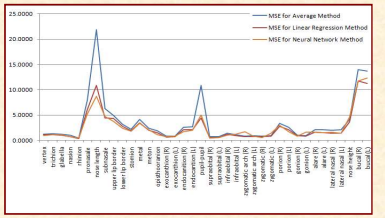
N#	OUTPUT	INPUT	LINEAR EQUATION	MSE
1	vertex	cranial breadth	y = -0.038041x + 10.8251	1.1230
2	trichion	cranial height	y = 0.07284x - 4.6447	1.1500
3	glabella	forehead width (ft-ft)	y = 0.073272x - 2.2482	1.0456
4	nasion	cranial height	y = 0.070439x - 5.022	0.8300
5	rhinion	molar-molar	y = -0.036784x + 4.1817	0.3635
6	pronasale	base nose length	y = 0.34191x + 5.6906	6.7684
7	nose_length	n-rh	y = 1.1274x + 27.5733	11.8050
8	subnasale	bn-bn	y = -0.3371x + 22.5646	4.7101
9	upper_lip_border	molar-molar	y = 0.12137x + 5.0732	4.5644
10	lower_lip_border	cranial height	y = 0.086747x + 1.7837	2.9479
11	stomion	base facial length (ba-pr)	y = -0.072432x + 10.843	2.0073
12	metal	al-al	y = 0.18113x + 3.5632	3.7307
13	meton	al-al	y = 0.13342x + 1.0783	2.1684
14	opisthooranion	al-al	y = 0.14536x - 0.019573	1.5853
15	exocanthion_(R)	cranial height	y = 0.052174x - 3.2308	0.7072
16	exocanthion_(L)	cranial height	y = 0.054596x - 3.4705	0.7609
17	endocanition_(R)	cranial height	y = 0.10877x - 8.8266	2.2855
18	endocantion_(L)	cranial height	y = 0.13074x - 11.5992	2.1918
19	pupil-pupil	ex-ex	y = 0.71282x - 5.9472	4.6317
20	supraobital_(R)	en-en	y = 0.083979x + 2.6781	0.5880
21	supraobital_(L)	al-al	y = 0.097903x + 1.0674	0.5861
22	infraobital_(R)	cranial height	y = 0.051155x - 2.4011	1.2943
23	infraobital_(L)	cranial height	y = 0.055695x - 2.9922	1.0309
24	zygomatic_arch_(R)	n-rh	y = 0.070673x + 3.49	0.8013
25	zygomatic_arch_(L)	base cranial length (n-ba)	y = -0.049215x + 9.3495	0.7973
26	zygomatic_(R)	base facial length(ba-pr)	y = -0.042995x + 8.556	0.7596
27	zygomatic_(L)	base facial length(ba-pr)	y = -0.051253x + 9.3569	0.8386
28	porion_(R)	bn-bn	y = 0.1512x + 4.5823	3.0310
29	porion_(L)	bn-bn	y = 0.16467x + 4.1336	2.1702
30	gonion_(R)	al-al	y = 0.088104x + 0.53022	0.9684
31	gonion_(L)	nasal projection	y = 0.10235x + 3.5032	0.8845
32	alare_(R)	al-al	y = 0.18611x + 1.0906	1.7071
33	alare_(L)	al-al	y = 0.2063x + 0.33053	1.6000
34	lateral_nasal_(R)	al-al	y = 0.23816x - 2.0783	1.4152
35	lateral_nasal_(L)	al-al	y = 0.2648x - 3.1083	1.3845
36	nose_height	base nose length	y = 0.17297x + 15.4149	3.7506
37	bucal_(R)	bn-bn	y = 0.31662x + 6.9254	12.2240
38	bucal_(L)	bn-bn	y = 0.31206x + 7.0209	12.3088

Comparisons

- **Ten-fold cross validation is used**
- **Linear Regression and Neural Network techniques were implemented**
  - The results are compared with the 'average method' - which is used in most facial reconstruction systems

MSE values for 'average method' (AVG), Linear Regression (LR), and Neural Network (NN). The best performance is in boldface.

N#	OUTPUT	AVG	LR	NN
1	vertex	1.1914	1.0625	**0.8928**
2	trichion	1.2945	1.0877	**1.0664**
3	glabella	1.2074	**1.0110**	1.0706
4	nasion	0.9699	0.7571	**0.7220**
5	rhinion	0.3886	**0.3400**	0.3797
6	pronasale	7.9621	6.0558	**5.2456**
7	nose_length	21.8621	10.8344	**8.7059**
8	subnasale	6.3008	**4.3927**	4.6878
9	upper_lip_border	4.9468	4.3581	**3.7205**
10	lower_lip_border	3.1674	2.7312	**2.4167**
11	stomion	2.2193	1.8766	**1.8168**
12	metal	4.1007	3.4298	**3.3625**
13	meton	2.3685	**1.9901**	2.0885
14	opisthooranion	1.8909	1.5124	**1.1001**
15	exocanthion_(R)	0.7884	**0.6635**	0.7084
16	exocanthion_(L)	0.8609	**0.7121**	0.8459
17	endocanition_(R)	2.5804	2.0950	**1.7213**
18	endocantion_(L)	2.6779	2.0706	**2.0099**
19	pupil-pupil	10.8380	**4.4587**	4.9687
20	supraobital_(R)	0.6689	0.5533	**0.4556**
21	supraobital_(L)	0.6859	0.5340	**0.4986**
22	infraobital_(R)	1.4038	1.2479	**1.0475**
23	infraobital_(L)	1.1147	**0.9573**	1.1920
24	zygomatic_arch_(R)	0.8485	**0.7432**	1.6805
25	zygomatic_arch_(L)	0.8857	**0.7400**	0.7982
26	zygomatic_(R)	0.8326	0.6982	**0.5635**
27	zygomatic_(L)	0.9557	**0.7722**	1.3729
28	porion_(R)	3.3546	**2.7241**	2.9786
29	porion_(L)	2.5552	2.0471	**1.7367**
30	gonion_(R)	1.0521	0.9333	**0.8245**
31	gonion_(L)	0.9360	**0.8330**	1.5443
32	alare_(R)	2.0965	1.6396	**1.5934**
33	alare_(L)	2.0342	1.5304	**1.4494**
34	lateral_nasal_(R)	1.9751	**1.4220**	1.5541
35	lateral_nasal_(L)	2.0908	1.3537	**1.3495**
36	nose_height	4.1012	**3.5995**	4.5687
37	bucal_(R)	13.6992	**11.2034**	12.2837
38	bucal_(L)	13.9451	**11.6959**	11.7598



Conclusions

- **Proposed an approach for automatic discovery of relationships between anthropometric features**
  - Critical in facial reconstruction systems
- **Evaluation results show that the approach has better performance than the 'average method' which is used in most facial reconstruction systems**
- **Although the data is collected from Vietnamese, the study can be applied for any race**
  - Need separate database collected from target race