

Forensic Facial Reconstruction from Skeletal Remains

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Abstract — The identity of a skull in forensic is of critical importance. Forensic facial reconstruction is the reproduction of the lost or unknown facial features of an individual. In this paper, we propose the automation of the reconstruction process. For a given skull, a data-driven 3D generative model of the face is constructed using a database of CT head scans. The reconstruction can be constrained based on prior knowledge of parameters such as bone thickness measurements, cranial landmark distance measurements and demographics (age, weight, height, and BMI). The CT scan slices are segmented and a 3D model skull of 2D slices is generated with the help of Marching Cubes Algorithm. The 66 Landmark points are then calculated using Active Shape Models and PCA algorithm and placed on the skull. These Landmark points act as references for tissue generation. The facial soft tissue thickness is measured and estimated at the 66 craniometric landmarks used in forensic facial reconstruction. The skin mesh is generated using Delaunay automatic triangulation method. The performance of this model is then measured using RSME technique. The aim of this study is to develop a combination of techniques and algorithms to give the most accurate and efficient results.

Keywords — *forensic facial reconstruction; remodeling 3d face; generating 3d face; volume rendering; marching cubes; mesh generation; Delaunay's Triangle*

I. INTRODUCTION

The subject of forensic facial restoration is concerned with the reproduction of the facial features of an individual for the purposes of recognition and identification. At a more scientific level, it is concerned with examining and measuring the thickness and form of the soft tissues to understand how these tissues are spatially related to the underlying skull. So far, this task has been performed by traditional 'plastic' methods, using clay. This process is carried out by artists, who models the soft tissue knowing tissue depth in some landmark points on the skull. Depths elsewhere are interpolated between these points by intuition. This procedure has many disadvantages, an important one amongst which is, that it is an artistic method meaning that the process is subjective. Current computer based reconstruction techniques build the final reconstruction starting from a reference facial model.

Because a standard method for creating three-dimensional forensic facial reconstructions has not been widely agreed upon, multiple methods and techniques are used. We will propose an automated facial reconstruction technique that will generate 3D model of the face. In this project, we will use a combination of techniques to get better and accurate results.

We will propose a system based on non-parametric model that will include to predict the facial tissue depths based on a unique skull input which will lead to more accurate results. The Implementation will be carried out in MATLAB. Data collection for this project requires Computed Tomography (CT) head scans that would be used to compute the facial tissue thicknesses and possible bony structure predictors. A 3D model will be generated with the help of these 2D slices. Then, Landmark points will be placed at 66 craniometrical locations. We are using 66 landmarks to achieve better results. The tissue will be measured at this landmarks based on the parameters such as: age, weight, height, BMI, Bone depth measurements and bone distance measurements. These parameters will help to constrained the automation of the face that will be developed in future. A skin mesh will be generated over the skull to make the face more identifiable. Thus, in this report, we propose a system that will automate the 3D generation of facial reconstruction techniques. The main aim of the study is to obtain best possible and accurate results. The performance of the system will also be evaluated at the end of the project to compare the results obtained.

II. EXISTING MODELS

Number of papers were studied and analyzed. There are several ways to construct a 3d face from skeletal remains and in this paper, we have tried to optimize the existing solutions.

In this technique [1], they have proposed the collection of a CT head scan database for the purposes of creating a face space that is constrained by the shape of an unknown skull. Skin and bone surfaces are extracted from the CT heads cans. Via bone-to-bone registration of the database against the unknown skull, each skin surface becomes an estimate of the unknown face. In this work, the warped skin surfaces along with their age and weight information are represented as structurally identical vectors. This means that vector elements representing semantically identical points such as the tip of the nose and the corners of the eyes will be in correspondence. Principle Component Analysis (PCA) on these skin vectors constitute a face-space tailored to the unknown skull. Prior knowledge such as the estimated age and/or weight of the unknown individual can be used to constraint the face space. For Photo identification, they use landmark approach. Such image landmarks are found using Active Appearance Models(AAM). Projection residuals are then calculated providing a ranking of the missing person image. In the second approach, boosting is used to construct a strong match/no-match classifier.

In this paper [2], two human identification methods have been presented. A graphic application has been developed implementing those techniques. First technique enables to generate the soft tissue of any individual, starting only from the skull and a set of 66 reference points where tissue depth is known. The method consists in generating a great number of intermediate points, where tissue depth is interpolated from tissue thickness in landmark points. This process only comprises projections, normal calculations, arithmetic operations, and finally, triangulation to build the final reconstruction. Moreover, the complexity of the application database is low, as it only consists of a set of soft tissue thickness values in the reference points. These two facts contribute to the low computational cost of the application.

In this technique [4], forensic artists place average facial tissue markers at 21 specific anatomical locations on the skull and use clay to model the face based on the length of the markers. The soft tissue thicknesses or marker lengths used in the forensic facial reconstruction are currently the average tissue depths of various examined cadavers of different ethnicity, whereas this technique uses a non-parametric modeling technique to predict the facial tissue depths based on a unique skull input. This is since a non-parametric empirical technique does not use set parameters to define the model like the parametric modeling technique mentioned above. The non-parametric techniques use the actual training data to understand future predictions and store the training data in a

"memory matrix". Non-parametric methods are easily updated as additional data becomes available by simply appending the new data to the historical database or memory matrix. The tissue and bone measurements were performed using the software package IDAS. Hetero-Associative Kernel Regression (HAKR) and Inferential Kernel Regression models were built using the measurements from the 100 male subjects. The performance of the empirical model was initially judged by comparing the predicted facial tissue depths to the actual known tissue depths for each skull in the database.

III. ENHANCEMENTS TO EXISTING MODELS

Studying several IEEE papers, we analyzed various advantages and disadvantages of methods used in the past systems. Current computer based reconstruction techniques build the final reconstruction starting from a reference facial model. We found that most published computerized techniques use a generic facial template, or a specific best look alike template, based on several subject properties (BMI, gender and age). This reference template is then fitted to the target skull knowing tissue thickness in some landmarks on that skull, and interpolating thickness in between these reference facial points, based on a generic smooth deformation. Finally, they add some extra information to improve the results, such as manual modeling features (nose, eyes, etc.) or a texture simulating the skin. The main problem of these procedures is they focus on human resemblance, instead of reliability: using a specific facial template, unwanted facial features of that template remain visible in the final reconstruction. Besides, applying a generic deformation means a problem when the differences between the reference depth tissue values in landmarks and the reference face thickness are considerably large. On the other hand, the results are not skull specific, but just "smooth".

To solve the previous shortcomings, some techniques use specific deformations over the generic facial template. This deformation is obtained from a reference skull, which is deformed towards the target skull. Then, that deformation is extrapolated and applied to the facial template. Other computer based facial reconstruction proposals instead of starting from a generic facial surface, they build a reference statistical model from a database of 3D scanned real faces. Thus, the problem of unrealistic and unreliable characteristics of the reconstructions is minimized.

All the previous methods and their results are limited, though, in the shape of the reference facial template they use to build the final craniofacial reconstruction: the output results will always contain specific features present in the reference template, which may distort the physical appearance of target person to identify. In addition, those techniques only use the information given by some points on the skull, instead of considering the complete skull surface; this disregards any individual particularity which should affect the final

reconstruction morphology. Moreover, all these techniques require high complexity databases and procedures to perform the final reconstruction. To decrease complexity, and to avoid any unsuitable information which may be introduced by that reference facial surface, and trying to consider as much information as may provide the skull geometry, we propose an alternative computer based craniofacial reconstruction technique, which is not based on a reference facial template. This reconstruction technique has been implemented in an application, which only starts from anthropological information, consisting in statistical soft tissue depth values in a set of points on the skull. Thus, complexity of the application database is considerably reduced.

IV. IMPLEMENTATION

A. Flow of the Model

The block diagram of the proposed system has been represented below and the model can be clearly understood. We will give skull, 66 craniofacial landmark points, demographics value such as input age, weight, BMI as input. The landmark will be calculated based on the parameters discussed and the constrained face will be produced in the face space accordingly. The landmark points will act as reference points for tissue thickness measurement. The tissues will be evaluated and stored in a table and the values will be inserted at a landmark point on a skull referring to the table. A skin mesh will be generated using automated triangulation approach. The skull will be deformed and skin will be warped using the triangulation approach since it has proven to be effective in the past.

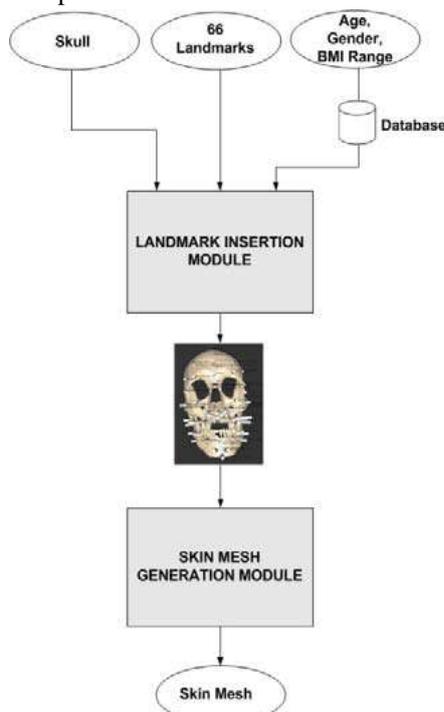


Figure 1. Proposed system of automated facial reconstruction technique

B. Collection and processing of CT scan database:

Data collection for this project required Computed Tomography (CT) scans that would be used to compute the facial tissue thicknesses and possible bony structure predictors for the non-parametric kernel regression model. We will collect 200-250 sample of CT scans for the database and will identify weight, height, age, bone depth measurement, bone distance measurement of each CT scan. The CT scans will first be processed and basic image processing operations will be applied on it. After this, the important part comes where the bone structure must be separated or segmented from the rest of the facial tissue using Marching cubes algorithm. Segmentation is the process of separating the cranium and mandible bone from the surrounding facial soft tissue. The segmentation process creates a surface model of the cranium and mandible. Then a 3D model will be generated of the segmented skull using the same Marching Cubes algorithm. Also, various other aspects will be processed and taken into consideration such as the size of the CT scan slices, the threshold values for marching cubes algorithm during the implementation.

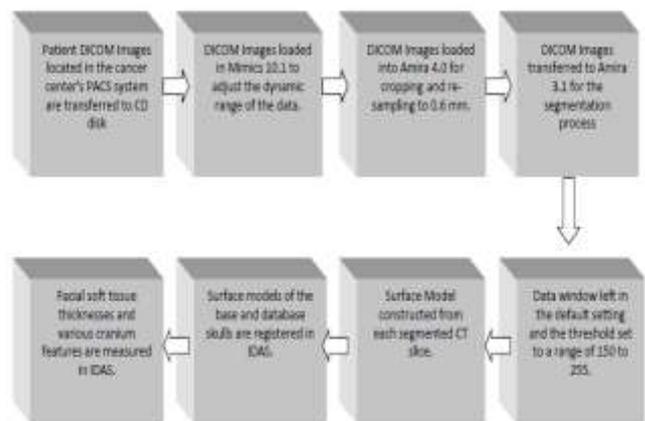


Figure 2. Detailed diagram of DICOM segmentation and processing

C. Landmark Insertion:

The Landmark Insertion consists placing 66 reference points on the skull surface, and assigning them a tissue depth value, based on a set of parameters of the person: age, gender and BMI range. In the automatic procedure, all the landmarks will be placed automatically on the image. In order to perform that task, the skull 3D image is projected on the front, right and left planes, and landmark positions are calculated into these projection planes, since those positions are quasi invariant in every skull. We will use Active Shape Models and Principle Component Analysis (PCA) to automatically calculate the various landmark positions on the input skull with the help of a reference model. Once all points have been placed on the projected images, an inverse transformation is

applied over them to recover the whole 3D image, with all the landmarks placed on it.

The segmented skull and the 3d model is then processed and landmarks are calculated and placed on them. The landmarks are measured using PCA and Active Shape models.

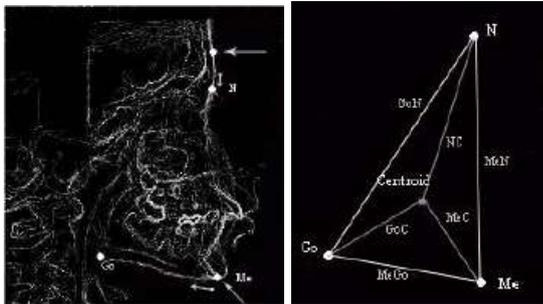


Figure 3. Landmark detection and calculation using Active Shape Models

D. Tissue Generation:

Once all reference points have been placed on the skull 3D image, tissue thickness is assigned to each one, as per the age, gender, BMI range, Bone depth measurements and bone distance measurements parameters previously introduced. The tissue thickness measured for the given datasets is included in the database and a table is generated of all the values. To ensure the most accurate measurements possible, about 20-40 points are picked at each location. This will allow for an average tissue thickness and bone thickness to be calculated from the 20-40 points for a single location on the skull. The tissue thickness is the distance in centimeters from the point picked on the model's surface along the profile line until the pixel value in the DICOMs drops to zero, which is equivalent to air. The soft tissue depths are set out starting from the landmarks on the skin surface perpendicular to the skin surface.

After the landmarks, have been identified and placed on the skull, a database of tissue thickness measurements is included. Based on these values the tissue thickness and the parameters is calculated and an average is computed of the values measure ay 20-40 locations.

Table 1. List of measures (in cm.) taken in 7 skulls and reconstructions.

Individual	Distance 1-10 (facial length)			Distance 23-44 (bizygomatic breadth)		
	Skull	20<BMI<25	BMI>25	Skull	20<BMI<25	BMI>25
25-year-old man	15.19	15.85	15.9	10.99	13.65	14.06
34-year-old man	16.18	17.17	17.26	11.64	13.24	13.85
39-year-old man	15.29	16.27	16.39	12.21	13.85	14.67
45-year-old woman	14.09	15.06	15.15	11.22	13.21	13.57
53-year-old man	15.42	16.62	16.9	12.2	14.25	14.59
73-year-old woman	14.18	15.37	16.45	11.9	13.65	13.87
75-year-old woman	14.51	16.62	16.7	11.15	12.96	13.24

Figure 4. Tissue thickness measurement Indexes

E. Skin Mesh Generation

The Skin Mesh Generation Module (SMGM) represents the main functional module in the 3D Reconstruction application here presented. From output data generated in LIM, it manages to construct a full 3D mesh representing soft tissue (skin) belonging to the skull. The general aim of this module is to generate a set of intermediate points on the skull surface, whose depth values can be interpolated from thickness values in reference points.

The whole set of points (landmarks and intermediate points) will integrate the final skin mesh. For this purpose, the module receives the set of 66 reference points (their positions and depths), and determines new tissue thickness values in each intermediate point, attending to its location (closeness to the rest of landmarks). For this reason, the presented craniofacial reconstruction technique considers all the information contained in the skull geometry, not only soft tissue thickness in the landmark points.

Therefore, the main functions participating in the whole process are the intermediate point generation and projection, the interpolation of intermediate depths and normal, and the soft tissue mesh generation. In the subsequent subsections, these four processes will be analyzed.

a) Intermediate Points Generation

First step in skin mesh generation process is the creation of a set of new intermediate points, which will integrate the resulting final mesh. Those new intermediate points are created by using a new triangulation (transparent to the user). In a further process, those new generated points will be projected towards the skull geometry, so that new tissue depth can be obtained on them. Therefore, the whole process of intermediate point generation comprises two main tasks: the construction of the reference triangle network, and the creation of the new intermediate points in those reference triangles. First task is carried out from the 66landmarks positions. Then, a manual triangulation is performed, to optimize the number of resulting triangles, and their shape and distribution. Fig. 5 illustrates the definition of the reference triangle network.

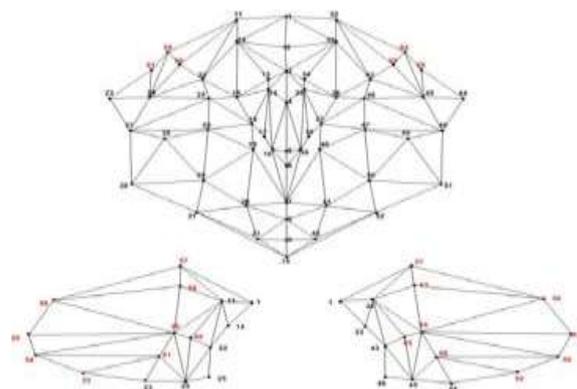


Figure 5. Triangle Network

b) *Intermediate Points Projection*

Once a set of numerous intermediate points has been generated, next step is to project all those points on the skull surface, to obtain a set of intermediate points where soft tissue depth can be added. Projection process is different depending on the location of the intermediate point to be projected. Based on this fact, two types of projections are performed: projection of points inside a reference triangle, and projection of points in a triangle edge. Projection of intermediate points located inside a reference triangle is performed using the normal vector of that triangle.

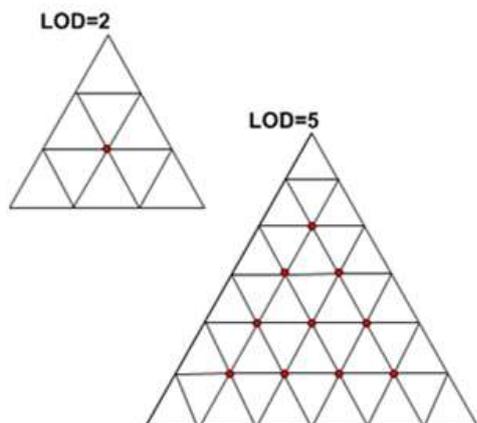


Figure 6. Examples of inner triangle subdivision

c) *Intermediate Depth and Normal Interpolation*

In the previous step, a set of intermediate points on the skull surface were calculated. Next task is to calculate their tissue depth values to obtain the final set of points which will integrate the skin mesh.

d) *Mesh Generation*

Once the set of intermediate tissue points has been generated (from the original 66landmarks), the next step is to build a 3D mesh from both sets of points. Considering that the final number of points is greater than 11000, an automatic triangulation algorithm is required. For this purpose, a Delaunay triangulation has been implemented.

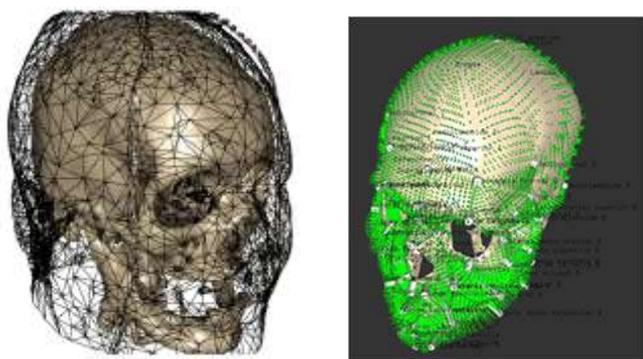


Figure 7. Triangular Mesh Generation over a skull

V. PERFORMANCE ANALYSIS

To measure the performance of the models' ability, two metrics are used. The first, model RMSE, is a root mean squared error of the model's predictions and the actual measured tissue thicknesses. The second, Table RMSE, is a root mean squared error of the model's actual tissue thicknesses in its memory matrix and the obese tabled tissue thicknesses used in current forensic facial reconstructions. The obese tabled values were used due to most the subjects in the model's database are overweight to obese in stature. The similarity metric used is simply the average of the maximum kernel weights computed for the query input. The closer the value is to 1 the more similar the query is to a skull in the memory matrix. The model's prediction uncertainty was also computed. It is shown as a percentage of the prediction values. The metrics displayed in the result tables are the average for the LOOCV that was performed.

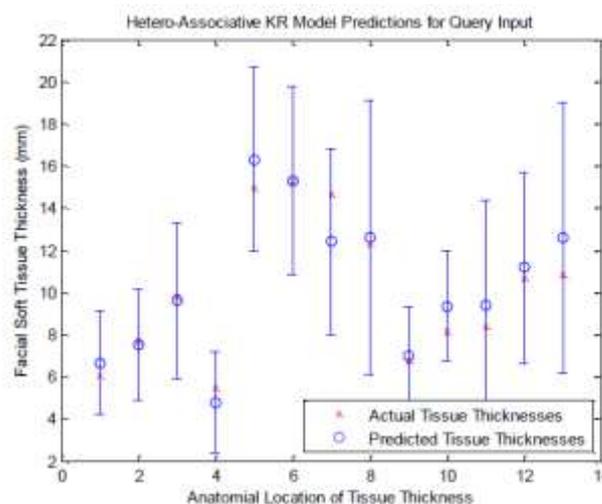


Figure 8. RSME techniques to test the models' ability.

VI. CONCLUSION

We must hence have implemented the plan proposed above by the end of this project. We researched on various techniques in this field heavily, and realised the best possible combination of algorithms for accurate results. We successfully understood the slicing in Marching Cubes to make the skull a 3D structure, we used Principle Component Analysis to draw a mean for a better landmark location. We used Active Shape Models based on the principle component axis and adjusted the template to the input skull that will yield us landmark locations. The landmark locations will further build tissue structure by using averaging and training data sets. We will smoothen the surface by using Delaunay Triangulation Method and warp the skin mesh on the given landmark points as per tissue structure.

We however did not delve deep into detailing due to time and scope constraints. We hope that this project will be further worked upon making the faces more recognisable in a human

perspective by addition of extra features like eyebrows, hair, eyes, etc. These features help in facial recognition substantially.

Scope

This project is vast and expansive. We must ensure that we don't climb the requirement creep by setting well defined boundaries in the initial stage itself. Part of the reason as to why we went through so much literature rigorously was that we wanted to have an absolute plan in place so that we meet the deadlines assigned to us. We will stick to the above-mentioned plan and only follow through as many major algorithms. We plan to improve upon the existing research by trying the best possible combination of different stages of facial reconstruction.

- We will limit our accuracy towards the last stages.
- We will focus mainly on tissue thickness, landmark structure and mesh warping.
- We will not get carried away with excess of detailing for better feature recognition.

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