Landmark-based 3D Mesh Warping for bone-skin reconstruction

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ABSTRACT

This paper proposes a mathematical model to obtain a portion of the skin of a human head, warping the corresponding portion of neurocranium, using the skin thickness in the craneometrical points that defines the portion of neurocranium and the mesh of the skull contents in the triangle defined by this craneometrical points.

Keywords : warping, mesh, skull, facial, reconstruction, landmark.

INTRODUCTION

The bony remainders of the skull, are carriers of information that must be deciphered and translated to the language of numbers. Facial reconstruction methodologies have been developed in the last two decades [Cal86], [Geo93], [Leb93] and have been listed by [Tyr97].

Some specialist in this field consider that the researches undertaken up to now have not been sufficient concerning facial reconstruction techniques [Tyr97]. But the use of computerized tools to solve this kind problem is a fact in forensic sciences [Evi96].

Facial reconstruction softwares for identification purposes have been developed by [Van89], [Ube92], [Miy95], [Sei96], [Sha96]. There are different kind of solutions using computational geometry techniques, based on: deformable templates [Dea96], [Qua95], radial basis functions [Sei96a], volume distortion using disk fields, [Mic97] and hierarchical B-Splines [Arc97].

Most of these solutions starts on the consideration that it is possible to define a "standard" skull and "standard" face. But in our case it is impossible to define them because of the great admixture of the cuban population. So the main consideration of our solution is that we can't have "standard" data to solve the reconstruction problem for this kind of populations.

We postulated a mathematical model, based on [Leb93], in order to obtain a portion of the surface of the skin warping the corresponding portion of the surface of the skull [Plas96].

MATHEMATICAL MODEL

In order to postulate the mathematical model of the transformation bone-skin, let be three craneometrical points C_i, C_j, C_k , three normal vectors N_i, N_j, N_k, to each of them, the skin thickness in normal direction in each of them δ_i, δ_j, δ_k, and a set $\mathbf{P}$ of m points of the cranium contents in the triangle formed by C_i, C_j, C_k. Let be the triangulation $\mathbf{T} \subset \mathbf{P}^n$ where $h_r = (p_u, p_v, p_w)$, $h_r \in \mathbf{T}$, and $p_u, p_v, p_w \in \mathbf{P}$ and $u, v, w \in [1,m]$.

Then:

$P = (p_1, p_2, p_3., p_m)$ where $p_i = (x_i, y_i, z_i)$

$C_i = (x^c_i, y^c_i, z^c_i)$ $N_i = (x^n_i, y^n_i, z^n_i)$
$C_j = (x^c_j, y^c_j, z^c_j)$ $N_i = (x^n_j, y^n_j, z^n_j)$
$C_k = (x^c_k, y^c_k, z^c_k)$ $N_k = (x^n_k, y^n_k, z^n_k)$

Let the triangle $h_c = (C_i, C_j, C_k)$ be. We have to warp all the elements of **P** to obtain an image set:

$$P^* = (p^*_1, p^*_2 , p^*_3,..., p^*_m)$$

$$\text{where } p^*_i = (x^*_i , y^*_i , z^*_i)$$

and the warped mesh of triangles T^*

Let the function be:

$$\delta_s = f (C_i, C_j, C_k, N_i, N_j, N_k, \delta_i, \delta_j, \delta_k, p_s, n)$$

where δ_s is the skin thickness in $p_s \in$ **P** and n is the normal vector to p_s.

$p_s = (x_s, y_s, z_s)$ $n = (n_x, n_y, n_z)$

After applying a bilineal interpolation that is (showed in figure 1) we obtain these formulas:

$$t_q = (y_p-y_j)/(y_i-y_j) \quad \text{(i)}$$

$$t_r = (y_p-y_k)/(y_i-y_k) \quad \text{(ii)}$$

$$t_p = (x_p-x_q)/(x_r-x_q) \quad \text{(iii)}$$

substituting (i) and (ii) in (iii) we have

$$t_p = A/(B+C)$$

Where

$$A = x_s-[x^c_j+(y_s-y^c_j)(x^c_i-x^c_j)/(y^c_i-y^c_j)]$$

$$B = [x^c_k+(y_s-y^c_k)(x^c_i-x^c_k)/(y^c_i-y^c_k)]$$

$$C = [x^c_j+(y_s-y^c_j)(x^c_i-x^c_j)/(y^c_i-y^c_j)]$$

then, in order to get the skin thickness in p_s

$$\delta_s = \delta_i [t_q(1-t_p) + t_r t_p] + \delta_j [(1-t_q)(1-t_p)] + \delta_k [t_p(1-t_r)]$$

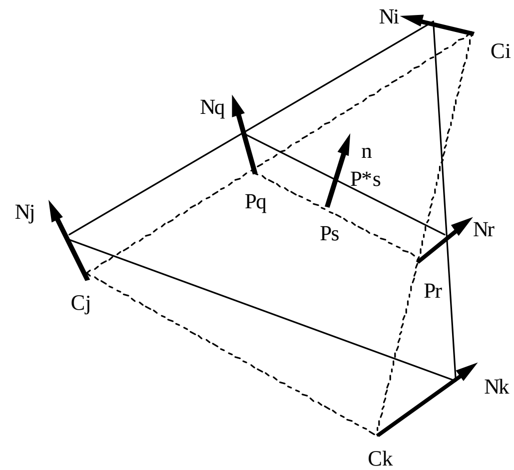

Fig1. Warping process.

After obtaining δ_s, and in order to get the coordinates of p^* we applied :

$$x^*_s = x_s + \delta_s n_x$$

$$y^*_s = y_s + \delta_s n_y$$

$$z^*_s = z_s + \delta_s n_z$$

In this way we obtain p^*, and it is a point of the surface of the face that guarantees that the surface is acceptable according to [Fuc77] since only they have modified the x, y, z coordinates, and didn't get hold of their normal vectors and their connections in the mesh of triangles T so we can obtain T^*.

RESULTS

Using a computerized tool to model the skull [Pla96] based on the mathematical model that we describe in this paper, we have obtained the results shown in figures 2,3 and 4.

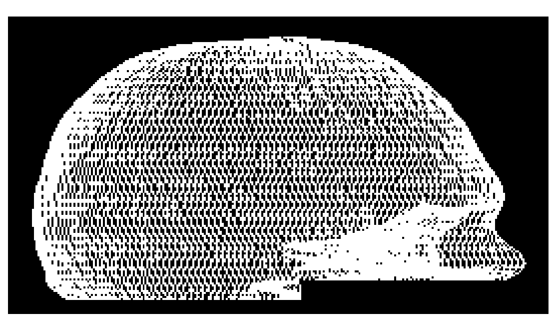

Fig 2. Mesh of the Neurocranium.

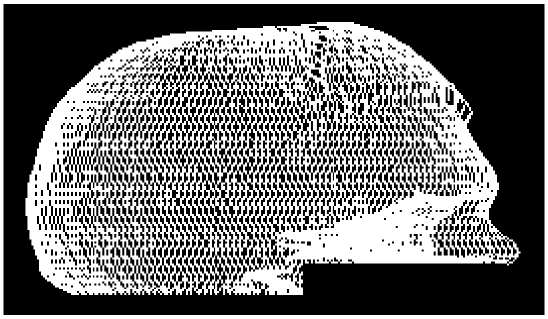

Fig 3. Warped mesh of the Neurocranium.

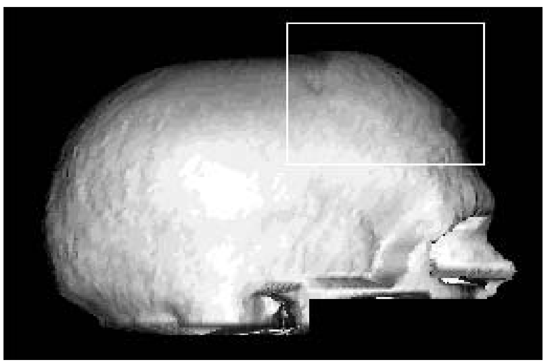

Fig 4. Portion of the skin-covered neurocranium (the skin thicknesses were triplicated in this image in order to achieve a better visual effect.)

To obtain this example was used triad of craneometrical points: Bregma, Metopio and Estefanio.

4.CONCLUTIONS

We have presented a mathematical model for landmark-based 3D mesh warping for skull-based face reconstruction. We have postulated the model based on the methodology [Leb93] accomplishing the conditions of acceptability stated by [Fuc77]. The model is applicable to warp any type of surface that fulfill the following conditions:

1. The starting surface is defined by a mesh of triangles and it's acceptable according to [Fuc77].
2. The behavior of the resulting surface in a number of characteristic points (that is to say the variation of the coordinates in normal direction to each one of them) is known.

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