CALCULATION OF ASYMMETRY PARAMETERS FOR LATTICE BASED FACIAL MODELS

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Abstract—Construction of human like avatars is a key to produce realistic animation in virtual reality environments and has been a commonplace in present day applications. However most of the models proposed to date intuitively assume human face as a symmetric entity. Such assumptions produce unfavorable drawbacks in applications where the analysis and estimation of facial deformation patterns play a major role. Thus in this work we propose an approach to define asymmetry parameters of facial expressions and a method to evaluate them. The proposed method is based on capturing facial expressions in three-dimension by using a rangefinder system. Three-dimensional range data acquired by the sy6 tem are analyzed by adapting a generic LATTICE with facial topology. The asymmetry parameters are defined based on the elements of the generic mash and evaluated for facial expressions of normal subjects and patients with facial nerve paralysis disorders. The proposed system can be used to store asymmetric details of expressions and well fitted to remote doctor-patient environments.

Keywords- Generic 3d models, morphing, animation, texture etc.

I. INTRODUCTION

The construction of facial models that interpret human like behaviors date back to 1970’s, where Parke [1] introduced first known “realistic” CG animation model to move facial parts to mimic human-like expressions. Since then, a noticeable interest in producing virtual realistic facial models with different levels of sophistication has been seen in the areas of animation industry, tele-communication, identification and medical related areas etc. However, most of these models have inherently assumed that the human face as a symmetric entity. The relevance and the importance of defining asymmetric properties of facial models can be illustrated in many application areas. In this study, its relevance in the field of Otorhinolaryngology in Medicine is illustrated. A major requirement in such an application is to construct robust facial parameters that determine the asymmetric deformation patterns in expressions of patients with facial nerve paralysis disorders. These parameters can be used to estimate the level deformation in different facial parts, as well as to transmit and receive at the ends of remote doctor-patient environments.

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Yukio Sat0 Dept. of Electrical and Computer Engineering Nagoya Institute of Technology Many attempts have been made in the past by researches to develop systems to analyze and represent the levels of facial motion dysfunction in expressions. Pioneering work of Neely et al. [2] reported a method to analyze the movement dysfunction in the paretic side of a face by capturing expressions with 2D video frames. Selected frames of expressions are subtracted from the similar frames captured at the rest condition with image subtraction techniques. Similarly, most of other attempts proposed to date are based on 2D intensity images and they inherently possess the drawbacks associated with inconstant lighting in the environment, change of skin colors etc. To eliminate these drawbacks, use of 3D models is observed to be of commonplace. Although there are many techniques available today for the construction of 3D models, a laser-scanned method that accurately produces high-density range data is used here to acquire 3D facial data of expressions. Construction of 3D models from scanned data can he done by approximating measured surface by continuous or discrete techniques. The continuous forms, such as spline curve approximations can be found in some previous animation works [3], 141. A great disadvantage in these approaches is the inevitable loss of subtle information of facial surface during the approximation. To make it more realistic and preserve the subtle information, there must be intensive computations, in the way of introducing more control points, which makes it difficult to implement in analysis stages. On contrary, LATTICE based methods make it less complicated to implement and widely used in modeling tasks. Thus the approach proposed here adheres to LATTICE based 3D facial models in deriving asymmetry parameters.

2. CONSTRUCTION OF 3D MODEL

Predesigned facial actions are measured hy a rangefinder system [5], which produces &bit 512 x 242 resolution frontal range images and color texture images. A symmetric generic face LATTICE with triangular patches is adapted to each of these range images to produce 3D models to he used in asymmetry estimations.
The LATTICE adaptation is a tedious and time consuming process if it involves segmentation of range images to extract feature points for mapping. Instead, here we resort to a much simpler approach by extracting feature points from the texture images since both range and texture images captured by this system have one-to-one correspondence. Forty-two evenly distributed feature points are selected as mapping points, of which the corresponding LATTICE locations are predetermined. We then calculate the displacements between these feature points and corresponding LATTICE locations. The least squares approximation method is used to fit the face LATTICE to the feature points, by minimizing the displacements between mapping points. We use a polynomial of degree N, shown in Eq. (1) as the mapping function \( f(x,y) \) of the least squares estimation.

\[
f(x, y) = a_{00} + \sum_{j=1}^{N} \sum_{i=0}^{J} (a_{j-i}, x^i y^j) \tag{1}
\]

Thus, 3D model construction for each facial action consists of following steps.

- Extract 42 feature points from the color image, whose corresponding mapping nodes on the generic face LATTICE are known.
- Calculate the displacement vectors between the mapping points and the feature points.
- Apply the polynomial function in Eq. (1) with order \( N = 2 \) for initial mapping and calculate the coefficients \( a_{00}, \ldots, a_{0z} \) by minimizing the error term of the least squares estimator for the best fit.
- Once evaluating the second order mapping function [Eq. (1)] with the coefficients \( a_{00}, \ldots, a_{0z} \) map all other points accordingly.
- Calculate the error term of the least squares estimator for all these points and compare it with a pre-defined threshold value.
- If the fitting error exceeds the threshold value, increase the order of the polynomial (N) and repeat the fitting process by evaluating new coefficients.

Thus, once the fitting error lies within a satisfactory margin of the threshold value, depth values from the corresponding range images are mapped to the vertices of the face LATTICE to produce a 3D model of the measured expression 161. Constructed 3D models of a patient with Bell’s palsy are depicted in Fig.1 with eyelid closure and grin facial expressions.

### 3. ESTIMATION OF DEFORMATION ASYMMETRY

The facial deformations during expressions are calculated based on the 3D models generated for each expression as described in previous section. Since facial expressions do modifications to the facial surface at rest, 30 models we generated also reflect these deformations in their constituent triangular patches. To estimate these deformations, we implement the 3D LATTICE model as a LATTICE of connected linear springs. Suppose a particular patch in the left side consist of three springs with their gained lengths at the rest condition, from the equilibrium as \( C_{L1}, C_{L2} \), and \( L < r, \) respectively (Fig. 2).

Thus, the energy stored in the patch at the rest condition is,

\[
E_{Lrest} = \frac{1}{2} k \sum_{i=1}^{3} \xi_i^2. \tag{2}
\]

Where \( IC \) is the spring constant identical to all springs. Suppose during an expression this patch deforms to a new state with each edge modifying to lengths **...**
and respectively. Thus the change of energy from the rest condition can be stated as,

\[ \Delta E_L = \frac{1}{2} k \sum_{i=1}^{3} ||\xi_L i - \xi'_L i||^2. \]  

(3)

Similarly, the energy change of its mirror patch in the right side can be stated as. Thus, if we let

\[ \Delta E_R = \frac{1}{2} k \sum_{i=1}^{3} ||\xi_R i - \xi'_R i||^2. \]  

(4)

Thus, if we let

\[ \omega_L^2 = \sum_{i=1}^{3} ||\xi_L i - \xi'_L i||^2 \]  

(5)

and

\[ \omega_R^2 = \sum_{i=1}^{3} ||\xi_R i - \xi'_R i||^2, \]  

(6)

as deformations of left and right sides respectively, from Eq. (3) and Eq. (4) we can deduce \( \text{AEL} = k \omega_L \) and \( \text{AER} = k \omega_R \). Ignoring constant parts, \( \text{WL} \) and \( \text{WR} \) can be considered as candidate parameters to describe the deformation of the triangular patches.

4 ESTIMATION OF ORIENTATION ASYMMETRY

Apart from the measure of asymmetry in deformations, locally to the patches, another factor that contributes to the asymmetry is global orientation of patches in both sides even when they have identical deformations. Suppose a particular patch in the left side has the orientation \( \text{PL} \) in the rest condition. It changes the orientation to \( \text{PL} \) during an expression. The change in orientation during the expression can be estimated by considering the following transformations.

- Let the center of gravity of both patches PL and PL’ be GL and GL’ respectively
- Let NL and NL’ denote the surface normal vectors of patches PL and PL’
- Translate GL and GL to the origin, so that they coincide with each other
- Align surface normal vectors NL and NL along the Z-axis so as to make the patches co-planer with the XY-plane
- Calculate the direction vectors \( r_1 \) and \( r_2 \) from the center of the gravity of each patch to a similar vertex.
- 8 Rotate the patch in XY-plane so that \( r_1 \) and \( r_2 \) coincide with X axis.

This transformation scenario is depicted in Fig.3. Thus, resulting transformation can be expressed as,

\[ T_L R_L R_{LL} = T'_L R'_L R'_{LL}. \]  

(7)

We can now define the transformation parameter for the left side patches as,

\[ \sigma_L = T_L R_L R_{LL} - T'_L R'_L R'_{LL}. \]  

(8)

Similarly, the transformation parameter for the right side can be derived as,

\[ T_R R_R R_{RR} = T'_R R'_R R'_{RR}. \]

(9)

Therefore the composite orientation parameter can be stated as,
\[ \sigma = \| \sigma_L - \sigma_R \|. \] (10)

For identical orientations of left and right side patches, \( u = 0 \). For the patches with little or no deformation during expressions compared to the rest condition, TLNTL, TRZTt, RLER, and RLLSR. Therefore, \( U_L = U_R = 0 \). Thus the orientation asymmetry can be estimated for all the patches in left and right sides. Let \( \eta \) be the composite asymmetry parameter, where, \( \eta = \sigma + \sigma' \). Evaluating \( \eta \) for left and right side patches of different expressions give a measure of asymmetric deformation in different expressions.

5. RESULTS

In this work we measured patients as well as normal subjects to assess the reliability of estimation. Five facial expressions, namely, eye closure, lines on the forehead, sniff, grin and lip purse are measured. In each case, frontal range and texture images are obtained by the rangefinder system. Then we construct 3D models of the expressions as described in section 2. Once the 3D LATTICE models are generated, surface deformations are estimated for each facial action as described in section 3. To calculate the composite deformation asymmetries, orientation of the patches in 3D space is evaluated as described in section 4. Here we present the results of eye closure and grin actions of two subjects, one is a normal subject with no apparent expression asymmetries and the other is a patient with Bell's paralysis. Surface deformation and 3D orientation estimations are done for the left and right sides separately. The composite asymmetry \( \eta \) is calculated for each patch in the left and right sides. For the left side patches \( \eta_L = W_L + U_L \) and for the right side patches \( \eta_R = W_R + U_E \) is evaluated. For ideally symmetric deformations, the correlation between \( \eta \) and \( \eta' \) should confirm to a straight line of \( y = mz \) type. The Fig. 4 and Fig. 5 depict the respective correlations of the eye-closure and e-r in actions of the normal subject. Similarly, Fig. 6 and Fig. 7 depict the eyelid closure and grin actions of a patient with facial paralysis. Table 1 and Table 2 summarize the mean and standard deviation of \( \eta_L \) and \( \eta_R \) for normal and patient subjects in eye closure and grin actions respectively.

6. SUMMARY

In this work we have presented an approach to estimate the asymmetric deformations in facial expressions in 3D. By analyzing the correlations of asymmetry in left and right sides of the normal subject and the patient, we can confirm that the patient has paralysis in the right side in both facial actions. His distributions in both expressions lean towards the X-axis (left side) since that side produce most of the movements during expressions. Therefore with two proposed parameters \( w \) and \( U \) we have shown that it is possible to encode the asymmetric properties of facial expressions. Although the proposed method is illustrated on a triangular patch based model, it does not impose constraints on the underline LATTICE structure. Thus it can be readily applied on different LATTICE topologies.

REFERENCES


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