ALGORITHM FOR FACIAL WEIGHT-CHANGE

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ABSTRACT

A facial weight-change simulator is presented. It is intended for use in the evaluation of self-perception distortion of Anorexia Nervosa (AN) patients. Processing begins with the extraction of the face from the background. Using minimal user intervention, the face is then divided into regions characterized by different weight-change patterns. A mathematical transformation that models growth and shape modification in living organisms is applied to each region. Finally, a unified color face image is generated, in which the face appears fatter or thinner as intended.

1. INTRODUCTION

Modifying a face image to show the person fatter or thinner is a significant challenge. A successful facial weight-change simulator has to present convincing weight-change while maintaining the natural appearance of the face. Potential applications domains for a facial weight-change simulator include the beauty industry, security and police work. Our motivation is medical, namely the search for better ways to diagnose, evaluate and treat various eating disorders, especially Anorexia Nervosa (AN). AN is a life-threatening psychiatric disorder. It is characterized by low body weight, an intensive fear of gaining weight, and an inaccurate perception of body weight or shape. The distorted perception of one's own body weight or shape, known as *body-image distortion*, is one of the major diagnostic criteria of AN, and is also indicative of changes during treatment.

Two state of the art measurement methods for body image distortion are described in Benson *et al* [1] and Harari *et al* [5]. Despite significant differences, they share important characteristics. In both methods, the subjects wear uniformly colored close-fitting leotards. Their image is taken in a standard posture with uniform dark background. With some level of operator intervention, the body is extracted and segmented to body parts. Each body part is fattened or thinned and a unified image is finally displayed. The subjects adjust their image, or select an image from a set, that corresponds to their own body-image perception. However, full-body photography while wearing leotards is emotionally-demanding for eating-disorders patients. Furthermore, the need for a dressing room, supplied with clean leotards of various sizes, can be a burden.

Face images are easy to take. The logistic requirements are trivial, and the experience should be acceptable even for eating disorders patients. There are indications in the literature that perceptual distortion of the face in anorexia nervosa patients exists [6]. This gives hope that, given a good facial weight-change simulator, diagnosis of anorexia nervosa via face images could be accomplished. The purpose of this research is the creation of a fast and easy-to-operate facial weight-change simulator, that will be able to create natural-looking versions of a given face image, fattened or thinned to the level required.

In [1] and [5], fattening and thinning of the whole body are done by parts, but the face is left unchanged. One possible reason is that virtual fattening or thinning of the face, in a visible but natural-looking way, using modest computing resources and with minimal operator intervention, was simply not available and did not seem feasible.

A versatile technique for 3D face synthesis was introduced in [2]. Based on hundreds of 3D face scans, a morphable 3D face model was built. By manual labeling of the database, facial attributes (such as weight) were mapped to the parameter space of the morphable face model. Given a new 2D face image, the morphable 3D model is matched to the image (by optimizing the model parameters for similarity between the image and a 2D rendering of the model). From that point, the 3D model can be morphed with respect to any facial attribute, and a modified 2D image can be obtained by rendering. This remarkable method is capable of weight-change simulation. However, from the specific perspective of an eating disorders clinic, the system has several undesirable features. One is the computing time and computational resources needed. Another is that the hair is excluded or has to be replaced by a hat or by a standard hair style. Finally, 3D reconstruction from a 2D image is essentially ill-posed. This may lead to results that, while adequate for people who have only seen an anonymous 2D source image, may not be acceptable to a patient viewing her own image.

2. FACIAL WEIGHT-CHANGE SIMULATION

The shape of the face is determined by the skull and by soft tissues. In the upper part of the face, in the forehead and around the eyes, the soft tissue is thin, and the shape is essentially determined by the skull. The position of the chin is determined by the jaw. The shape of the nose is also largely determined by bone and cartilaginous structures. The effect of fattening and thinning is thus mostly in the cheeks and in the upper neck. In this research, weight change simulation is applied to frontal face images, and performed in the two dimensional image plane itself. The cheeks and the upper neck are first extracted. They are fattened or thinned as necessary, based on a mathematical model of biological shape change [3]. They are then recombined with the face, taking care to preserve the natural appearance and global characteristics of the face. In the rest of this section, the method is presented in detail.

2.1. Image acquisition and preprocessing

Frontal-view 640×480 face images are captured using a digital camera (Sony MVC-FD91). To facilitate accurate face extraction, a uniform matte blue screen is used as background. The face is positioned at the center of the image, and the subject is requested to maintain a neutral facial expression.

The first task is to isolate the face from the background. Since any error in the extraction process might be amplified in the weight-change stage, sharp and precise segmentation is necessary. The known structure of the image allows to adapt the face extraction process to variations in the screen color and illumination. Pixels near the top and side borders of the image are assumed to belong to the background. A sample of of these pixels is collected, and referred to as the background-set. All other pixels in the image are classified as belonging to the background or the face by thresholding their Mahalanobis distance to the background-set. This yields a binary mask for preliminary face extraction.

The binary mask successfully removes the background and maintains the face-pixels. The result, however, is not yet adequate, since the edges of the extracted face are quite jagged. In order to eliminate the serration, a 5×5 blur kernel is applied to a gray-level version of the preliminary face extraction result. The blurred image is thresholded to produce a second binary mask. Applying this mask to the original image yields sharp and accurate face extraction. At this stage the actual background is replaced by synthetic background of similar color.

2.2. Weight-change simulation

The effect of weight-gain or loss on facial features is most noticeable in the cheeks and neck, and is quite insignificant in the rest of the face. The weight-change simulation is initially applied to each of the cheeks and the neck separately. Then the whole weight-modified face is integrated.

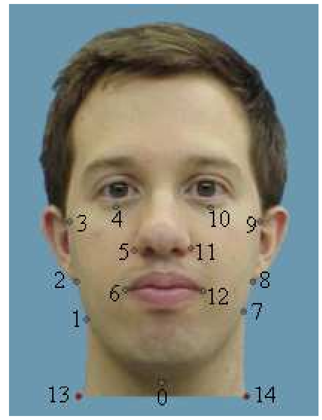

Figure 1: User-provided landmarks.

2.2.1. Obtaining face-part outlines

The suggested facial weight-change algorithm follows Bookstein's shape change model [3]. The basic assumption is that the correspondence between an original and modified body part is strictly defined by their boundaries. The outlines of the cheeks and neck in the original image must be therefore extracted.

First, the user points at thirteen landmarks on the isolated face image (points 0-12 in Fig. 1); then, two additional points (13 and 14) on the neck outline are calculated. This modest manual intervention is a compromise between the goal of fully automatic operation, and the need for uncompromised accuracy and reliability. Manual labeling of a much larger number (up to hundreds) of feature points, is required in other applications, see e.g. [2].

As shown in Fig. 1, the neck area is determined by the points $\{1, 0, 7, 13, 14\}$. The outline is approximated by straight line segments between points $\{1, 13\}$, $\{7, 14\}$ and $\{13, 14\}$, and by a parabola between points $\{1, 0, 7\}$ (Fig. 2-left).

The extraction of the cheeks is slightly more delicate. Maintaining the notations of Fig. 1, the left and right cheeks are respectively determined by the points $\{1, 2, 3, 4, 5, 6\}$ and $\{7, 8, 9, 10, 11, 12\}$. The contours of the cheeks are obtained by connecting each pair of neighboring points by a linear segment, with an exception. The contours connecting points $\{1, 2\}$ in the left cheek, and points $\{7, 8\}$ in the right cheek, that will be referred to as the cheek-lines, play a critical role in the weight-change simulation and must be precisely represented. Thus, between those two pairs of points, all pixels along the edge of the extracted face mask are included. See Fig. 2-right.

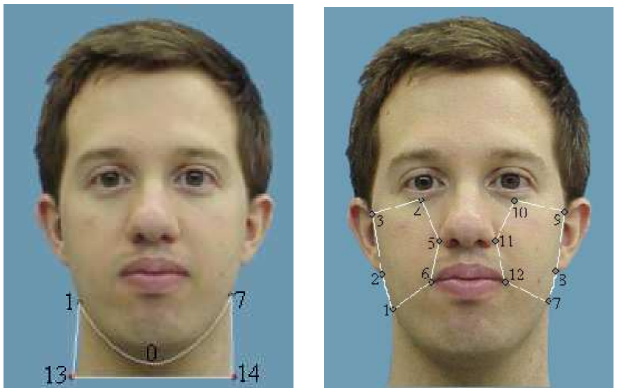

Figure 2: The approximate outlines of the neck (left) and the cheeks (right).

2.2.2. *Transforming the face-part outlines*

Following the previous stage, the outline of each cheek is represented by six landmarks provided by the user and (say, N) additional points along the cheek-line. The outline of the neck is represented by the four user-provided landmarks. Using Bookstein's shape change model requires pairs of corresponding landmarks on the outlines of the original and modified shapes. We therefore compute $N+6$ homologous points for each cheek and 5 homologous points for the neck.

Consider first the left cheek; the treatment of the right cheek is symmetric. Let $\{\mathbf{p}^c(i)\}_{i=1}^{6}$ denote the cheek landmarks $\{1,2,3,4,5,6\}$. The 2D coordinates of each point $\mathbf{p}^c(i)$ are $p_x^c(i)$ and $p_y^c(i)$. The N additional cheek-line points are denoted $\{\mathbf{p}^c(i)\}_{i=7}^{N+6}$. A reference point $\mathbf{c}_0$ is set to be the centroid of the six user-provided landmarks.

The transformation between the original and modified cheek outlines is defined by stretching or shortening the vectors connecting the reference point to the landmarks on the boundary of the cheek. Given the points $\{\mathbf{p}^c(i)\}_{i=1}^{N+6}$ on the outline of the original cheek, the homologous points $\{\mathbf{q}^c(i)\}_{i=1}^{N+6}$ in the modified cheek outline are given by

$$\mathbf{q}^{\mathbf{c}}(i) = \mathbf{c}_0 + \alpha_i(\omega)\cdot\mathbf{p}^c(i) \qquad 1 \le i \le N+6, \quad (1)$$

where ω is the weight change factor (percent).

To maintain the natural appearance of the modified face, for the case of fattening, the most suitable stretching coefficients $\alpha_i(\omega)$ were empirically found to be

$$\alpha_i(\omega) = \begin{cases} 1+\frac{\omega}{100} & i=1,2 \\ 1 & 3\le i\le 6 \\ 1+\frac{\omega}{100} & 7\le i\le N+6 \end{cases} \quad (2)$$

For slimming, the most suitable coefficients found are

$$\alpha_i(\omega) = \begin{cases} 1+\frac{\omega}{100} & i=1 \\ 1 & 2\le i\le 6 \\ 1+\frac{N+7-i}{N+6}\cdot\frac{\omega}{100} & 7\le i\le N+6 \end{cases} \quad (3)$$

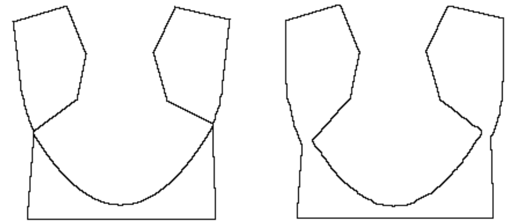

Figure 3: *Left:* The outline of the weight-modified area in the original image, consisting of the cheeks and the neck. *Right:* The merged outline, following a fattening transformation.

The outline of the neck is determined by key-points $\{1,0,7,13,14\}$, see Fig. 2-left. The modified position of points 1 and 7 is determined in the cheek transformation process. The position of point 0 is somewhat arbitrary, and its distance from the baseline of the neck (the segment connecting points 13 and 14, that coincides with bottom boundary of the image) varies between photographs. Point 0 is therefore not moved, and the only remaining change is in the horizontal position of points 13 and 14, i.e., in the length of the baseline, by an empirically determined factor of $0.35\cdot\omega$.

Following the transformation of the outlines of both cheeks and the neck, three separate outlines are obtained. They are merged to create a single outline. Note that, in the case of fattening, overlaps between the modified cheeks and neck are discarded, see Fig. 3.

2.2.3. *Transformation of interior points*

Having obtained the complete outline of the weight-modified area in the face image, the next step is to transform interior points from the original image to their corresponding location in the modified face image. The transformation is specified by selecting M pairs of corresponding landmarks from the original and modified outlines, where M is about 10% of the total number of pixels along the outline.

Formally, suppose we are given a shape P that should be transformed into a shape Q. Let $\{p_i = (x_i, y_i)\}_{i=1}^{M}$ be M of the points on the outline of P and $\{q_i = (u_i, v_i)\}_{i=1}^{M}$ be their respective homologous points on the outline of Q. Based on these corresponding pairs, Bookstein [3] defined the following transformation from any point $p=(x,y)\in P$ to a point $q=(u,v)\in Q$:

$$\begin{aligned} u &= a_1^u + a_x^u\cdot x + a_y^u\cdot y + \sum_{i=1}^{M}\omega_i^u\cdot U\{\eta(p_i,p)\} \\ v &= a_1^v + a_x^v\cdot x + a_y^v\cdot y + \sum_{i=1}^{M}\omega_i^v\cdot U\{\eta(p_i,p)\} \quad (4) \end{aligned}$$

where $\eta(p_i, p)$ is the Euclidean distance between p_i and p and $U(\eta) \equiv \eta^2 log \eta^2$. The $2M + 6$ parameters a_1^u,a_x^u,a_y^u,$\{\omega_i^u\}_{i=1}^M$, a_1^v,a_x^v,a_y^v,$\{\omega_i^v\}_{i=1}^M$ are determined using the following constraints:

$$\sum_{i=1}^{M} \omega_i^u = \sum_{i=1}^{M} \omega_i^v = 0$$
$$\sum_{i=1}^{M} \omega_i^u \cdot x_i = \sum_{i=1}^{M} \omega_i^v \cdot x_i = 0$$
$$\sum_{i=1}^{M} \omega_i^u \cdot y_i = \sum_{i=1}^{M} \omega_i^v \cdot y_i = 0 \qquad (5)$$

The set of equations derived from substituting the M corresponding pairs $p_j \rightarrow q_j$ in (4) and in (5) fully determines the $2M + 6$ transformation parameters. The transformation (4) can now be applied to all points $p \in P$. This procedure is referred to as thin plate spline warping [3].

The non-linear transformation maps cheek and neck pixels from the original image onto the weight-modified image plane. In the case of fattening, due to discretization, some pixels in the transformed plane have no corresponding source pixels in the original image; hence, they lack color attributes. The gaps are filled using local interpolation.

Having created the transformed versions of the neck and both cheeks, they have to be combined with the entire face image. In the case of weight gain this is accomplished by simply pasting the transformed parts onto the original image. In the case of weight loss, since the transformed parts are smaller than the original ones, the original cheeks and necks are first removed and replaced by background. Then the weight-modified parts can be pasted.

The overall result of the weight-change process is a clear, sharp, color face image, in which the face is simulated to be fatter or thinner as specified. Typical results are shown in Fig. 4. The weight-modified images are produced in seconds on a PC.

To evaluate the performance of the suggested method, two validation experiments, with thirty participants, were conducted. One experiment was designed to determine whether the simulated face images are sufficiently realistic. The objective of the other experiment was to check whether the changes made in the images are indeed perceived as fattening or thinning. Encouraging results were obtained in both experiments. For details see [4].

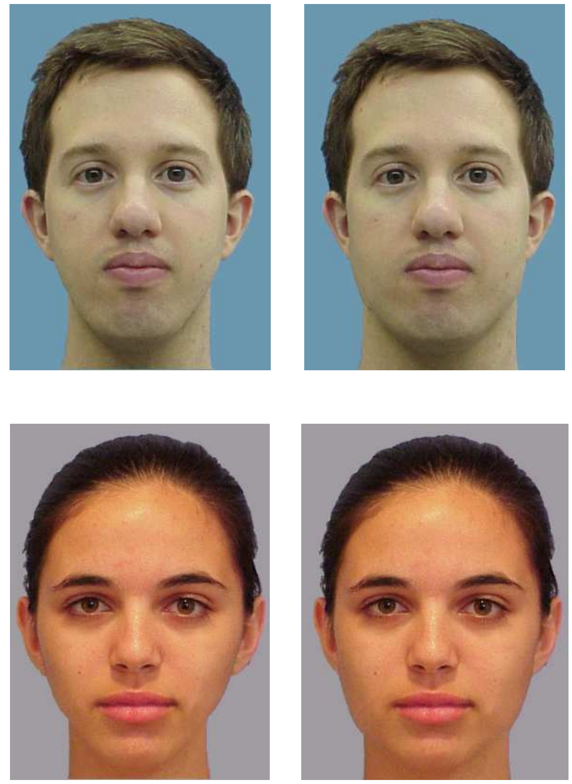

Figure 4: *Left column:* Computer-generated face images, thinned with $\omega = -14\%$. *Right column:* Weight-modified images, fattened with $\omega = 14\%$.

3. REFERENCES

[1] Benson P.J., Emery J.L., Cohen-Tovée E.M. and Tovée M.J., "A computer-graphic technique for the study of body size perception and body types", *Behavior Research Methods, Instrumentation and Computers*, Vol. 31, pp. 446-454, 1999.

[2] Blanz V. and Vetter T., "A morphable model for the synthesis of 3D faces", *Proc. SIGGRAPH'99*, pp. 187-194, 1999.

[3] Bookstein F.L., "Principal Warps: thin-plate splines and the decomposition of deformations", *IEEE Transaction on Pattern Analysis and Machine Intelligence*, Vol. 11, pp. 567-585, 1989.

[4] Danino U., *Facial Weight-Change Simulation*, MSc Thesis, Department of Electrical Engineering–Systems, Tel Aviv University, 2003.

[5] Harari D., Furst M., Kiryati N., Caspi A. and Davidson M., "A computer-based method for the assessment of body-image distortions in anorexia nervosa patients", *IEEE Transactions on Information Technology in Biomedicine*, Vol. 5, pp. 311-319, 2001.

[6] Sepúlveda A.R., Botella J. and Leon J.A., "Body image disturbance in eating disorders: a meta-analysis", *Psychology in Spain*, Vol. 6, pp. 83-95, 2002.