A FACE IMAGE GENERATION SYSTEM FOR TRANSFORMING THREE DIMENSIONS OF HIGHER-ORDER IMPRESSION

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ABSTRACT

The present paper describes the application of an improved impression transfer vector method (Sakurai et al., 2007) to transform the three basic dimensions (Evaluation, Activity, and Potency) of higher-order impression. First, a set of shapes and surface textures of faces was represented by multi-dimensional vectors. Second, the variation among faces was coded in reduced parameters derived by applying principal component analysis. Third, a facial attribute along a given impression dimension was analyzed to select discriminative parameters from among principal components with higher sensitivity to impressions, and obtain an impression transfer vector. Finally, the parametric coordinates were changed by adding or subtracting the impression transfer vector and the image was manipulated so that its facial appearance clearly exhibits the transformed impression. A psychological rating experiment confirmed that the impression transfer vector modulated three dimensions of higher-order impression. We discussed the versatility of the impression transfer vector method.

Keywords: face, impression transformation, semantic differential method, higher-order impression

1. INTRODUCTION

A face provides a wealth of information about a person, such as identity, gender, age, and emotion. The appearance of a face also leads people to create different impressions of a person, for example ‘elegant’ or ‘friendly’. Thus, in human relations, people communicate with each other based on useful information conveyed by a person’s facial appearance. This is especially true when meeting new people and communicating face-to-face with them. Even in virtual and online communities such as internet-based social networks, users can communicate with each other not only through text messages but also through visual communication interfaces such as virtual face animation. The virtual representations of a face are expected to provide users with a virtual face-to-face communication environment. By incorporating the practical characteristics of facial appearance in real communication, the visualized face could function as the face and facilitate communication by conveying affective and social messages. It is important to obtain a favorable appearance that reflects the user’s intentions, which would depend on the situation. In this paper, we explore a useful application system for image generation to transform affective facial impressions for vision-based human communication.

Recently, some research reported that the image generation trials artificially transformed the impressions of facial images, for example [1, 2, and 3]. In this context, Kobayashi et al.[4] developed an image generation method called the ‘impression transfer vector method’, which changes the appearance of a human face by manipulating the parameters of 2D face images to produce the intended impression changes of gender and age. This method involves multi-dimensional vector representation of the shape and texture of 2D faces, low-dimensional parameter description of facial variations obtained by principal component analysis (PCA), and the application of Fisher’s linear discriminant analysis to manipulate the face image and transform its focus impression. This method has been improving and extending the range of application such as 3D faces [5].

The previous study of impression transformation by the impression transfer vector method [4 and 5] focused as much on the biologically-related impressions of age (younger-older) and gender (feminine-masculine). Such impressions are perceived based on the biological features of face. On the other hand, the present study focuses on the more social and subjective higher-order impressions such as ‘elegant’ and ‘friendly’. For the transformation of higher-order impressions, we utilize the improved image manipulation scheme [6] for the impression transfer vector method, so that a more effective transformation can be achieved for subjective higher-order impressions of the face. This work experimentally verifies the effect of the impression transformation of various impressions by applying the proposed procedure to transform these impressions.

This paper is organized as follows. Section 2 describes the outline of the principles and procedures of the impression transformation of faces. Section 3 discusses the psychological aspects of subjective higher-order impressions of faces and introduces a method to quantify them. Section 4 describes an improved procedure for treating higher-order impressions. Section 5 presents experimental results on the impression transformation of the dimensions of higher-order impressions with examples of generated images. Moreover, a summary of the human evaluation results confirms the validity of the method. Finally, Section 6 we discusses our work and future plans.

2. IMPRESSION TRANSFORMATION OF FACE IMAGES BY IMPRESSION TRANSFER VECTOR METHOD

In this section, we summarize the sequence of procedures of the impression transfer vector method, which Kobayashi et al. [4] proposed.

2.1 Parametric Representation of Face Image

A set of faces is first represented in high-dimensional vectors by separating the shape and texture information. In this study, a facial image morphing system called 'FUTON' [7] obtained the vector representation of a 2D face image by searching for pixel correspondence among a set of face images. The shape vector is defined as a 182-dimensional vector consisting of the x and y coordinates of the 91 feature points on the face; as a 16,384-dimensional vector, the texture vector consists of gray level values of the corresponding pixels of the image obtained after the face pattern is warped to an average face shape.

The shape/texture vector of an arbitrary face image is then represented by K-dimensional feature vector in the shape/texture parameter space of reduced dimensions, defined by separately applying PCA to the shape and texture vectors of the set of face images. Thus variation in the appearance of face images is coded in a small number of shape and texture parameters [8].

2.2 Defining the Impression Transfer Vector

The scope of impression transformation can be defined by a specific pair of adjectives indicating opposite impressions. We define the two groups of training faces giving opposite impressions, such as masculine and feminine, as Classes 1 and 2, respectively. Fisher's linear discriminant is a classification method that finds the optimal projection axis in a feature space to discriminate the training samples of two given classes. This principle was applied to two sets of feature vectors, $F^{(1)} = \{\mathbf{f}^{(1)}_1, \mathbf{f}^{(1)}_2, \ldots \mathbf{f}^{(1)}_{M1}\}$ and $F^{(2)} = \{\mathbf{f}^{(2)}_1, \mathbf{f}^{(2)}_2, \ldots \mathbf{f}^{(2)}_{M2}\}$, both of which were obtained as parameters of reduced dimension K as a result of PCA coding of the training faces for the two classes. Assume that **e** denotes a unit vector representing the direction of Fisher's projection axis, which indicates direction in K-dimensional parameter space, along which impressions given by the two classes differ most greatly. Therefore, if feature **f** representing an arbitrary face pattern is moved along the direction indicated by vector **e** in the K-dimensional parameter space, the impression given by the face is expected to be transformed in the direction represented by either of the opposing two classes. Thus, an impression transfer vector is defined by this unit vector **e**.

2.3 Image Manipulation for Impression Transformation

The transformation of original shape/texture vector **X** to modified vector $\hat{\mathbf{X}}_c$ by impression transfer vector **e** with a multiplicative factor q_c is formulated as

$$\hat{\mathbf{X}}_c = \mathbf{X} + \sum_{k=1}^{K} q_c \delta \cdot e_k \cdot \mathbf{U}_k, \qquad (1)$$

where δ denotes the distance defined in the K-dimensional dimensional parameter space between the average vectors of Classes 1 and 2, e_k denotes the k-th element of impression transfer vector **e**, and $\mathbf{U}_k$ is the k-th eigenvector obtained by PCA coding of the training faces. Visual output of face images after impression transformation is obtained by the FUTON system that combines the two modified vectors that represent the shape and texture of the face, respectively.

3. PSYCHOLOGICAL ASPECTS OF FACIAL IMPRESSION

Impressions from the appearances of faces reflect human perception of them. We define impressions as 'subjective or affective images distinctively perceived from various objects that reflect viewer feelings, past experiences, knowledge, or an affective evaluation.' Next we discuss how to quantify the impressions and the psychological aspects of facial impressions.

3.1 Measurement of Subjective Impression

To investigate the relationships between impressions perceived by human and physical features as a mathematical model, determining measures to quantify the results of subjective perception is crucial; this can be performed by the Semantic Differential (SD) method [9].

The SD method, originally developed by Osgood et al., broadly and quantitatively measures impressions of various materials such as form, color, face, and so on [10, 11, and 12]. In its general procedure, participants rate their impressions of various stimuli along several bipolar adjectives (e.g., active-passive) on 5- or 7-point scales. When factor analysis is conducted on data rated by the SD method, factor loadings are calculated for each impression dimension represented by a pair of bipolar adjectives. Semantic differential data are generally summarized into three main factors interpreted as Evaluation (such adjectives as beautiful-ugly or likable-unlikable), Activity (such adjectives as active-passive or cheerful-cheerless), and Potency (such adjectives as powerful-weak or hard-soft). The factor scores for the faces obtained by factor analysis and varimax rotation provide a quantitative measure for the impression perceived by the subjects of each face image.

3.2 Three Basic Dimensions of Facial Impression

Experimental results of the SD method have revealed that many impressions given by faces are summarized by the three main dimensions of Evaluation, Activity, and Potency, as described in 3.1. Therefore various aspects of the impressions of faces such as 'elegant' and 'friendly' can be condensed and represented by these three main dimensions that in this paper we call the higher-order impressions of the face.

Such impressions as apparent age (younger-older) and gender (feminine-masculine) are perceived based on fairly simple biological features. The relatively distinct causal relationship is found between the biologically related impressions of faces and their physical features by earlier studies [13]. On the other hand, higher-order impressions are more subjective and presumably perceived through the social and higher-level cognitive processes of human beings. Therefore, for the transformation of higher-order impression of face, it is necessary to improve the impression transfer vector method to be suitable for the cognitive properties of facial impression by human.

4. IMPROVED SHEME FOR HIGHER-ORDER IMPRESSION TRANSFORMATION

The impression transfer vector method is applied to transform the higher-order impressions of faces with the following additional procedures [6].

4.1 Selection of Effective Components for Defining the Impression Transfer Vector

When the impression transfer vector method was applied to the transformation of biologically related impressions such as gender and age [4], Fisher's linear discriminant function was designed with a specific number of high-ranking principal components with larger eigenvalues. This means that the components used as discriminative parameters accounted well for the variations in the physical appearance of the faces. More subjective higher-order impressions, however, may be diversely affected by multiple factors concerning the physical appearance of faces, and therefore components that most accounted for the image variations may not necessarily be more effective for impression transformation. For the transformation of higher-order impressions, therefore, discriminative parameters were not selected from among principal components with larger eigenvalues, but from among those that revealed higher sensitivity to the changes of the specific impressions from the SD method results.

First, this parameter selection procedure visualizes the variation of faces represented by each major principal component of the shape/texture vectors. Along the k-th principal component axis, a series of composite shape/texture vectors, $\hat{\mathbf{X}}_{k,c}$ $(c = 1, 2, \cdots)$, was synthesized while varying weight P_c as:

$$\hat{\mathbf{X}}_{k,c} = \boldsymbol{\mu} + p_c \sigma_k \cdot \mathbf{U}_k \quad , \qquad (2)$$

where $\boldsymbol{\mu}$ is the average of shape/texture vectors $\mathbf{X}_m$ of the training samples and σ_k is the standard deviation of the k-th component of K-dimensional feature vector $\mathbf{f}_m$. Visualization of the composite faces was done by combining either a synthesized shape vector with the average texture or vice versa, both by the FUTON system.

For all the composite faces, impression rating by the SD method is conducted. SD data factor analysis is conducted with the principle factor method and varimax rotation to obtain the factor score for each composite face. If the scores largely vary with the change of weight P_c along a given k-th principal component axis, the k-th component is selected as one crucial component suitable for defining the impression transfer vector.

Using this procedure, prospective principal components that effectively transform the specific higher-order impression can be found, even though their corresponding eigenvalues are relatively small. The validity of this additional procedure was experimentally confirmed in comparison with the previous method that simply selected components with larger eigenvalues.

4.2 Training the Impression Transfer Vector by Impression Ratings

To obtain impression transfer vector **e** by Fisher's linear discriminant analysis, two groups of training faces must be prepared for Classes 1 and 2, respectively, each of which gives opposite impressions (see 2.2). For impression transformation by gender or age, the two groups could be defined based on the person's biological attributes, i.e., gender distinctions or the actual age. For the transformation of more subjective and complex impressions, however, the two groups cannot be defined in the same way as the case of person's biological attributes. Therefore we selected the training faces giving opposite impressions based on the SD method results. For all the actual faces collected for training, an impression rating by the SD method was conducted, and factor analysis was conducted on the SD data with the principle factor method and varimax rotation to obtain a factor score for each training face. Training samples for the two classes were selected by the value of the factor score, e.g., faces with higher scores are Class 1 and those with lower scores Class 2.

5. EXPERIMENTS ON HIGH-ORDER IMPRESSION TRANSFORMATION

The improved scheme (see 4.1 and 4.2) was used to treat the higher-order impressions (Evaluation, Activity, and Potency), which are the three condensed dimensions of the various impressions defined by the SD method (see 3.2). Further, image manipulation was performed on the average face for the dimensions of Evaluation, Activity, and Potency, and the validity of the manipulation was checked by the psychological rating.

5.1 Set of Images for Experiments on Facial Impression Transformation

We used the face images of 20 people (10 males and 10 females) selected from the facial expression database provided by the ATR Human Information Processing Research Laboratories. All face images were frontal and totaled 200 because each subject displayed 10 facial expressions: neutral, happy (opened and closed mouths), angry (opened and closed mouths), fear, surprise, sorrow, disgust, and contempt. In the training stage, both sets of shape and texture feature vectors obtained from these 200 images were subjected to PCA to build a low-dimensional parameter description of facial variations. In the component selection and image manipulation stages, the average face generated from these 200 images was used as a sample pattern to be manipulated.

5.2 Experiments on Impression Transformation for Higher-order Impressions

By using the proposed parameter selection procedure (see 4.1), we selected effective components as discriminant parameters that were used to define the impression transfer vector of each impression dimension. Ten pairs of rating adjectives were used in the SD method: bright-dark, extraverted-introverted, powerful-weak, elegant-inelegant, excellent-incompetent, mild-violent, attractive-unattractive, distinctive–non-distinctive, old-young, and feminine-masculine. One hundred students (50 males and 50 females) rated the composite faces using these ten adjectives on a 7-point scale (e.g., 1: extremely bright to 7: extremely dark) at their own pace. Three different questionnaire patterns varied the orders of the adjective pairs and their polarities. As factor analysis results with the principal factor method and varimax rotation, three factors were extracted: Activity (contribution ratio: 22.35%), Evaluation (17.45%), and Potency (11.41%), which are listed according to their contribution ratio. Then, based on the factor scores calculated for all the composite faces, the components were selected in which the factor score greatly changed along the degree of the weight (p_c) in Formula (2) for each impression dimension (Table 1). For example, S12 means the 12th principal component of the shape feature, and T23 means the 23rd principal component of the texture feature. Thus we specified the effective principal components for each impression dimension, even if their eigenvalues were relatively small.

Table 1: Principal components selected for designing impression transfer vector.

Evaluation dimension [6]										
Shape	S2	S1	S7	S10	S6	S9	S17	S21	S4	S18
Texture	T14	T34	T33	T1	T13	T3	T25	T15	T38	T5
Activity dimension										
Shape	S12	S10	S7	S4	S21	S3	S15	S9	S11	S1
Texture	T23	T24	T29	T34	T14	T12	T25	T20	T10	T6
Potency dimension										
Shape	S17	S12	S8	S7	S3	S6	S4	S2	S21	S10
Texture	T38	T15	T34	T40	T3	T2	T22	T1	T14	T30

(Attached number shows the magnitude of eigenvalues)

Next, we prepared two groups of training faces for Classes 1 and 2 to define the impression transfer vector using the selection procedure of the training sample faces (see 4.2). To create these groups, the same impression rating was conducted on the actual individual faces to different participants. As factor analysis results with the principal factor method and varimax rotation, three factors were extracted: Activity (contribution ratio: 22.38%), Evaluation (21.13%), and Potency (14.27%), which are listed according to their contribution ratio. Based on the calculated factor scores for each face, we made a set of two groups of faces with high scores (Class 1) and low scores (Class 2) for Evaluation, Activity, and Potency factors. The impression transfer vectors for shape and texture were obtained as a result of Fisher's linear discriminant analysis on the two sets of respective features, as described in 2.2.

5.3 Psychological Validity

Image manipulation was performed on the average face of the 200 training samples (e.g., Figure 1) varying the q_c parameter in Formula (1) on nine steps from -2.0 to +2.0 (in 0.5 steps) for the Evaluation dimension [6] and on seven steps from -3.0 to +3.0 (in 1.0 steps) for the Activity and Potency dimensions. All stimuli were printed on A6-sized pieces of paper and divided into sets to be rated.

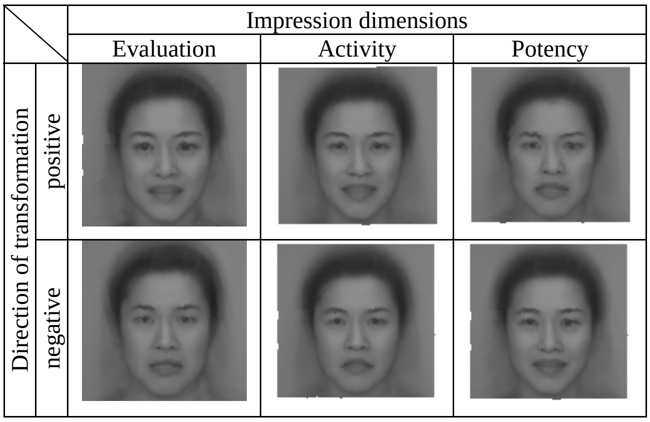


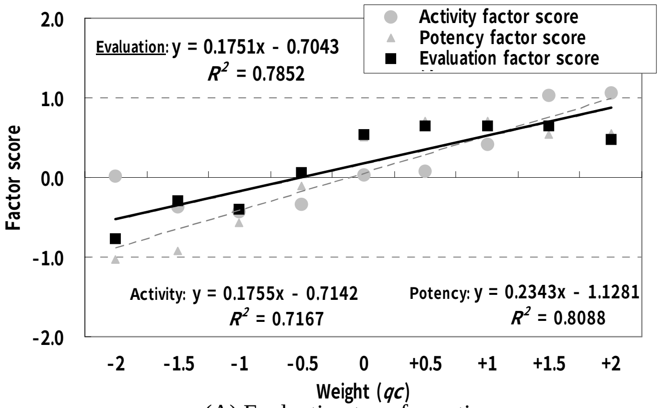
Figure 1: Examples of synthesized faces by impression transformation based on average face.

The same impression rating was conducted again to check whether the image manipulation worked well in terms of the impression transformation in accordance with human perceptions. One hundred and eight students (54 males and 54 females) rated the synthesized faces concerning the Evaluation dimension [6], and eighty-one students (41 males and 40 females) rated the synthesized faces concerning the Activity or Potency dimensions. We combined the SD data and performed factor analysis with the principal factor method and varimax rotation. As factor analysis results with the principal factor method and varimax rotation, three factors were extracted (Table 2): Activity (contribution ratio: 24.95%), Evaluation (16.01%), and Potency (15.80%), which are listed according to their contribution ratio.

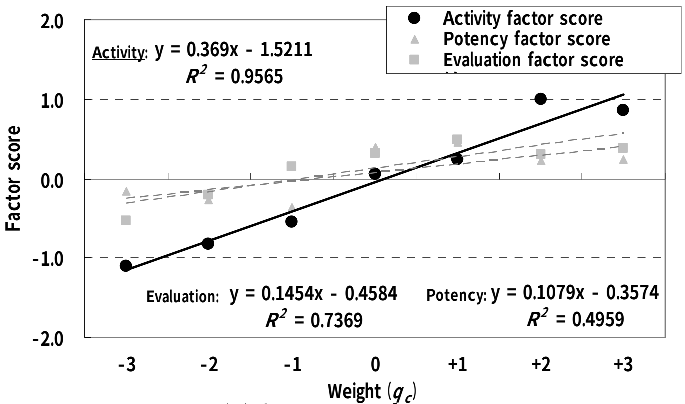
Table 2: Factor loadings after varimax rotation on the SD data.

Factors	Adjectives	Activity	Evaluation	Potency
Activity	extaverted - introverted	**.803**	.159	-.043
	bright - dark	**.795**	.270	.189
	distinctive - non distinctive	**.633**	.204	-.121
	young - old	**.483**	.300	.137
Evaluation	elegant - inelegant	.184	**.693**	.349
	excellent - incompetent	.283	**.657**	.014
	attractive - non attractive	.500	**.601**	.292
Potency	violent - mild	.147	.174	**.760**
	powerful - weak	.435	.080	**-.684**
	masculine - feminine	.093	.247	**.506**
Variance explained by each factor after rotation		2.495	1.602	1.580
Contribution of each factor		24.950	16.016	15.802
Cumulative contribution		24.950	40.966	56.768

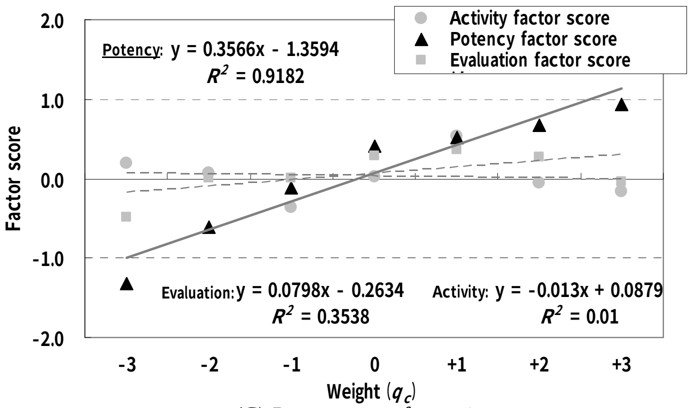
Factor scores were calculated for all the faces. We focused on the composite faces given the same q_c parameter in Formula (1) for both the shape and the texture features and performed linear regression analyses using the factor scores. Figure 3 shows the results. For Evaluation transformation (Figure 2A), the targeted Evaluation factor scores increased along the growth of q_c , and relatively good fitting (R^2 = 0.785) was found with a positive slope. The Activity and Potency factor scores also increased along the growth of q_c . For Activity transformation (Figure 2B), the targeted Activity factor scores increased linearly along the growth of q_c. Moreover, good fitting (R^2 = 0.956) was found for the Activity factor with the biggest positive slope among the three factors. For Potency transformation (Figure 2C), the targeted Potency factor scores increased linearly along the growth of q_c. Good fitting (R^2 = 0.918) was found for the Potency factors with the biggest positive slope among the three factors.



(A) Evaluation transformation



(B) Activity transformation



(C) Potency transformation

Figure 2: Plotting factor scores as a function of q_c parameter.

These results showed that the synthesized faces produced the intended changes with all the dimensions of the Evaluation, Activity, and Potency impressions. For the Activity and Potency dimensions, the manipulation specifically improved the targeted dimension. We confirmed the validity of the impression transformation method for each dimension of higher-order impressions, with a few exceptions in the Evaluation dimension.

6. DISCUSSION AND FUTURE WORK

In this paper, we applied the impression transfer vector method to the higher-order impressions (Evaluation, Activity, and Potency) of faces; these impressions were the three summarized dimensions of facial impressions defined by the SD method. Based on the experimental results of facial impression transformation and validity check by psychological evaluation, the perceived impressions were found to correspond to the weight changes in the impression transfer vector. This showed the validity of the impression transfer vector to transform the higher-order impressions of faces.

The higher-order impressions, defined by the SD method, were generally considered as basic dimensions used by humans to judge the various aspects of facial impressions. In our present work, since we confirmed the validity of the impression transformation of these impression dimensions, we concluded that the impression transfer vector method was capable of wide applications, including its general use for various facial impressions. We regarded the impression transfer method as a face image generation system for general impression transformation.

As the next step, we aim to translate the impression transfer vector method into practical applications. As a useful interface in social settings or an effective tool in psychological experiments, efforts need to be made to conduct additional experiments on the impression transformation of actual individual faces or of common objects other than faces, and to check the efficiency of the transformation. Some trials are already underway. For example, the impression-driven design scheme based on the impression transfer vector method is currently being explored [14], and the cognitive process of some features of face perception [15] is at present being experimentally investigated by utilizing the facial images wherein facial impressions are quantitatively manipulated as a psychological visual stimuli.

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