IMPRESSION-DRIVEN DESIGN SCHEME FOR A CLASS OF 3D OBJECTS BASED ON MORPHABLE 3D SHAPE MODEL, AND ITS AUTOMATIC BUILDUP BY SUPPLEMENTARY FEATURE SAMPLING

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ABSTRACT

This paper describes a method for achieving a novel design within a class of 3D objects that would create a preferred impression on users. Physical parameters of the 3D objects that might strongly contribute to their visual impressions are sought through computational investigation of the impression ratings obtained for learning samples. “Car body” was selected as the class of 3D objects to be investigated. A morphable 3D model of car bodies that describes the variations in appearance using a smaller number of parameters was obtained. Based on each car body’s rating for the impression of speediness obtained by paired comparison, the visual impression was transformed by manipulating the parameters defined in the morphable 3D model. The validity of the proposed method was confirmed by psychological experiments. A new scheme is also proposed to properly re-sample a novel object of a peculiar shape so that such an object could also be represented by the morphable 3D model.

Keywords: KANSEI information processing, impression-driven design, morphable 3D model, PCA, method of paired comparison, supplementary feature sampling

1. INTRODUCTION

In present-day manufacturing, creating a design that looks attractive to many users is very important. Any higher-order impression such as attractiveness perceived by humans for either an artificial or natural object rests so largely on the individual feeling and sensibility of each person that it is rather difficult to make a design that suits the preference of a large majority of users from the start of the design stage. Thus, any technique valid for creating design that matches the common feeling of the majority seems to be potentially in high demand.

The authors have been investigating the effects of physical features of a 3D object such as its shape and viewing conditions of the object on higher-order impressions received by most observers in common, to seek a computational model describing the relation between the two. With a view to putting the investigation to some practical use in the manufacturing business, a new scheme to generate a novel design for the class of artificial 3D objects that might attract a large number of users was proposed, in which subjective assessment on impressions created by several designs prepared as the case examples was made by a number of ordinary people and physical parameters of the 3D object were manipulated based on the rating results.

In this paper, a car body is selected as the class of 3D object that might give different impressions depending on its shape. A morphable 3D model of car bodies is obtained to describe the variations in appearance using a smaller number of parameters. Based on each car body’s rating for the given impression, a scheme to transform the visual impression by manipulating the parameters is proposed and validity of the proposed method is tested by psychological experiments. Moreover, a new scheme is also presented to properly represent any sample having a novel shape by automatically reconfiguring the morphable 3D model.

2. BACKGROUND

We previously developed a method that changes the appearance of a person’s face by manipulating the parameters of a morphable face image model to produce an intended change of impression.

The morphable face image model is constructed by multi-dimensional vector representation of the shape and texture of 2D face images, and low-dimensional parameter description of facial variations was obtained by applying principal component analysis (PCA) to the vectors extracted from the training face images.[1] This model describes the variation of 2D appearance in the set of training faces in terms of a smaller number of parameters. A similar approach was applied to high-dimensional vectors representing 3D shape and surface texture of the 3D face measured by a range finder, and a morphable 3D face model was obtained.[2]

In the low-dimensional parameter space provided by the morphable face model, an impression transfer vector for impression transformation was obtained by Fisher’s linear discriminant analysis. Experimental results showed that the method effectively transformed categorical impressions between the two attributes, such as age and gender.[3] We then applied this method to the face’s higher-order impression, focusing on gracefulness as an example, with some improvement made in obtaining the impression transfer vector. Psychological evaluation of the impression transformation was conducted by applying a semantic differential (SD) method, and factor analysis revealed that the impression transfer vector did modulate higher-order impressions.[4]

The impression transfer vector method was also applied to the morphable 3D face model to transform impressions conveyed by 3D faces. Experimental results on transformation of gender impressions confirmed the superiority of manipulating the 3D information of faces over a previous approach using only 2D face information.[5] On the premise of introducing the morphable 3D model, the key issue in obtaining the vector representation of 3D faces is registration of range images of different faces captured by a range finder. We proposed a method that automatically registers the 3D shape of the face using the ICP algorithm.[6]

Another example of building a morphable 3D model for a class of 3D objects was also reported, in which PCA was applied to the CAD data of various car body shapes. A GUI environment was constructed to display variations of car body shapes controlled by a small number of parameters. [7] On the basis of these early studies, we intend to develop an impression-driven design scheme of 3D objects using the morphable 3D model, and extend its assumed application target from faces to artificial materials with an immediate focus on car bodies.[8]

3. BUILDING MORPHABLE 3D MODEL OF CAR BODIES

3.1 3D measurement of car bodies

3D objects used in this research are 1/24 scale plastic models of various types of cars. A commercial range finder, Danae-R made by NEC, was used for 3D measurement of the objects. 3D coordinate values and color information for 150,000-300,000 points sampled on the surface were obtained with this device. The set of measurement points was structured into a 3D shape and texture model of the face by using a reverse modeling software, RapidForm 2006.

3.2 Vector representation of 3D shape

Since the number and distribution of measured points on the body surface are different among object samples, the shape representation obtained by the range finder is not consistent. So it is not possible to compare the shapes of two different objects with this representation. To solve this problem, body shape should be represented in the form of a vector, and thus the process of re-sampling the surface is necessary. The re-sampling process aims at keeping the number of sampled points on each surface constant and the physical implication of each sampled point consistent. This enables every shape of the object to be consistently represented in a multi-dimensional vector, and even different shapes become comparable. In addition, once represented in vector form, the multi-component shape data can be compressed in dimension by applying statistical multivariate analysis. And so, the following procedure toward vector representation was followed in this research.

First, 68 feature points are selected as anchoring points for re-sampling, manually on the platform of 3D modeling software, RapidForm 2006. These anchoring points are defined from the necessity of approximating arbitrary body shape by bunching of segmentalized triangular elements. As a result of this procedure, an arbitrary car body could be approximated by 105 triangles as shown in Figure 1.

A definite number of sampling points are required to be located in each triangular area. In order that sampling points could be allocated evenly within an arbitrary triangle, an alignment of the sampling points in a standard triangle was defined. This set of points defined in the standard triangle is called the Standard-Sampling-Point-Array. In an arbitrary triangle newly defined on the surface by the feature points, sampling points are allocated by the Standard-Sampling-Point-Array when the standard triangle is transformed onto the given triangle. Figure 2 shows the Standard-Sampling-Point-Array before and after the transformation. The number of sampling points obtained in each triangle became 465 points because each side of the standard triangle is segmented by 30 points.

With this arrangement, the number of sampling points covering each car body became, 48,825 which equals the number of points within the Standard-Sampling-Point-Array multiplied by the number of triangles covering the object. Moreover, the definition of each sampling point corresponds to others among different car types.

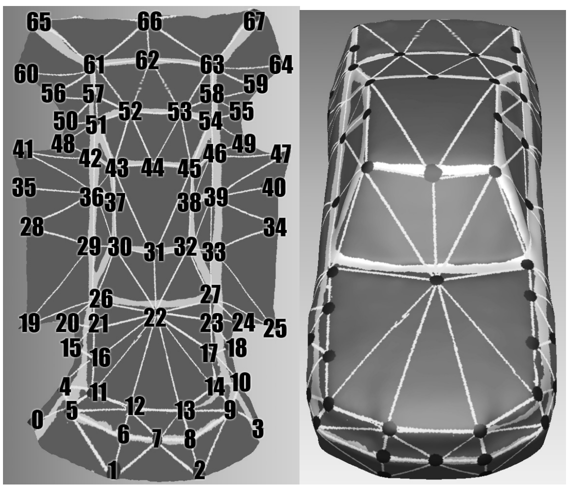

Fig. 1: Triangular approximation and feature point number

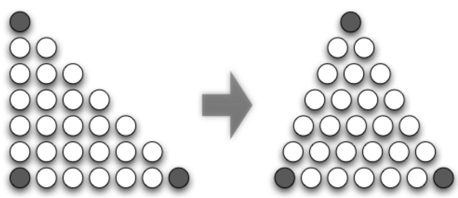

Fig. 2: Standard-Sampling-Point-Array before and after transformation

3.3 Morphable 3D model

When 3D design of each car is represented by multi-dimensional vectors indicating the measured shape and texture of the plastic model, variations of the body design among different car types are described as a small number of parameters obtained by applying principal component analysis (PCA) to the set of multi-dimensional vectors.

Let N-dimensional vectors $\mathbf{x}_m (m = 1,2,\cdots M)$ represent either a shape or the surface texture of the set of M body types. Each $\mathbf{x}_m$ is represented by vector $\mathbf{f}_m$ of reduced dimensionality K. The k-th component of $\mathbf{f}_m$ described as $f_{m,k}$ is obtained as shown in Eq. (1):

$$f_{m,k} = \mathbf{U}_k{}^t \cdot (\mathbf{X}_m - \overline{\mathbf{x}}) \quad (k = 1,2,\cdots K, K \le M) \tag{1}$$

Where $\overline{\mathbf{x}}$ is the average of $\mathbf{x}_m (m = 1,2,\cdots M)$ in the training set and $\mathbf{U}_k (k = 1,2,\cdots,K)$ is obtained as the eigenvector of the covariance matrix of $\mathbf{x}_m (m = 1,2,\cdots M)$ corresponding to the k-th largest eigenvalue.

On the contrary, linear combination of parameters $\hat{f}_k (k = 1,2,\cdots,K)$ and orthonormal base $\mathbf{U}_k (k = 1,2,\cdots,K)$, as shown in Eq. (2), represents a body shape:

$$\hat{\mathbf{x}} = \overline{\mathbf{x}} + \sum_{k=1}^{K} \hat{f}_k \cdot \mathbf{U}_k \tag{2}$$

Arbitrary change of parameters $\hat{f}_k (k = 1,2,\cdots,K)$ generates a variation of the 3D car bodies, and thus it is expected that a novel car design is approximately represented by a set of parameters $\hat{f}_k (k = 1,2,\cdots,K)$ defined by this model, which is denoted as a morphable 3D model.

4. EXPERIMENTS ON DESIGNING A CAR SHAPE BY ITS VISUAL IMPRESSION

4.1 Quantification of visual impression by method of paired comparison and its application to impression transformation

In the earlier study in which a method for transforming the higher-order impression of the face image was proposed, subjective rating of impressions was made on each sample of the face images by the Semantic Differential (SD) method. And strength of the rated impression either positive or negative along the specified dimension was quantified in terms of factor scores as a result of factor analysis applied to the data obtained by the SD method. The training samples of face images were then divided into two classes according to the sign of the factor score calculated for each sample, and the impression transfer vector was obtained as a result of the Fisher's linear discriminant analysis made for discriminating the two classes.

In this research, however, a method of paired comparison was used to quantify the visual impression of car body shape in place of the SD method. This is because the latter method demands many more subjects and rating trials for quantification of the impression, and thus is more costly and time-consuming. Neither was Fisher's linear discriminant analysis used in this experiment for obtaining the impression transfer vector because a requirement of the method is that the number of training samples for each class be larger than the dimension of the feature vectors, but this is rather difficult to make in this experimental conditions.

To start with, 3D data for ten samples of different car types as well as their average shape were synthesized by the parameters corresponding to the top nine principal components defined in the morphable 3D model, and were visualized as polygon-based 2D images with the aid of RapidForm. For each of the eleven generated images, strength of visual impression in the specified impression dimension was measured by subjective assessment test based on Thurston's method of paired comparison, and with the evaluated values, car shape samples were classified into two groups. In this experiment, apparent speediness was chosen as the impression dimension to be investigated. For the experiment of subjective assessment, images about 7cm square were displayed on a 24-inch PC display placed about 70cm ahead of the subject. Standard values of the impression in terms of apparent speediness obtained for each car shape by the method of paired comparison are shown in Figure 3. LEXUS and SKYLINE were judged to give a "fast" impression, and bB, HIACE, SUBARU360, and TODAY were judged to give a "slow" impression.

And let a unit vector $\mathbf{e}$ indicate the direction in the K dimensional parameter space heading from the average parameter $\overline{\mathbf{f}}_1$ of the samples with a "slow" impression to the average parameter $\overline{\mathbf{f}}_2$ of the samples with a "fast" impression. and take the place of the impression transfer vector proposed in the previous work. In this experiment, all the components of the feature vector $\mathbf{f}_m$ were treated equally in impression transformation manipulation regardless of the difference in corresponding eigenvalues. This is because it was confirmed in the previous work done on impression transformation of face images that higher-order components corresponding to smaller eigenvalues do not necessarily have less influence on manipulation of the visual impression of the pattern.

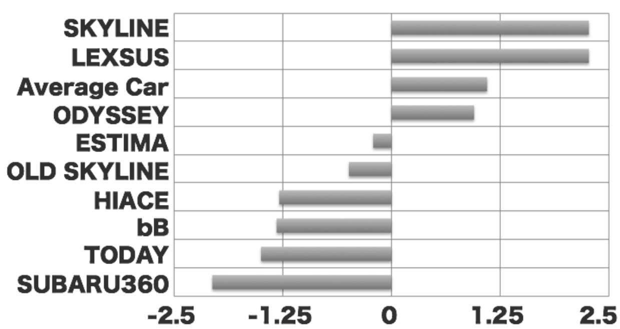

Fig. 3: Strength of the impression of apparent speediness measured by the method of paired comparison

In order to test manipulation of the impression of apparent speediness with the average-shaped car, the parameter $\bar{\mathbf{f}}$ of the average shape obtained from averaging the ten car samples was transformed with the weighting factor $-0.8 \le Q_c \le 0.8$ and the impression transfer vector $\mathbf{e}$ as shown in Eq. (3):

$$\hat{\mathbf{f}} = \bar{\mathbf{f}} + Q_c \cdot \mathbf{e} \tag{3}$$

Figure 4 shows the image of car bodies represented by the parameter $\hat{\mathbf{f}}$ when gradually changing the value of the weighting factor Q_c.

Among these images of car bodies generated from the average shape by changing the amount of physical manipulation Q_c shown in Eq. (3), strength of visual impression in terms of apparent speediness was measured by the method of paired comparison as shown above. As shown in Figure 5, in terms of apparent speediness was found to increase almost linearly with the physical weighting factor Q_c for the range from -0.6 to +0.4., but saturated with the value Q_c of -0.8, +0.6, and +0.8.

According to the survey of subjects after the experiment, there was a fair amount of feedback claiming that the shape obtained by +0.6 and +0.8 as the weighting factor Q_c provided a fairly "fast" impression, but at the same time a rather "slow" impression was found because of enlarged size of the car bodies. This observation might agree with Brown's law indicating that a larger object induces slower motion perception.

5. RECONFIGURATION OF THE MORPHABLE 3D MODEL REPRESENTING OBJECTS OF NOVEL SHAPE

In the early studies, target objects for impression transformation do not involve those of peculiar shape. On the other hand, if a novel car has the shape of either a convertible without a ceiling or a truck, whichever is greatly different from usual sedans, but it should be represented by the existing morphable 3D model mostly constructed from samples of sedans, the conventional way of obtaining feature points of the object will surely encounter difficulties because the position for extracting feature points is already fixed as shown in Figure 1. A new scheme will be presented in order to reconfigure the morphable 3D model so that objects of novel shape could be represented by the model.

5.1 Proposed scheme

In order to reproduce the novel object of peculiar shape properly out of re-sampled data, the following two steps were proposed: 1) to make a flexible rule to decide the position of feature points, and 2) to add extra feature points.

To evaluate quantitatively how accurate is the original shape reproduced after re-sampling, an error index was introduced. The error index was defined, for each triangular area specified by the feature points, as the average value of the Euclidian distance between each sampled point obtained before the re-sampling and its nearest sampled point given after the re-sampling. Shape is not reproduced well when this value is large, and when it is small, it is shown that shape is excellently reproduced. By using this value, the reproducibility error between before and after re-sampling could be evaluated.

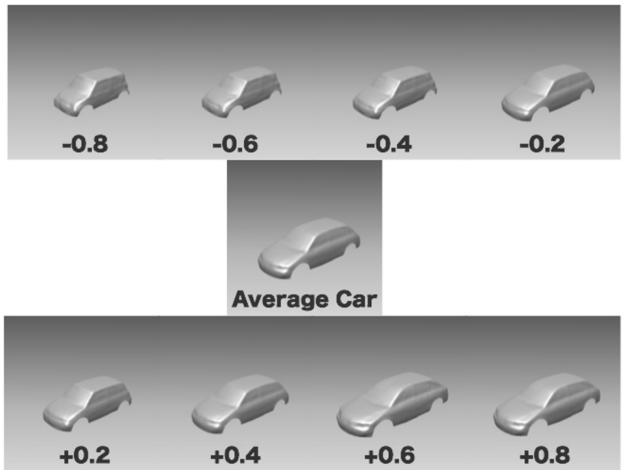

Fig. 4: Results of impression manipulation of the average shaped body

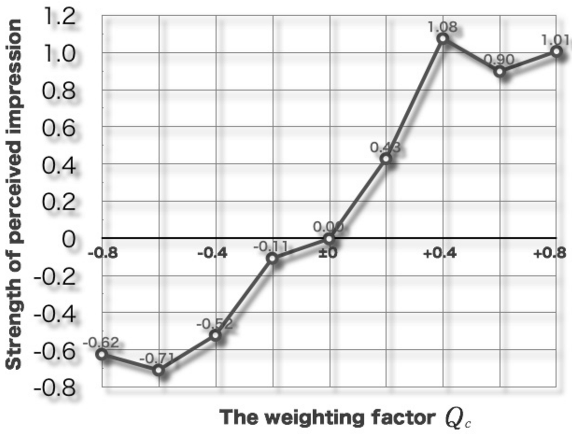

Fig. 5: Strength of perceived impression in terms of apparent speediness measured by the method of paired comparison

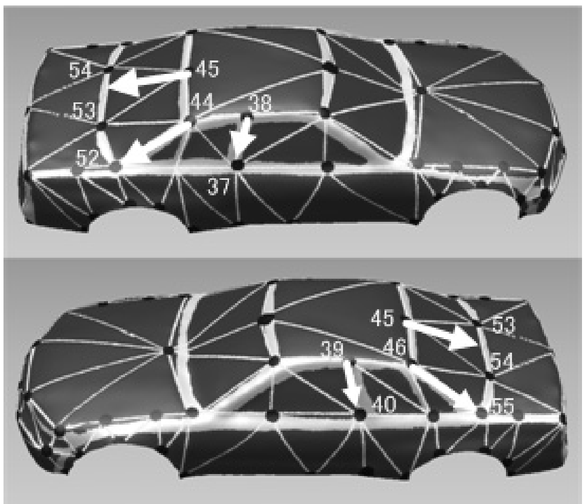

Fig. 6: Example of feature point degeneracy by the flexible rule

5.1.1 Making a flexible rule to decide the position of feature points

In order to represent the shape of singular object, such as a convertible (open car), with which a part of the existing morphable 3D model is missing, a flexible rule to decide the position of feature points was made. For example, the ceiling part of a convertible was regarded as a result of degeneracy occurring with the ceiling of a standard sedan. As shown in Figure 6, the degeneracy could be described by moving the feature point in the ceiling part on the lower side; points 38, 39, 44, 45, and 46 would be moved onto points 37, 40, 52, the mid-point of 53 and 54, and 55, respectively. Figure 7 shows the result of re-sampled points made by this rule. Figure 8 shows a display in gray values of the error index obtained on the surface of this convertible, indicating the accuracy of reproduction made after the re-sampling based on the degenerate feature points.

An advantage of this method would be that an object of new shape could be included in the model without adding extra feature points to the existing data. A demerit of this technique, however, would be that it is difficult to decrease the error index for the novel object whose shape is far different from those of the existing samples assumed by the morphable 3D model.

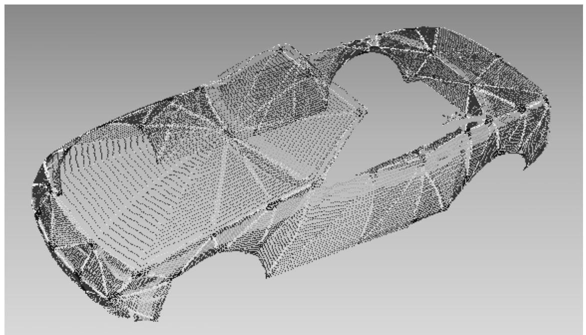

Fig. 7: Resampled car body obtained after the feature point degeneracy

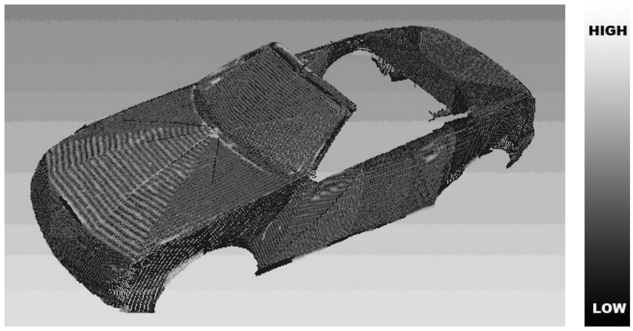

Fig. 8: Error index image that indicates the accuracy of reproduction obtained after the feature point degeneracy

5.1.2 Adding extra feature points

In order to represent an object whose shape is far different from those of the existing samples assumed by the morphable 3D model, such as an auto truck for example, additional extraction of feature points was proposed. When any of the triangles covering the object after re-sampling has a value of the error index that exceeds the threshold, extra feature points are added within the triangle, and this operation is repeated until the error index becomes below the threshold. A flow diagram of this scheme is shown in Figure 9.

This process would make it possible to add an object of quite different shape to the morphable 3D model. An issue to be resolved is to design an algorithm for deciding the position of feature points to be added on the basis of the spatial configuration of prepositioned feature points in the existing samples. To implement such an algorithm, not the position coordinates of each feature point itself, but the ID code of the triangle involving the feature point and its relative address within the region should be stored and read out in the adding operation. Such source of information is called a “recipe,” and extra feature points could be defined for existing samples following the instructions provided by the recipe.

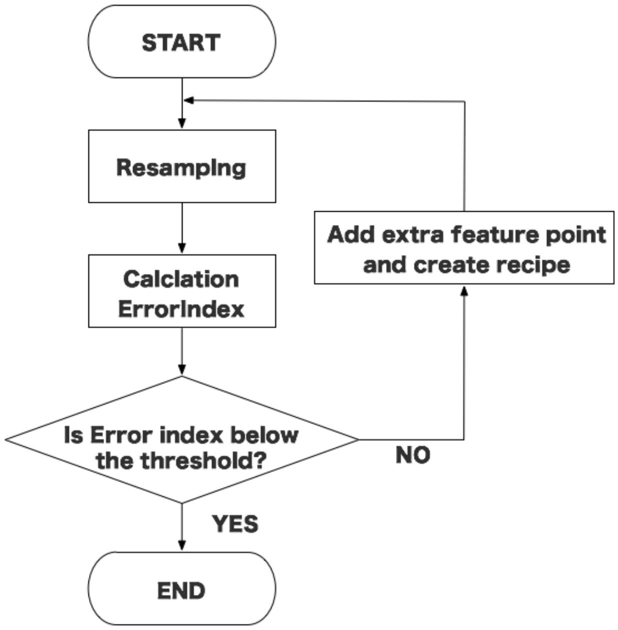

Fig. 9: Flow diagram of adding extra feature points

6. CONCLUSION

A method to achieve a novel design within a class of 3D objects that would create a preferred impression on users was proposed. Physical parameters of the 3D objects that might strongly contribute to their visual impressions were sought through computational investigation of the impression ratings obtained for learning samples. “Car body” was selected as the class of 3D objects to be investigated, and a set of 3D shape data for various car types was obtained by measuring plastic models of different car lines with a range-finder. A morphable 3D model of car bodies, which describes the variations in appearance using a smaller number of parameters, was obtained by applying PCA to a set of high-dimensional vectors representing the 3D shapes. Based on each car body’s rating for the impression of speediness obtained by the method of paired comparison, the visual impression was transformed by manipulating the parameters defined in the morphable 3D model. The validity of the proposed method was confirmed by psychological experiments.

A new scheme was also proposed to properly represent any sample having a peculiar shape by reconfiguring the morphable 3D model with automatically supplemented feature points as extra landmarks, even when the previous set of feature points defined as landmarks for re-sampling 3D objects of the class turned out to be invalid for representing the novel shape. The proposed scheme calculated the difference in shape between the novel object and its reconstruction generated by the parameters of the morphable 3D model; and named the value as the error index. The error index was calculated for each triangular region approximating the object surface. Then, to better re-sample the object, interpolated landmarks were added in particular regions yielding larger values of the error index.

7. ACKNOWLEDGEMENT

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