2014 International Conference on Cyberworlds

A Study on Perceived Similarity Between Photograph And Shape Exaggerated Caricature

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***Abstract*—This paper investigates the relationship between the extent of exaggeration in a caricature and its face identification ability. As face recognition is largely influenced by facial deformations, we focused on finding the borderline between likeness and unlikeness by applying gradual alterations to the face shape of the subject being studied. Suggestions on manipulating the degree of similarity when generating a caricature will be given. The experimental environment in this research can be used as a user-friendly caricature generation system based on "Exaggerating the Difference From the Mean face", which allows a user to freely control each generation step and design his or her own unique caricature portrait.**

***Keywords*-AAM; Caricature; Cartoon; EDFM; Exaggeration; Face Recognition; Feature Proportion**

I. Introduction

Caricatures can be found in various media and situations in our daily lives because they are expressive, simple, and amusing. The essence of traditional caricature art is to represent the personalized features of a person in an exaggerated way. Using caricature portraits, which preserve key features of the subjects, usually makes it easier to recognize and remember the subjects. In recent years, it has become more and more popular to use caricatures in social media and digital entertainment. In social media, such as Facebook, a subject may post a caricatured face on their profile page instead of his or her real image. Personalized avatars in interactive movies and computer games are caricatures. Nintendos Wii games allow users to combine facial parts to create the caricature for a character. One of the most important issues for those applications is privacy protection. In many cases, instead of generating a profile as similar as possible to the person, a caricature that preserves some features of the person but cannot be easily identified is more preferable [26]. This raises the issue of how to control likeness when designing caricatures.

However, to the best of our knowledge, how the degree of face change is related to likeness has not been thoroughly addressed by existing research on computer-based caricature generation, and it has not been quantitatively measured in the research of face recognition. In the past decades, large amounts of technology have been developed for generating caricatures automatically or with user assistance. Automatic approaches mainly focus on how to detect personalized features and represent these features as real as possible or make it more impressive through exaggeration. Interactive systems leave likeness and exaggeration control entirely up to users. Without detailed guidelines, it can be very difficult for a non-professional user to have a control over the likeness. For example, in Wii games, it is usually very hard to create an avatar similar to a particular person. On the other side, some researches on face recognition deformed the face using a caricatured way, and experimented to see whether face distortion affects the process of human recognition. The results of [24] and [28] showed that caricatured face seems to be better recognized than veridical face. Hole et al. [13] found global stretching of face shape in vertical and horizontal direction may impair human recognition. He concluded that there is no simple measurements between facial features and recognition. However, the deformation in their experiments did not consider the features of the original face, which is different from the case of caricature where a face is usually deformed to exaggerate its characteristic features. Although the above mentioned researches found deformation is related to the face recognition performance, to what extent the deformation will impaired the face recognition performance, or to what extent of the exaggeration will aid the face recognition performance hasn't been addressed.

In this paper, we present several user studies designed for achieving insight into the control of likeness against the exaggeration of face shape. Here, face shape means the overall impression of face contour shape. We chose face shape because it is known to be the most important feature for identifying a person. A person can become hardly recognizable simply by replacing his or her face shape with that of another's. As universally claimed by caricaturists([22] [25] [12]), the first step of drawing a caricature is to

978-1-4799-4677-8/14 $31.00 © 2014 IEEE
DOI 10.1109/CW.2014.37

sketch the face shape. The famous caricaturist Redman [22] said the face shape is the Sun and the other face elements are planets to its Sun. Many existing computer caricature generation techniques are based on such a claim and select face shape as the most important feature for performing exaggerations. Some researchers conducted experiments and stated deformation of face shape affects the process of face recognition [13]. However, none of them has quantitatively verified how the exaggeration of face shape affects likeness. Motivated by the aforementioned research, we built a semi-automatic caricature generation system, which we used as a test bed to conduct an experience that aimed to reveal to what extent a change in face width and length will affect a caricatures resemblance to the original photograph. As change in one feature will have an impact on the other features, we considered the importance of relative locations of facial components. We ask the subjects to relocate the facial components into proper positions after the deformation of face contour. We find:

- The borderline of likeness and unlikeness when changing the shape of a female face by elongating and widening the face contour
- The fact that human eyes are more sensitive to change in face width than face length

In addition to the above contribution, the test bed we built can be viewed as a user-friendly caricature design system, which provides free control to the degree of exaggeration. The aforementioned findings can be used as a guideline to control likeness.

II. Related Works

Computer generation of caricatures may be based on verbal descriptions of facial features, or start from an input face photograph [3]. Since the 1980's, there has been tremendous research on the automatic or semi-automatic processing of an input face image into a caricature. The existing approaches can be roughly classified into three categories [26]:

- Interactive approach
  In this approach, the facial features to be exaggerated and their exaggeration rates are interactively appointed by the user. Akleman et al. [2] provided a simple morphing template for the user to manually deform the facial features. Later, they improved the algorithm with a new deformation algorithm that uses simplicial complex [1]. Gooch et al. [11] converted a photograph to a simple line illustration, and then manipulated the feature grid imposed on the illustration.
- Rule-based approach
  This approach simulates the predefined rules to draw caricatures. One widely used rule is "*Exaggerating the Difference From the Mean face*" (EDFM). It was first proposed by Brennan [7]. Brennan placed 165 feature points onto the input face image and 165 reference points on the "*average face*". In EDFM, feature points are moved with an amount proportional to the difference from the corresponding reference points and are connected to create a line-drawing caricature. Koshimizu et al. [15] applied the same idea in their interactive system (PICASSO). They defined the EDFM rule in formula:
  $$Q = P + b * (P - S) \tag{1}$$
  where P is the source image, Q is the resulting caricature, S is the mean face, b is the exaggeration rate and $P - S$ is the difference between the input image and the mean face. With a piece of caricature drawn by the artist and a photograph, Chiang et al. [21] morphed the artist's work into a caricatured person in the photograph based on EDFM. Mo et al. [31] used normalized deviation from the average model to exaggerate distinctive features. Tseng et al. [29] [30] used both inter- and intra-correlations of size, shape, and position features for exaggeration. They subdued some of the features to emphasize the other features. Chen et al. [9] considered the two relative principles described in Redman's study [22], and proposed the "T-Shape" rule for emphasizing the relative position relationship between facial elements. They measured the similarity between the caricature and the photograph with modified Hausdorff distance (MHD), and minimized the distance to improve their results.
- Training-based approach
  This approach tries to mimic a caricaturist's drawing style through machine learning methods. Liang et al. [17] attempted to learn the style of a caricature using partial least squares. Chen et al. [8] drew the facial components using a local model, and rearranged them using a global model based on examples. Shet et al. [27] used cascade correlation neural network to learn exaggeration degrees of caricaturist. Liu et al. [18] applied principle component analysis (PCA) to obtain the principle components of the facial features, and then used support vector regression (SVR) to predict a result for the face provided in the study. They [19] further proposed a non-linear mapping model using semi-supervised manifold regularization learning.

In most of the above mentioned caricature generation literatures, however, how the extent of exaggeration is related to likeness hasn't been quantitatively studied. In interactive approach, the exaggeration rate is user specified. It usually requires professional skill or rich user experience to control likeness. In rule-based approach, the value of b in Equation 1 is set by users, and no guideline for manipulating likeness is provided. In training-based approach, the exaggeration styles learned from the examples are directly applied to the input, and additional likeness control is not allowed.

Although some existing approaches noticed that the relative position of facial components is important for identifying a person, as mentioned in the rule-based approach paragraph, they selected the features described in the literature [22] and exaggerated each of these features according to the differences in the average model. Recently, Klare et al. [14] used crowdsourcing to qualitatively describe 25 features and labeled the importance of each feature through machine learning. They concluded that Level 1 features, including face length and face shape, were more discriminative than Level 2 features, including eye separation, nose to eye distance, nose to mouth distance, and mouth to chin distance, in recognizing a person. From this conclusion, we suggest that the change in Level 1 features has a greater influence on likeness than change in Level 2 features. But as the importance of features was evaluated in a qualitative way, the relationship between the amount of change and likeness was not studied, thus limited the applicability of their research work.

In the research area of face recognition, some researches have concluded that face recognition is affected by geometrical distortions of the face, and what is important in the process of recognition is the difference between individual face and the average face [23] [4] [5]. For example, Berger et al. [6] simplified the stokes and geometric shape of a face image in levels, and an abstraction of the face occurred. As can be inferred from the result, even using only a few sketches, human eyes can still relate the portrait to the original image. To discover face identification performance under face deformation, Hole et al. [13] designed three experiments to learn whether or not stretching a face horizontally or vertically will impair the face recognition process. In experiments 1 and 2, global linear transformations in vertical and horizontal directions were applied to the entire image. By conducting a user study, the authors concluded that vertical and horizontal stretching have little impact on face recognition. It is unclear why they chose to stretch the face in vertical and horizontal directions instead of along the feature vector. Feature vector is usually a high dimensional vector represented by feature points. It was not explained why the tested images were stretched to 150% and 200%. In experiment 3, either the top or the bottom half of the face was stretched vertically twice to its original height, leaving the other half untouched. In this case, face recognition was found to be impaired. It was not explained how the extent of this non-global vertical deformation is related to face recognition performance. Sinha et al. [28] presented 19 basic results about the face recognition process. Among the 19 results, they pointed out that "face-shape appears to be encoded in a slightly caricatured manner". More specifically, they declared the rule that caricatured departure from veridical face performance better in human face recognition process.

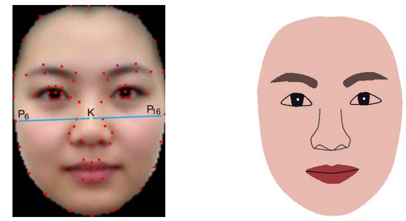

Figure 1. (a) The "average face" labeled with feature points. (b) The corresponding caricature.

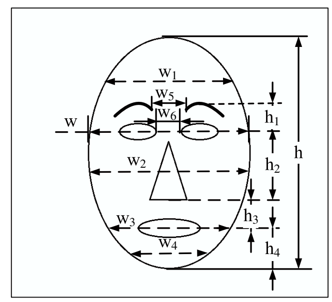

Figure 2. Features about face width and length.

III. Building of Experiment System

A. Caricature Generation

Generating a caricature relies on capturing face features. In this paper, we described 82 facial feature points. As shown in Figure 1(a), we placed 22 points around the face contour, 7 points around each eyebrow, 11 points around each eye, 13 points around the nose, and 11 points around the mouth. Hair is currently removed to eliminate the effect of hairstyle. For a given frontal face image, the feature points are automatically located using active appearance model (AAM) [10] trained by 30 photographs of young Asian females. We interpolated each group of feature points using piecewise Catmull-Rom spline, which passed through all the points. We did this to obtain a simple yet smooth geometrical description of face contour and each facial component. The result of the perception experiments might differ somewhat depending on whether cartoon faces with color information or line-drawn faces are used [23] [4] [5]. To obtain more information from the original image, a cartoon style was created by filling face, eyebrows, pupils, and lips with colors sampled from the photograph. An example of a rendering result is shown in Figure 1(b).

B. Exaggeration of Face Shape

We focused on the exaggeration of face shape with widening and elongating operations. We exaggerated the face contour with an amount proportional to its difference from the "average face". The more a feature deviates

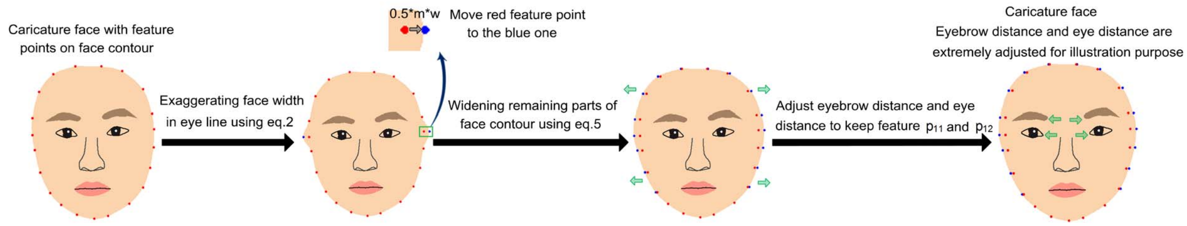

Figure 3. The procedures for widening the face.

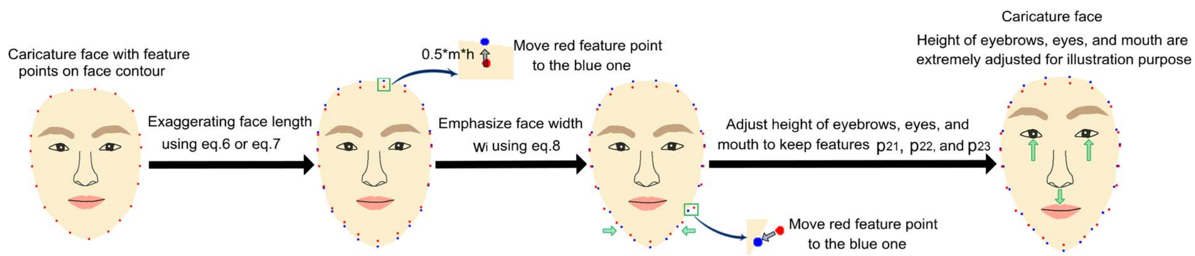

Figure 4. The procedures for elongating the face.

from that of the "average face", the more it is emphasized in the resulting caricature. In this paper, the "average face" (Figure 1(a)) is generated by first normalizing and then averaging the photographs used in training AAM. Examples of exaggerated faces are shown in Figure 5. In the following, we will first introduce the definition of face features, and then explain the detailed exaggeration steps.

1) Features: As suggested by Redman [22], we used width at five different heights of the face as the personalized feature of face shape. These five widths are width in eye line w, cranium width w_1, width in nose line w_2, width in mouth line w_3, and chin width w_4 (Figure 2). To measure the relative positions between facial components, we calculated the distance between pairs of facial components. For horizontal directions, we computed the distance between two eyes w_5 and between two eyebrows w_6. For vertical directions, we computed the space between eyes and eyebrows h_1, space between eye and nose h_2, space between nose and mouth h_3, and space between mouth and bottom of the face h_4. Because each input face image is of a different size, we defined the features in the form of ratio instead of value. The currently defined face shape features are listed in Table I, and relative position features of facial components are listed in Table II.

2) Exaggeration: The exaggeration steps for stretching face width are illustrated in Figure 3. To widen the face by a factor of m, we first increase the face width in eye line w to w' with the factor m:

$$w' = w(1+m) \tag{2}$$

Then the other widths w_i $(i = 1, \dots, 4)$ were scaled to w'_i,

Table I
FACE SHAPE FEATURES

Face width in eye line	$p = \frac{w}{h}$
Cranium width	$p_1 = \frac{w_1}{h}$
Face width in nose line	$p_2 = \frac{w_2}{h}$
Face width in mouth line	$p_3 = \frac{w_3}{h}$
Chin width	$p_4 = \frac{w_4}{h}$

Table II
RELATIVE POSITION FEATURES

Distance of two eyebrows	$p_{11} = \frac{w_5}{w}$
Distance of two eyes	$p_{12} = \frac{w_6}{w}$
Space between eyes and eyebrows	$p_{21} = \frac{h_1}{h}$
Space between eyes and nose	$p_{22} = \frac{h_2}{h}$
Space between nose and mouth	$p_{23} = \frac{h_3}{h}$
Space between mouth and bottom of the face	$p_{24} = \frac{h_4}{h}$

accordingly. We calculated the normalized deviation n of w from the "average face" by Equation 3 and the normalized deviation n_i of w_i from the "average face" by Equation 4. The change of width w_i is an amount proportional to the ratio of deviation n_i to n as given in Equation 5.

$$n = \frac{p - p^a}{v} \tag{3}$$

$$n_i = \frac{p_i - p_i^a}{v_i^a} \tag{4}$$

$$w'_i = w_i(1 + m * clamp(\frac{n_i}{n}, t_1, t_2)) \tag{5}$$

where p_i^a is the mean of p_i, and v_i^a is the covariance of p_i. p_i^a and v_i^a were calculated using the 30 aforementioned

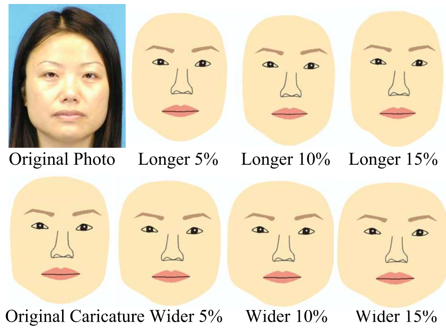

Figure 5. Examples of exaggerated faces.

images in the database. Function $clamp()$ restricted the change within a reasonable scope $[t_1, t_2]$. The distance of eyebrows w_5 and eyes w_6 were adjusted to keep relative position features p_{11} and p_{12}.

The exaggeration steps for stretching face length are illustrated in Figure 4. We fixed the position of the nose, and used point $K = \frac{1}{2}(P_6 + P_{16})$ (Figure 1(a)) as the origin point for deformation. To increase the face length by a factor of m, point k above the origin point is raised to point $k^{'}$:

$$k^{'} = k + m(k_y - K_y) \tag{6}$$

point k below the origin point is lowered to point $k^{'}$:

$$k^{'} = k + m(k_y - K_y) \tag{7}$$

We further emphasized the widths of face contour w_i $(i = 1, \ldots, 4)$ if they were more distinctive than feature w, according to Equation 8:

$$w_i^{\prime} = \begin{cases} w_i(1 - \frac{m}{4} min(abs(\frac{n_i - n}{n}), t)) & (n_i < n) \\ w_i(1 + \frac{m}{4} min(abs(\frac{n_i - n}{n}), t)) & (n_i > n \& n_i > 0) \end{cases} \tag{8}$$

Function $abs()$ calculates absolute value, and function $min()$ limits the maximum amount of change up to t. Finally, we adjusted the height of eyebrows, eyes, and mouth to keep relative position features p_{21}, p_{22}, and p_{23}.

IV. Experiment and Analysis

We conducted three experiments in an aim to reveal how gradual change in face width and length influence likeness. In Experiment 1, the subjects were asked to deform the shape of their face in horizontal and vertical directions. In Experiment 2, they were asked to adjust the position of facial components accordingly after the face shape was deformed. To investigate whether the result of Experiment 2 is related to the aspect ratio of faces, as in Experiment 3, we asked the subjects to classify these faces into long, average, and wide shapes.

The relationship between likeness and the extent of exaggeration might change depending on ethics, age, and sex. In this work, we limited our investigations to young

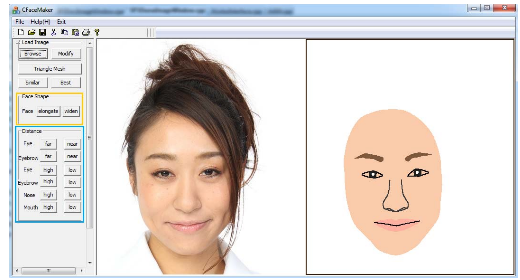

Figure 6. Interface of our experiment system.

Asian females. The 21 photographs used in the experiment were collected from volunteers, free download site, and the databases of [16] and [20]. The interface of our caricature generation system is shown in Figure 6. With each click of the "elongate" or "widen" button (in the yellow box), the face is elongated or widened by 5%. By clicking the buttons shown in the blue box, the eyes and eyebrows are moved inward or outward, and the eyes, eyebrows, nose, and mouth are moved upward or downward. In our experiment, the photograph (rendered in the left window) and exaggerated result (rendered in the right window) are shown to the subjects at the same time.

The subjects who participated in the experiment were university students between 20 to 30 years old. Before all three experiments, we first taught them how to interactively stretch the face length and width and adjust the relative position of facial components. They were given 5 minutes to try the system. During the tests, the photographs and corresponding caricatures were simultaneously displayed on a 24-inch PC monitor. The participants were told there was no time limit for the tests.

A. Experiment 1: Change the Face Shape

In this test, the subjects were first asked to elongate faces until they thought the images did not resemble the original photographs. This was performed using the exaggeration function in the system described in Sect. III-B2. Secondly, They were asked to widen faces until they thought they did not resemble the original people. We counted the number of subjects who thought the deformed faces remained similar to the photographs for each 5% of deformation. Eighteen subjects participated in this test. We collected 375 samples from this test. The percentage of subjects who thought the exaggerated faces remained similar to the photographs is listed in Table III.

Discussion

After analyzing the data, we found that the subjects were more sensitive to the change in a face's width than a change in a face's length. In Table III, 10% of elongated faces were thought to be similar to the original photographs by more than half of the subjects. When the faces were elongated by 15%, the number of subjects who thought the caricatures were similar to the original photographs was reduced to 30.8%. The number of subjects who thought that the deformed caricatures were similar to the original faces was lower than 40%. With a 20% widening of the faces, one in 375 subjects thought the widened faces were similar to the original faces. To help ensure that widened faces remain similar to the original face, the change should be within 10%. For elongated faces, the borderline of likeness and unlikeness was between 10% and 15%.

B. Experiment 2: Change the Face Shape with the Adjustment of Facial Components' Position

In Experiment 1, the position of facial components was adjusted in the system after changing face shape using the rule explained in the third step of Figure 3 or Figure 4. To keep the relative position features shown in Table II when the participants elongated the face, eyebrows, eyes, nose, and mouth were moved in a vertical direction, which automatically maintains relative position features. When the participants widened the face, eyebrow distance and eye distance were modified automatically to keep features p_{11} and p_{12}. However, these adjustments might not lead to the most similar result perceptually. To eliminate a factor related to the position of facial components, we conducted Experiment 2. First, each subject was asked to elongate a face by 5% each time, and adjust the height of eyes, eyebrows, nose, and mouth to create the best combination until they could not produce a caricature that was similar to the original.Second, each subject was asked to widen a face by 5% each time and adjust the distance between each eye and each eyebrow to create the best combination until they could not produce a caricature that resembled the original. Eleven subjects participated in this test. We counted the number of subjects who thought the deformed face was similar to the photograph in each step. We collected 229 samples from the tests. The percentage of subjects who thought the exaggerated face was similar to the photograph is listed in Table IV.

Discussion

After comparing the data, the number of subjects who thought that the caricatures were similar to the original faces increased when the positions of facial components were allowed to be adjusted by 5% to 10%. The borderline remained the same in Experiments 1 and 2. In both cases, the results showed that there was more resistance to likeness in face length changes than face width changes.

C. Experiment 3: Subjective Classification of Face Shape

In Experiment 1 and Experiment 2, the face resists deformation more in the horizontal direction than the vertical direction. However, it still raised the concern about whether the difference between the elongating operation and widening operation is due to the subjective perception of aspect ratio of faces. Is a long-shaped face more resistant to the elongating operation than other face shapes? Is a wide-shaped face more resistant to the widening operation than other face shapes? To answer such questions, we conducted a subject study asking the subjects to classify the faces into three categories: long faces, average faces, and wide faces. As different subject had different opinion of whether a face is roughly the average length, longer, or shorter, after randomly interviewing five subjects that participated in Experiment 2, we selected generally agreed six long faces, four average faces, and three wide faces. We reanalyzed the data collected in Experiment 2. We classified the test data of Experiment 2 into 77 samples for the case of long faces, 43 samples for the case of average faces, and 33 samples for the case of wide faces. The percentage of subjects who thought the exaggerated faces were similar to the photographs is listed in Table V and Table VI.

Discussion

We found that the results were consistent with those in Table IV because the subjects were less sensitive in all three categories to elongating the faces compared to widening the faces. The highest percentage of subjects believed widened faces were similar to the original photographs for the long faces. This conflicts with the conventional assumption that an exaggeration toward the direction of deviation from an average model is always the most desirable one for better depicting a person's features. Long faces are more resistant to change than other face shapes when widened or elongated within a factor of 10%.

Table III
RESULT OF EXPERIMENT 1: PERCENTAGE OF SUBJECTS WHO THOUGHT THE STRETCHED FACE IS SIMILAR TO THE PHOTOGRAPH.

Direction \ Deformation degree	+ 5%	+ 10%	+ 15%	+ 20%
Vertical	99.6%	81.2%	30.8%	4.4%
Horizontal	86.9%	36.3%	5.6%	0.3%

Table IV
RESULT OF EXPERIMENT 2: PERCENTAGE OF SUBJECTS WHO THOUGHT THE STRETCHED FACE IS SIMILAR TO THE PHOTOGRAPH.

Direction \ Deformation degree	+ 5%	+ 10%	+ 15%	+ 20%
Vertical	99.5%	85.4%	28.5%	4.3%
Horizontal	98.7%	39.7%	4.8%	0%

V. CONCLUSION AND FUTURE WORK

In this paper, we investigated how the change in face shape and the position of facial components influence the similarity of a caricature through a subject study. The experiment system released in this research work can also be utilized as a semi-automatic caricature generation system,

Table V
RESULT OF EXPERIMENT 3: PERCENTAGE OF SUBJECTS WHO THOUGHT THE ELONGATED FACE IS SIMILAR TO THE PHOTOGRAPH.

Face shape \ Length	+ 5%	+ 10%	+ 15%	+ 20%
Long face	100%	89.6%	35.1%	5.2%
Average face	97.7%	83.7%	23.3%	4.7%
Wide face	100%	81.8%	30.3%	6.1%

Table VI
RESULT OF EXPERIMENT 3: PERCENTAGE OF SUBJECTS WHO THOUGHT THE WIDENED FACE IS SIMILAR TO THE PHOTOGRAPH.

Face shape \ Width	+ 5%	+ 10%	+ 15%	+ 20%
Long face	98.7%	45.5%	3.9%	0
Average face	95.3%	27.9%	4.7%	0
Wide face	97.0%	39.4%	6.1%	0

which provides users with control of likeness under quantitative guidelines.

The rendering style of caricature may affect the likeness of a caricature. In future work, we will experiment with caricature in other rendering styles, such as line-drawing style. Although face shape is considered to be the most important feature, the exaggeration of other facial components should also affect likeness. Therefore, we will continue conducting experiments to investigate the effect of exaggerating facial components. In the current study, we do not consider the influence of hair on the recognition of a person. In the future, we will investigate whether a change in hair style has a strong influence on the likeness of a caricature. We will further extend our experiments to males, and explore whether or not the same rules are applicable to both males and females.

ACKNOWLEDGEMENTS

This research was supported by the Natural Science Foundation of Zhejiang Province, China (No. Q12F020007), the Zhejiang Provincial Education Department of China (No. Y201121352), and the Zhejiang Provincial Key Innovation Team on 3D Technology, China (No. 2011R50009).

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