Flexible facial morphing

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Abstract: In the paper, we propose a facial morphing system that uses the triangulation algorithm and linear interpolation associated with a set of indicated control points to introduce a sequence of intermediate images between the source image and the target image. The proposed system provides a guidance mode for the users so that they can follow the online instruction to mark each of the control points. With those control points the system can automatically perform triangulation algorithm and produce the intermediate images for morphing. The experimental results show that the proposed system is flexible to use and provides quite natural morphing results. In addition, the system has no limit to the shape, size, and plane rotation of the faces in both the source image and the target image.

Keywords: active appearance model; AAM; image morphing; triangulation algorithm; linear interpolation; control points.

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1 Introduction

Owing to recent advances in digital technology, topics in image processing and computational photography have drawn the attention of many researchers. Image morphing is one of those topics, for producing smooth transitions between images. Morphing techniques are not limited only to entertainment purposes. Morphing is a powerful tool that can enhance many multimedia projects such as presentations, education, electronic book illustrations, and computer-based training.

Image morphing techniques have been widely used in creating special effects for television commercials and movies, ageing simulation (Hubball et al., 2007; Jayasinghe and Dharmaratne, 2009; Patterson et al., 2006), and forensic sciences (Barbier and Perrot, 2008). Image morphing is an image processing technique used to compute a transformation, that is, a metamorphosis, from one image to another. The process is called ‘morph’ for short. The idea is to create a sequence of intermediate images, which when put together with the original images, represents the transition from one image to the other. The morphed pictures in sequence can be shown as a dynamic process like a movie.

In early morphing techniques, the intermediate images were produced simply using linear interpolation between two images. Those methods were restricted and produced unnatural results. Kouzani et al. (2000) proposed a method of face image morphing that performed a mapping for deformation of the source face image onto the target face image. This is done to map the pixels in the source face image to the location of their corresponding pixels in the target image. Wolberg (1990) effectively covered the fundamentals of digital image warping, culminating in a mesh warping technique which uses spline mapping in two dimensions. Image morphing is the combination of image warping with a cross-dissolve between images. Bui et al. (2003) proposed a method of automatically finding the training set of radial basis function (RBF) networks for morphing a prototype face to represent a new face. Karungaru et al. (2007) proposed a genetic algorithm guided control point extraction method that enables automatic face image morphing. A face detection neural network (FDNN) and medium filters are employed to detect the face position and features. Five control points, for both the source and target images, are then extracted based on the facial features. A triangulation method is then used to match and warp the source to the target image using the control points. Finally, colour interpolation is done using a colour Gaussian model that calculates the colour for each particular frame depending on the number of frames used. Wolberg (1998) surveyed the growth of image morphing and described recent advances in the field and concluded that morphing algorithms all share the following components: feature specification, warp generation, and transition control. The ease with which an artist can effectively use morphing tools is determined by the manner in which these components are addressed. Hassanien and Nakajima (1998) proposed a morphing algorithm which uses a Navier elastic body spline to generate warp functions for interpolating scattered data points. Lin and Huang (1999) applied local warping techniques to construct a framework of image-based morphing for facial expressions animation. They utilised two transformations to deal with local deformations: piecewise polynomial transformation and RBF transformation. Liu et al. (2008) presented an image-based facial animation system using active appearance models (AAM) for precisely detecting feature points in the human face, which are required for selecting mouth images from the database of the face model. Hu et al. (2009) presented a point matching method to overcome the dense point-to-point alignment of scanned 3D faces. They adopted the thin plate spline (TPS) transformation to model the deformation of different 3D faces. Hubball et al. (2007) presented a data-driven framework for facial age progression automatically in conjunction with a database of facial images. They built parameterised local models for face modelling, age-transformation and image warping based on a subset of imagery data selected according to an input image and associated metadata. Jayasinghe and Dharmaratne (2009) presented a way of synthesising a facial image with the ageing effects. Their main goal is to find out whether a conclusion can be arrived at as to how the appearance of a face changes subject to age levels.

In this paper, we propose a facial image morphing system, which uses a corresponding set of carefully indicated control points for each of the two images, employs the linear interpolation between two sets of control points to build a set of control points for each of the intermediate images, and finally, applies the triangulation algorithm to give colours to each of the intermediate images. The system can also be applied on face aging and morphing of objects other than faces. Besides, the system has no restriction to the shape, size or plane rotation of both the source facial image and target facial image. As a result, the system is highly flexible. The experimental results show that the morphing results provided by our proposed system look natural.

The rest of this paper is organised as follows. In Section 2, we introduce the proposed facial morphing method. Experimental results and comparisons are given in Section 3. Then the evaluation part of the proposed method is described and finally the paper will be winded up with the conclusions.

2 Image morphing

Image morphing means creating a sequence of morphed images which when played in sequence, show one image being slowly changed into another image. The main issue is how to create such a sequence of morphed images, so that dynamic process looks natural like a movie. This section will introduce two of the early morphing techniques, and the proposed morphing techniques.

2.1 Method by simple linear interpolation

One of the early morphing techniques used simple linear interpolation between the source image S and the target image T. It simply creates a sequence intermediated morphed images, L_1, L_2, …, and L_m, as defined in equation (1). This method is limited on size, shape, and location of the objects in the two images. The result of morphing between two images whose objects are different in size, shape, or location is poor because significant overlap effect is produced.

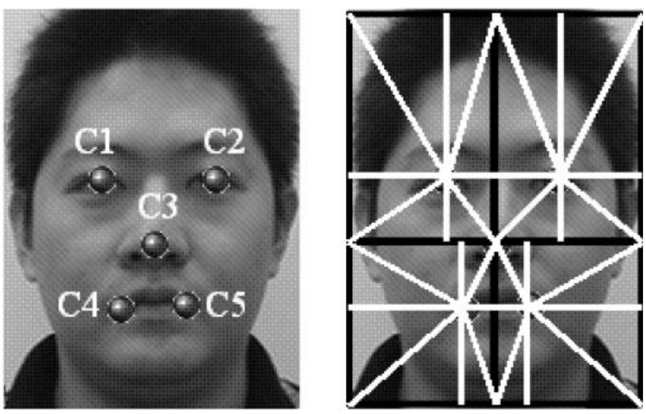
Noise candidates include both noises and edge points. By observing many images taken in low light conditions, the noises from high ISO have blobs with size not larger than 3 × 3, whereas the edges points usually form blobs larger than that. Therefore, by connected component (CC) analysis on those noise candidates, we label those candidates to be noises if the CC has the size not larger than 3 × 3. To smooth noises, the intensity of every noise point *P* is replaced by the average intensity value taken from non-noise points of a 5 × 5 window on *I* (centred at *P*). Figure 2(b) shows the smoothed result *D*.

$$L_j(x_i, y_i) = \frac{m+1-j}{m+1} S(x_i, y_i) + \frac{j}{m+1} T(x_i, y_i), \quad \text{for } j = 1, 2, \ldots, m. \tag{1}$$

2.2 Karungaru's facial morphing method

Karungaru et al. (2007) proposed a facial morphing method, which first used a neural network method, called FDNN, to detect human faces in the images. Firstly the location of nose tip is detected according to skin colour, as marked by C3 in Figure 1(a). The eyes and lips were then detected using the genetic algorithm, as indicated by C1, C2, C4, and C5 in Figure 1(a). These five points, called the control points, are used to segment the whole image into 32 triangles, as shown in Figure 1(b). The morphed image is made by linear interpolation between two corresponding triangular regions from the two input images.

Figure 1 Karungaru's method, (a) control points (b) triangle segmentation



(a) (b)

2.3 The proposed method

To address the overlap effect, we use the triangulation algorithm based on the corresponding control points from the two images. The proposed facial morphing system consists of the following steps: control point selection, segmentation by triangulation algorithm, creating a sequence of intermediate images of triangulation segmentation, rendering colours to each of the intermediate images. Each step will be described in the following sub-sections.

2.3.1 Selection of control points and triangulation segmentation

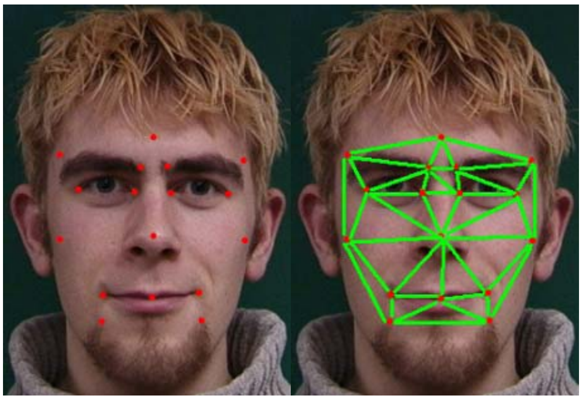
AAM decouples and models two parts of an object: shape and texture. The shape is a vector formed by concatenating the position elements of the control points (or landmarks), while the texture means the measure of pixels, which is usually represented by intensities or colours. Also, both the source image and the target image with corresponding control points are required for facial feature replacement, so the corresponding replacing colour for each point in the target image can be determined. Two sample images with corresponding control points are shown in Figure 2, where control point a_i in image 1 corresponds to control point b_i in image 2, i = 1, 2, ..., 5. The control points can be automatically generated or given (marked) by the users. The control points are given by the users for our system, since this method provides more flexibility.

Figure 2 Two face images with corresponding control points, (a) image 1 (b) image 2 (see online version for colours)

(a) (b)

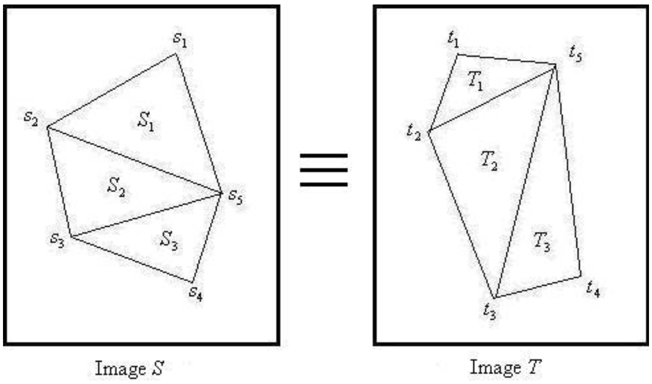
As soon as the source image and target image are provided with corresponding control points, the triangulation algorithm is utilised to segment each of the two images into triangular regions in the same way, and to warp and paste each triangular region in the source image on the corresponding region in the target image. An example of a face image segmented into triangular regions by the triangulation algorithm, according to the marked control points shown in Figure 3(a), is shown in Figure 3(b).

Figure 3 Triangulation segmentation, (a) image with control points (b) triangulation model (see online version for colours)

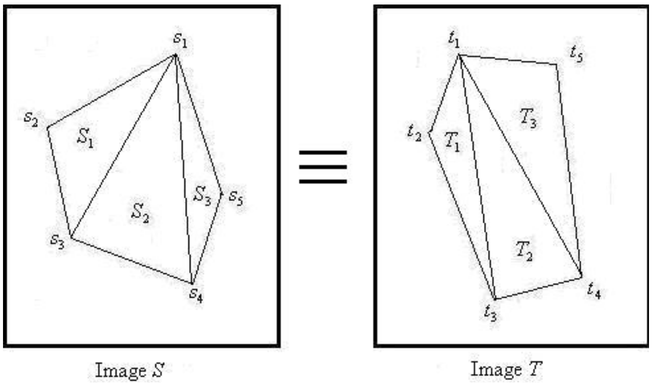


(a) (b)

Figure 4 Image S and image T with corresponding control points were segmented into triangular regions in the same way (a) segmentation 1 (b) segmentation 2



(a)



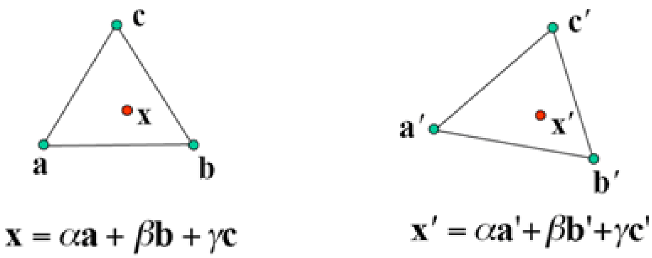
(b)

The source image and the target image must be segmented in the same way. For example, if the source image S and the target image T are provided with the sequences of corresponding control points ($s_1, s_2, \ldots, s_n$) and ($t_1, t_2, \ldots, t_n$), respectively, then for each segmented triangular region $\Delta s_i s_j s_k$ in S the corresponding triangular region $\Delta t_i t_j t_k$ must exist in T. Figure 4 shows two segmentation examples for two images, in each of which the two images are segmented into triangular regions in the same way according to their corresponding control points.

2.3.2 *Intermediate shapes of triangulation segmentation*

To make natural morphing results, we first create shapes of triangular regions in the intermediate morphed images. Suppose the source image S are provided with k control points $s_i = S(x_i, y_i)$, $i = 1, \ldots, k$, and the target image T is also provided with k corresponding control points $t_i = T(x_i', y_i')$, $i = 1, \ldots, k$. As shown in Figure 5, the triangle Δabc in the source image and the triangle $\Delta a'b'c'$ in the target image are formed by the triangulation algorithm, where a, b, and c are three control points in the source image corresponding to the control points a', b', and c' in the target image. Let x be a point lies in Δabc, then its corresponding point x' in the target image must lies in $\Delta a'b'c'$. Further, there must exist a unique set of non-negative real numbers α, β, and γ such that $\alpha + \beta + \gamma = 1$, $x = \alpha a + \beta b + \gamma c$, and $x' = \alpha a' + \beta b' + \gamma c'$. For any given point x' in the target image, which lies in a triangle $\Delta a'b'c'$ produced by a triangulation algorithm, the non-negative real numbers α, β, and γ can be solved by solving a linear system. As a result, the corresponding point x lying in the corresponding triangle $\Delta a'b'c'$ of the source image can be found.

Figure 5 Correspondence between (a) source image and (b) target image (see online version for colours)

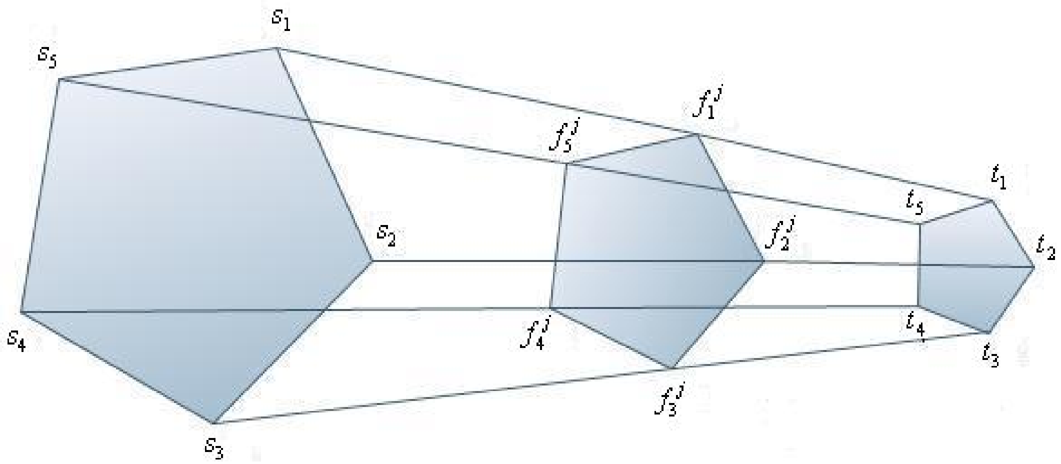


(a) (b)

Let F^1, F^2, ..., and F^m be the intermediate morphed images, each of which also has its own set of corresponding control points. The corresponding k control points for the image F^j are $f_i^j = F^j(x_i'', y_i'')$, for $j = 1, 2, \ldots, k$, where x_i'' and y_i'' are defined in equation (2). Figure 6 shows an example of warped image F^j its relationship with the source S and target T.

$$x_i'' = \left[\frac{m+1-j}{m+1} x_i + \frac{j}{m+1} x_i'\right],$$
$$y_i'' = \left[\frac{m+1-j}{m+1} y_i + \frac{j}{m+1} y_i'\right] \tag{2}$$

Figure 6 Shape corresponding to control point morphing process (see online version for colours)



2.3.3 *Colour rendering to intermediate images*

The last step is to render a colour to each pixel, $F^i(x'', y'')$ in each of the intermediate images, F^j. To do so, we need to find its corresponding point in *S*, say *S*(*x*, *y*) in a triangular region Sh, and its corresponding point in *T*, say *T*(*x*′, *y*′) in a triangular region Th. This can be done by using equation (2). Rendering colour to $F^i(x'', y'')$ can be done by linear interpolation between the colours of *S*(*x*, *y*) and *T*(*x*′, *y*′), as given in equation (3).

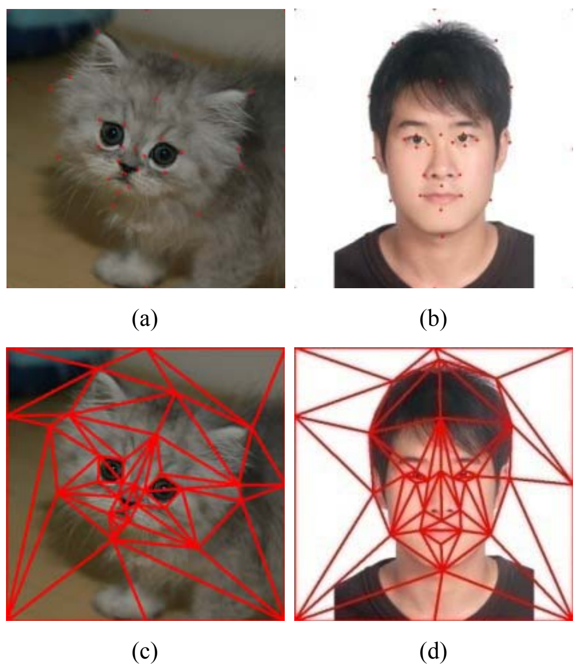
$$colour\left(F_j(x'', y'')\right) = \frac{m+1-j}{m+1} colour(S(x, y)) + \frac{j}{m+1} colour\left(T\left(x', y'\right)\right) \tag{3}$$

3 Experimental results

In this section, we show a set of experimental results to demonstrate the performance of the proposed system and compare our method with two other methods. Our experiments were implemented in Windows XP operating system, with MATLAB 7.0, and tested on a 2.26 GHz Core 2 Duo PC with 3GB memory. Two test images shown in Figure 7 are selected from the free AAM database (http://www2.imm.dtu.dk/~aam/). The proposed facial morphing system requires average 58 seconds for generating facial morphing of an intermediate image with size of 315 × 443.

The proposed system provides an interface for users to mark control points and form triangles for segmentation. Figures 7(a) and 7(b) show two test images of different plane-rotation angles, both with control points provided, and Figures 7(c) and 7(d) show the corresponding triangulation segmentation, and Figure 8 shows the morphing result based on those control points. Figures 10 and 11 show the morphing results of the face images shown in Figure 9, by the method proposed by Karungaru et al. (2007) and our proposed method (with 22 control points), respectively. It is evident that our method indeed provides much more natural morphing results than the other two methods. Figure 12 shows another morphing example produced by our method.

Figure 7 (a) and (b) Test images with control points (c) and (d) Triangulation segmentation results (see online version for colours)



(a) (b) (c) (d)

Figure 8 Morphing result of images shown in Figure 7 (see online version for colours)

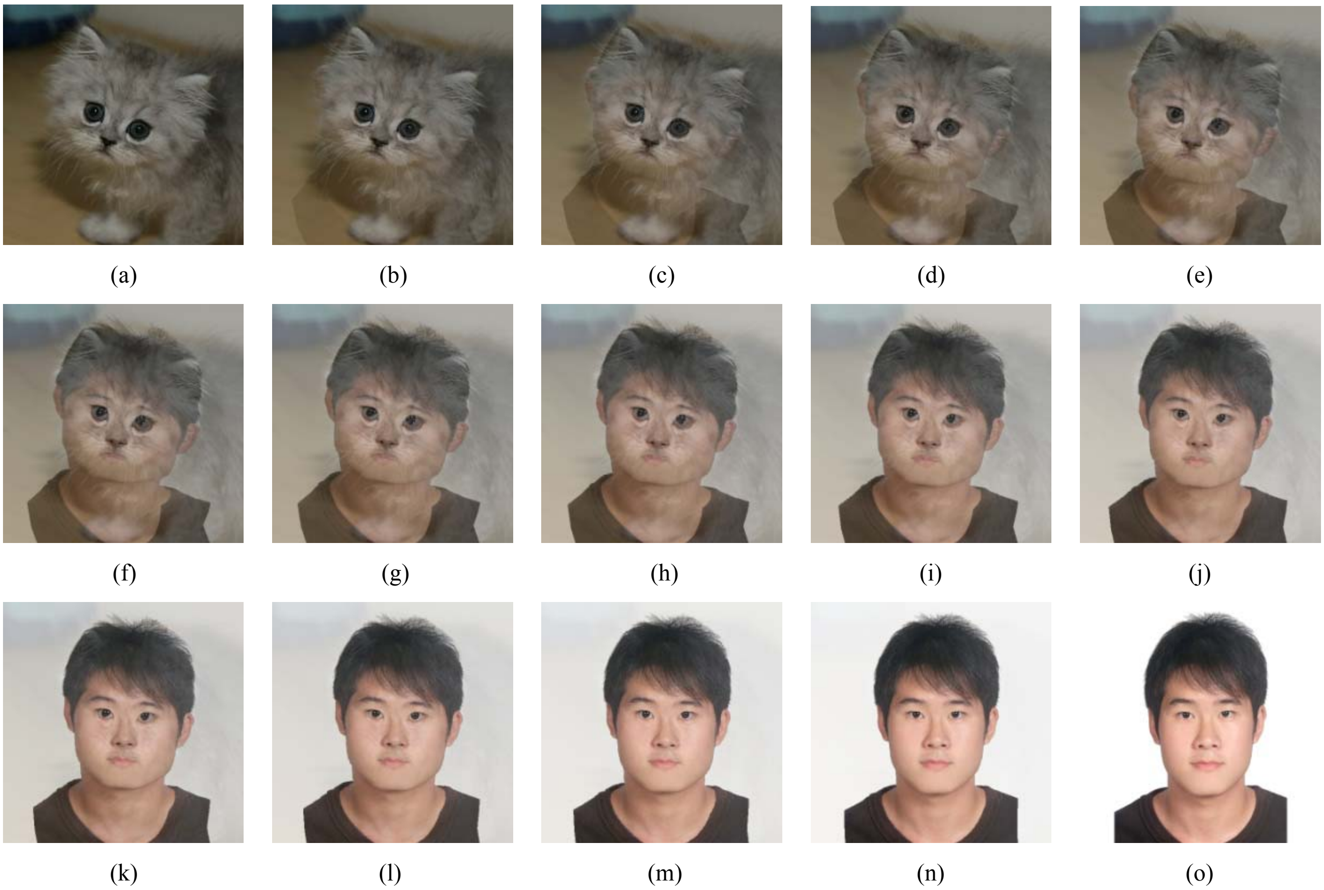


Figure 9 Test images, (a) source image (b) target image (see online version for colours)

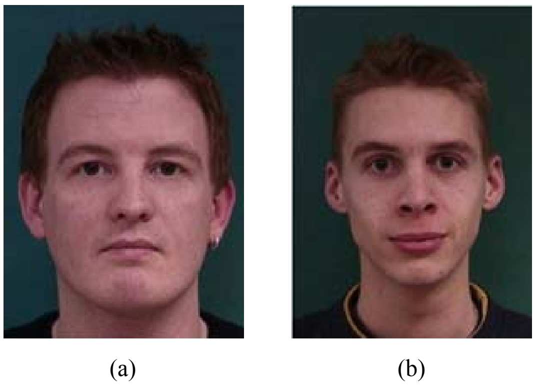


Figure 10 Morphing result provided by Karungaru et al. (see online version for colours)

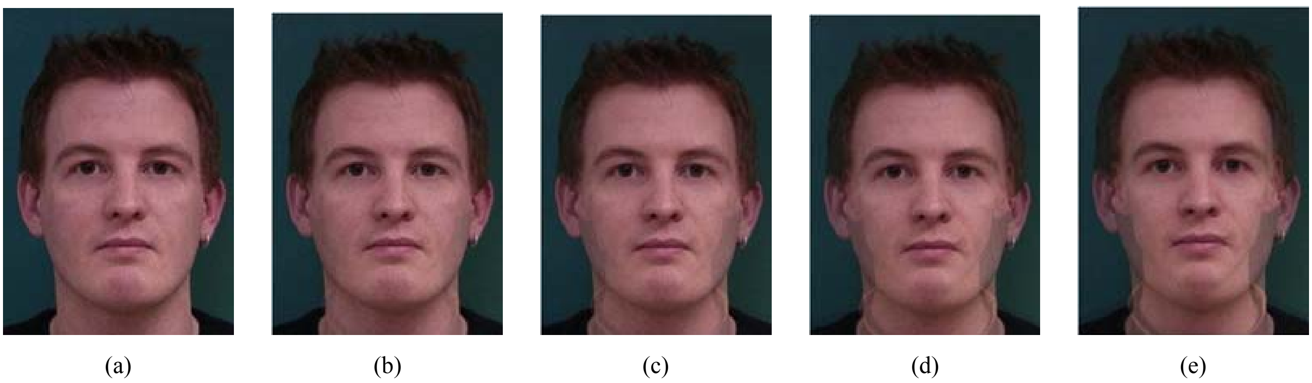
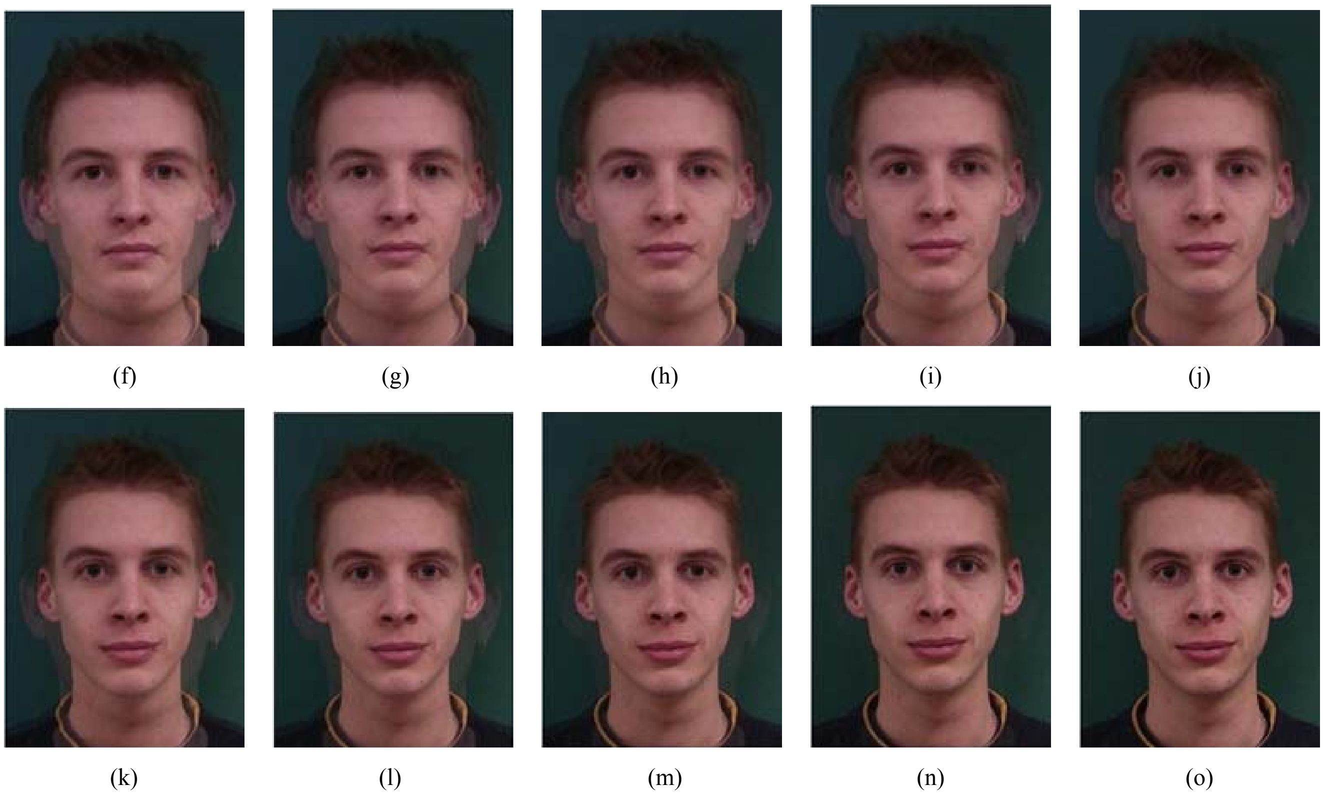


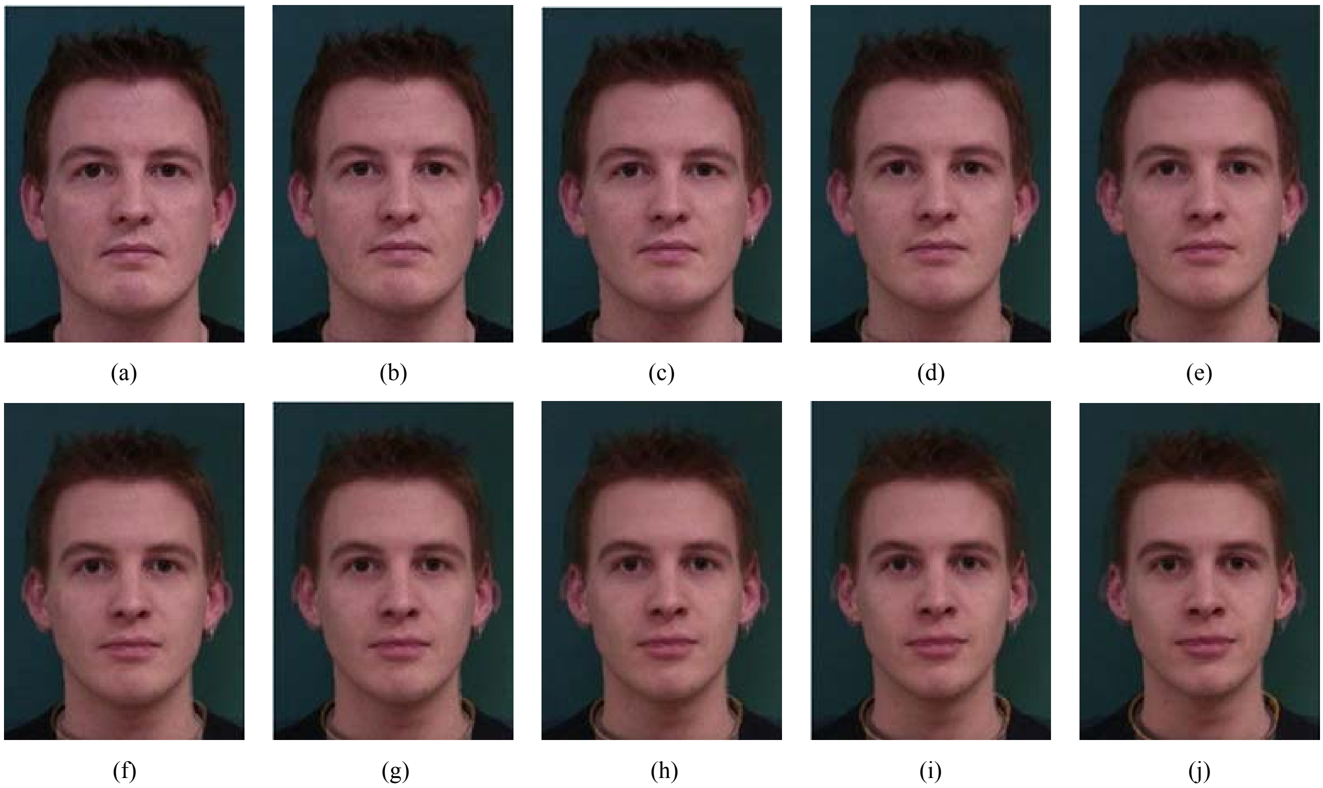
Figure 10 Morphing result provided by Karungaru et al. (continued) (see online version for colours)



(f) (g) (h) (i) (j)

(k) (l) (m) (n) (o)

Figure 11 Morphing result provided by our proposed method (with 22 control points) (see online version for colours)



(a) (b) (c) (d) (e)

(f) (g) (h) (i) (j)

Figure 11 Morphing result provided by our proposed method (with 22 control points) (continued) (see online version for colours)

(k) (l) (m) (n) (o)

Figure 12 Morphing result of face paintings (see online version for colours)

(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j) (k) (l)

(m) (n) (o) (p)

4 Evaluation

To evaluate the performance of our proposed method, 100 human face photographs were randomly chosen from the free AAM database (http://www2.imm.dtu.dk/~aam/) to form 50 pairs of source and target images. A selected group of ten college students were allowed to use this system. They used the guidance mode to morph each of the 50 pairs of images and produce a sequence of ten intermediate images. And this was mainly evaluated based on a questionnaire by another group of 30 students. For each pair of test images, the students evaluated the results obtained by the first group of ten students using our system and both the results yielded by the two compared methods.

The question is whether the sequence of intermediate images is of high quality and the students are required to give their opinion in five different categories (each with a specific users' expectation rate) as follows.

- strongly high quality: expectation rate 100%; percentage p_1
- high quality: expectation rate: 75%; percentage p_2
- fair quality: expectation rate: 50%; percentage p_3
- low quality: expectation rate 25%; percentage p_4
- strongly low quality: expectation rate 0%; percentage p_5.

Opinions on the results obtained by the simple interpolation method, Karungaru et al.s' method, and our method are summarised in Table 1. The rates p of users' expectations, as defined in equation (4), for the three methods are 1.5%, 41.0%, and 81.5%. Although the results provided by our method gain the highest users' expectation rate, they can be further improved by selecting more control points for morphing.

$$p = 1\times p_1 + 0.75\times p_2 + 0.5\times p_3 + 0.25\times p_4 + 0\times p_5 \tag{4}$$

5 Conclusions

In this paper, we proposed a flexible facial morphing system, which uses sets of corresponding control points from the source image and from the target image to segment the images into triangular regions, and create a sequence of intermediate morphed images with this correspondence. The users can have the results they desired by controlling the two sets of corresponding points from the two input images. The experimental results show that our method provides more natural morphing results than the other compared methods. The advantages and characteristics of our system are summarised in the following.

1. it has no restriction on the sizes, shapes, or even in-plane rotation angles of the objects (faces) in the images
2. morphing range can be part of the object (face), such as facial features including or not including hair, ears or chin, or the whole object
3. if the users want a finer result, they may choose more control points to obtain the result they desire
4. the application of the proposed system could be extended to deal with non-face images.

As mentioned above, the number of control points is determined by the users. The more control points provided, the finer the result. The result shown in Figure 10 taking the default of 22 control points has slight overlapping effect on the ears of the intermediate images. However, it could be solved by providing a couple more control points on the ears. In the future, we will provide more options of guidance modes, including coarse, median, and fine levels, each giving a specific number of control points. The proposed system has no restriction on in-plane rotation, but it tolerates only a small range of off-plane rotation. How to address this problem is also included in our future work.

Table 1 Evaluation of expectation for three methods

Percentages \ *Methods*	*Simple interpolation*	*Karungaru et al.'s method*	*Our method*
Strongly high (p_1)	0/750 ≈ 0.00%	4/750 ≈ 0.53%	488/7,500 ≈ 6.51%
High (p_2)	0/750 ≈ 0.00%	18/750 ≈ 2.40%	6,726/7,500 ≈ 89.68%
Fair (p_3)	1/750 ≈ 0.13%	549/750 ≈ 73.20%	284/7,500 ≈ 3.78%
Low (p_4)	15/750 ≈ 2.00%	158/750 ≈ 21.07%	2/7,500 ≈ 0.03%
Strongly (p_5)	734/750 ≈ 97.87%	21/750 ≈ 2.80%	0/7,500 ≈ 0.00%
Rate (p)	0.57%	44.20%	75.67%

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