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Automatic Transformation of "KOGAO" (Small Face) based on Fast B-spline Approximation

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Abstract. *Many female and male want to show more attractive their facial images. "KOGAO" which is a Japanese word and means "small-face" or "make face look smaller" is considered as an attractive face. In this paper, we propose an automatic "KOGAO" transformation method based on a fast B-spline approximation. We use an Active Appearance Model to extract landmarks (feature points) on the face outline automatically and these landmark points are warped to corresponding target points, which are also automatically generated, in order to generate a "KOGAO" based on B-spline approximation. We also propose a warping domain reduction method in order to speed up the transformation, which can be considered as a kind of fast B-spline approximation method.*
Keywords: B-spline approximation, facial image, KOGAO (small face), warping warping domain reduction method, automatic image warping.

1. **Introduction.** As the spread of the digital camera and the cellular phone, people can easily take a digital picture. Many female and male want to show more attractive their facial images in the picture. "KOGAO" which is a Japanese word and means "small-face" or "make face look smaller" is considered as an attractive face [1]. In this paper, we propose a image warping technique to generate a "KOGAO" automatically.

Recently, image warping has been of great interest in computer vision and multimedia [2,3]; moreover, it is an important step in many applications of image analysis such as image morphing and image deformation. Various warping algorithms have been proposed such as mesh warping [4], radial basis functions [5], thin plate splines [6, 7], and B-splines (free-form deformations) [8, 9, 10]. In particular, the B-spline approximation based free form deformation is a powerful and widely used morphing algorithm; it has been proven to possess the one-to-one property that prevents the warped image from folding back upon itself. But, the B-spline approximation is computationally expensive. Therefore, it is still a challenge to obtain precisely warped images with improved efficiency. In this study, a fast B-spline method is proposed for automatic "KOGAO" transformation. This method can also maintain the warping precision. Furthermore, in conventional B-spline approximation, there are numerous parameters that are to be decided by the users, such as feature points, target points, and control lattices. In the proposed method, all these parameters are determined automatically. Therefore, it is simple to implement and can reduce subjective deformation errors.

This paper is organized as follows. Section 2 reviews the conventional B-spline approximation. Automatic image warping method for "KOGAO" transformation is presented in Section 3, and a newly proposed warping domain selection method for fast and efficient image deformation is presented in Section 4. Experimental results are presented in Section 5. The conclusion and future work are given in Section 6.

2. **B-spline Approximation.** In this section, we briefly describe B-spline approximation, which is a popular method used for image warping. As shown in FIGURE 1, we first give a set of feature points and corresponding target points. The goal of image warping based on B-spline approximation is to transform the feature points (landmarks) to the target points while the other points in the original image are transformed based on B-spline interpolation.

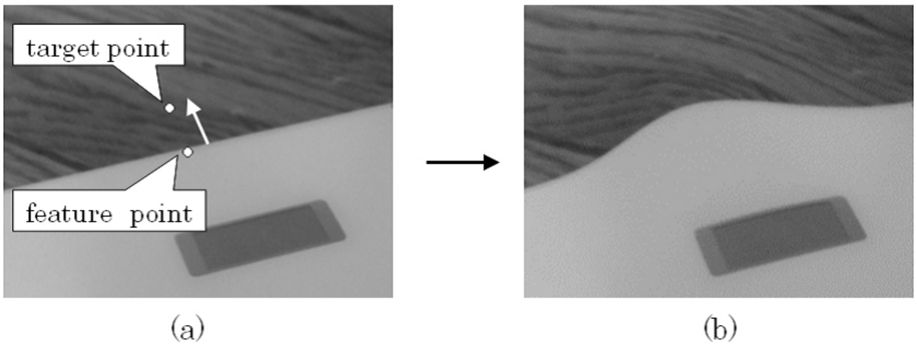


FIGURE 1. Example of image transformation (image warping) based on B-spline approximation (a) Feature point and target point, (b) Transformed image

2.1. **Basic B-spline Approximation.** Image warping is a form of transformation that changes the spatial configuration of an image using a warping function $f(x, y)$. As shown in FIGURE 2, B-spline approximation is performed using control lattice. A local domain containing 9 blocks and 16 control points (the light gray region) is defined. The warping is performed in this local domain after which the local domain is shifted, and then warping is performed in a new region. This process is repeated until all the pixels in an image are covered.

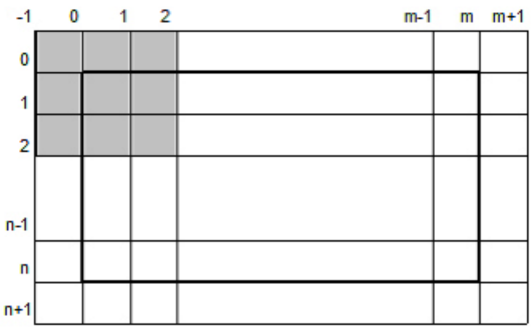


FIGURE 2. Control lattice of B-spline approximation

Let $\Omega = \{(x, y)| - 1 \le x \le m + 1, -1 \le y \le n + 1\}$ be a rectangular domain in a two-dimensional space, and Φ be the top (control point) group of the control lattice. Let there also be a set of scattered points $P = \{(x, y, z)\}$ in the three-dimensional space, where $\{(x, y)\}$ are inputs (coordinates of landmarks in Ω) and $\{z\}$ is the output (target coordinates x' or y').

A B-spline function approximates the scattered data P using the control lattice and is defined as the approximation function.

Let ϕ_{ij} be the value of the ij-th control point on Φ. The approximation function f is defined in terms of these control points by

$$z = f(x, y) = \sum_{k=0}^{3} \sum_{l=0}^{3} B_k(s) B_l(t) \phi_{(i+k)(j+l)} \tag{1}$$

where $i = [x] - 1,\ j = [y] - 1,\ s = x - [x],\ t = y - [y]$ (note that $[x]$ refers the greatest integer less than x). B_k and B_l are uniform cubic B-spline basis functions defined as

$$\begin{aligned} B_0(s) &= (1 - s)^3/6 \\ B_1(s) &= (3s^3 - 6s^2 + 4)/6 \\ B_2(s) &= (-3s^3 + 3s^2 + 3s + 1)/6 \\ B_3(s) &= s^3/6 \end{aligned} \tag{2}$$

where $0 \le s < 1$. These functions calculate the contribution of each control point to the function $f(x, y)$.

In image warping, given a set of corresponding landmarks, feature points and target points are defined as follows:

$featurepoints : \{(x_1, y_1), (x_2, y_2), \cdots (x_n, y_n)\}$

and

$targetpoints : \{(x'_1, y'_1), (x'_2, y'_2), \cdots (x'_n, y'_n)\}$.

The warping parameters of the control points $(\phi^x_{kl}, \phi^y_{kl})$ can be estimated using the following equations [7].

$$\begin{aligned} \phi^x_{kl} &= \frac{\sum_{i=1}^{n} \sum_{k=0}^{3} \sum_{l=0}^{3} B_k(s_i) B_l(t_i) x'_i}{\sum_{k=0}^{3} \sum_{l=0}^{3} (B_k(s_i) B_l(t_i))^2} \\ \phi^y_{kl} &= \frac{\sum_{i=1}^{n} \sum_{k=0}^{3} \sum_{l=0}^{3} B_k(s_i) B_l(t_i) y'_i}{\sum_{k=0}^{3} \sum_{l=0}^{3} (B_k(s_i) B_l(t_i))^2} \end{aligned} \tag{3}$$

2.2. **Adaptation to Local Warping.** FIGURE 3 shows that neighborhoods involving the control points may overlap, if two feature points are sufficiently close to each other. In such cases, different values can be assigned to these shared control points. An accurate solution for this problem remains to be found. This problem still awaits accurate solution.

Let ϕ_{ij} be the correct value of the common ij-th control point on Φ and ϕ^c_{ij} be the value of the ij-th control point assigned by proximity landmark c. The correct value of ϕ_{ij} can then be estimated as following equation [7].

$$E(\phi_{ij}) = \sum_c (\sum_{k=0}^{3} \sum_{l=0}^{3} B_k(s) B_l(t) \phi_{(i+k)(j+l)} - \sum_{k=0}^{3} \sum_{l=0}^{3} B_k(s) B_l(t) \phi^c_{(i+k)(j+l)})^2 \tag{4}$$

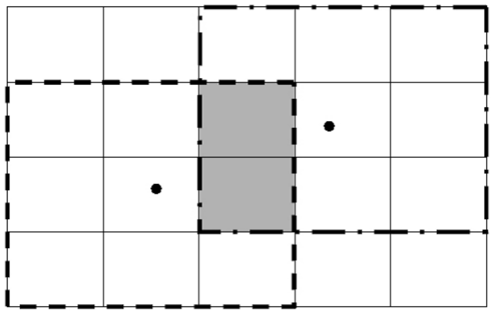


FIGURE 3. Overlap of influence domains

Using B-spline approximation, natural and smooth image warping can be achieved. However, it is computationally intensive and many parameters need to be specified.

3. **Automatic "KOGAO" Transformation.** In this study, we propose an automatic "KOGAO" transformation method based on the B-spline approximation. An example is shown in FIGURE 4.

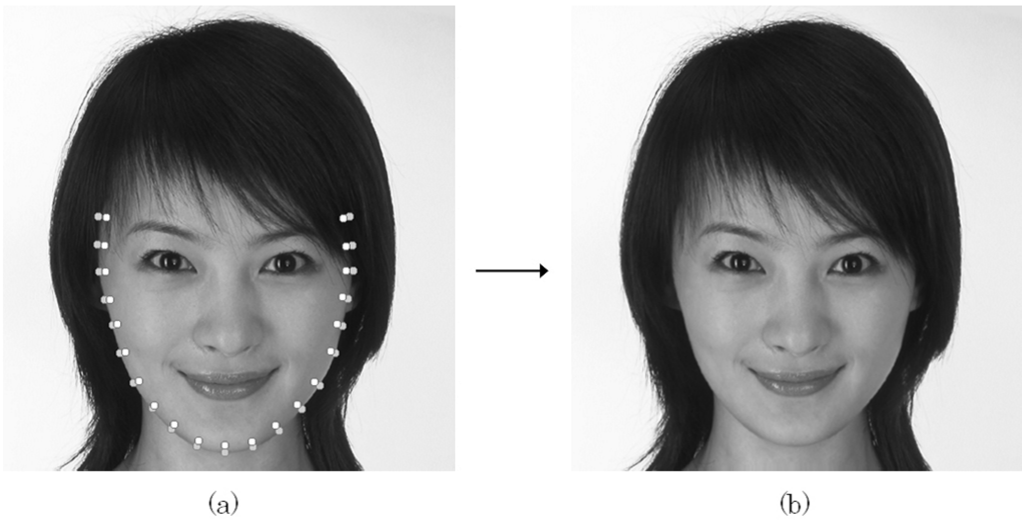
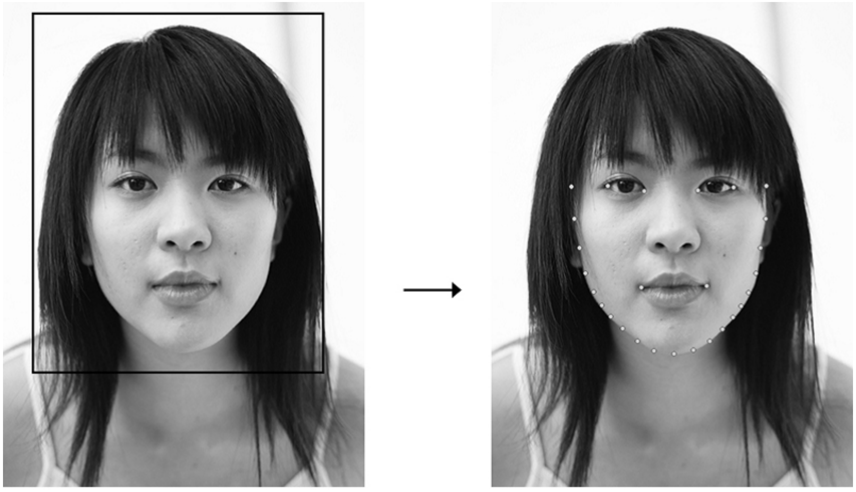


FIGURE 4. "KOGAO" transformation (a) Feature points and target points, (b) Transformed image

The method can be divided into following three phases:
(1) automatic extraction of feature points
(2) automatic determination of corresponding target points
(3) optimization of control lattice size

3.1. **Automatic Extraction of Feature Points.** We first detect the face area in the picture (FIGURE 5(a)) and then 27 feature points are extracted by using Active Appearance Model (AAM) in this area as shown in FIGURE 5(b) [11]: furthermore, this model's accuracy is improved by extracting the face area beforehand. Points belonging to the eyes and the mouth are extracted together with feature points on the outline of the face.

3.2. **Automatic Determination of Corresponding Target Points.** 21 feature points in the outline of the face are used as landmarks for transformation. The keypoint for transformation of a natural "KOGAO" is how to select corresponding target points. In



(a) (b)

FIGURE 5. Flow of feature points extraction (a) Face extraction, (b) Feature points extraction

many image warping applications, the target points are usually selected by users manually. It is time-consuming and it becomes the user's load.

In this study, we propose an automatic method to determine the target points. The idea is shown in FIGURE 6. We first set a center point and then each target point is set on the line that connects the corresponding landmark with the center point. The position of center point and the distance between the target point and the landmark are determined by psychological tests, respectively.

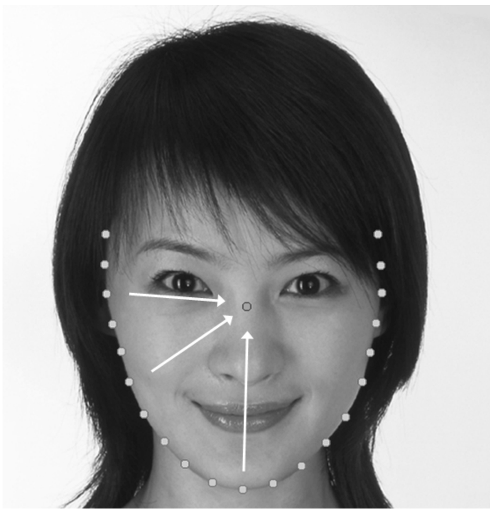
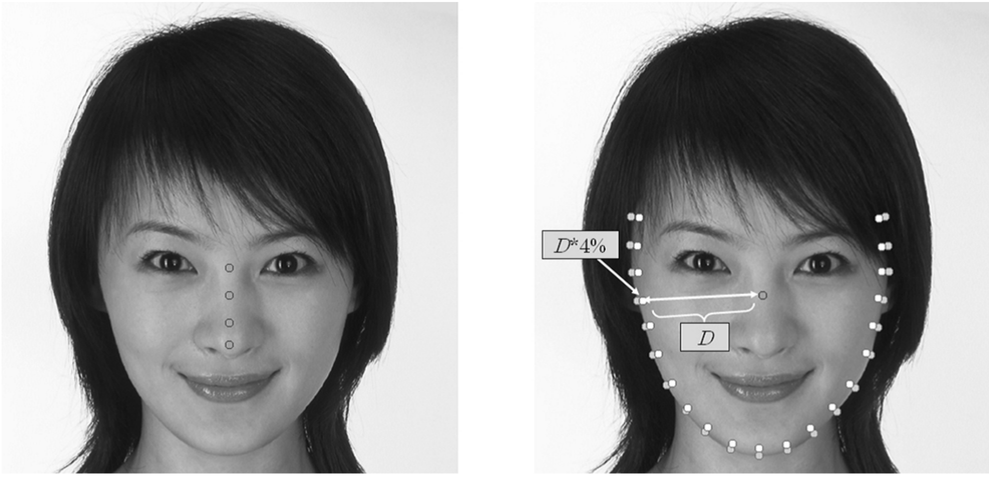


FIGURE 6. Movement direction of feature points

We select 4 candidates on the line that connects the center of the eyes and the center of the mouth as center points as shown in FIGURE 7 (a). The ratios (distance to the center of eyes/ distance to the center of mouth) are 10:0, 8:2, 6:4 and 4.7:5.3, respectively. It should be noted that the ratio for the 4th candidate point is set to ensure the point on the tip of nose.



(a) (b)

FIGURE 7. Candidate of center point and warping distance (a) Candidate points of center point, (b) Warping distance

The distance between the target points and the landmarks decides the degree of "KOGAO", which is called as warping distance. It should be dependent on the size of face. Let D be the distance between the landmark and the center point (approximate radius of the face). Five warping distance of $D * 2\%$, $D * 4\%$, $D * 6\%$, $D * 8\%$, $D * 10\%$ are used as candidates for evaluation as shown in FIGURE 7 (b). We transformed the facial image with different combination of center point and the warping distance. Totally we obtained 20 transformed "KOGAO" images for one subject.

In psychological tests, 25 subjects' facial images (500 transformed "KOGAO" images) are used for test. 32 college students are asked to answer the question. The question is that "the transformed image is natural or unnatural". The ratio answered as unnatural in the respondent was used as a measure of unnaturalness. The unnaturalness for each transformed "KOGAO" image is shown in TABLE 1.

TABLE 1. Unnaturalness of the transformed "KOGAO" images with different combination of candidate center points and the target distance

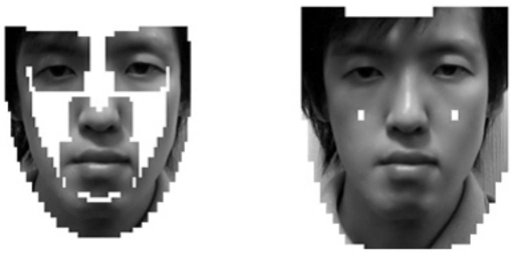
	Warping distance (%)				
	2	4	6	8	10
candidate point 1	0.625%	1.250%	6.250%	35.000%	67.500%
candidate point 2	0.625%	0.000%	5.000%	29.375%	70.000%
candidate point 3	1.250%	0.625%	5.000%	45.000%	76.875%
candidate point 4	0.625%	4.375%	6.825%	44.375%	76.250%

As shown in TABLE 1, the transformation with larger warping distance will generate an unnatural "KOGAO" image and the warping distance should be less than 6% of the radius of the face (D). There is no significant difference among four candidate center points. When we choose the candidate point 2 as center point and the warping distance as 4% of the radius of the face, the transformed "KOGAO" image is the most natural. So in our proposed method the center point is set in the position of candidate 2 and the warping distance is set as 4% of radius of the face.

3.3. **Optimization of Control Lattice Size.** In conventional B-spline based warping techniques, whole image is started with a uniform lattice for warping. On the other hand, the size of lattice (the number of control points) will significantly effect the transformation, several examples are shown in FIGURE 8. FIGURE 8 (a) is the original image and FIGURE 8 (b) is the warped image with optimum lattice size (suitable control points). If the lattice size is very small (very much control points), the transformed image is becoming an unnatural image as shown in FIGURE 8 (c) (the unnatural part is indicated with a white circle), while if the lattice size is very large (very fewer control points), the warping accuracy will be very low as shown in FIGURE 9 and we need to use a multi-level technique [12] to reduce the warping error, which is time-consuming technique.

(a) (b) (c)

FIGURE 8. Transformation with very small lattice size (a) Original image, (b) Transformed image with optimum lattice size, (c) Transformed image with very small lattice size



(a) (b)

FIGURE 9. Transformation with very large lattice size (a) Transformation domain with optimum lattice size, (b) Transformation domain with very large lattice size

In order to find an optimum lattice size, we performed a psychological test again. We transformed the image to "KOGAO" with 4 different lattice sizes which are normalized by the distance between the landmarks. 25 subjects' facial images (100 transformed "KOGAO" images) are used for test. Three subject' transformed images are shown in FIGURE 10 as examples. As well as the previous psychological test, 32 college students are asked to answer the question. The question is that "the transformed image is natural or unnatural". The ratio answered as unnatural in the respondent was used as a measure of unnaturalness. The unnaturalness for each transformed "KOGAO" image is plotted in FIGURE 11.

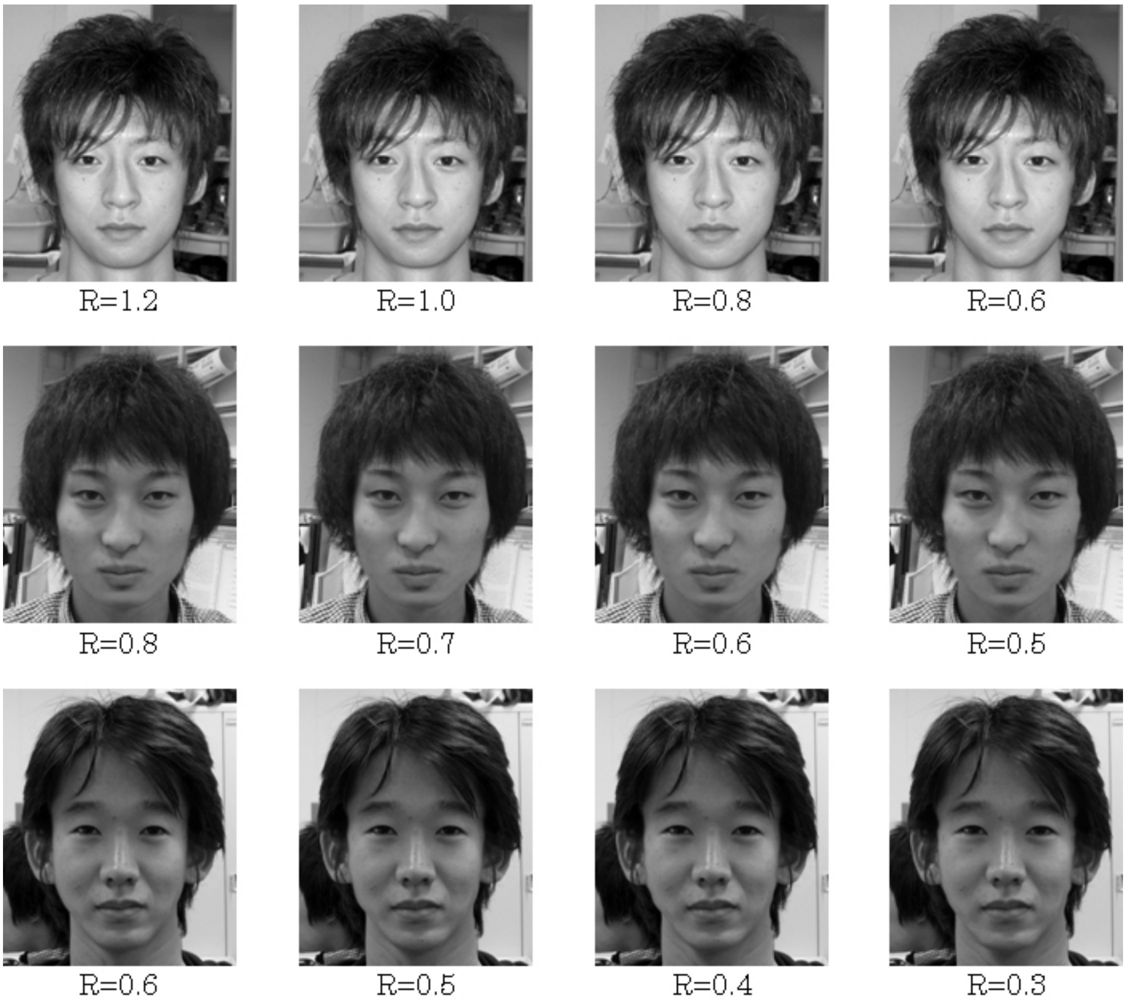


FIGURE 10. Transformed images are used for psychological test (R=lattice size / warping distance of landmarks)

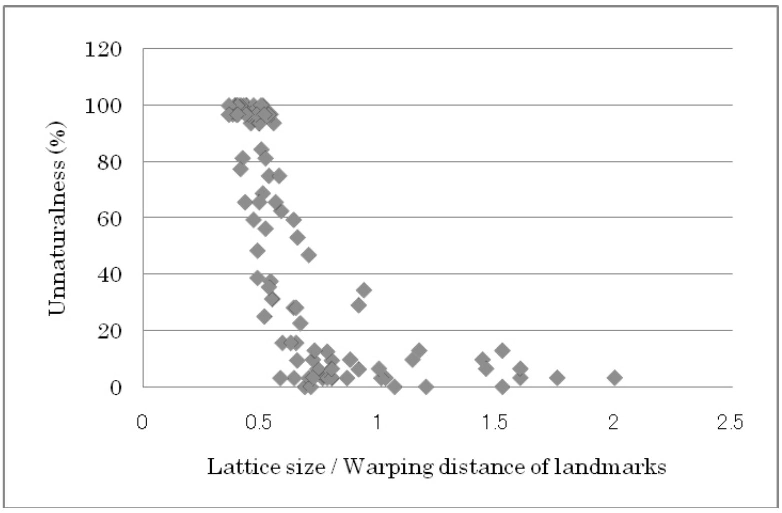


FIGURE 11. Unnaturalness vs. lattice size / warping distance

As shown in FIGURE 11, unnatural shapes were not recognized when the control lattice size exceeded the warping distance. Therefore, our proposed method is suitable when the warping distance is equal to the control lattice size.

4. **Warping Domain Reduction Method.** We propose a warping domain reduction method for B-spline approximation in order to reduce the large computation cost.

4.1. **Control Points Selection.** In B-spline approximation, only the 3*3 neighboring control points of a given feature points are used for calculation. We do not need to do calculations for other control points. In conventional B-spline based methods, all the control points are calculated for a given landmark (feature point) as shown in FIGURE 12 (a). In our proposed control points selection method, we first propose to use only the neighboring control points for calculation as shown in FIGURE 12 (b). In FIGURE 12, we have 4 landmarks as indicated by points.

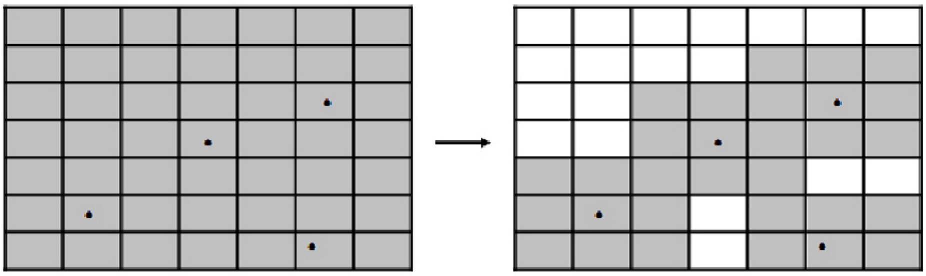


FIGURE 12. Transformation domains in B-spline

4.2. **Thresholding.** Since we have to perform the transform or transformation process for each pixel of the selected domain, it takes a large computation cost. If the calculated position change is small, there will be no significant visual change in the transformed image. So we set a threshold and if the position change of a pixel is smaller than the threshold, we do not make the transform and go to next pixel. By using the proposed thresholding method, the number of pixels should be processed are significantly reduced as shown in FIGURE 13. In FIGURE 13, the gray regions show the pixels should be processed or transformed.

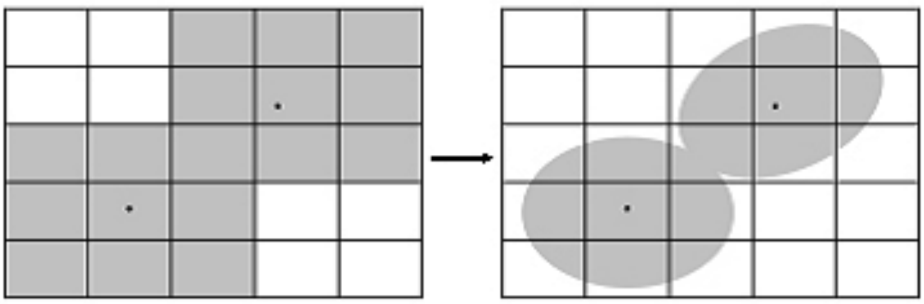


FIGURE 13. Localization of influence domain using threshold

Some examples are shown in FIGURE 14 and 15. The result by using control point selection is shown in FIGURE 14. The white pixels are those which do not need to be processed. It means the warping domain is significantly reduced. The warping domain can be reduced further by using the thresholding method, which is shown in FIGURE 15. The number of pixels should be processed (white pixels) are reduced further.

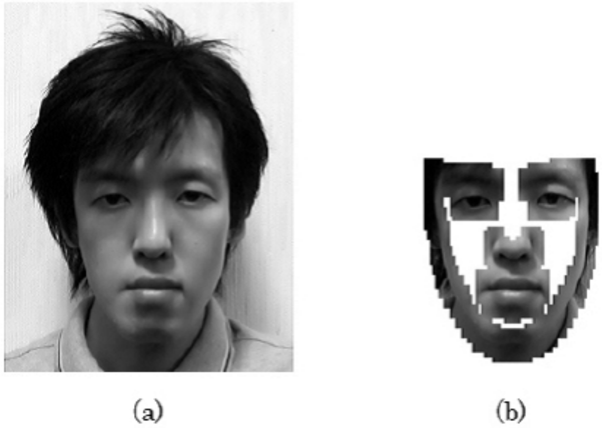


Figure 14. Transformation domains using control points selection (a) Conventional transformation domain, (b) Localized transformation domain using control points selection

Figure 15. Transformation domains using threshold (a)Localized transformation domain using control points selection, (b) Further localized transformation domain using threshold

5. **Experiment Results.** In order to validate our proposed methods, we carried out experiments for evaluations. The comparison of computation time is shown in TABLE 2. It can be seen that in conventional manual ”KOGAO” transformation (landmarks and target points are set by the user manually), it takes about 20sec, while by using our proposed automatic ”KOGAO” transformation method, the processing time is reduced to 6.3sec. The computation time can be reduced to 3.2sec further by using our proposed warping domain reduction method. The transformation image sizes are 960*720 pixels. The personal computer that was used has an Intel Core Duo T2300 1.66GHz CPU and 1.0GB RAM.

Table 2. Comparison of computation time

	setting time	computing time	total time
Conventional method	20sec	5.896sec	25.896sec
Warping domain reduction (Wdr)	20sec	3.576sec	23.576sec
Automatic ”KOGAO” transformation (Akt)	less than 1sec	6.102sec	7.102sec
Dual method (Wdr + Akt)	less than 1sec	3.722sec	4.722sec

FIGURE 16. Examples of transformed "KOGAO" image (a)Original images, (b)Transformed images

Our proposed automatic KOGAO transformation method has also been evaluated by 20 users (10 females and 10 males). Several examples of transformed KOGAO images are shown in FIGURE 16. FIGURE 16 (a) are original facial images and 16 (b) are automatically transformed KOGAO images. There was no opinion of feeling unnatural for these images. The satisfaction rating was graded by the user to his or her transformed KOGAO image. The averaged satisfaction rating is about 92proposed KOGAO transformation method is practicable.

6. Conclusion In this study, we proposed an automatic KOGAO transformation method to generate an attractive facial image by using B-spline approximation. The landmarks for warping are extracted automatically by using AAM. We developed novel methods for automatically finding the corresponding target points and optimum lattice size, which are validated by psychological tests. We also proposed a warping domain reduction method to reduce the computation time. Experimental results show that the processing time can be significantly reduced to only 4.722sec by our proposed methods and automatically transformed KOGAO images are also satisfactory with a satisfaction rating of 92

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