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The facial texture analysis for the automatic portrait drawing

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ABSTRACT

It is important to draw the portrait by the facial textures automatically. In order to analyze the detailed textures located at the neighborhood of the eyes, the texture analyzing method is studied. Firstly, we propose the principle of selecting the feature points and the portrait drawing method by B-spline curves using the self-reference parameter. Then, the wavelet transform is used to analyze the position, the direction and the intensity of the double-fold eyelid textures. Experimental results have shown that the facial texture analyzing method is effective for drawing portraits automatically.

1. Introduction

As we know, a portrait generating on a computer is to figure out some facial feature points by image processing method. Obviously, some main facial features like the eyes, the nose, the mouth and the eyebrows are prominent enough to recognize [1–5]. On the contrary, few papers focus on how to discover some detailed facial textures. Although they are not the primary factors to generate a portrait, the textures can enrich and enhance the portrait expressions. Some automatic portrait approaches have been proposed in recent years. Chen has presented an example-based approach for generating portraits with various styles [6]. Based on an inhomogeneous Markov random field model, the portrait is modeled. In [7], the authors refer that the hair is synthesized from the face independently. With different mechanism, a facial image is dissected into five regions. They match some templates in a database and the best result is selected. The *n*-best matches can be chosen to create a range of pictures for a user. The components are warped and assembled into an overall model for the hair. Thus, the details are added based upon the subject image. Additionally, another example-based approach has been proposed for the texture synthesis and the image synthesis including image analogies by Hertzmann et al. [8]. A framework has been presented to localize the prominent irregularities in facial skin (moles, birthmarks) by Pierrard et al. [9]. The characteristic configuration over a face is used to encode the person's identity independent of the pose and illumination. The system detects potential nevi with a very sensitive multi-scale template matching procedure. The candidate points are filtered according to their discriminative potential by using two complementary methods. One is a skin segmentation scheme based on gray scale texture analysis. The other is a local saliency measure to express the point's uniqueness. The authors take neighborhood's texture characteristics into account. In [10], the authors present a method for novice users to interactively create partial self-similar manifold surfaces without relying on shape grammars or fractal methods. More concretely, Ref. [11] proposes a system capable of detailed analysis of eye region images including the positions of the iris, degree of eyelid opening and shape and texture of eyelid. The system is based on an eye model that defines fine structures and motions of the eye. The structure parameters represent the structural individuality of the eye, including the size and color of the iris, the width and boldness of the double-fold eyelid, the width of the bulge below the eye and of the illumination reflection on the bulge. By adjusting the structure parameters, the system can individualize the model.

Some of the methods mentioned above take many discussions on how to describe the whole detailed features like the custom strokes generation and the style transformation [6–8]. And others focus on revealing individual features, such as some moles, birthmarks, eye details and the hair style using statistic model [6–11]. In addition, all those methods count on gray model, so their robustness is weak. More importantly, few papers have discussed how to detect these details around certain positions and connect them to portraits. Although the authors in [10] have presented a method to build up an individual eye according to the details, they do not discuss how to detect them. Obviously, aiming at the automatic portrait, we encounter a difficulty of revealing the individual details like double-fold eyelids, bulges, facial traces and wrinkles. So, differing from the gray model, a novel method for selecting feature points and detecting facial details is studied. That is to search the information of the textures located at the main features. In a facial image, the detailed features under different hierarchies will be revealed in different decomposition images transformed by wavelet method. In this way,

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those textures must be provided with certain indicatory meaning. For example, the ones located above the eyelid must involve the information of the double-fold eyelid. So, we expect that the details can be recognized effectively with high robustness.

The proposed overall algorithm is described in Section 2. In Section 3, we will discuss how to draw a portrait by detecting some feature points based on anthropometry. And in Section 4, an example for detecting the textures located around the region of the eyelid is given by wavelet transform, and we will show how to find out a double-fold eyelid. Some experiments are achieved in Section 5. Finally, the conclusion is made in Section 6.

2. System overview

In order to recognize the detailed facial textures, the ASM (active shape model) is employed to detect some main feature points at first [4,5]. The ASM proposed by Cootes is appropriate to spot the feature points in a facial image with given character distribution. And then, some detailed textures located around the points will be searched. It is clear that the textures indicate the details of faces. For obtaining some credible textures, the Daubechies wavelet transformation (DWT) is involved.

The overall algorithm flow chart is shown in Fig. 1. The whole portrait is drawn with some B-spline curves. Of course, it does not include any details. After the main feature points are detected by ASM, they will be fitted by some B-spline curves called main curves. And then, they can form a facial portrait. Thus, the facial image is decomposed by wavelet transform. Having collected the textures located around the feature points, we can build up some detailed textures. At last, they will be transformed to some additional feature points and fitted by B-spline curves. The latter curves are called individual ones. Combining the main and individual curves, a facial portrait with individual details can be built up.

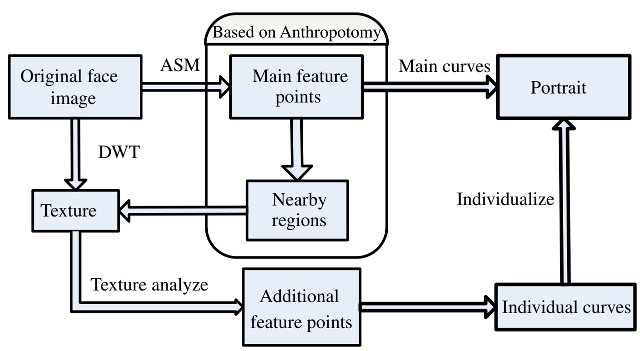

Fig. 1. The overall algorithm.

3. The portrait composition and drawing

3.1. The principle of selecting for feature points

During the detection, the main feature points should be selected by some rules of anthropometry. Based on the Polyclitos drawing rule [12] and anthropometry, assuming the height of the forehead is u, the width and height of the head W and H can be calculated by

$$H = 3.5u, \quad W = 2.5u \tag{1}$$

So, according to u, H and W, the whole composition will be arranged as Fig. 2(a). In the Ployclitos drawing rule, if u is obtained, the whole composition will be achieved rightly. Thereby, based on drawing skills, u will be regarded as a self-reference parameter. Unfortunately, because the forehead is enveloped by hair, it is difficult to discern forehead's height exactly in an algorithm. As a result, we need a self-reference parameter recognized by the certain algorithm easily and properly. In the field of face recognition, the problem about the eye location has attracted many researchers in the past few years [1,13,14]. So, we assume that the eye width can be identified by computer algorithm easily. Then it will be regarded as a self-reference parameter too. In fact, in some drawing skill literatures the eye width is an auxiliary reference [15]. Let the eye width be w, then H and W are determined by

$$H = 7w, \quad W = 5w \tag{2}$$

Based on w, H, W, the composition is shown in Fig. 2(b). Obviously, there is a simple relation between w and u:

$$u = 2w \tag{3}$$

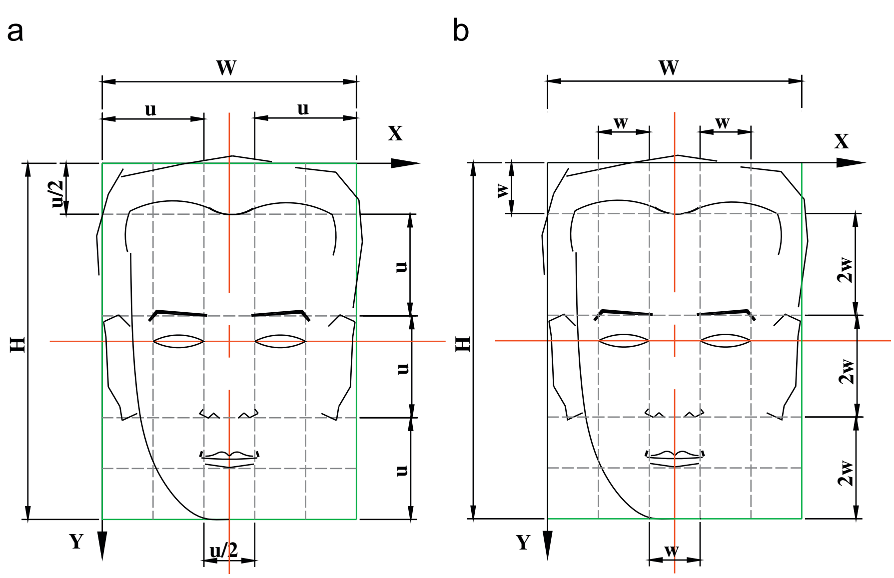

Fig. 2. The facial composition.

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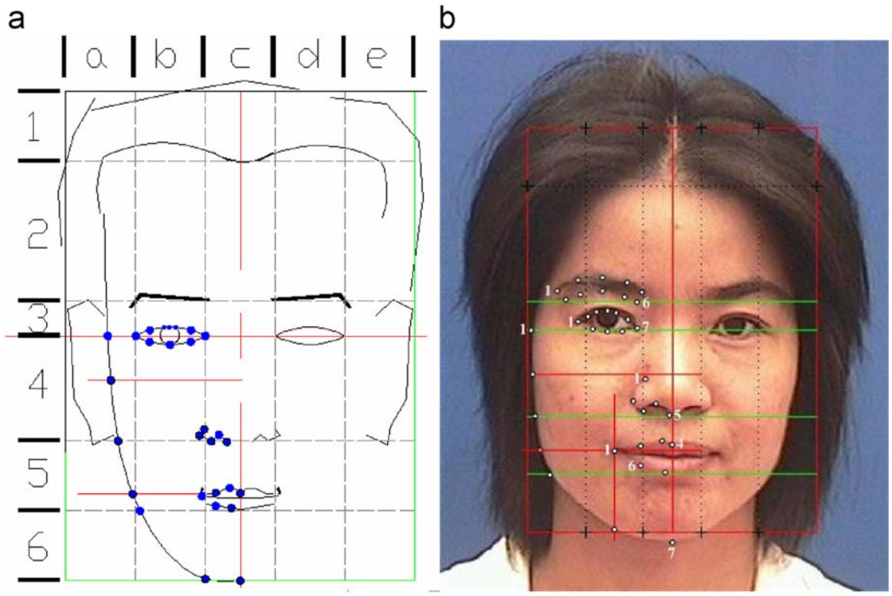

Fig. 3. The main feature points selected by the face composition.

Table 1
The distribution of facial feature and the main feature points in different parts of face.

No.	Facial features	Regions	Number of points	Symbols
1	Left eye	(3, b), (4, b)	10	*e*
2	Right eye	(3, d), (4, d)		
3	Left eyebrow	(2, b), (3, b)	10	*a*
4	Right eyebrow	(2, d), (3, d)		
5	Nose	(4, b), (4, c), (4, d), (5, b), (5, c), (5, d)	5	*n*
6	Mouth	(5, b), (5, c), (5, d), (6, b), (6, c), (6,d)	6	*m*
7	Left zygomatic	(4, a)	7	*f*
8	Right zygomatic	(4, e)		
9	Mandible (symmetry)	(5, a), (5, b), (5, c)		

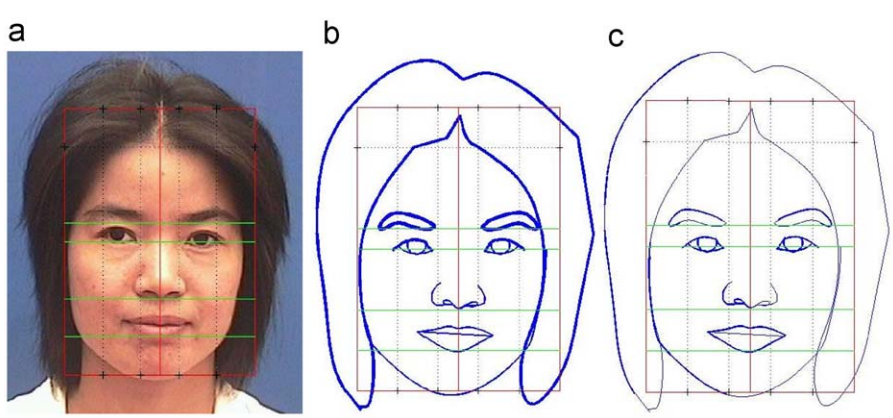

Fig. 4. Sketching a portrait with B-spline curves.

So, w is called the self-reference parameter determining the composition and facial feature sizes (see Fig. 2(b)). In the following discussion, all facial features are founded on the self-reference parameter. Obviously, it is necessary to spot some main feature points in face. They will be selected according to the principle of composition above. Fig. 3(a) shows the feature points in the composition, and Fig. 3(b) indicates the ones in a facial image. Considering the symmetry of the face, we only need to search for the points in half a face.

According to the facial composition, the face can be divided into 30 small regions marked by a, b, c, d, e and 1, 2, 3, 4, 5, 6 (see Fig. 3(a)). In an input image, if the positions of eyes (four canthi) are discovered, the other parts of the face can be anchored in some

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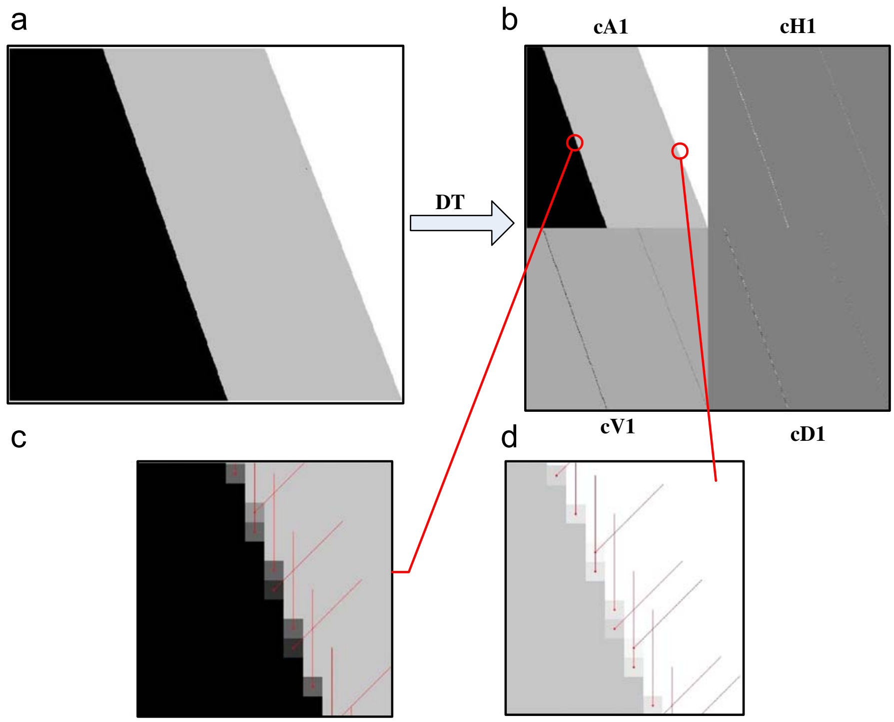


Fig. 5. The position, direction and intensity of the texture.

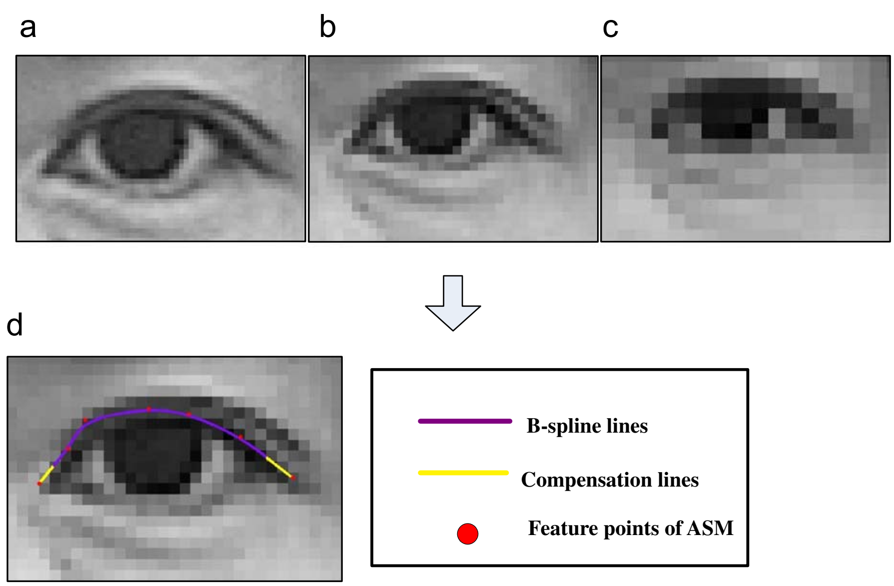


Fig. 6. Decomposing the eye image and building up the eye line with B-spline curves.

regions roughly. Table 1 lists those regions. The main feature points of each part are numbered by a serial of consecutive numbers (see Fig. 3 (a)).

3.2. Drawing the portrait by B-spline curves

Generally, in order to make a curve smooth and independent, the B-spline is suitable for a curve fitting [19]. More importantly, if there are c points, we will need c-2 quadric B-spline curves to fit them. The quadric B-spline curves can be calculated by

$$P_{i,n}(t) = \sum_{k=0}^{n} P_{i+k} \cdot F_{k,n}(t), \quad 0 \le t \le 1; \quad i = 0, 1, 2, \ldots, n; \quad n = k-c \qquad (4)$$

where $P_{i,n}(t)$ denotes the position vector, P_{i+k} denotes the control point, $F_{k,n}(t)$ is the Bezier blending function.

$$F_{k,n}(t) = \frac{1}{n!} \sum_{j=0}^{n-k} (-1)^j \cdot C_{n+1}^{j} (t+n-k-j)^n \qquad (5)$$

where $k=0,1,2,\ldots,n$. If the spline curve is quadric, then $n=2$:

$$P(t)=\sum_{k=0}^{2}F_{k,2}(t)\cdot B_k=[t^2\ \ t\ \ 1]\frac{1}{2}\begin{bmatrix}1 & -2 & 1\\ -2 & 2 & 0\\ 1 & 1 & 0\end{bmatrix}\begin{bmatrix}B_0\\ B_1\\ B_2\end{bmatrix} \tag{6}$$

where B_0,B_1,B_2 are three consecutive vertexes needing fitting.

Consequently, it is possible that different curves can be handled by different strokes [16–18]. Fig. 4 shows some portraits sketched by the B-spline curves with different strokes. So, 38 points mentioned in Fig. 3(b) can sketch a portrait. But it cannot find out any face details in this way. Therefore, it is necessary to analyze the detailed textures like the double-fold eyelid and wrinkles for portrait drawing.

4. The analysis of the detailed textures

4.1. Analyzing position, direction and intensity of textures

Generally, the wavelet transform is a processing of the low-pass filtering and high-pass filtering to reveal the textures in an image. Based on the processing, the image can be decomposed into different scales. Each decomposition will separate the approximation part from previous image. Differing from presented methods based on gray, the wavelet has several advantages as follows [20]:

(1) By decomposition, the detailed part of a face image can be filtered. Different hierarchy means different texture intensity.
(2) The wavelet transform can indicate the texture direction quickly. In order to locate the texture, the FFT method needs a Butterworth filter and an IFFT (inverse fast Fourier transform) to recover the image. However, the wavelet transform has only expected a decomposition processing. Further, the Mallat algorithm will make the wavelet transform more efficient.
(3) The textures discovered by the wavelet will show some characters directly.
(4) The wavelet coefficient will point out the strength of the textures directly.

We employ the Daubechies (db2) wavelet function to decompose the image [20]:

$$\begin{aligned}&[cA_l, cH_l, cV_l, cD_l]=W(L,H)\\ &L=[-0.12941\ \ 0.22414\ \ 0.83652\ \ 0.48296]\\ &H(n^*)=(-1)^{n^*}L(n^*+1)\end{aligned} \tag{7}$$

where W is the wavelet transform, L is the low-pass filter associated with the orthogonal wavelet db2, H is the high-pass filter associated with the orthogonal wavelet, cA_l, cH_l, cV_l and cD_l are the approximate detail, horizontal detail, vertical detail and diagonal detail component in the lth decomposition respectively (see Fig. 5(b)).

In order to get the directions and positions of the textures, the strength of the texture located at (i,j) in an image can be obtained by

$$s_l=\sqrt{cH_l^2(i,j)+cV_l^2(i,j)} \tag{8}$$

And the direction of the textures is

$$\theta_l=\arctan(cV_l(i,j)/cH_l(i,j)) \tag{9}$$

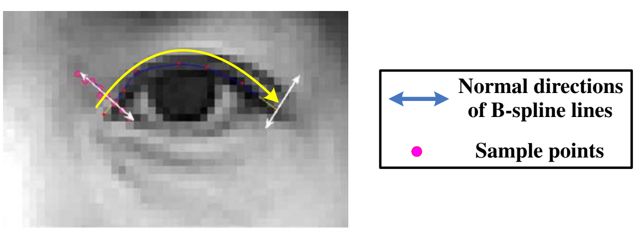


Fig. 7. Expanding the textures around the eye line.

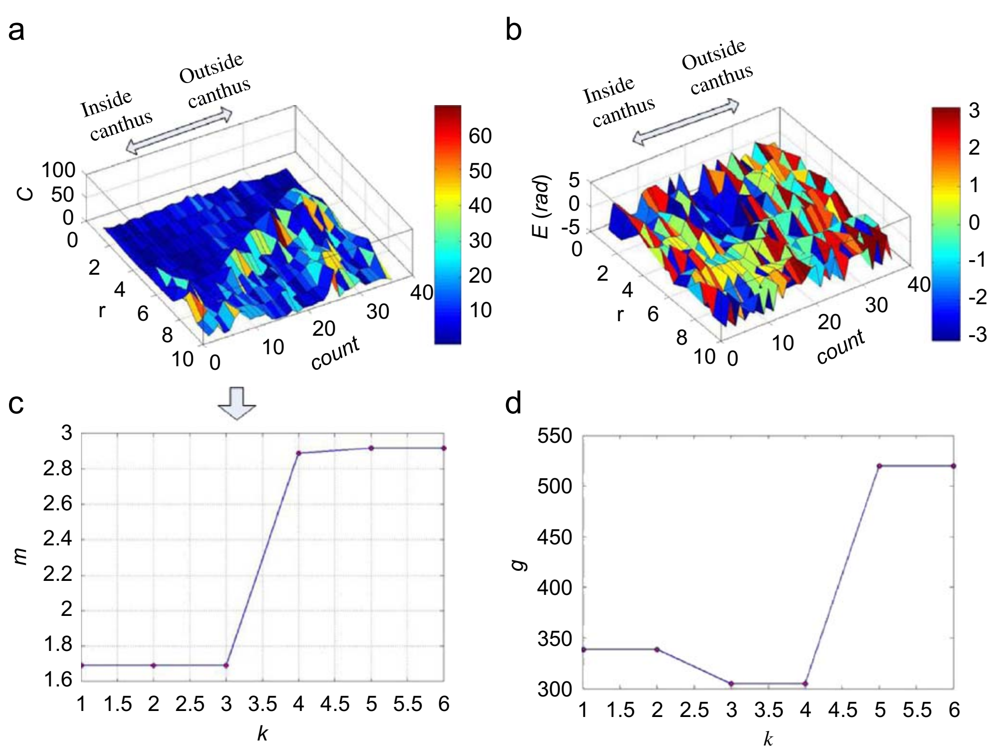


Fig. 8. The distributions of C and E.

In Fig. 5(c), the gray level of the left black block is 0, while the one of the right brighter block is 192. The s_1 located at the boundary between them is 192. In Fig. 5(d), the gray level of the left dark block is 192, and the one of the right white block is 255. The s_2 located at the boundary between them is 44.83. So, we can conclude that the intensive gray variance means greater wavelet coefficient. In Fig. 5(c) and (d), the red lines indicate texture directions derived from θ_1.

Now, we can say that the position, direction and intensity of a texture are evaluated by the wavelet transform properly. So, the wavelet transform is a reliable method of analyzing the facial details. In next section we will discuss an example about how to detect a double-fold eyelid in a facial image.

4.2. Detecting the double-fold eyelid

As we know, not all the people have the features of the double-fold eyelid. So, it is difficult to build up the statistic model of the eyelids. In the previous discussion, the ASM is credible to detect the eye line. But it has failed to distinguish the double-fold eyelid from the eye line.

In order to seek for the double-fold eyelid, we decompose an image once. Generally, the first decomposition will eliminate some sharp noise. Compared with the noise, the double-fold eyelid is a detailed feature. For visual observation, the figures are set in the same size in Fig. 6. Fig. 6(b) and (c) show the first and second decomposition respectively. In the region of the eye, the first decomposition will express the detail better than the second one. We must notice that the resolution of the Fig. 6(a–c) is reduced to a quarter of its former.

As shown in Fig. 6, some details will be lost after the second decomposition. Therefore we should analyze the double-fold eyelid in the first decomposition. The feature points $e_i(x_i, y_i)$ $(i = 1,\ldots,7)$ of the ASM are shown in Fig. 6(d), which are converted from an original image. The quadratic B-spline curves fit them to several lines. There are five lines because of seven feature points. So, the start point p_s and the end point p_e of the B-spline curves can be calculated according to

$$p_s = [1\ \ 1\ \ 0][e_1\ \ e_2\ \ e_3]^T \tag{10}$$

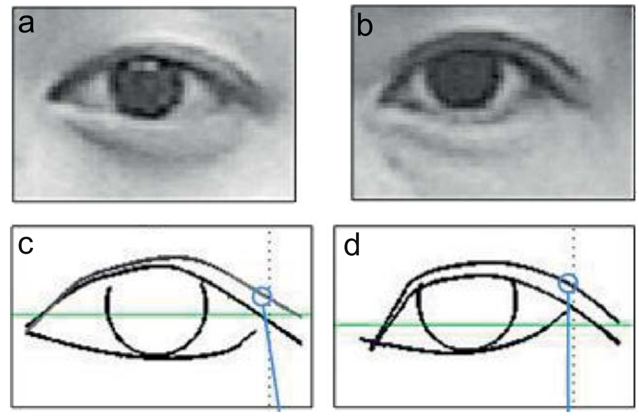
$$p_e = [0\ \ 1\ \ 1][e_5\ \ e_6\ \ e_7]^T \tag{11}$$

In Fig. 6, the two compensation lines connect p_s with e_1, and p_e with e_7, respectively. In order to detect the details located around the spline curves, the characters along their normal directions should be expanded. Thus, it is convenient to obtain the normal directions (shown in Fig. 7) by differentiating Eq. (6):

$$N(t) = [2t\ \ 1\ \ 0]\frac{1}{2}\begin{bmatrix} 1 & -2 & 1 \\ -2 & 2 & 0 \\ 1 & 1 & 0 \end{bmatrix}\begin{bmatrix} B_0 \\ B_1 \\ B_2 \end{bmatrix} \tag{12}$$

In the compensation lines, we calculate their gradients. In Fig. 7 the sample points indicate the normal direction of the B-spline curve. From e_1 to e_7, each point of the B-spline curves is calculated ($t = 0$–1 with interval of 0.05 in Eq. (6)).

Now, the texture distributions near the eye line can be computed by a so-called expanding process. In the process the normal directions along the eye line are calculated, too. In this way, the eye textures will be plotted in a 3D figure, which can indicate the texture distribution clearly. If it is handled to a compensation line, the process will be called *CEP* (the compensation expanding process). Otherwise, the process will be named *BEP* (the B-spline expanding process). The algorithm is described as follows:



Gray value: 121 Gray value:41

Fig. 9. Drawing the double-fold eyelid with different g_k.

low = 3; *up* = 5; *count* = 1
For (i = 1–7 *interval* 1)
For (t = 0–1 *interval* 0.05)
If CEP then

$$d = \begin{cases} \sqrt{(e_1 \cdot x - p_s \cdot x)^2 + (e_1 \cdot y - p_s \cdot y)^2} & \text{if } p \in [e_1\ \ p_s] \\ \sqrt{(e_2 \cdot x - p_e \cdot x)^2 + (e_2 \cdot y - p_e \cdot y)^2} & \text{if } p \in [p_e\ \ e_2] \end{cases} \tag{13}$$

$$\alpha = \begin{cases} \arctan\left(\dfrac{p_s \cdot y - e_1 \cdot y}{p_s \cdot x - e_1 \cdot x}\right) & \text{if } p \in [e_1\ \ p_s] \\ \arctan\left(\dfrac{p_e \cdot y - e_7 \cdot y}{p_e \cdot x - e_7 \cdot x}\right) & \text{if } p \in [p_e\ \ e_2] \end{cases} \tag{14}$$

$$p = \begin{cases} e_1 + [dt\cos(\alpha)\ \ dt\sin(\alpha)]^T & \text{if } p \in [e_1\ \ p_s] \\ p_e + [dt\cos(\alpha)\ \ dt\sin(\alpha)]^T & \text{if } p \in [p_e\ \ e_2] \end{cases} \tag{15}$$

Else if BEP then

$$\alpha = N(t) \tag{16}$$

$$p = P(t) \tag{17}$$

End If
For ($k = -low$ *To up Interval* 1)

$$NP = p + [k\cos\ \alpha\ \ k\sin\ \alpha]^T \tag{18}$$

$$C(k + low + 1, count) = s_1(NP) \tag{19}$$

$$E(k + low + 1, count) = \theta_1(NP) \tag{20}$$

End Loop k
count = *count*+1
End Loop t
End Loop i

where d is the length of a compensation line. α is the angle for the normal direction at a given point p (in Eqs. (15) and (17)).

In the algorithm, some aspects should be paid attention to:

(1) In Eqs. (13)–(15), if *CEP* deals with the line between e_1 and p_s, the top equation will be employed. Otherwise, the other one below will be used.

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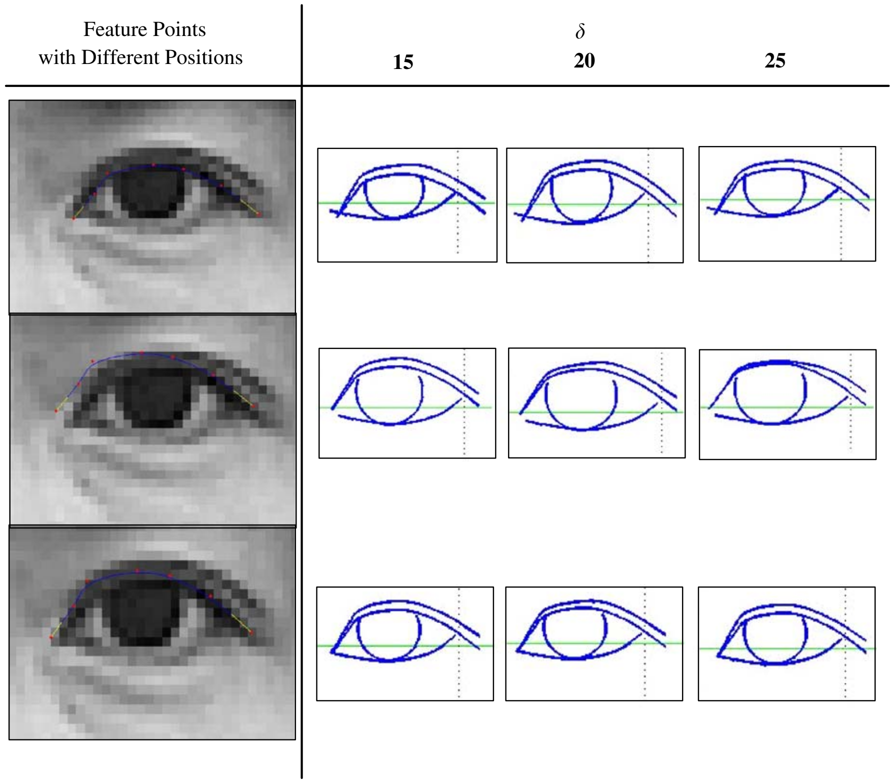

Fig. 10. Drawing the eye portrait with different δ and eye line positions.

(2) In each loop, if the previous point is the same as the latter one, the latter one will be ignored.
(3) The parameters *low* and *up* stand for the width of the expanding. The width $r = up + low$. Generally, *low* covers the region below the eye line, and *up* covers the region above the eye line. So, it is reasonable to make *up* bigger than *low* because the double-fold eyelid locates above.
(4) The *count*−1 denotes the length of the expanding. So, both *C* and *E* are matrixes with dimension of $r^*(count-1)$, which contain the strength and direction of texture respectively (shown in Fig. 8(a) and (b)).

Obviously, the distribution of *C* puts up some obvious characters. The distribution of inside canthus is more concentrative than the one outside. In fact, the more dispersion means that the double-fold eyelid should emerge. So, by calculating the dispersion degree we can find the double-fold eyelid. A simple way of estimating the dispersion is to compute the secondary moment at different *count* ranges. Generally, we divide *count* into 6 segments equidistantly.

$$f(i,j) = \begin{cases} 1 & \text{if } C(i,j) > \delta \\ 0 & \text{if } C(i,j) < \delta \end{cases}, \quad i = 1,2,\ldots,r,\ j = 1,2,\ldots,count-1 \qquad (21)$$

where $\delta = 20$ is the threshold for separating the smooth region from sharp one.

The average line c_k of textures can be derived by

$$c_k = \sum_{i=1,j=\sigma(k-1)+1}^{r,\sigma k} f(i,j) * i/n_1, \quad k = 1,2,\ldots,6 \qquad (22)$$

where σ equals to $(count-1)/6$, n_1 is the number of the points with $f(i,j) = 1$.

Then, the secondary moment can be evaluated by

$$m_k = \frac{2\sum_{i=1,j=\sigma(k-1)+1}^{r,\sigma k} f(i,j) * |(i-c_k)|}{n_1}, \quad k = 1,2,\ldots,6 \qquad (23)$$

Based on Fig. 8(a), m_k handled by median filter is plotted in Fig. 8(c). m_k indicates the dispersion degree, and the vertical axis is the distance between the eye line and the double-fold eyelid in pixels. Furthermore, the texture strength of the double-fold eyelid can be computed by

$$g_k = \frac{\sum_{i=1,j=\sigma(k-1)+1}^{r,\sigma k} f(i,j) * C(i,j)}{n_1}, \quad k = 1,2,\ldots,6 \qquad (24)$$

Fig. 8(d) shows the distribution of g_k. Now, we can assign some additional feature points for the double-fold eyelid by

$$e_{ai} = e_i - m_i, \quad i = 1,\ldots,6$$

Fitted by the B-spline curves, the additional feature points form several individual curves. Then the individual curves are added to a portrait. In this way, we can get the portrait with some details of the double-fold eyelid features.

5. Parameter analyzing and experiments

In the discussion above, the two key factors influence the textures. The first one is the position of the eye line, which is made up of several B-spline curves generated by corresponding feature points of the ASM. The other one is the strength of textures g_k. In the experiment, the portraits of Fig. 9(a) and (c) are shown in Fig. 9(b) and (d) respectively. Obviously, the textures in Fig. 9(c) are stronger than the ones in Fig. 9(a). So, the two portraits have different texture

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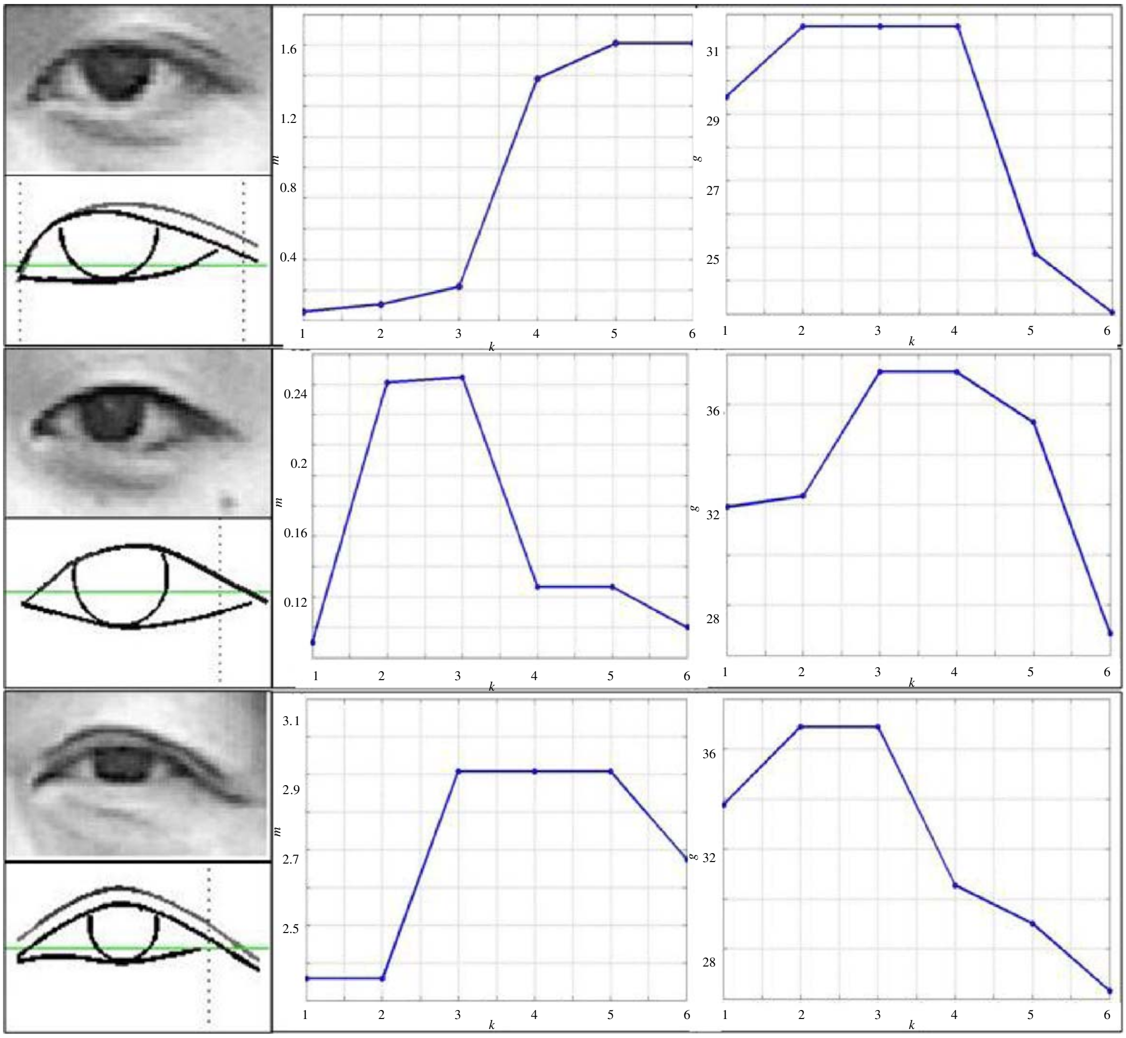

Fig. 11. Some recognized results and their m_k and g_k: (a) the original eye and its portrait with details of eyelid, (b) m_k and (c) g_k.

effect. The stronger textures will generate the curves with lower gray level.

Now, we change the position of eye line slightly and analyze the feature distribution. In Fig. 10, the left column lists three distributions of the feature points of the eye line with the blue color. There are three portraits on the right from each image with different δ. Therefore, when the situations change, the portraits will demonstrate the basic characters of the double-fold eyelids stably. That is to say, the double-fold eyelid of outer canthus is more obvious than the internal one. Fig. 11 shows more results of m_k and g_k indicated the dispersion degree and the texture strength of the double-fold eyelid. Fig. 12 shows the experimental caricatures generated by the B-spline curves with the textures of double-fold eyelid. In Fig. 12, the second column is the portrait like the original photo in the first column. The third column is the caricatured face exaggerated to be contractible for their fat and thin features.

6. Conclusion

The paper studied the facial texture analyzing method for the automatic portrait drawing. Using the method the double-fold eyelid can be found out to reveal the textures around the eyes. The wavelet transform is employed to describe the position, the direction and the intensity of textures, which can be organized into two matrixes g_k and m_k. Based on m_k, we can compute several additional feature points and individual curves drawn by some strokes with different gray levels defined by g_k. Finally, the mentioned parameters m_k and g_k are analyzed, and the result turns out that the double-fold eyelid can be drawn in a proper way. The experimental caricatures generated by the B-spline curves show that the facial texture analyzing method can be used further to draw the computer cartoon portrait by some knowledge transfer methods. Furthermore, the other facial details can be discovered in the same way. In our future work, all textures will be revealed around certain feature points using the analyzing method. For example, as the textures of double-fold eyelid are expected to emerge above the eyes, the textures of some wrinkle of the forehead are expected to emerge above the eyebrows.

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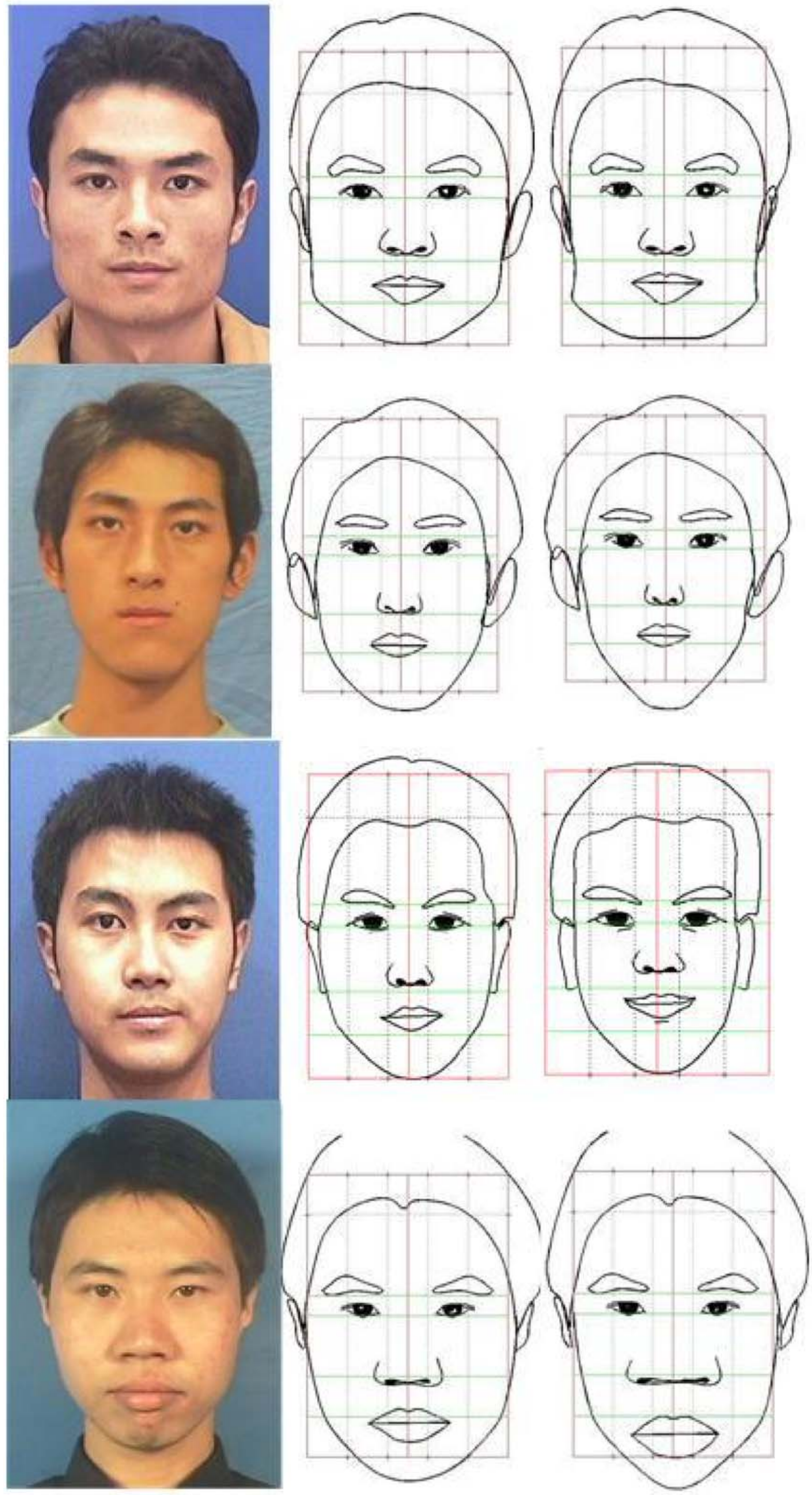

Fig. 12. Some caricatures drawed with the double-fold eyelid texture.

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