A Nonlinear Filter System for Beautifying Facial Images with Contrast Enhancement

Shuji Ohchi, Shinichiro Sumi†, and Kaoru Arakawa*
Dept. of Computer Science, Meiji University, Japan
E-mail: † ce06023@meiji.ac.jp, * karakawa@cs.meiji.ac.jp
Tel: +81-44-934-7445

***Abstract*— A nonlinear image processing system for beautifying human facial images is proposed using contrast enhancement which effects highlighting and shading. Authors proposed before a nonlinear digital filter bank system, which removes undesirable skin components, such as wrinkles and spots, to make the skin look smoothed and beautified. Also, edge enhancement is utilized in this system to make the features of the face look clear-cut. This system is designed optimally on the basis of human subjective criteria and taste, using interactive evolutionary computing (IEC). Now, contrast enhancement is newly introduced to this system. By enhancing the contrast of the base component of the face image, which is extracted by the nonlinear filter bank, the face looks deeply chiseled from the effect of highlighting and shading. Especially, the dark shade around the outline of the face makes the face look slim and sharp. The degree of contrast enhancement is optimally set by IEC as well as other parameters in the nonlinear filter bank system. The proposed system is verified to be effective in experiments of processing an actual facial image.**

I. INTRODUCTION

In multimedia communications, it is sometimes desirable to modify our face images to look better than actual on the computer displays, while keeping the features of the faces unchanged. Authors proposed before a nonlinear digital filter bank named as an ε-filter bank for such beautification of facial images[1]. This filter bank is composed of nonlinear digital filters named as ε-filters. The ε-filter effectively removes small-amplitude high-frequency noise which is added to image signals, while keeping the sharpness of the edges in images unchanged[2]. The ε-filter bank separates the input signal into multiple components in both the frequency and the amplitude domain.

The ε-filter bank system is effective for beautifying face images by removing undesirable skin components such as wrinkles and spots from face, since these undesirable components are limited within a certain area in the frequency and amplitude domain. Moreover, the ε-filter bank can remove only wrinkles and spots, while retaining the natural roughness of skin, because they occupy different areas in the frequency and amplitude domain.

Since the face image tends to get a little blurred by applying the ε-filter bank, edge enhancement is added to the ε-filter bank as post processing. By applying the edge enhancement, the features of faces, such as eyes and mouth, become clear-cut, while the skin is kept smoothed [3].

On the other hand, it is well known in the field of facial makeup that highlighting and shading should be applied on the face to make the face look deeply chiseled. That is to say the protruding parts of the face, such as the forehead, the ridge of the nose, and the upper part of the cheeks around eyes should be lightened, while the sinking part, such as the hollows above the eyes and the lower part of the cheeks, should be shaded. Especially, shading around the outline of the face makes the face look slim and sharp.

In this paper, a method to realize such highlighting and shading is proposed by applying contrast enhancement to the base component of the face image. The base component is obtained from the ε-filter bank, because it separates the input image into various frequency and amplitude components. The highlighting and shading can be realized by enhancing the luminance of the base component of the face image.

The proposed facial image beautification system is composed of the ε-filter bank system with edge enhancement and the contrast enhancement. Consequently, the proposed system realizes facial image beautification in which the skin gets smoothed, the features get clear-cut, and moreover the face gets deeply chiseled.

Here, the problem is how to set the degree of the contrast enhancement. The degree must be dependent on each person's face and the user's subjective criteria. Thus, the parameter to represent the degree of the contrast enhancement is proposed here to be set using interactive evolutionary computing (IEC) [4]. IEC is a method to optimize parameters in a system, using the genetic algorithm (GA)[5], but subjective evaluation is utilized instead of quantitative evaluation in GA. That is to say, user's subjective criteria are utilized to select survivors to the next generation. Previously, authors proposed to apply IEC to set the parameters in the facial image beautification system using ε-filter bank and edge enhancement[3][6]. This is because IEC can optimize multiple parameters in complicated nonlinear systems easily, and moreover user's subjective criteria and taste can be considered in the optimization. Since the human subjective criteria and taste are especially important for face images, IEC is suitable to set the parameters in the system for facial image beautification. Thus, the parameter for contrast enhancement is also to be optimized by IEC. In the proposed system, the parameter for

contrast enhancement is optimized by IEC with the other parameters in the filter bank system.

In this paper, firstly, the previous facial beautifying system composed of the ε-filter bank and edge enhancement is described, and then contrast enhancement for base component is proposed. Next, the method to determine all the parameters in this system using IEC is shown. Finally, computer simulations for an actual facial image verify its high performance.

II. Principle of Facial Image Beautification System with Contrast Enhancement

A. The Previous Facial Image Beautification System Composed of ε-filter Bank and Edge Enhancement

Facial images can be beautified by smoothing the skin and enhancing the edges of the features of face with a system as shown in Fig.1. The former part is for removing undesirable skin roughness, such as wrinkle and spots, and the latter is edge enhancement to make the features of face clear-cut.

The former part is realized by a nonlinear filter system, named as an ε-filter bank. The ε-filter bank is composed of a linear low-pass filter and ε-filters as shown in Fig. 2[1]. Here, L denotes a linear low-pass filter and E_k (k=1,2,3) ε-filters. The ε-filter is a nonlinear digital filter expressed as the following equation [2].

$$y(n) = x(n) + \sum_{m=-N}^{N} a_m F\big(x(n-m) - x(n)\big) \qquad (1)$$

Here, *x(n)* and *y(n)* are the input and the output signal at time *n* respectively. a_m is the filter coefficient of a linear non-recursive low-pass filter, satisfying the following condition to keep the DC level unchanged.

$$\sum_{m=-N}^{N} a_m = 1 \qquad (2)$$

F is a nonlinear function which takes a form as Fig.3, bounded within a certain value ε as follows.

$$|F(p)| \le \varepsilon \qquad ; -\infty \le p \le \infty \qquad (3)$$

and *F(p)=p,* when $|p| \le \varepsilon$.

This filter can remove small-amplitude high-frequency noise from the input signal which contains abruptly jumping component, while preserving the abruptness of the signal unchanged. If the amplitude of the added noise is less than ε*/2,* this filter can smooth the noisy input signal in the part where the original signal does not change much. On the other hand, in the part where the original signal largely changes, this filter preserves the changes in the original signal, since the difference between the input and the output of this filter *u(n)*, that is *x(n)-y(n)*, is limited to a certain value ε' as follows.

$$|u(n)| = \left| \sum_{m=-N}^{N} a_m F\big(x(n+m) - x(n)\big) \right| \le \sum_{m=-N}^{N} a_m \varepsilon \equiv \varepsilon' \qquad (4)$$

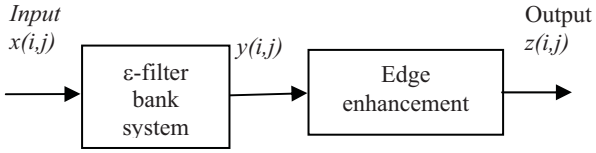


Fig. 1 The schematic diagram of the previous facial image beautification system.

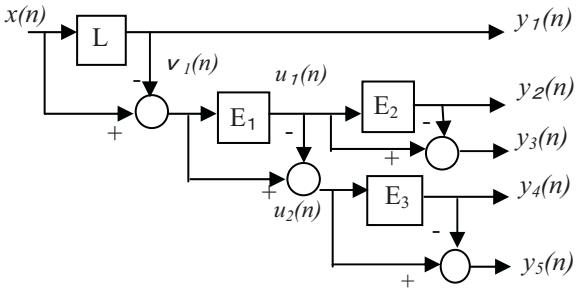


Fig. 2 The structure of the ε-filter bank.

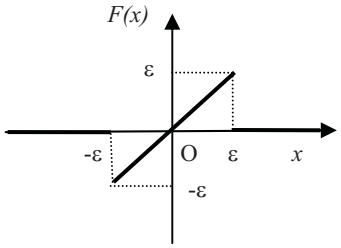


Fig.3 An example of nonlinear function F.

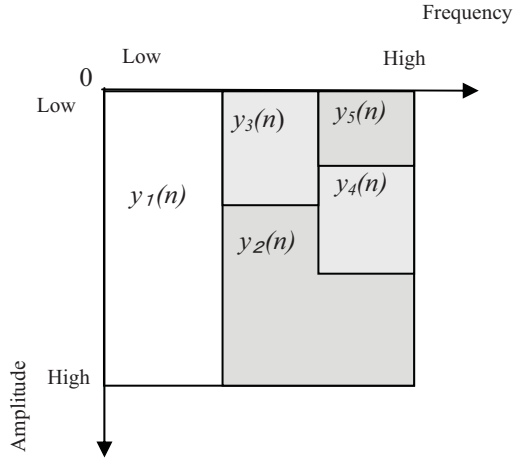


Fig.4 Signal separation performed by the ε-filter bank as Fig.2.

In this way, the ε-filter reduces small-amplitude high-frequency signal components, while preserving large-amplitude high-frequency ones in the input.

Using the ε-filters, the ε-filter bank separates the frequency and amplitude domain of the input signal as shown in Fig.4.

Here, the filters L and E_2 have the same window size w_0 and E_1 and E_3 have the same one w_1, where $w_0 > w_1$. The values of ε in E_1, E_2, and E_3 are set at ε_1, ε_2, and ε_3 respectively, which satisfy $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$. When a face image is the input signal, the wrinkles on skin can be extracted as a small-amplitude and high-frequency component $y_4(n)$ and the spots on skin can be as a small-amplitude and medium-frequency component $y_3(n)$, if the values of the parameters w_0, w_1, ε_1, ε_2, and ε_3 are appropriately set. Moreover, the base component of face is obtained in $y_1(n)$ and strong edges of face features are in $y_2(n)$. The component $y_5(n)$ corresponds to natural roughness of skin. Thus, by eliminating $y_3(n)$ and $y_4(n)$ from the input, the skin gets smoothed while keeping the natural roughness. For image signals, n denotes the location of the image pixel (i,j) and the filtering is performed in two dimension. The output of the ε-filter bank system $y(i,j)$ in Fig.1 is obtained as follows.

$$\begin{aligned} y(i,j) &= x(i,j) - y_3(i,j) - y_4(i,j) \\ &= y_1(i,j) + y_2(i,j) + y_5(i,j) \end{aligned} \tag{5}$$

For images, the ε-filter can remove small-amplitude and high-frequency signal component, while preserving the sharpness of the edges of the images. However, if the height of the edges is not large enough, the sharp component in the edges are regarded as small-amplitude and high-frequency signal, and thus the sharpness of the edges is also reduced. In this way, the face features tend to get blurred in the output of the ε-filter bank $y(i,j)$ in eq.(5). In order to avoid the blur of the face features, edge enhancement is applied as post processing of the ε-filter bank. Here, unsharp masking is adopted as the edge enhancement. The final output $z(i,j)$ of the facial image beautification system is obtained as follows.

$$\begin{aligned} z(i,j) = \{1+(4a/5)\}y(i,j) - a/5\{&y(i-1,j)+y(i+1,j)+ \\ &y(i,j-1)+y(i,j+1)\} \end{aligned} \tag{6}$$

Here, a denotes a parameter to control the strength of enhancement; the larger the value a is, the stronger the enhancement is.

B. *Facial Image Beautification System Using Contrast Enhancement*

Suppose that the luminance of image pixel is transformed with a nonlinear function as Fig. 5, the light area becomes lighter and the dark area becomes darker, and accordingly highlighting and shading is realized.

Here, the contrast of only the base component is proposed to be enhanced. That is to say, a nonlinear function G as shown in Fig.5 is applied to the output $y_1(i,j)$ of the ε-filter bank as the following equation.

$$\hat{y}_1(i,j) = y_1(i,j) + b(G(y_1(i,j)) - y_1(i,j)) \tag{7}$$

Here, b is a parameter to represent the degree of the enhancement which takes a value from 0 to 1; when b is small, the contrast enhancement is weak, but when b is large the enhancement is strong. The nonlinear function G is expressed as a sigmoid function as follows, where $G(t)$ is in the range [0, 255].

$$G(t) = 255/(1+\exp(-\gamma(t-127.5))) \tag{8}$$

Here, γ is set at 1/30. The contrast enhancement is added to the ε-filter bank as shown in Fig. 6. The output $y(i,j)$ is processed by the edge enhancement in the next stage. If the contrast enhancement is directly applied to the input face image, the wrinkles, spots and roughness of skin becomes emphasized also. If the contrast enhancement is applied to the output of the ε-filter bank system $y(i,j)$ or the output of edge enhancement $z(i,j)$, the small-amplitude high-frequency components, which remain in the output image although the amplitude is quite small, also becomes emphasized. Thus, preferable highlighting and shading can be realized by applying the contrast enhancement only to the base component of the face image, such as y_1 in Fig.2.

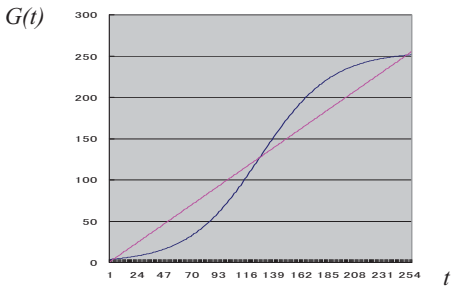


Fig.5 The dark curve shows a nonlinear function G to enhance the contrast. $G(t)$-t corresponds to the difference between the dark curve and the pink straight line.

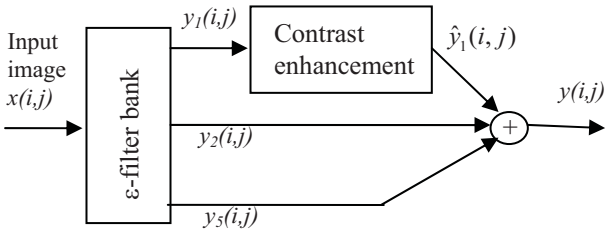


Fig. 6 The block diagram of the ε-filter bank system with contrast enhancement.

III. Design of the Facial Image Beautification System with Contrast Enhancement Using Interactive Evolutionary Computing

The strength of the contrast enhancement is determined by the parameter *b*, which depends on each face and the user's subjective criterion and taste. In the previous facial image beautification system, the parameters w_0, w_1, ε_1, ε_2, ε_3, and *a* are set optimally by IEC, considering the user's subjective criterion and taste. The parameter *b* can be also set by IEC in the same way.

IEC is a method to design a system optimally using the genetic algorithm (GA) on the basis of human subjective criterion. In this method, the system parameters to be set are coded as a binary number which represents a chromosome, corresponding to an individual. The algorithm is shown in Fig. 7. The population contains *M* individuals which are initially created at random. The individual to represent the parameters of this system is as shown in Fig.8, which include the new parameter *b*. The input facial image is processed using these *M* individuals to make *M* output images. By watching these *M* output images on the computer display, the user selects *S* of them which he/she thinks the most satisfactory on the basis of his/her subjective criterion and taste. The individuals used in the *S* selected output images are survived to the next generation. New individuals are additionally created from the survivors by crossover and mutation, using the genetic algorithm (GA). Here T_1 individuals are supposed to be created by crossover, T_2 are by mutation, and the total sum of *S*, T_1, and T_2 is set equal to *M*. The population in the second generation is composed of these *M* individuals. Then, image processing for the input facial image is processed using the *M* individuals in the second generation, and the selection by the user, crossover, and mutation are repeatedly performed until at least one of the *M* output images is satisfactory enough for the user. The most satisfactory image in the last generation is the final output image. The values of the parameters which are utilized in the final output image are regarded as the optimal values of the system for the given facial image which take the user's subjective criteria and taste into consideration.

IV. Computer Simulations

A human facial image is processed with the proposed facial image beautification system with contrast enhancement. The parameters in this system are optimized with IEC. Here, *S* is set at 3, T_1 is 4, and T_2 3. The best 3 output images are selected from 10. One-point crossover is applied where the crossover point is randomly determined, and a single bit is reversed in the mutation where the locus is also determined randomly. w_0 is fixed at 11 for simplicity in calculation, and the code lengths allocated for the parameters are 4, 5, 5, 4, 4, and 4 for w_1, ε_1, ε_2, ε_3, *a*, and *b* respectively. Fig.9(a) shows the input facial image for beautification. Fig.9(b) shows the previous final output when contrast enhancement is not applied. Fig9(c) shows the final output image of the proposed system with contrast enhancement. This image is obtained in the fifth generation. We can see the wrinkles and unevenness of skin are effectively removed and also highlighting and shading are appropriately applied, which make the face look deeply chiseled. Especially the shade around the outline of the face makes the face look slim. For reference, Fig. 9(d) shows the result of applying contrast enhancement directly to the input face image. In this case, we can see that the wrinkles and roughness of skin are also enhanced. By applying contrast enhancement only to the base component of the face, the skin in kept smooth in the output face image.

V. Conclusions

A facial image beautification system composed of the ε-filter bank system and contrast enhancement is proposed. This system can realize highlightig and shading in the face, which make the face look deeply chiseled, as well as removing the

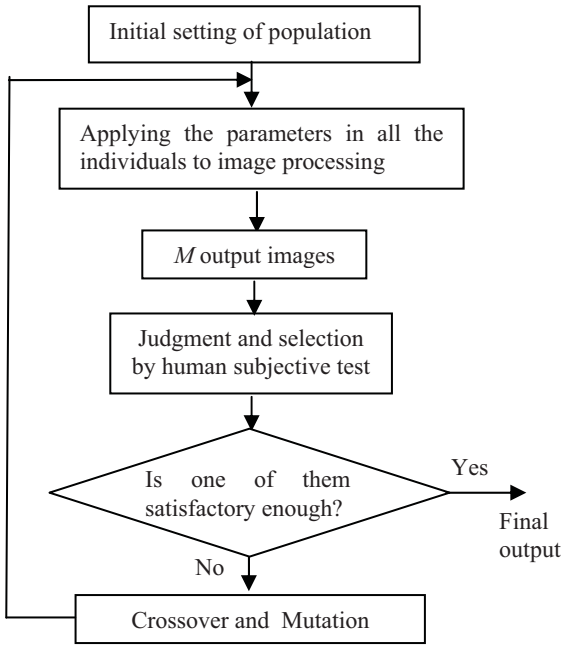


Fig.7 The algorithm of the IEC.

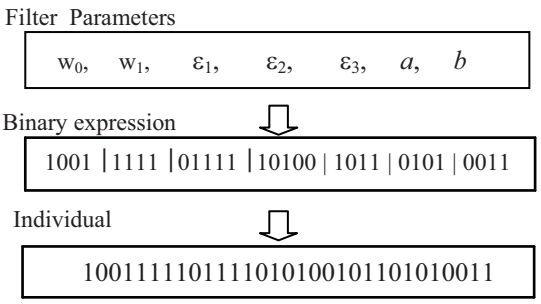


Fig.8 Coding of a genotype in an individual from parameters.

undesireble skin roughness such as wrinkle and spots. In this method, the parameters in the system is determined by IEC, so that the output facial image can be satisfied enough on the basis of human subjective criteria and taste. Here, it takes time to get the fully satisfactory result in GA, but once the paramaeters are determined, they can be applied to another facial image of the same person with a little modification. How to modify the parameters for another situation and how to get the final result faster are for further research. Moreover, the contrast enhancement influences other area than face and changes the luminance in the whole image. How to restrain the influence in the other area is also for further research.

REFERENCES

[1] K. Arakawa and T. Okada, "ε-Separating Nonlinear Filter Bank and Its Application to Face Image Beautification", *IEICE Trans.,* vol. J88-A, no.11, pp.1216-1225, Nov. 2005.

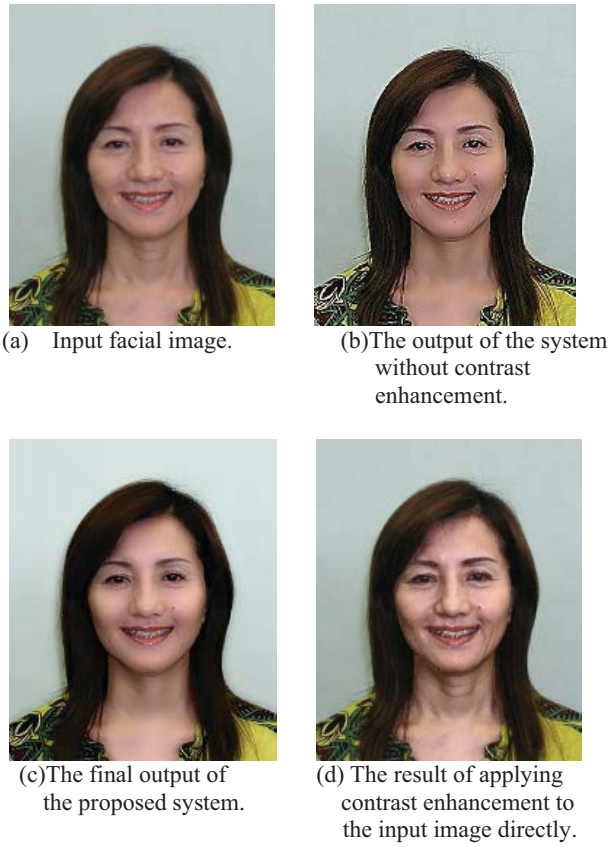
[2] H. Harashima, K. Odajima, Y. Shishikui, and H.Miyakawa, " e-Separating Nonlinear Digital Filter and Its Applications", *IEICE Trans.*, vol.J65-A, no. 4, pp.297-304, April. 1982.

[3] T. Matsui, K. Arakawa, and K. Nomoto, "A nonlinear filter system for beautifying face images with enhancement using interactive evolutionary computing," *Proc. IEEE ISPACS 2006,* pp. 534 – 537, Dec. 2006.

[4] H.Takagi, "Humanized Computational Intelligence with Interactive Evolutionary Computation," in *Computational Intelligence: The Experts Speak*, edited by D. B. Fogel and C. J. Robinson, Wiley, Ch.15, pp.207-218, May, 2003.

[5] M. Sakawa and M. Tanaka, *Genetic Algorithm*, Asakura-Shoten, 1995(in Japanese).

[6] K. Arakawa and K. Nomoto, "A System for Beautifying Face Images Using Interactive Evolutionary Computing", *IEEE Proc. ISPACS 2005*, Dec. 2005.



(a) Input facial image.

(b)The output of the system without contrast enhancement.

(c)The final output of the proposed system.

(d) The result of applying contrast enhancement to the input image directly.

Fig.9 Results of computer simulations.