

NONLINEAR DIGITAL FILTERS FOR BEAUTIFYING FACIAL IMAGES IN MULTI-MEDIA SYSTEMS

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ABSTRACT

Nonlinear digital filters for new application in multi-media systems, that is beautification of face images, are proposed. These filters can remove undesirable skin components such as wrinkles and spots on face images, and accordingly make the skin look smooth and clear without affecting other principal components in the images. Three types of nonlinear filters are proposed; one is quite a simple one which is effective for removing roughness and small spots on skin and can be easily realized by simple hardware, one is an extended one which is a little more complicated but can smooth the roughness and small spots more naturally, and the other more complicated one which can preserve the natural roughness on skin and can remove relatively large spots on skin. Computer simulations verify the high performance of these filters.

1. INTRODUCTION

In multimedia systems, such as TV phone and video conferences, we have a lot of opportunities to transmit face images. Conventionally, information systems have been developed to transmit and display the original information as correctly as possible, however, this principle may not be valid in recent multi-media systems, because multi-media information appeals to human sense.

In this paper, new types of nonlinear digital filters are proposed for such multi-media systems considering human sense in the way that human face images are automatically beautified on the display. These filters perform signal separation based on the signal amplitude as well as the frequency, thus they can filter out small-amplitude random fluctuation in face images corresponding to the wrinkles, spots, rash and so on, and which are unnecessary components on skin and make the skin look bad. Using the filters proposed here, these rough components on skin can be automatically removed, and the face images come to look beautified.

These filters have nonlinear structures, since linear filters cannot remove such small-amplitude fluctuation without blurring the edges in the images. Three types of nonlinear filters are proposed here. The first one is quite a simple one which is effective for smoothing the skin completely, removing roughness and small spots on skin. This filter can be easily realized by simple hardware. The second is an extended form of the first, which is a little more complicated but can smooth the skin more naturally. The last is more complicated one but can preserve the natural roughness on skin and can remove relatively large spots on skin. Finally in this paper, computer simulations for actual face images are shown to verify their high performance.

2. ϵ -FILTER: A SIMPLE METHOD TO BEAUTIFY SKIN IN FACE IMAGES

The ϵ -filter is a nonlinear digital filter proposed by the author's group before for noise reduction of nonstationary signals such as images[1]. The input-output relationship of the ϵ -filter is represented as

$$y(n) = x(n) + \sum_{i=-N}^N a_i F(x(n+i) - x(n)) \quad (1)$$

where $x(n)$ and $y(n)$ are the input and the output signal at time n respectively. $x(n)$ is supposed to be the sum of an original signal and small-amplitude random noise. a_i is the filter coefficient of a linear non-recursive low-pass filter, satisfying the following condition to keep the DC level unchanged.

$$\sum_{i=-N}^N a_i = 1 \quad (2)$$

F is a nonlinear function which takes a form as Fig.1, bounded within a certain value ϵ as follows.

$$|F(p)| \leq \epsilon \quad ; \quad -\infty \leq p \leq \infty \quad (3)$$

When $|p| \leq \epsilon$, $F(p)=p$ and this filter works as a linear nonrecursive low-pass filter. Thus, if the amplitude of the added noise is less than $\epsilon/2$, 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 is limited to a certain value ε' as follows.

$$F \cdot |y(n) - x(n)| = \left| \sum_{i=-N}^N a_i F(x(n+i) - x(n)) \right| \leq \sum_{i=-N}^N |a_i| \varepsilon \equiv \varepsilon' \quad (4)$$

Thus, this filter smoothes out small-amplitude high-frequency noises, while preserving large-amplitude changes in the original signal, even if these changes contain high-frequency abrupt components. This filter is named as an ε -filter and can be easily implemented by adding the simple nonlinear function to the conventional nonrecursive linear low-pass filter. The ε -filter equals to a linear nonrecursive low-pass filter, when the value ε is large enough.

In this explanation, signals are expressed in a one-dimensional form, but when the filter is applied to images, the filter is modified into a two-dimensional form by replacing the time point n with the pixel (n, m) , a_i with a_{ij} , and the summation with a two-dimensional one.

3. COMPONENT-SEPARATING ε -FILTER: AN EXTENDED FORM OF THE ε -FILTER

The ε -filter is powerful to reduce small-amplitude random noise, while preserving the abrupt jumps in the input signals. However, the performance of the ε -filter is not satisfactory enough, when the signal contains continuous changes, such as a slope and a sinusoidal hump, since the ε -filter is designed to be ideal when the signal contains just flat components and discontinuous jumps. When the signal contains continuous changes, noise remaining and signal distortion occur. In order to solve this problem, a component separating ε -filter (CS filter for short) is proposed[3].

The CS filter consists of three ε -filters H, E, E' as shown in Fig. 2. In this figure, first, the filter H extracts a rough signal component $s(n)$ from the input signal $x(n)$. Next, the residual $t(n)$, that is $x(n) - s(n)$, is processed by the filter E, and $s(n)$ is processed by E'. Finally, the output $y(n)$ is obtained by combining these outputs $v(n)$ and $z(n)$. Here, H adopts a large value for ε , which means that H is close to a linear low-pass filter in order to extract the rough structure $s(n)$. On the other hand, E and E' are strongly nonlinear ε -filters, which remove small-amplitude

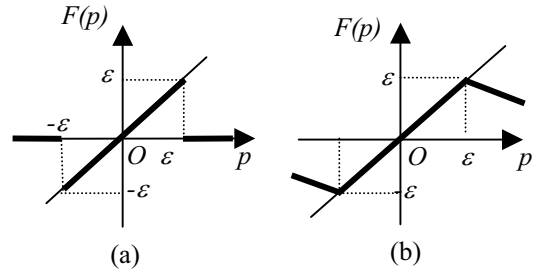


Fig. 1 Examples of nonlinear functions F .

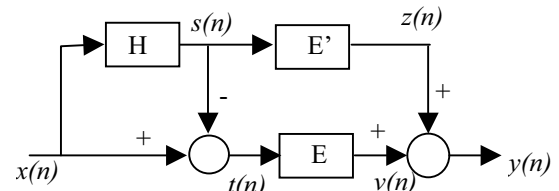


Fig.2 Schematic diagram of CS filter.

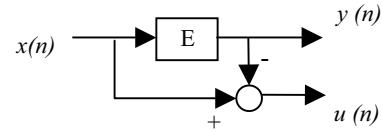


Fig.3 Signal separation using the ε -filter.

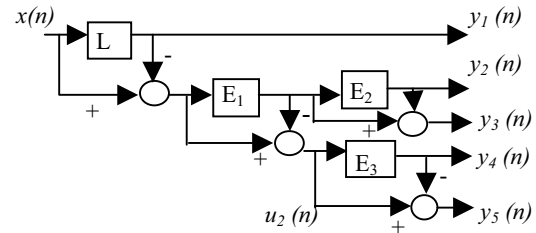


Fig.4 Schematic diagram of an ε -nonlinear filter bank.

high-frequency noise while preserving the large-amplitude abrupt changes in the input. Since continuous changes in the input is subtracted before ε -filtering, noise remaining and signal distortion are avoided. Suppose that the filter coefficients in E and E' are denoted as a_i and a'_i , the window sizes are as N and N' , and the nonlinear functions are as F_E and F'_E respectively, $y(n)$ is expressed as

$$y(n) = x(n) + \sum_{i=-N}^N a_i F_E(t(n-i) - t(n)) + \sum_{i=-N'}^{N'} a'_i F'_E(s(n-i) - s(n)) \quad (5)$$

Since the amplitude of F_E and F_E' are limited, the difference between the input and the output $|y(n)-x(n)|$ are also limited to a certain value, thus this filter can preserve the large-amplitude abrupt changes while removing the small amplitude random noises in the same way as the ε -filter.

4. FACE IMAGE PROCESSING USING ε -NONLINEAR FILTER BANK

Since the ε -filter removes noise considering its amplitude as well as the frequency, signal separation considering both the signal amplitude and frequency can be realized using the ε -filter as shown in Fig.3. Here, the input $x(n)$ is separated into $y(n)$ and $u(n)$, where $y(n)$ is the output of the ε -filter, composed of large-amplitude or low-frequency components and $u(n)$ of small-amplitude and high-frequency ones. Since all the values a_i 's can set to be positive, the amplitude of $u(n)$ can be limited to ε from eq(4). Using this idea, a filter bank, named as a ε -nonlinear filter bank (ε -filter bank for short), as shown in Fig.4 can be realized[4]. Here, L denotes a linear low-pass filter, and $E_1 \sim E_3$ denote ε -filters. First, the filter L separates the input to a low-frequency component and a high-frequency one. Here, the low-frequency components corresponds to a rough signal structure of face image, and the high corresponds to the fine structure of the face. In the fine structure, the outputs $y_2(n)$ and $y_3(n)$ correspond to a relatively low-frequency component compared with $y_4(n)$ and $y_5(n)$, and also $y_3(n)$ and $y_5(n)$ correspond to small-amplitude components compared with $y_2(n)$ and $y_4(n)$ respectively. When we think of our actual face, wrinkles are usually represented as small-amplitude and high-frequency signals, while spots are small-amplitude and intermediate-frequency ones. Thus, wrinkles can be extracted in the signal $y_4(n)$ and spots in $y_3(n)$. Natural roughness of skin, represented as quite small-amplitude and high-frequency signals are obtained in $y_5(n)$. Such roughness of skin should be preserved in the output image in order to show the face as a natural one. The human face beautifying system proposed here first separates the face image components into $y_k(n)$ ($1 \leq k \leq 5$) by the ε -nonlinear filter bank and then subtract $y_3(n)$ and $y_4(n)$ from the input. Undesirable wrinkles and spots can be removed from the input image automatically.

However, if this system is applied to actual face images, some small-amplitude edges around weak components such as lips are also degraded, since such small edges contain some components close to $y_3(n)$ and $y_4(n)$. Therefore, this system must be modified so that $y_3(n)$ and $y_4(n)$ are subtracted only when the pixel is not around the edge. Moreover, in order to avoid the output image from blurring, the subtracted value should be limited within a certain small value. Finally, the output image $z(n)$ of this

system is described as a rule-based system using the ε -filter bank as follows.

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IF  $|med(n)-x(n)| < \delta_2$ 
THEN  $y'_3(n) = 0$ , ELSE  $y'_3(n) = y_3(n)$ 
IF  $|u_2(n)| > \delta_1$  AND  $|med(n)-x(n)| < \delta_2$ 
THEN  $y'_4(n) = 0$ , ELSE  $y'_4(n) = y_4(n)$ 
 $z(n) = x(n) - G(y'_3(n) + y'_4(n))$ 

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Here, $med(n)$ denotes the output of a median filter around the pixel n , G a nonlinear function as Fig.1(b), and δ_1 and δ_2 are positive parameters; these parameters and the value ε in G are set experimentally. Pixels on edges are detected from the difference between the input and the median, because the difference is smaller on the edges. In order not to suppress small-amplitude wrinkles, the condition $|u_2(n)| > \delta_1$ is added for $y'_4(n)$.

5. COMPUTER SIMULATIONS

Fig. 5 shows the performance of the ε -filter, the simplest one, compared with that of a conventional linear smoothing filter. Here, the window sizes are 5×5 for both. We can see that the ε -filter can smooth the skin without blurring the entire image, and make the face look young and beautified. Fig.6 shows the comparison of the performance of the three nonlinear filters proposed here. We can see that the boundary between the light area and a dark one is too sharply emphasized in the case of the simple ε -filter, while that is softer in the CS filter. In the case of the ε -filter bank, the boundary especially at the noise is more smooth and natural. Moreover, the outputs of the ε -filter and the CS filter are too much smoothed, but the output using the ε -filter bank contains small amount of roughness which make the face look more natural. Fig. 7 shows the performance for relatively large spots on skin. We can see that such large spots can be also removed naturally as well as wrinkles in the case of the ε -filter bank.

6. CONCLUSIONS

Three types of nonlinear filters for beautifying face image in multimedia systems are proposed. They can remove undesirable roughness on skin, such as wrinkles and spots, in order to make the skin look better, and are based on the idea of signal separation considering both the frequency and the amplitude of the signal. These filters are different in the complexity in implementation and the quality of output image; the more the system is complicated, the more natural the output face image becomes. Which one should be used depends on each situation. Computer simulations for actual face images show the high performance of these filters.

In these filters, the way to design them optimally is already proposed for the ε -filter and the CS-filter[3]. As to the ε -nonlinear filter bank, the parameters are still set experimentally. If this system is applied only to face images, such experimental setting is usually valid, since the quantitative characteristics of the signal are almost the same for every face image. But considering the change of the brightness and the size of the face image, some database of the filter parameters for various circumstances must be prepared. Details on this subject is for further research.

7. REFERENCES

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(a) Input face image. (b) Output of a linear smoothing filter. (c) Output of the ε -filter.

Fig.5 Results of processing an face image by a conventional linear smoothing filter and the ε -filter.



(a) Output of the ε -filter. (b) Output of the CS filter. (c) Output using the ε -filter bank.

Fig.6 Comparison of the performance of the three nonlinear filters proposed here.



(a) Input face image. (b) Output of the ε -filter. (c) Output using the ε -filter bank.

Fig.7 Performance of the ε -filter bank for spots on a face compared with that of the ε -filter.