IMAGE PROCESSING APPLICATIONS USING IIR FILTER BANKS

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ABSTRACT

In this paper, we demonstrate the use of octave-band all-pass infinite impulse response (IIR) filter banks in multiscale edge detection and image enhancement. IIR filter banks offer the advantage of lower computational complexity. Also the improvement of signal to noise ratio (SNR) is shown to be greater than those of finite impulse response (FIR) bank structure in the case of image enhancement application. The simulation results are presented to show the performance of this method.

Key-Words: *multiscale edge detection, image enhancement, IIR filter banks.*

ÖZET

Bu çalışmada çok-ölçekli kenar belirleme ve görüntü iyileştirme uygulamalarında sonsuz birim dürtü cevaplı (IIR) süzgeç öbeklerinin kullanılabileceĝi gösterilmiştir. IIR süzgeç öbeklerinin kullanılmasının avantajı hesaplama karmaşıklıĝının düşük olmasıdır. Aynı zamanda görüntü iyileştirme uygulamasında işaret-gürültü oranı açısından sonlu birim dürtü cevaplı süzgeç öbeĝi yapısına göre daha iyi sonuç verdiĝi gösterilmiştir. Bu yöntemin performansını gösteren benzetim sonuçları verilmiştir.

Anahtar kelimeler: *çok-ölçekli kenar belirleme, görüntü iyileştirme, IIR süzgeç öbeĝi.*

1. INTRODUCTION

Some successful applications of multiband signal analysis to image processing have been carried out in the areas of edge detection and image enhancement [1]-[3]. Edge detection is used for detecting discontinuities in an image. The techniques are mainly based on the computation of a local derivative of the signal. Several researchers introduced the concept of multiscale edge detection [4]- [6] which lends itself to detecting the details of an image as well as boundaries of larger objects. Since points of sharp variations are crucial features in the analysis of properties of non-stationary signals, the multiscale edge detection techniques have been widely used. In multiscale edge detection, the image is smoothed at different scales and the edges are detected from their first or second derivatives. The ability to reconstruct images from multiscale edges allows us to process the image with edge-based algorithms. Mallat and Zhong [4] used the approach that multiscale edges can be detected and characterized from local maxima of a wavelet transform. On the other hand, it is also well known [7] that the wavelet transform is related to the octave-band FIR filter bank tree structure which constitutes a special case. Therefore the edges at different scales can be detected by octave-band FIR filter banks.

Multiscale edges provide local support for image enhancement. The principle of image enhancement techniques is to modify the contrast of an image. Since the contrast of an image is related to high frequency components of an image which are fine details or edges in an image, the high frequency components have to be emphasized. To this end, the local contrast is increased by high-pass filtering. One approach for this purpose is splitting the degraded image into frequency bands and the sub-band images obtained by filtering are processed individually. In the application of image enhancement, the coarse and fine sub-band images are modified individually.

In this paper, image enhancement and multiscale edge detection techniques using octave-band IIR filter banks are proposed. We use all-pass based IIR filter banks. The results of this technique are compared with that of existing

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FIR structures [3], [4]. Our proposed technique provides to have better signal to noise ratio as compared to the technique using FIR filter bank in the case of image enhancement application since the IIR filter characteristic has narrow transition band. Also the advantage of using an IIR structure is that many channels can be used because of their low complexity [8]. This property is very important considering the number of delay elements for the implementation.

The organization of this paper is as follows: Section 2 presents the use of IIR filter bank for multiscale edge detection and image enhancement applications. In Section 3, conclusions are given.

2. MULTISCALE EDGE DETECTION AND IMAGE ENHANCEMENT USING IIR FILTER BANKS

In this study, we apply the IIR filter banks to the problems of multiscale edge detection and image enhancement. The octave-band all-pass IIR filter banks offer the advantage of lower computational complexity.

2.1 MULTISCALE EDGE DETECTION

Multiscale edge detection technique first proposed by Marr and Hilderith [9], is based on filtering an image by low-pass filters which have different band-widths and then applying traditional edge detection methods to low-pass filtered image. This process provides to obtain edges occurring at different scales (resolution) in an image.

The general definition of the function used for low-pass filtering, also called smoothing function, is given as:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathcal{S}(x,y)dxdy = 1, \qquad \mathcal{S}(x,y)|_{x,y\to\mp\infty} = 0 \quad (1)$$

Let us denote $\psi^{(1)}(x,y)$ and $\psi^{(2)}(x,y)$ as the Gradient and Laplacian of a smoothing function:

$$\psi^{(1)}(x,y) = \nabla\mathcal{S}(x,y), \qquad \psi^{(2)}(x,y) = \nabla^2\mathcal{S}(x,y) \quad (2)$$

By the definition of a wavelet [10] $\psi^{(1)}(x,y)$ and $\psi^{(2)}(x,y)$ can be considered as 2D wavelets. The dilated wavelets are denoted as:

$$\begin{aligned} {\psi_a}^{(1)}(x,y) &= \frac{1}{a^2}\psi^{(1)}(\frac{x}{a},\frac{y}{a}) \\ {\psi_a}^{(2)}(x,y) &= \frac{1}{a^2}\psi^{(2)}(\frac{x}{a},\frac{y}{a}) \end{aligned} \quad (3)$$

The wavelet transform of $f(x,y)$ is computed by convolving $f(x,y)$ with a dilated wavelet and is defined by:

$$\begin{aligned} {W_a}^{(1)}[f(x,y)] &= f(x,y) * {\psi_a}^{(1)}(x,y) \\ {W_a}^{(2)}[f(x,y)] &= f(x,y) * {\psi_a}^{(2)}(x,y) \end{aligned} \quad (4)$$

Substituting (2) into (4) yields

$$\begin{aligned} {W_a}^{(1)}[f(x,y)] &= f(x,y) * \nabla\mathcal{S}(\frac{x}{a},\frac{y}{a}) \\ {W_a}^{(2)}[f(x,y)] &= f(x,y) * \nabla^2\mathcal{S}(\frac{x}{a},\frac{y}{a}) \end{aligned} \quad (5)$$

It is clear from (5) that the wavelet transform provides edge detection at scale a. If a is chosen as 2^j, the special case of wavelet transform called as dyadic wavelet transform of $f(x,y)$ is obtained. It is well known that the dyadic wavelet transform is related to the octave-band FIR filter banks [7]. Consequently edges at different scales can be detected by using the octave-band FIR filter banks.

Since the FIR filters do not have sharp transition bands and also suffer from ripples, it is difficult to split the input image into sub-bands properly. For example, in Fig. 1 (a) the test image has two different edges which consist of slow and sharp variations. Figs. 1(b), (c) and (d) show that the slow and sharp variations are not distinguishable since the filters do not have sharp transition bands. These disadvantages are avoidable at the expense of an increase in the complexity.

The use of IIR PRQMF banks is preferable since an IIR filter usually requires a much lower order for the same set of magnitude response specifications. This implies fewer multipliers and adders. We use all-pass based IIR filter banks with dyadic tree-structure where each IIR filter is obtained from all-pass filters. The transfer functions of low-pass ($H_0(z)$) and high-pass ($H_1(z)$) filters used in the dyadic tree-structure can be expressed as:

$$\begin{aligned} H_0(z) &= a_0(z^2) + z^{-1}a_1(z^2) \\ H_1(z) &= a_0(z^2) - z^{-1}a_1(z^2) \end{aligned} \quad (6)$$

where $a_0(z)$ and $a_1(z)$ are stable and real coefficient allpass functions

$$a_0(z) = \frac{\alpha + z^{-1}}{1+\alpha z^{-1}}, \qquad a_1(z) = 1 \quad (7)$$

Fig.2 illustrates the advantage of the use of IIR PRQMF bank. The slow variations in the horizontal direction are distinguishable in the high-pass sub-band as opposed to FIR case shown in Fig. 1.

2.2 IMAGE ENHANCEMENT

The essential idea in image enhancement is to improve the appearance to human viewers. The image quality, intelligibility, or visual appearance are improved by enhancing an image.

It is well known that the edges in an image contain very important information that may be used in image understanding applications. The first step in such an application may be to preprocess an image into an edge map that consists of only edges. Since more accurate detection of edges in an image can enhance the performance of an image understanding system that exploits such information, converting an image to its corresponding edge map may be viewed as an enhancement process.

The principle is to modify the contrast of an image. Since the contrast of an image is related to its high frequency components which are fine details or edges in an image, these are the components that have to be emphasized. To this end, the local contrast is increased by high-pass filtering. One approach for this purpose is splitting the image, which is degraded, into frequency bands and process them individually. In many applications, depending on the resolution requirements only the fine or coarse sub-band images are considered. Then the processing of the image is carried out on the reconstructed image obtained from these more significant bands. In the application of image enhancement, the coarse and fine sub-band images are modified individually.

The enhanced image is obtained by modifying the responses of low-pass and high-pass filters to the degraded image as:

$$p(m,n) = \beta d(m,n) * h_0(m,n) + \eta d(m,n) * h_1(m,n) \quad (8)$$

where $p(m,n)$ is the processed image, $d(m,n)$ is the degraded image, $h_0(m,n)$ and $h_1(m,n)$ are the 2-D low-pass and high-pass filter coefficients obtained from 1-D filter coefficients which are chosen as Daubechies wavelet coefficients [10], respectively. β and η are parameters to be optimized to maximize SNR. The SNR improvement due to processing is defined by

$$SNR = 10log_{10}\frac{Var[f(m,n) - d(m,n)]}{Var[f(m,n) - p(m,n)]} \quad (9)$$

where $Var[.]$ is the variance operator and $f(m,n)$ is the original image.

Fig. 3 illustrates the performance of our proposed method. Fig. 3 (a) shows original image of 256x256 pixels. Fig. 3 (b) shows the image degraded by white Gaussian noise at an SNR of 2.47 dB. Fig. 3 (c) shows the processed image obtained using FIR filter bank, with an SNR improvement of 3.42 dB. Fig. 3 (d) depicts the processed image obtained using IIR filter bank, with SNR improvement of 6.17 dB. After optimization, β and η are found as 0.53 and 0.034, respectively in FIR case and 0.8 and 0.02, respectively in IIR case.

3. CONCLUSIONS

In this paper, we considered the application of IIR filter banks to multiscale edge detection and image enhancement. The motivation is that IIR filter structures can be implemented with low complexity as compared to FIR filter counterpart.

We observed that the edges which occur at different scales in an image can be detected by using IIR filter bank structure. Fig. 2 illustrates that both slow and sharp variations are distinguishable. In addition to that it is possible to implement IIR filter bank structure with low complexity. Since the order of the FIR filters is three, it is required two multiplications and two additions to implement one stage of FIR analysis bank structure. The total complexity of the implementation becomes four multiplications and four additions for two stage. In the IIR structure whose the analysis filter transfer functions are given in (6), the order of the transfer functions is two. Here one multiplication and two additions are necessary to implement IIR analysis bank structure for one stage. In the case of using two stages, the number of complexity is two multiplications and four additions. Moreover the SNR improvement has been shown to be greater than that of FIR structure in the case of image enhancement application.

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