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Research Article

Design of direction oriented filters using McClellan Transform for edge detection

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Abstract

Edge detection is a process that detects the presence and location of edges constituted by sharp changes in intensity of an image. Edges define the boundaries between regions in an image, which helps with segmentation and object recognition. Edge detection of an image significantly reduces the amount of data and filters out useless information, while preserving the important structural properties in an image. The general method of edge detection is to study the changes of a single image pixel in an area, uses the variation of the edge neighbouring first order or second-order to detect the edge. This paper describes an edge detection using multi scale Directional Filter Bank (DFB). The directional responses of DFB that represent the edge information can be used for edge detection.

Keywords: *McClellan Transform, Directional Analysis, Edge Detection.*

1. Introduction

Edge is a boundary between two different regions. Edge detection is the process of identifying and locating sharp discontinuities in an image. Now a day's edge detection is an important tool in image processing in the field of feature detection and feature extraction. It is to simplify the image analysis by reducing the amount of data and preserving useful structural information. However, for the discrete signal data, edges are often defined as the local maxima of the derivative(s). Essentially an edge detector is a high pass filter (operator) that can be applied to extract the edge points in a signal. There are classical 2-D gradient operators such as Roberts, Prewitt, Sobel and Fri-Chen for edge detection. All these "operators have high pass filters that are sensitive to noise". They are simple but have limitation in extracting the directional edge information due to separable implementation. To ride on this difficulty either 2-D non-separable filters or directional edge filters are used. To combat with noise, Marr and Hildreth operator is devised and these pre-smoothing approaches combine Gaussian smoothing while estimating gradient. They are useful in higher noise conditions and attractive due to low complexity linear implementation. All the above approaches have weakness that the optimal result may not be obtained by using a fixed size operator.

The developments in the field of multi-resolution wavelet transforms with their ability to detect and characterize singularities, attracted many researchers to explore the optimal edge detection problem in higher noise conditions. However, the usefulness of wavelet based singularity detection is widely known from the literature; in general, wavelets have two limitations (i) isotropy and (ii) limited directions due to separable implementation. To analyse and represent an image, DFB can be employed and it can capture and represent signal singularities in the form of edges lying on smooth surfaces. Bamberger and Smith proposed DFB for 2-D signals, and widely used in anisotropic multi resolution transforms found in (Javad *et al*, 2004), (Minh *et al*, 2005) (Arthur et al, 2006) (Yue Lu et al, 2007). Directional oriented representations of images are of great interest for many years. Directional information is important in variety of image applications like image enhancement, de-noising, edge detection and segmentation, classification and feature extraction (Anand *et al*, 2012). This paper proposes an approach to detect edges by scaled version of directional filter bank which is applied in steerable manner and McClellan Transform. This provides directional specific information along with scale information.

In this paper, we show how to construct a DFB that preserves the visually important geometric characteristics of the image for edge detection but without sacrificing the structural information using McClellan Transform. The following sections provide a useful intuitive framework to examine DFB construction.

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2. Directional filter bank

A filter bank is an array of band-pass filters that separates the input signal into multiple components, each one carrying a single frequency sub-band of the original signal. One application of a filter bank is a graphic equalizer, which can attenuate the components differently and recombine them into a modified version of the original signal. The process of decomposition performed by the filter bank is called *analysis* (meaning analysis of the signal in terms of its components in each sub-band); the output of analysis is referred to as a sub-band signal with as many sub-bands as there are filters in the filter bank. The reconstruction process is called *synthesis*, meaning reconstitution of a complete signal resulting from the filtering process.

Another application of filter banks is edge detection, when some frequencies are more important than others in specific direction. After decomposition, the important frequencies can be coded with a fine resolution. Small differences at these frequencies are significant and a coding scheme that preserves these differences must be used. On the other hand, less important frequencies do not have to be exact.

Bamberger and Smith proposed a 2D directional filter bank (DFB). The DFB is efficiently implemented via an *l*-level tree-structured decomposition that leads to 2^l sub-bands with wedge-shaped frequency partition.

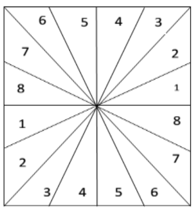

Fig 1: Frequency partitioning of a 2-D directional filter bank with 2^3=8 real wedge-shaped frequency bands (Anand *et al*, 2012)

3. McClellan Transform

McClellan Transform is one of the most powerful and popular techniques for designing 2-D FIR digital filters. The transformation consists of mapping 1-D prototype filters into 2-D filters by a change of variables. First, a low-order 2-D transformation sub filter, which is the kernel of the transformation, is designed so that the contour of the cut-off edge can meet the requirement for the designed 2-D filter. Then, a high-order 1-D prototype filter can be designed easily by the existing methods, for example, the Remez exchange algorithm. Furthermore, these 2-D filters can be implemented with highly structured architecture (Jong-Jy Shyu *et al*, 2009). The McClellan transformation can be used to design 2-D fan-type, circularly symmetric, elliptically symmetric, and diamond-shape filters,

1D FIR filter impulse response $h\ (n)$ can be noted as

$$H(\omega) = \sum_{n=0}^{N} a_p(n)\cos(\omega n) \quad (1)$$

Where,

$$a_p(n) = \sum_{m=0}^{M} a(n,m)p^m \quad (2)$$

Use Chebyshev polynomial substituting the $\cos(n\omega)$,

$$H(\omega) = \sum_{n=0}^{N} a_p(n)T_n\,(\cos(\omega)) \quad (3)$$

Where,

$$\cos n\omega = T_n \cos\omega \quad (4)$$

$T_n = n^{th}$ Chebyshev polynomial.

According to McClellan transform, design the 2D filter with 1D ones, the frequency response is

$$H(\omega_1,\omega_2) = \sum_{n=0}^{N} a(n)T_n\big(\varphi(\omega_1,\omega_2)\big) \quad (5)$$

Where, $\varphi(\omega_1,\omega_2)$ = Chebyshev transform function

$$\varphi(\omega_1,\omega_2) = cos(\omega) = t_{00} + t_{10}\,cos(\omega_1) + t_{01}\,cos(\omega_2) + t_{11}\cos(\omega_1)\cos(\omega_2) \quad (6)$$

The transform function is equivalently written as,

$$\varphi(\omega_1,\omega_2) = A + B\,cos(\omega_1) + C\,cos(\omega_2) + D\,cos(\omega_1-\omega_2) + E cos(\omega_1+\omega_2) \quad (7)$$

As, $cosAcosB = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$

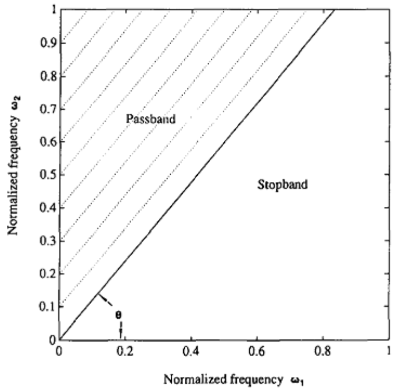

Fig. 2: Specification of ideal fan filter within the first quadrant (Emmanouil *at el*, 1990)

4. Proposed Work

- A 1D prototype filter using Kaiser Window is designed with following parameters: -
  - Pass Frequency, $\omega_p = 0.45\pi$
  - Stop Frequency, $\omega_s = 0.55\pi$
  - Pass band Amplitude = 1
  - Peak passband ripple $\alpha_p = 0.5dB$
  - Minimum stopband attenuation $\alpha_s = 40dB$
- With the transform function $\varphi(\omega_1,\omega_2)$, we can get different 90° wedge filters and parallelogram filters with different transform function and different value of $\{A,\ B,\ C,\ D,\ E\}$
- These wedge filters can be used to design four 8-directional sub-band filters by multiplying 4-directional filters and parallelogram filters
- Then subtracting the four 8-directional from the 4-directional filters, we get other 8-directional sub-band filters.

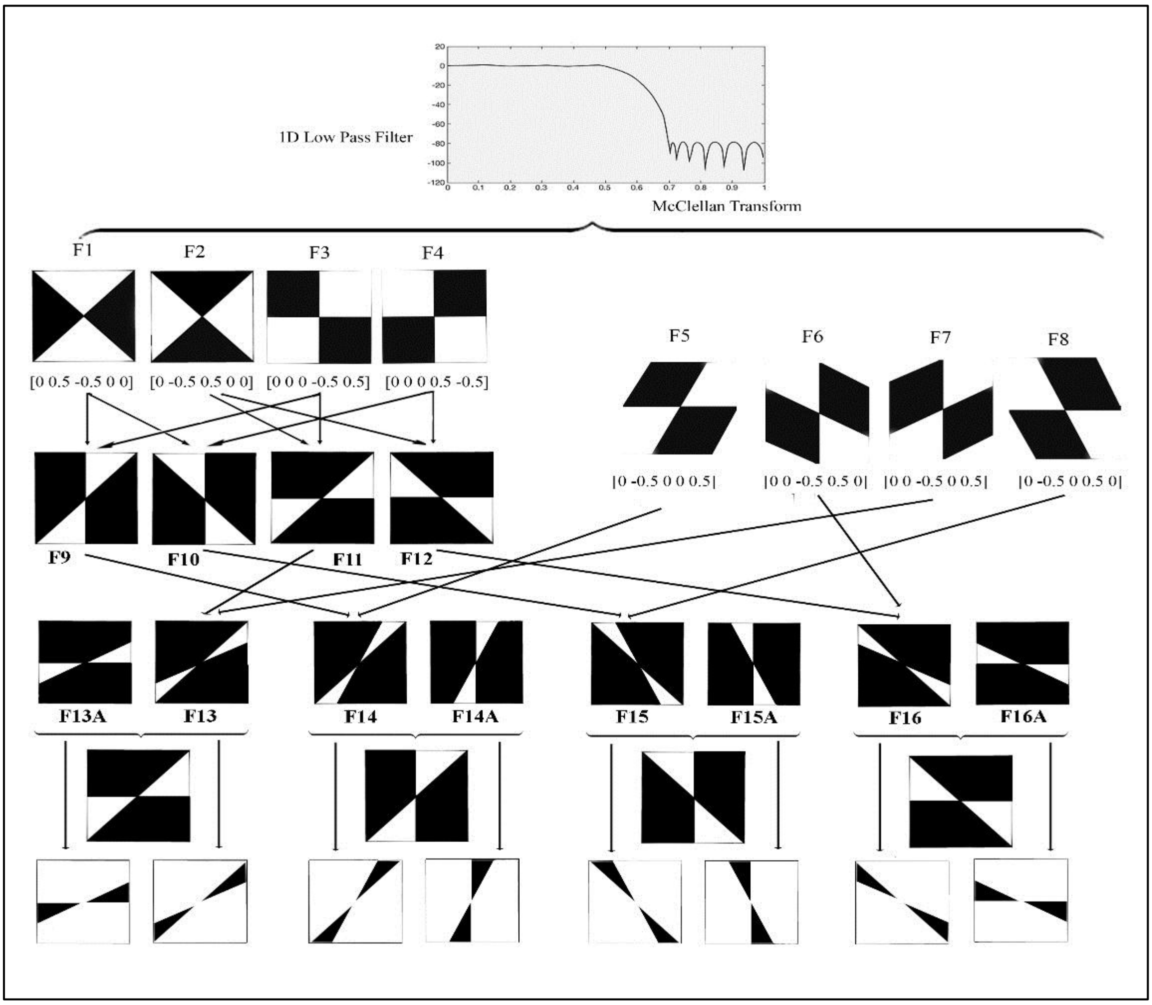

Fig.3: 8-directional filters design based on McClellan Transform. (Changbo *at el*, 2014)

5. Calculation of parameters.

For calculating parameter of equation (7) from (6), following is obtained.

- A = t_{00}
- B = t_{10}
- C = t_{01}
- D = $t_{11}/2$
- E = $t_{11}/2$

Let, $\omega_0$be the cut-off frequency of the 1-D prototype zero phase low-pass filter. Let also θ be the angle given by the 2-D fan filter specifications, (as shown in Fig. 1). Since due to quadrant symmetry, it will limit to the first quadrant. Notice that the $(0,\pi),(\pi,0)$points are in the passband and stopband, respectively. Thus we require the original McClellan transform (6) to satisfy the following condition:

$$-1 = \varphi(\pi,0) \leq \varphi(\omega_1,\omega_2) \leq \varphi(0,\pi) = 1$$

Applying this condition in eqn. (6),

$$t_{11} = t_{00}$$

$$t_{10} = 1 + t_{01} \quad (8)$$

From (6) and (8),

$$\varphi(\omega_1,\omega_2) = t_{11}\big(1+\cos(\omega_1)\cos(\omega_2)\big) +(t_{01}+1)\cos(\omega_1) + t_{01}\cos(\omega_2) \quad (9)$$

After calculating the t_{00} t_{10} t_{01} and t_{11} parameters we get A, B, C, D, and E (Emmanouil *at el*, 1990), and using these coefficients we will get 2-D fan filters. Applying these directional filters on an image we can detect the edges in desired direction in steerable manner.

6. Result

128×128 2D filters are designed. The 2D filter responses and their corresponding results of edge detection for different examples are shown in Fig. (4), Fig. (5), Fig. (6), Fig. (7) and Fig. (8).

Filters shown here are in frequency domain and the resultant images are in time domain.

Example 1: Spiral

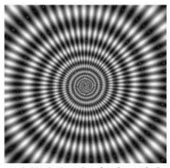

Fig.(4)(a):Original image

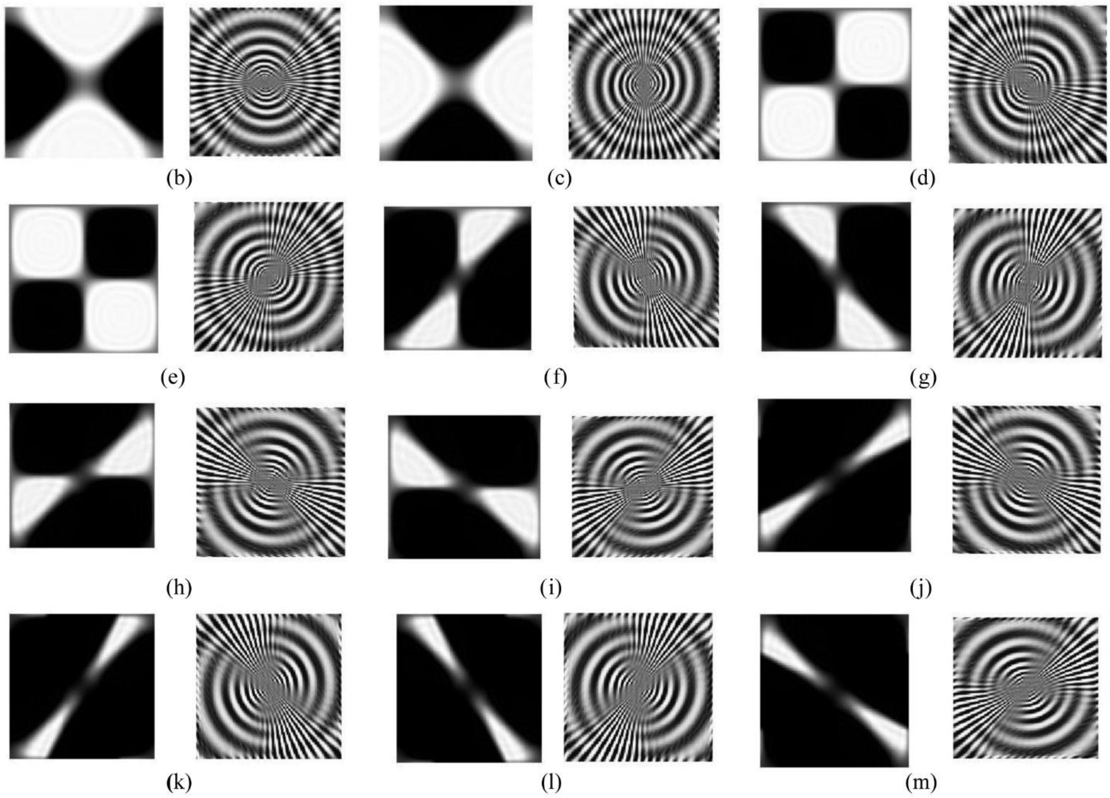

Fig.4: (b), (c), (d), (e), (f), (g), (h), (i), (j), (k), (l) and (m) Resultant output of filter F1, F2, F3, F4, F9, F10, F11, F12, F13, F14, F15 and F16 respectively

Example 2: Wooden texture

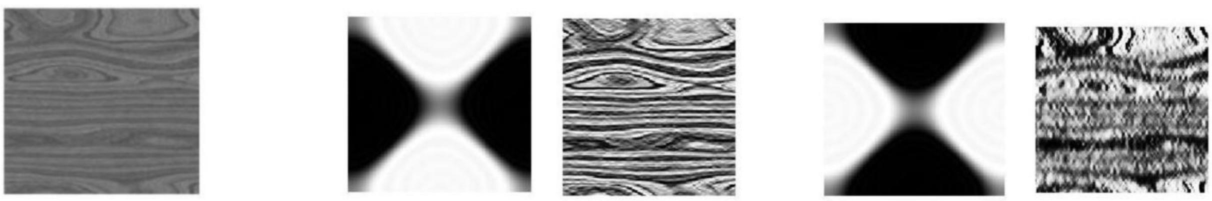

Fig 5: (a)Original Image (b) F1 Filtered Image (c) F2 Filtered Image

Example 3: Face

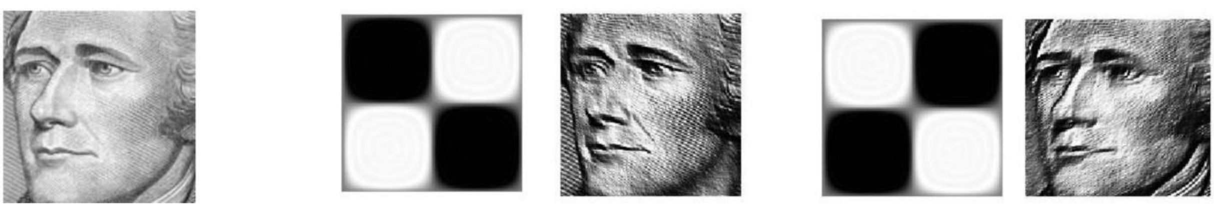

Fig 6: (a)Original Image (b) F3 Filtered Image (c) F4 Filtered Image

Example 4: Face

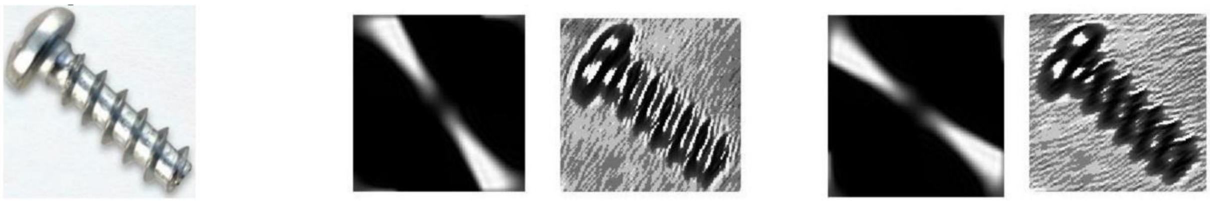

Fig 7: (a)Original Image (b) F15 Filtered Image (c) F16 Filtered Image

Example 5: x-ray image showing fractured Bone

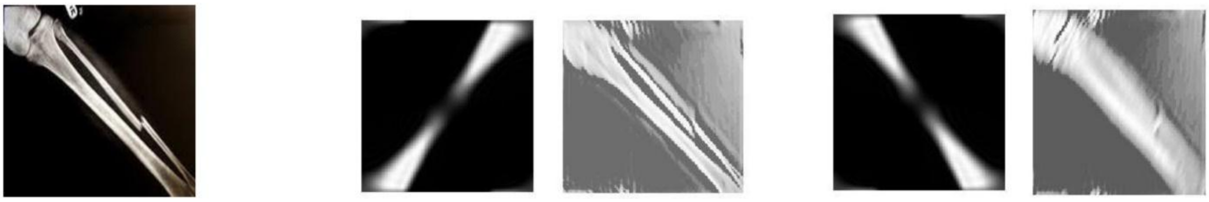

Fig 8: (a)Original Image (b) F14 Filtered Image (c) F15 Filtered Image

Table 1 Filters F9 to F16A derived from various filters

S. No	Filter name	Filter combination
1	F9	F2 * F3
2	F10	F2 * F4
3	F11	F1 * F3
4	F12	F1 * F4
5	F13	F7 * F11
6	F13A	F11 – F13
7	F14	F5 * F9
8	F14A	F9 – F14
9	F15	F8 * F10
10	F15A	F9 – F14
11	F16	F6 * F12
12	F16A	F12 – F16

Conclusion and Future work

This paper proposed the directional filter by McClellan Transform for edge detection which is useful in capturing and representing edges in various directions and scales. This approach helps in providing directional specific information along with scale, hence collecting more information. From the results it is observed that the proposed method for edge detection provides a better result and acts as the good method of extracting the information along the edges in specific direction.

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