FPGA Implementation of Image Enhancement Using Gabor Filter

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ABSTRACT
The aim of Image Enhancement is to improve the specific features of an image. Gabor filter will help in enhancing the quality of an image. By tuning the filter to a particular frequency and direction the local frequency and orientation information can be obtained. The complex part in fingerprint identification process is the fingerprint image enhancement. Here we study the features of multipurpose Gabor filter by implementing the filter along with fingerprint enhancement algorithm on FPGA using Verilog HDL.

Keywords
Gabor Filter, Fingerprint Enhancement algorithm, MATLAB, VerilogHDL, FPGA,

INTRODUCTION
Texture can be defined as a property of an image which is characterized by a high concentration of localized spatial frequencies. In Gabor filtering the texture images are represented by multiple frequency and orientation channels. Fourier transforms are not suitable for spatial frequency analysis of an image, because Fourier transformation gives the global spatial frequency information of an image. The specific frequency and orientation characteristics of Gabor filter make it suitable for texture analysis of an image. The motivation for deploying Gabor filters in computer vision application is the similarity of 2D Gabor filters with the receptive field of neurons in the visual cortex [4].

Here we have done the fingerprint enhancement to make a study on the specific features of Gabor filter. Though many of the existing algorithms give a reliable orientation estimate for the corrupted images they are computationally expensive. Similarly in the existing system the top level verification of the filter cannot be done due to software limitation [3].

General function of Gabor filter can be represented as below:

g(x, y, \theta, f_\theta) = \exp\left[-\frac{1}{2} \left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right] \cos(2\pi f_\theta x_\theta)

where

\[\begin{bmatrix} x_	heta \\ y_	heta \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}\]

The performance of a fingerprint feature extraction and comparison algorithm relies heavily on the quality of the input fingerprint images. Up to now, many approaches for fingerprint enhancement have been introduced. Fingerprint enhancement algorithms can be classified into two groups: spatial domain filtering enhancement techniques [5] and transformed domain enhancement techniques [6], such as Fourier domain and wavelet domain, filtering. Gabor filter have been widely used to facilitate various fingerprint applications such as fingerprint matching and classification. Gabor filters are band pass filters that have both frequency-selective and orientation selective properties [1]. Hence these filters can be effectively tuned to specific frequency and orientation values.

Hong et al. [2] introduced the method of Gabor filtering for fingerprint image. Yang et al. [7] propose a novel filter design method for fingerprint image enhancement. The development of an improved version of the traditional Gabor filter (TGF), called the modified Gabor filter (MGF). Its parameter selection scheme is image-independent. Sherlock and Monro [6] perform contextual filtering completely in the Fourier domain. Each image is convolved with precomputed filters of the same size as the image. The precomputed filter bank is oriented in eight different directions in intervals of 22.5. However the algorithm assumes that the ridge frequency is constant throughout the image in order to prevent having large number of precomputed filters. Therefore the algorithm does not utilize the full contextual information provided by the fingerprint image.

The performance of any fingerprint recognizer system highly depends on the fingerprint image quality; therefore fingerprint image enhancement is an essential stage in these systems. Wavelet
The discrete wavelet transform is a good tool for non-stationary signal processing and has a wide range of applications. In [8] a wavelet-based method for fingerprint image enhancement has been proposed. In this, Gabor wavelet and Gabor filter are used for this purpose. First, the image is divided into blocks. 64 Gabor wavelet based on 4 frequencies and 16 directions are defined then the orientation and frequency of any image block are estimated. By using these estimations, a suitable Gabor filter is designed and then the image blocks are filtered. But the computational complexity of the system makes it unsuitable for FPGA implementation.

There exist different methods to implement Gabor filter on FPGA. Implementing Gabor-type Filters on Field Programmable Gate Arrays [4] was implemented using cellular neural network (CNN). The implementation of Gabor kernel on FPGA by parallel execution of multiplication and addition [3] cause inefficiency in the top level implementation due to the lack of memory.

Comparing the aforementioned methods a better enhancement algorithm and Gabor kernel implementation with a little modification forms the base of this work.

**METHODOLOGY**

The main steps of the algorithm [2] include:

1. Normalize the input fingerprint image to a predefined mean and variance.
2. Obtain the orientation image from the normalized input fingerprint image using gradient operator in MATLAB.
3. Estimate the local frequency image from the normalized input fingerprint image and the estimated orientation image.
4. Apply the Gabor filter banks tuned to local ridge orientation and frequency to the normalized input fingerprint image to obtain an enhanced fingerprint image.

The system is simulated both in MATLAB (R2012b) and ModelSim 10 and finally implemented on FPGA (Spartan 3E). The programs needed for converting the noisy image into binary values are done using MATLAB program. It is then serially send to the FPGA. The image enhancement algorithm using the Gabor filter is implemented on FPGA. The Gabor filter now denoise the pixel values in binary form and send it back to the PC.

where it is converted back into the image using MATLAB program.

**Fig 1: Proposed System Architecture**

**Fingerprint Image Enhancement on FPGA**

The main steps in Image Enhancement on FPGA are:

1. **Normalization**
   - The value of the mean and variance of the given input image is calculated. Applied the normalization equation to make the ridge and valley contrast to a maximum extend.

2. **Ridge Orientation**
   - 2.1) The normalized image is divided into 16x16 blocks.
   - 2.2) Each pixel of the block is made as the central pixel for calculating the gradient vectors along the x and y direction. A simple sobel operator is used for the same. The edge pixels are made central pixels by providing the zero padding to the entire array.
   - 2.3) Inverse tangent operation on the approximated y and x gradient ratio will provide the orientation of each pixel.

3. **Ridge Frequency**
   - In the case of fingerprint images the value of the estimated frequency will remain in the range [1/3 1/25]. In our case the value is estimated to be 1/7 by calculating the inverse of the inter ridge distance.

The calculation of inter ridge distance (x - signature) is done on FPGA by counting the non-zero value pixels (representing the ridges) of the normalized fingerprint image between two zeros value pixels.
(which represents the valley region). The obtained output value is saved in an array and median of which provide the required x-signature.

4. The value of standard deviations of the Gaussian function which forms another important parameter to be determined which is found to be 4 using empirical data.

5. The obtained values are used to calculate the Gabor kernel and the kernel values are convolved with the normalized input image.

Fig 3: a) Input Image b) Normalized Image c) output of Gabor Kernel Angle= -22.5, freq= 1/7 d) output of Gabor Kernel Angle= -22.5, freq= 1/7 e) Enhanced Image

In the modelsim simulation the values obtained are similar to MATLAB results. 

Gabor kernel is estimated using the obtained frequency and orientation value. In order to calculate the kernel, corresponding cosine and exponential values in the look up table are multiplied and the output value is displayed, which is found equivalent to the MATLAB result.

RESULT ANALYSIS

Enhanced finger print image was obtained in MATLAB. As the number of Gabor band pass filters increases the image is getting more enhanced.

CONCLUSION

Gabor filters have tunable frequency and orientations and can achieve joint resolution in the spatial and frequency domains. This property makes
them an integral part of many image processing applications. In fingerprint enhancement the fast enhancement algorithm provide the enhancement required for the post enhancement stage in fingerprint identification, which is the best security that ever exists. The implementation on Gabor filter on FPGA makes them more compact, cost effective and reconfigurable. The simulation results points that the enhancement achieved by the algorithm is appropriate for our application.

The use of Gabor filters is driven by the potential they have to isolate texture according to particular frequencies and orientations. The parameters that define a Gabor filter are its frequency, standard deviation and orientation. By varying these parameters, a filter bank is obtained that covers the frequency domain almost completely. Feature information of image is also needed in applications like medical imaging for tumour detection, crack detection, texture analysis of remote sensing images and satellite images for landscape classification, object tracking etc.

The proposed method requires less space as it is a recursive system. So it reduces the space requirements compared to the existing ones. It can be used in real time implementations. A specific application of the proposed system is the replacement of existing security systems of cell phones with fingerprints.

**Ideas for Future Extension**
- The proposed implementation can be extended by implementing reconfigurable Gabor filter.
- A better system on chip can be implemented for fingerprint identification with reconfigurable Gabor filter.

**REFERENCES**


