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Banknote Image Retrieval Using Rotated Quaternion Wavelet Filters

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Abstract

A new method of banknote image retrieval is proposed by using new set of rotated quaternion wavelet filters (RQWF) and standard quaternion wavelet transform (QWT) jointly. The robust and rotationally invariant features are extracted from QWT and RQWF decomposed sub-bands of banknote image. Three different sets of databases are used to demonstrate the effectiveness of the proposed method. The experimental results show that the proposed method improves the recognition rate from 78.79% to 91.22% on (16000 images) database D1, form 74.08% to 94.62% on (20000 images) database D2 and from 76.44% to 88.78% on (10000 images) database D3. The proposed method can also obtain a reasonable level of computational complexity.

Keywords: discrete wavelet transform (DWT), complex wavelet transform (CWT), quaternion wavelet transform (QWT), rotated quaternion wavelet filters (RQWF), feature extraction, support vector machine (SVM).

1. Introduction

With the development of modern science,the banknote recognition system becomes more and more important.The goal of the system is to sort the banknotes according to their value and face automatically. Feature extraction and classification are very important components in banknote recognition system.

Several authors have proposed many feature extraction methods.Liu and Picard [1] used wold features for image modeling and retrieval. Manjunath and Ma [2] used Gabor wavelet coefficients for image retrieval.Discrete wavelet transform (DWT) [3-8] was proposed for image feature extraction.Do and Vetterli[9] proposed wavelet based texture retrieval by the use of generalized Gaussian density and Kullback-Leibler distance metric.A comparative study of rotation invariant texture analysis method was proposed by Janney et al [10].Magnitude of a discrete Fourier transform in the rotation dimension of features obtained with a multi-resolution [11-12].Chen [13] modeled the features of wavelet sub-band as a hidden Markov model (HMM).In [14],Manthalkar presented rotation-invariant texture features using a wavelet packet transform.The real DWT has two drawbacks of shift sensitivity and poor directionality [15].Selesnick and Kingsbury [16]proposed DT-CWT which can represent image texture efficiently in six directions.Also,reference [17] obtained improved retrieval performance by the use of DT-CWT. But DT-CWT is a single phase, which can't resolve the image shift in both the horizontal and vertical directions from the change of only one CWT coefficient phase.

The new quaternion wavelet transform (QWT) [18-19] was proposed in recent years for overcoming drawbacks of DWT and DT-CWT.The QWT can provide three phases for image analysis by using the phase concept.QWT used the Gabor kernel as quaternion mother wavelet,and extended to multi-resolution analysis.Different phases are computed in different resolutions by the modulated quaternion Gabor filters.

To improve the retrieval performance both in terms of retrieval accuracy and retrieval time, a new set of 2-D rotated quaternion wavelet filters is proposed in this paper.The proposed banknote image retrieval method combined QWT and RQWF is used in banknote recognition system. The method is checked on three sets of large databases and compared with existing available methods on corresponding databases. The performance of the proposed method is better than that of the existing available methods on each database.

This paper is organized as follows.Rotated quaternion wavelet filters are proposed in section 2. Section 3 provides an overview of support vector machine (SVM). The banknote image retrieval system using QWT+RQWF+SVM is proposed in section 4. Experimental results are given in section 5, which is followed by the conclusion in section 6.

2. Rotated Quaternion Wavelet

2.1. Real Wavelet Transform

The one-dimensional (1-D) discrete real wavelet transform decomposes signal $f(x)$ with dilated and shifted mother wavelet $\varphi(x)$ and scaling function $\phi(x)$.

$$f(x) = \sum_{l \in Z} A_{j_0,l}\phi_{j_0,l}(x) + \sum_{j=1}^{j_0}\sum_{l \in Z} D_{j,l}\varphi_{j,l}(x) \qquad (1)$$

where the approximation coefficients $A_{j_0,l}$ and wavelet coefficients $D_{j,l}$ at scale j can be calculated using the standard inner product $A_{j_0,l} = \langle f, \phi_{j_0,l} \rangle$ and $D_{j,l} = \langle f, \varphi_{j,l} \rangle$, in which $\phi_{j_0,l}(x) = 2^{\sqrt{j_0}}\phi\left(2^{j_0}x - l\right)$ and mother wavelet function $\varphi_{j,l}(x) = 2^{\sqrt{j}}\varphi\left(2^{j}x - l\right)$.Given the approximation coefficients $A_{j,l}$ at scale j, then the approximation coefficients $A_{j+1,l}$ and wavelet coefficients $D_{j+1,l}$ at scale $j+1$ are obtained by passing $A_{j,l}$ through low-pass filter h and high-pass filter g.The operation of down-sampling is by a factor of two. The standard two-dimensional (2-D) wavelet transform is obtained using tensor products of 1-D wavelets transform over the vertical and horizontal directions. It decomposes the signal of image $f(x,y)$ in terms of a set of wavelet functions which are strongly oriented in $\{0^\circ, 90^\circ, \pm 45^\circ\}$ and scaling function.

$$f(x,y) = \sum_{l \in Z^2} A_{j_0,l}\phi_{j_0,l}(x,y) + \sum_{k \in \alpha}\sum_{j=1}^{j_0}\sum_{l \in Z^2} D^k_{j,l}\varphi^k_{j,l}(x,y) \qquad (2)$$

where $\phi_{j_0,l}(x,y) = 2^{j_0}\phi(2^{j_0}(x,y) - l)$ and $\varphi^k_{j,l}(x,y) = 2^j\varphi^k(2^j(x,y) - l)$. The 2-D separable wavelet transform is constructed in terms of 2-D scaling and three 2-D wavelet functions as follows

$$\begin{aligned} \phi(x,y) &= \phi(x)\phi(y) \\ \varphi^0(x,y) &= \phi(x)\varphi(y) \\ \varphi^{90}(x,y) &= \varphi(x)\phi(y) \\ \varphi^{\pm 45}(x,y) &= \varphi(x)\varphi(y) \end{aligned} \qquad (3)$$

where ϕ, φ are 1-D scaling function and wavelet functions as described in (1).The 2-D real wavelet transform of three sub-bands is shown in Fig1.

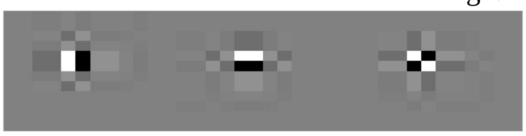

Fig. 1. Impulse response of 2-D wavelet filters