Chapter 1

Introduction

Storage constraints and bandwidth limitations in communication systems have necessitated the search for efficient image compression techniques. For real-time video and multimedia applications—where a reasonable approximation to the original signal can be tolerated—lossy compression is used. In the recent past, wavelet-based lossy image compression schemes have gained wide popularity. The inherent characteristics of the wavelet transform provide compression results that outperform other techniques such as the discrete cosine transform (DCT). Consequently, the JPEG2000 compression standard and the FBI fingerprint compression system have adopted a wavelet approach to image compression [3, 21].

The literature provides a plethora of wavelets and multiwavelets with different properties. Naturally, the following question arises: 'which wavelet is best suited to image compression?' The research to date does not give a comprehensive answer. This uncertainty motivates the search for: (1) a set of desirable properties suited to image compression and (2) wavelets and multiwavelets that possess such properties. Currently, scalar wavelets are well understood in the context of image compression; however, further research remains in the area of multiwavelets. This thesis studies the properties of a new class of multiwavelets called balanced multiwavelets and investigates their usefulness in image compression [10].

Furthermore, the literature indicates that objective quality metrics like peak signal-to-noise ratio (PSNR) do not correlate with perceived image quality at high compression ratios [23]. This motivates the need for incorporating characteristics of the human visual system (HVS) into compression schemes. This thesis uses a recent HVS-based transform technique where perceptually important frequencies are preserved in the compressed image; our results depict better subjective quality.

1.1 Past Research

Wavelet theory attained maturity in the late 1980s and early 1990s. The construction of compactly supported orthogonal wavelets by Ingrid Daubechies [6] and the formal development of the multiresolution framework for wavelet bases by Morlet, Grossman, Meyer and Mallat triggered the research in the application of wavelets to signal processing [12]. Since that time, several areas have benefited from wavelets. Image and video compression are amongst the applications that have benefited most.

Several researchers have extensively studied the performance of scalar wavelets (wavelet bases with a single scaling function and a single wavelet) in compression [1, 23, 30]. Symmetric extension methods, (which are known to give noticeable improvement over periodic extensions), have been developed for biorthogonal scalar wavelets [4]. In fact, the JPEG-2000 standard [21] has incorporated the (9,7)-tap biorthogonal scalar wavelet [1] into its compression scheme.

Multiwavelet-based compression is relatively new since it is based on the more recent multiwavelets (wavelet bases with multiple scaling and wavelet functions). Unlike the scalar wavelets, multiwavelets can simultaneously possess orthogonality and symmetry. Multiwavelet theory has been developed largely by Geronimo, Hardin, Massopust, Strela, Vetterli, Lebrun, Jiang, Tham and others [7, 8, 10, 25, 27, 33]. Recently, Lebrun and Vetterli introduced the concept of balanced multiwavelets (multiwavelets that obviate the input preprocessing step due to the good spectral characteristics of the scaling and wavelet functions) [10, 11]. Subsequently, Selesnick proposed the first symmetric FIR-based balanced multiwavelet [19].

Strela reported superior performance of multiwavelets over scalar wavelets in denoising applications [25]; moreover, some multiwavelet transforms are computationally more efficient than scalar wavelet transforms [27]. Although these observations favor multiwavelets, many of the proposed multiwavelet bases used for image compression have fallen short of the performance of the widely used biorthogonal scalar wavelets [25, 31]. This indicates the need to further investigate the characteristics of multiwavelets for image compression.

A good quantization technique is as important to compression as a good transform. Several lossy coding techniques for the wavelet transform have been proposed in the literature. In 1993, Shapiro presented the embedded zero tree (EZT) encoder [20]. Along similar lines is the set partitioning in hierarchical trees (SPIHT) algorithm introduced by Said and Pearlman in 1996 [18]. A slightly different coding technique is space-frequency quantization (SFQ) proposed by Ramchandran et. al. [34]. All of these coders exploit the self-similarities inherent in an image by compactly representing the spatial dependencies of the wavelet coefficients.

HVS modeling in wavelet-based compression is also a relatively new research area. Most of the schemes involve encoding perceptually important information with more bits. Ramos and Hemami proposed an image segmentation scheme to sort perceptually important regions by content type (smooth, edge and detail) [17]. Nadenau and others proposed a subband weighting/filtering step to preserve perceptually important spatial frequencies [16, 15]. Another scheme reported significant improvements with a perception-based model that used a predictive algorithm, but computational complexity was a limiting factor [9]. This thesis uses a recent technique in which a subband weighting mask is developed based on the contrast sensitivity function (CSF) of the HVS [2].

1.2 Significance of this Work

This thesis presents the performance evaluation of orthogonal, balanced multiwavelets in image compression. Our analysis suggests those multiwavelet characteristics that are important to image compression. Our results are based on a large database of natural and rendered images. The following are the contributions of this thesis.

1. A comprehensive analysis of the effect of the multiwavelet filter bank properties on image compression performance.

2. The modification of the balanced multiwavelet decomposition scheme to suit SPIHT quantization.

3. Subjective performance results of balanced multiwavelets with the HVS model.

1.3 Organization of this Thesis

This thesis is inspired and motivated by the promise of multiwavelets for image compression. The following chapters step the reader through the basics of image compression, wavelets, balanced multiwavelets and our results. Chapter 2 presents the fundamentals of the wavelet-transform and the SPIHT quantization technique. Chapter 3 discusses the multiwavelet transform implementation and balancing. Chapter 4 presents some examples of balanced multiwavelets and analyzes their properties. In Chapter 5, we evaluate the performance of these multiwavelets on many images using analytical and subjective measures. We also examine the effectiveness of using an HVS-based scheme. Finally, Chapter 6 concludes this thesis with a summary of our results and directions for future work.