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An Overview on Wavelet Software Packages

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Abstract: **Wavelet analysis provides very powerful problem-solving tools for analyzing, encoding, compressing, reconstructing, and modeling signals and images. The amount of wavelets-related software has been constantly multiplying. Many wavelet analysis tools are widely available. This overview represents a significant survey for many currently available packages. It will be of great benefit to engineers and researchers for using the toolkits and developing new software. The beginner to learning wavelets can also get a great help from the review. If you browse around at some of the Internet sites listed in the reference of this paper, you may find more plentiful wavelet resources.**

Key words: **wavelet transforms; image compression; matching pursuit; lifting; MATLAB**

CLC number: **O 174.2; TP 319**

0 Introduction

Wavelets are the functions that satisfy certain mathematical requirements and are used for representing data or signals, which having cut up data into different frequency components one analyze the each component with a resolution matched to its scale. Wavelets were developed independently in the many different fields such as mathematics, electrical engineering, quantum physics, seismic geology, and so on. During the last fifteen years interchanges between these fields have led to many new wavelet applications[1-5].

Wavelets provide very powerful problem-solving tools for analyzing, encoding, compressing, reconstructing, and modeling signals and images. They are useful in capturing, identifying, and analyzing local, multiscale, and nonstationary processes. Wavelet transforms can offer additional insight and performance in data analysis situations where Fourier techniques have previously been used. For example, signals and images with sharp changes and small or irregular detail are often better analyzed with wavelets than with more traditional Fourier techniques. With wavelet analysis, engineers and scientists can see and explore aspects of data that other analysis techniques miss, such as trends, breakdown points, discontinuities in higher derivatives, and self-similarity.

By now, the amount of wavelets-related software for workstations and PCs, has been constantly multiplying[6-9]. The scientific computing software such as MATLAB, *Mathematica*, and *Mathcad* integrates the wavelet application functions. Many wavelet analysis tools are widely available in commercial or free of charge, but the toolkits are not a panacea for any application —— no single can be. This review as an extension of Ref. [7] represents a significant survey for many currently available packages. It will be of great benefit to beginner to learning wavelets and to engineers and researchers in mastering and using the toolboxes and in developing new software.

This overview is organized as follows. In section 1 we gives a review of the wavelet toolkits for MATLAB. Section 2 is intended to represent a survey for the C++ class wavelet library. Review for the other packages including the wavelet soft-

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ware in Mathematica and S+PLUS, some applied systems with wavelet analysis functions, and much more, will be represented in section 3.

1 The Wavelet Toolkits for MATLAB

MATLAB that was developed from The MathWorks Inc. is an integrated scientific computing environment that combines numeric computation, advanced graphics and visualization, and a high-level programming language. It is widely used in a variety of application fields including signal and image processing, control system design, financial engineering, and medical research[10,11]. Now many wavelet packages are developed with the MATLAB software.

1.1 The MATLAB Wavelet Toolbox

The Wavelet Toolbox builds on the numeric and visualization capabilities of MATLAB to provide point-and-click graphical tools and command line functions for analysis, synthesis, de-noising, and compression of signals and images. It is designed to give data analysts and engineers practical and comprehensive access to the wavelet analysis techniques. It is one of over thirty toolboxes integrated in the MATLAB software system which provides the PDF format document for 626 pages and the online help for the toolbox.

The Wavelet Toolbox provides a comprehensive collection of routines for examining local, multiscale, and nonstationary phenomena. The Wavelet Toolbox is especially useful in many signal processing applications, including speech and audio processing, image and video processing, digital communications, geophysics, finance, and medicine.

The Wavelet Toolbox contains continuous wavelet transforms (CWT), 1-D and 2-D discrete wavelet transforms (DWT), multiresolution decomposition and analysis of signals and images, user-extensible selection of wavelet basis functions, 1-D and 2-D wavelet packet transforms, entropy-based wavelet packet tree pruning for "best-tree" and "best-level" analysis, soft and hard thresholding de-noising, and signal and image compression. Bundled with the Wavelet Toolbox is the book[12] by Gilbert Strang and Truong Nguyen, in which many exercises are drawn from the toolbox.

1.2 WavBox——ToolSmiths Wavelet Toolbox

WavBox Software is a full-featured original MATLAB toolbox by Carl Taswell. This toolbox provides both a function library and a computing environment for wavelet transforms and adaptive wavelet packet decompositions with FirWav Filter Library. It is the first available as free software in 1991, and the first available as commercial software in 1994. It contains 317 M-files implementing an extensive collection of these wavelet transforms, expansions, decompositions, wavelet filters, wavelets, and related functions. This function library performs multiresolution analyses of 1-D multichannel signals and 2-D images for arbitrary length and size data.

WavBox 4.5 includes: continuous wavelet transform valid for all wavelets including the complex Morlet, real Gabor, Meyer, and Mexican hat wavelets; overscaled pyramid transforms, discrete wavelet transforms, and adaptive wavelet and cosine packet decompositions by best basis and matching pursuit[4,13]; satisficing search algorithms for the selection of near-best basis decompositions with either additive or non-additive information costs, the systematized collection of FIR wavelet filters computable by spectral factorization of the Daubechies polynomial, and empirical tests for evaluating the parameters of multirate filter banks[14]; Donoho and Johnstone's wavelet shrinkage de-noising methods; as well as the fast wavelet based numerical methods[15] for the implementation of fast matrix multiplication and solution of linear systems in the wavelet domain. These latter methods can be used to implement pseudo-differential and integral operators.

1.3 WAVELAB —— A Library of MATLAB Routines for Wavelet

David Donoho and Iain Johnstone in the Stanford Statistics Department, the Stanford graduate students Jonathan Buckheit and Shaobing Chen, and Jeffrey Scargle at NASA-Ames Research Center have made publicly available: WaveLab, a library of MATLAB routines for wavelet analysis, wavelet-packet analysis, cosine-packet analysis and matching pursuit. The library, provided for use in MATLAB 5.X on three platforms: Macintosh, UNIX and Windows NT/98/2000, is avail-

able free of charge over the Internet. It performs elementary data compression and de-noising tasks, is the basis for wavelet research by the authors, and also has been used in teaching courses on adapted wavelet analysis and related Time-Frequency transforms at Stanford and at Berkeley.

WaveLab802, which is the most recent version, currently has over 1300 files consisting of scripts, M-files, MEX-files, datasets, self- running demonstrations, and on-line documentation. The files are documented, indexed and cross-referenced in various ways. This new library can also reproduce many figures for the book[13] written by Stéphane Mallat, and the figures in recent papers[16] by researchers from the Stanford Statistics Department and their collaborators.

1.4 WAVEKIT —— A Toolbox for MATLAB

The WAVEKIT is a wavelet toolbox written in MATLAB, by Harri Ojanen. The toolbox is a collection of functions for MATLAB that implement the following wavelet and wavelet packet algorithms: 1-D and 2-D (periodic) fast wavelet and wavelet packet transforms and the best basis algorithm for wavelet packets; an implementation of the fast matrix multiplication algorithm of Beylkin, Coifman, and Rokhlin[15] for both wavelets and wavelet packets; various demonstrations on visualizing wavelets, signal analysis, and the multiplication algorithm.

The original programs in this toolbox are intended for learning about wavelets, not for serious applications. Now the toolbox has matured to the point where it might prove useful to researches and applications of wavelets. Some of the visualization tools and demos are rather unique.

MATLAB 5. X and a compatible C-compiler are required, which must be able to work with MATLAB to produce MEX-files. At least on Unix platforms both the standard C-compiler cc and the GNU compiler gcc work with MATLAB. The details refers to Ref. [17].

1.5 Time-Frequency Toolbox for MATLAB

This free (copyrighted) software, by Francois Auger, Patrick Flandrin, Olivier Lemoine, and Paulo Goncalves, is a collection of about 100 M-files, developed for the analysis of non-stationary signals using time-frequency distributions. It performs signal generation files, processing and post-processing (including visualization). The toolbox contains numerous algorithms for time-frequency signal analysis, with special emphasis on quadratic energy distributions within Cohen's class and the affine class, including most recent developments based on reassignment. The toolbox is primary intended for researchers and engineers with some basic knowledge in signal processing. It requires MATLAB V5. 0 or later and the Signal Processing Toolbox V3. 0 or later.

1.6 Signal Processing Toolbox —— A Add-on Product of O-Matrix

The Signal Processing Toolbox (SPT) created by Richard Yeager is one of the add-on products of O-Matrix, which is a MATLAB-compatible interactive analysis and visualization tool that combines the programming flexibility and performance of a compiled language with the ease of use and functionality of an integrated environment. It provides a broad extensible set of functions and utilities which expand the capabilities of O-Matrix in the area of digital signal processing. Built on the high-performance and flexibility of O-Matrix, the toolbox has tools for algorithm development, data analysis, and visual presentation. The software runs under Windows 95/98/2000/NT.

The toolbox contains functions for performing many operations common to the area of digital signal processing. Linear FIR filter functions create several types of filters including lowpass, highpass, bandpass, bandstop, Hilbert transformers, and pulse-shaping filters (raised cosine types commonly used in digital communications systems). Similar capabilities are provided for IIR filters. Various signal generators such as random bit generators, noise generators, simple waveform generators, common carrier modulation waveforms, and general quadrature modulation are included for test and simulation purposes. Spectral smoothing, histogramming, data manipulation, and various mathematical functions add to the powerful RAD and analysis environment of O-Matrix.

2 The C++ Class Wavelet Library

The C++ or Visual C++ is a widely used object-oriented programming language and a powerful, effective and popular tool for the highest-

performance development for Windows and the Web. Specially, Visual C++ 6.0 contains greatly improved support for Web and Enterprise development. A great amount of wavelet library was written in C++ or Visual C++ language. Here is merely several applied software.

2.1 AWIC——Adaptive Wavelet Image Compression

The Adaptive Wavelet Image Compression (AWIC) algorithm is a fast, simple wavelet-based image compression technique that follows the classical paradigm of image transformation, quantization, and entropy encoding. A key component is a technique of channel symbol definition that provides greatly reduced Huffman table encoding costs, allowing optional Huffman codewords to be generated for each level of the wavelet transformed image. Further optimizations for compression performance were achieved by empirical studies.

AWIC software, which The MITRE Corporation owes, was designed with several goals in mind. The foremost goal was to attain the best compression performance possible for a wide range of image classes while minimizing the computational and implementation complexity of the algorithm. A secondary goal is to simplify the exploitation of some useful features provided by the wavelet transform decomposition.

2.2 EPWIC —— Embedded Predictive Wavelet Image Coder

EPWIC, by Robert W. Buccigrossi and Eero P. Simoncelli, stands for Embedded Predictive Wavelet Image Coder. EPWIC-1 is a grayscale image compression utility written in C. It is based on a wavelet pyramid decomposition whose coefficients are encoded (one bitplane at a time) using a static arithmetic encoder. The arithmetic encoder uses a generalized Laplacian (or generalized Gaussian) model of the first order statistics of the subbands. This coder was developed in summer 1996, and first presented at ICASSP-97 (Title: *Progressive Wavelet Image Coding Based on a Conditional Probability Model*). Compression quality is quite good (visit web site below), especially considering the simplicity of the algorithm. EPWIC-2 is a more powerful coder that uses a within-subband and inter-subband conditional statistical model for natural images. Both coders are described in detail in the paper[18] written by Robert W. Buccigrossi and Eero P. Simoncelli.

2.3 Image/Video Compression Software

Image/Video Compression Software Package, by Xuejun Li from the Wavelet Compression Laboratory in China, consists of two independent parts:

2.3.1 Low bit rate wavelet image/video compression software

Lastest low bitrate wavelet image/video compression software version 2.0 (for Win98/2000) includes Lossless Image Codec for BMP images, Near-Lossless Image Codec for BMP image, Lossy Image Codec with fast EZW algorithm and high compression rate for BMP image, a very low bit rate Video Codec including three compression modes and fast EZW algorithm for YUV raw video clips, and Video Player Software that read and play AVI, YUV, BGR format video files.

2.3.2 Image/video compression toolkit

Image/video compression toolkit (IVCT) version 1.0 is a library of the C and VC++ functions designed for the serious programmer wishing to write software or scientific applications which employ the elements of DCT, fractal, wavelet analysis, time-frequency analysis, image processing, image and video compression, as well as image and video play etc. IVCT is a carefully designed, thoroughly tested portable C source codes of reusable and extensible algorithms which allow the user to write efficient, fast executing programs in a wide image/video compression applications. IVCT comes with a make-file and compile on a Windows95/98/NT machine using Visual C++.

2.4 MR/1 and MR/2 —— The Software Package for Multiresolution Analysis

Multiscale methods provide a quantum leap forward in data analysis, have been described as furnishing the user with a "microscope" for analyzing data, and are an enabling technology for so many fields of application, with firm theoretical bases. MR/1 Multiresolution Analysis Environment, from Multi Resolution Ltd., is a software package written in C++ for implementing the methods. It is built on three classes: the image class, the multiresolution class, and the noise modeling class. It includes almost all applications presented in Ref. [19].

The package can meet for demanding and

high-performance applications such as scientific, engineering, medical, financial, media, and biological applications, implements visualization, filtering, noise modeling, deconvolution, compression, vision modeling, image registering, as well as feature detection. MR/1 V2. 0 released in July 1999, when MR/2 Multiresolution Entropy V1. 0 was also joined, provides more wavelet transforms, edge detection, multifractal analysis, Java user interface, and much more.

The package supports the most platforms such as WINDOWS 95/98/NT, Alpha, HP, Linux, Sun Solaris 2. 5, IBM RS/6000. A User Manual about 300 papers and other related files for MR/1 and MR/2 are available as Postscript or as compressed Postscript at the site of Ref. [20].

2. 5 XploRe —— A Interactive Statistical Computing Environment

XploRe, by W. Haerdle, S. Klinke, and M. Müller from Humboldt-University Berlin, Germany, is first developed for data analysis, research and teaching, then promoted as a powerful tool for computational statistics. The package contains a number of wavelet processing tools. The main features are an extensive set of parametric and nonparametric methods incorporating many statistical modelling approaches, a high level object-oriented programming language, an interactive graphic environment, a client/server architecture with a fully capable Java interface, an online help system, and a set of tutorials. XploRe contains a great variety of statistical methods that include generalized linear models and generalized partial linear models, nonparametric methods such as kernel estimation and smoothing, spline smoothing, nonlinear time series analysis, modern regression techniques, and wavelets and neural networks. The data are represented in C++ classes and all numerical algorithms, the administration of the symbol tables and of the flow control, and finally the most parts of the graphics are implemented in C++, too. XploRe can be installed on single computers (PC or workstation), and in networks. XploRe runs on almost any platform (Windows95/98/2000/NT, Solaris 2, HP-UX, SGI, and Linux 1. 2).

2. 6 WaveletKit

WaveletKit for building wavelet applications provides basic C code and tutorials for 1-D and 2-D processing. It, from Perfectly Scientific, Inc (PSI)— the algorithm company, does not pretend to be as fast as can be. Instead, it is a learning/construction kit, showing how you can process sound and images, the latter in color or grayscale. Note that PSI offers consulting services in speeding up wavelets and other transforms for specific customer needs.

This software package contains a library of functions for performing fast wavelet transforms (FWT) and a lossy wavelet image compressor. The wavelets of choice are the celebrated Daubechies wavelets. However, the basic algorithm structures easily extend to other wavelet classes. You may download the entire package at any time, free of charge, by following the link. The main sources, however, are encrypted. You may also purchase a decryption key for this and all future versions of WaveletKit.

2. 7 WaveThresh3 —— A Software of Statistics Based on Wavelet Techniques

WaveThresh3 is a software package for performing statistics based on wavelet techniques. The package is an add-on for the popular S—Plus statistical package that is based on the object—oriented S language developed at AT&T Bell Laboratories and is widely used in statistics for both research and applications.

The package contains many different wavelet transforms as well as a number of statistical techniques based on wavelet transforms. The package contains wavelet statistical techniques for curve estimation, time series analysis, survival data analysis, and image analysis. There are 1-D, 2-D and 3-D wavelet transforms and their inverses with a variety of wavelet families, non-decimated transforms, wavelet packets and non-decimated wavelet packet transforms.

Much of the WaveThresh is written in C. It is possible (and permissible) to use the C code independently as long as the acknowledgment is retained. Most of the package was written by Guy Nason from Department of Mathematics at University of Bristol, who maintains and distributes the package. However, Felix Abramovich and the others have kindly donated significant contributions to WaveThresh.

WaveThresh3 is available in free at the site of

Ref. [21], and runs for the operating system on Unix and S—Plus for Windows.

3 The Other Applied Software

This section will give the overview of other applied wavelet software excluding the wavelet toolkits for MATLAB and the C++ class wavelet library. It falls into two parts: one is several library in Mathematica and S+PLUS language; another is some applied software systems whose source code is not available whether it is free or commercial.

3.1 Wavelet Explorer

Wavelet Explorer is a new generation signal and image analysis tool. This package offers an excellent interactive tutorial for those new to wavelet theory as well as provides a complete set of tools for advanced wavelet research. Clear examples start with the basics about wavelets and how to explore wavelet properties, and demonstrate how you can use the system to apply wavelet analysis techniques in your field. Wavelet Explorer generates a variety of orthogonal and biorthogonal filters and computes scaling functions, wavelets, and wavelet packets from a given filter. It also contains 1-D and 2-D wavelet and wavelet packet transforms, 1-D and 2-D local trigonometric transforms and packet transforms, and it performs multiresolution decomposition as well as data compression and denoising tasks.

Wavelet Explorer's built-in functions and utilities are all fully programmable. You take advantage of Mathematica's thousands of powerful computational and visualization algorithms as you extend and customize your own wavelet analysis tools.

3.2 S + WAVELETS —— An Object-Oriented Wavelet Toolkit

S+WAVELETS is an object-oriented toolkit, from StatSci Division of MathSoft, Inc, includes an extensive set of over 500 analysis functions, for example, the discrete wavelet transforms, wide choice of wavelets basis functions, wavelet optimal signal estimation, optimum nonlinear extraction of non-smooth signals from noise, wavelet packet analysis, local cosine analysis, best basis adaptive choice of transforms, matching pursuit decompositions, time-frequency graphical displays, robust wavelets analysis, 1-D and 2-D data support with arbitrary sample sizes, full range of boundary correction methods appropriate for your data, and so on.

S+WAVELETS operates in conjunction with S-PLUS whose core is the object-oriented S language developed at Lucent Technologies (formerly AT&T Bell Laboratories). Working together with S-PLUS analysis software, the toolkit goes well beyond the capabilities of the Fourier transform for many kinds of signals and images. It can be used for many practical applications, including signal processing, medical imaging, time series analysis, pattern recognition, nonlinear signal estimation, and data compression. It helps you develop a complete understanding of data using time-frequency displays, multiresolution analysis, automatic signal estimation/extraction and denoising, and a comprehensive set of exploratory data analysis plots for wavelet decompositions.

The toolkit supports many platforms such as Windows 95/98/2000/NT4.0, IRX 6.2/6.5, AIX 4.3x, Solaris SPARC, Solaris 2.5x/2.6/2.7

3.3 Wavelets Extension Pack

The Wavelets Extension Pack is one of add-on Products in Mathcad 2000 which is a scientific computation software developed from MathSoft Inc., and lets you take a new approach to signal and image analysis, time series analysis, statistical signal estimation, data compression analysis, and special numerical methods. It creates an almost limitless number of functions that duplicate any natural or abstract environment, provides 1-D and 2-D discrete wavelet transforms, multiresolution analysis, and more. It includes extensively orthogonal and biorthogonal wavelet families including Haar, Daubechies, Symmlets, Coiflets, and B-spline wavelets.

The Wavelets Extension Pack integrates over 60 key wavelets functions, rivaling similar tools by MATLAB and Mathematica. Mathcad's versatile environment and Wavelets Extension Pack's superior integration with Mathcad and other add-on tools (including Signal Processing and Image Processing Extension Packs) are ideal for wavelets experimentation and performance of what-if scenarios. Plus, You can also get extensive interactive

documentation on wavelet fundamentals, applications, examples and reference tables.

3.4 Signal Processing Toolkit

The Signal Processing Toolkit (SPT) is an add-on of PV-WAVE 7.0 which is the visual data analysis software developed by Visual Numerics Inc., almost entirely written in PV-WAVE with the source code supplied. The Toolkit concentrates on 1-D signal processing, with many of the functions extensible to 2-D for image processing, etc. simply by adding to the source code.

In addition to the various functions which cover areas such as models and analysis, filter approximation and realisation, transforms and spectrum analysis, statistical signal processing, optimization and convenience routines for polynomial manipulation (of the transfer functions) and plotting functions, SPT computes the wavelet transform of a data sequence using compactly supported orthonormal wavelets using a quadrature mirror filters (QMF), and includes functions for computing and designing the QMF bank as well as a number of examples. It requires platforms for UNIX, Windows 95/98/2000/NT, and OpenVMS.

Furthermore, visiting the following site, you can also know the Advanced Image Processing Toolkit (AIPT) that is another add-on of PV-WAVE 7.0.

3.5 CREW —— Compression with Reversible Embedded Wavelets

CREW is a new type of still image compression system that is a unified lossless and lossy, progressive by resolution and pixel depth, bi-level and continuous-tone image compression system based on a reversible wavelet transform, and has embedded quantization allowing quantization decisions to be made after encoding. It is pyramidal (similar to hierarchical) and progressive by nature, and can preserve the source image at encode and quantize for the target device at decode or transmission.

CREW was developed by Ricoh Company Ltd. and Ricoh Silicon Valley at the California Research Center. RICOH offered this technology to the ACR-NEMA MED-PACS Working Group IV (DICOM) committee for new American medical image compression standard. RICOH also offered this technology to the ISO/IEC JTC1/SC29/WG1 (JPEG, JBIG) committee for a new international compression standard this submission lead to the new work item called JPEG 2000.

Ricoh is now fully supporting JPEG 2000, which should become an International Standard in December 2000, and will support all the features of CREW[9].

3.6 ER Mapper —— A Desktop Integrated Image Processing System

ER Mapper is the most powerful and popular desktop integrated image processing software.

Using the powerful ER Mapper wizards, you can easily integrate all of your imagery data into a single seamless mosaic, and create ER Mapper smart data algorithms to enhance your imagery, and experience real-time processing without the need for temporary disk files.

Best of all, share your images and smart data algorithms with GIS and Microsoft Office users with the free ER Mapper imagery plug-ins for Autodesk World, AutoCAD Map, ArcView 3.1, MapInfo, and OLE applications including Microsoft Word, Excel and Power Point.

The ER Mapper Compression Wizard achieves compression rates of 10 : 1 to 15 : 1 for grayscale imagery and 25 : 1 to 50 : 1 for color imagery resulting in very high quality compressed images. Higher or lower compression rates can also be used, so you can adjust your compression to the desired results. Compressed images can be viewed and processed using ER Mapper 6.0, and the free ER Mapper plug-ins for a wide range of GIS, Microsoft Office and CAD software products.

3.7 Wavelet Toolware for Wavelet Training

Wavelet Toolware is an easy-to-use companion software package to the Chui's book[22], which is not free software written by Charles K. Chui, Andrew K. Chan, and C. Steve Liu. This software is designed as a learning and experimentation tool (rather than for use in solving high-precision computational problems), and offers users hands-on practice in the area of wavelet analysis and its applications. It supports several different wavelets, and contains, among other algorithms and codes, 1-D and 2-D Discrete Wavelet Transforms (DWT) and their inverse transforms, as well as computations of the Continuous Wavelet Transforms (CWT) and the Short Time Fourier

Transforms (STFT). Simple signal processing applications, such as thresholding and noise removal are also included as examples of how to use the software.

The package includes an 80 pages users manual which provides the basics of wavelet theory and shows how they can apply to engineering problems. The manual also contains several major algorithms which can be applied during software practice sessions, giving the user the tools to apply the basic aspects of wavelet analysis to problems of their respective disciplines.

4 Conclusions

Undoubtedly, this overview should be an extremely good supplement and extension as Ref. [7]. This review along with Ref. [7] should be the foundation upon which more sophisticated wavelet library or toolkits can be built. In fact, there also is a number of wavelet software for special and accompanying published papers or books. If you browse around in some of the Internet sites listed Ref. [7], [16], [23], [24], and Andreas Klappenecker's site[25] at which over 200 People studying wavelets are listed, you may find more abundant wavelet resources, such as papers, books and other more sites where wavelet research is being done.

References:

[1] Daubechies I, Sweldens W. Factoring Wavelet Transforms into Lifting Steps. *The Journal of Fourier Analysis and Applications*, 1998,**4**(3), 247-269.

[2] Fernandez G, Periaswamy S, Sweldens W. LIFTPACK: A Software Package for Wavelet Transforms using Lifting. *Wavelet Applications in Signal and Image Processing* Ⅳ, Proc of SPIE, 1996,2825, 396-408.

[3] Shapiro J M. Embedded Image Coding Using Zerotrees of Wavelet Coefficients. *IEEE Trans Signal Processing*, 1993,**41**(12), 3445-3462.

[4] Wickerhauser M V. *Adapted Wavelet Analysis from Theory to Software*. Boston: A K Peters, Ltd, 1994.

[5] Carmona R, Hwang W-L, Torresani B. *Practical Time-Frequency Analysis: Gabor and Wavelet Transforms with an Implementation in S*. San Diego: Academic Press, 1998.

[6] Bruce A G, Donoho D, Gao H Y. Wavelet Analysis. *IEEE Spectrum*, 1996,**33**(10),26-35.

[7] Graps A. *Wavelet Software*. http://www. amara. com/current/wavesoft. html, June 2000.

[8] Earth Resource Mapping Pty Ltd. *ER Mapper Compression White Paper — Version2. 0*. http://www. ermapper. com, January 2001.

[9] Zandi A, Allen J D, Schwartz E L, *et al*. *CREW: Compression with Reversible Embedded Wavelets*. http://www. crc. ricoh. com/CREW/, August 2000.

[10] Fan Q, Li H. Functions and Characteristics on MATLAB with Applications. *Information and Engineering on Surveying and Mapping*,2000,**23**(4),29-32(Ch).

[11] Fan Q, Li H. The Investigations for Developing Applied Programs Using Wavelet Software WAVELAB. *Journal of Wuhan University (Information Sciences)*, 2001,**26**(2), 183-189(Ch).

[12] Strang G, Nguyen T. *Wavelets and Filter Banks*. Wellesley: Wellesley-Cambridge Press, 1996.

[13] Mallat S. *A Wavelet Tour of Signal Processing*. San Diego: Academic Press, 1998.

[14] Taswell C. *A Guide to Papers on Wavelets, Wavelet Transforms, WavBox Software, and the FirWav Filters Library*. http://www. toolsmiths. com/papers. htm, March 2000.

[15] Beylkin G, Coifman R, Rokhlin V. Fast Wavelet Transforms and Numerical Algorithms Ⅰ. *Commun Pure and Applied Math*, 1991,**44**(2), 141-183.

[16] Donoho D, Duncan M, Huo X M, *et al*. *About WAVELAB*. http://www-stat. stanford. edu/~ wavelab, August 2000.

[17] Ojanen H. *WAVEKIT: a Wavelet Toolbox for MATLAB*. http://www. math. rutgers. edu/~ ojanen/ wavekit/, December 2000.

[18] Buccigrossi R W, Simoncelli E P. Image Compression via Joint Statistical Characterization in the Wavelet Domain. *IEEE Transactions on Image Processing*, 1999,**8**(12),1688-1701.

[19] Starck J-L, Murtagh F, Bijaoui A. *Image Processing and Data Analysis: The Multiscale Approach*. Cambridge UK: Cambridge University Press, 1998.

[20] http://www. multiresolution. com/, October 2000.

[21] http://www. stats. bris. ac. uk/~ wavethresh/, December 2000.

[22] Chui C K. *An Introduction to Wavelets*. (Wavelet Analysis and Its Applications, Vol. 1). Boston: Academic Press Inc, 1992.

[23] http:// waveletresearch. easthome. net/, February 2001.

[24] MathSoft Inc. *Wavelet Resources*. http://www. mathsoft. com/splsprod/wavelets. html, September 2000.

[25] Klappenecker A. *List of Wavelet People*. http://i-aks-www. ira. uka. de/home/klappi/people. html, October 2000.