Wavelets in industrial applications: a review

F. Truchetet, O. Laligant
Le2i, Université de Bourgogne, France, f.truchetet@u-bourgogne.fr

ABSTRACT

This paper aims at reviewing the recent published works dealing with industrial applications of wavelet and, more generally speaking, multiresolution analysis. After a quick recall in a simple overview of the basics of wavelet transform and of its main variations, some of its applications are reviewed domain by domain, beginning with signal processing, continuous and discrete wavelet transform proceeding with image processing and applications. More than 150 recent papers are presented in these two sections.

1. INTRODUCTION

Wavelet transform is now an old story for signal and image processing specialists. It is indeed twenty years ago, in 1982, that a French engineer working on seismological data for an oil company, Jean Morlet, proposed the concept of wavelet analysis to reach automatically the best trade-off between time and frequency resolution [95] [44] . Later this proposition has been considered as an extension of the ideas of Haar (1910) and Gabor (1946) [38] , themselves being Fourier's followers (1888). As any discovery in science, wavelets resulted from numerous contributions, they are based on concepts that already existed before Morlet's idea and, clearly, it was in the mood of the signal processing community in the 1980's. Quickly after this seminal proposition the main elements have been fixed by Y. Meyer (1985) [91] , S. Mallat (1987)[86] , I. Daubechies (1988)[27] , and then numerous other contributors brought their stone in the 1990's amongst them a special mention to the lifting scheme and second generation wavelets proposed by W. Sweldens (1995) [120] should be done. Even more recently (2003) some very exciting papers have been published about new ideas (ridgelets[21] [29] , curvelets[31] , fresnelets, ...), they show that the subject is still alive and a rich ground for innovative propositions to blossom.

The wavelet transform, multiresolution analysis, and other space frequency or space scale approaches are now considered standard tools by researchers in image processing, and many applications have been proposed that point out the interest of these techniques. Wavelet analysis algorithm is included in every signal processing computing package and most of the undergraduate students in computing engineering have had some courses on the subject. The most known application field of wavelet transform is image compression for still and video imaging. This tool is included in the new norms JPEG and MPEG where it replaced the classical Discrete Cosine Transform. In audio and, more precisely, automatic speech analysis the wavelets are currently in the operational softwares. However, even if promising practical results in machine vision for industrial applications have recently been obtained, wavelet transform in operational industrial products is still rarely used and a lot of ideas are still to be involved in industrialist imaging projects. The reason is may be the, sometimes abstruse, mathematics involved in wavelet text books or on the contrary the false faith in the omnipotence of this new tool leading to disappointing experiences. Be that as it may, it seems more than ever necessary to propose opportunities for exchanging between practitioners and researchers about wavelets.

In this prospect, this paper aims at reviewing the recent published works dealing with industrial applications of wavelet and, more generally speaking, multiresolution analysis. In the first part we recall in a simple overview the basics of wavelet transform and of its main variations. Then, in the second part, some of its applications are reviewed domain by domain, beginning with signal processing, continuous and discrete wavelet transform proceeding with image processing and applications More than 150 recent papers are presented in these two sections. We conclude with an evocation of the last progress in wavelet analysis whose some of them have been presented in our conference in Providence in October 2003 [128] .

2. WAVELET TRANSFORM BASICS

Basically, as short time Fourier transform (STFT), the wavelet transform[87] [127] [136] [132] (WT) is a means of obtaining a representation of both time and frequency content of a signal. But in WT the window function width is dependent on the central frequency. Therefore, for a given analysis function the best trade-off between time and frequency resolution can be automatically obtained. A wavelet is a kernel function used in an integral transform. The wavelet transform (CWT) of a continuous signal x(t) is given by:

$$W_{a,b}(x) = \int_{-\infty}^{+\infty} x(t)\psi^*_{a,b}(t)dt$$

with the wavelet function defined by dilating and translating a ”mother” function as:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi(\frac{t-b}{a})$$

$\psi(t)$ being the ”mother” wavelet, a the dilation factor and b the translation parameter (both being real positive numbers). For practical reasons, these parameters are often discretized leading to the so-call discrete wavelet transform (DWT). After discretization the wavelet function is defined as:

$$\psi_{j,k}(t) = 2^{-\frac{j}{2}}\psi(2^{-j}t - k)$$

As for CW, the DWT is given by the inner product between signal and wavelet, the result being a series of coefficients:

$$d_x(j,k) = \langle x, \psi_{j,k}\rangle$$

j and k being integer scale and translation factors. S. Mallat [86] , I. Daubechies [27] and, in another manner, W. Sweldens [120] gave way to fast algorithm implementation of DWT (the only one to be in use for computer imaging applications). Wavelet transform is a very efficient tool for scale-time (or scale-space in imaging applications) signal analysis, characterization and processing. Its scale discrimination properties are widely used for practical applications in algorithms of denoising (selective coefficients thresholding), scale filtering (different from classical frequency filtering), fractal analysis or scalogram visualization. Its capability to organize and to concentrate information is also one of the main reasons of WT success in image compression.

3. SIGNAL PROCESSING APPLICATIONS

3.1 Acoustical signal processing

Applications of 1D-WT are numerous in acoustical signal processing. Kobayashi [71] presents some examples of WT-based acoustical signal processing techniques proposed by Japanese researchers for listening for defects in automated quality control mechanism. Analyzing of detonation signals in automobile engines by CWT (Gaussian-type wavelet) based scalogram and phase shift display [70] or using the same technique to detect irregularities in cement mixtures (sound emitted by the barrel spinning on a cement truck) [6] are just two examples of these techniques. In [2] , the wavelet transform (WT) is applied to time-frequency analysis of ultrasonic echo waveform obtained by an ultrasonic pulse-echo technique. The Gabor function is adopted as analyzing wavelet since it provides the best time frequency resolution as confirmed by the uncertainty principle. In this study, noise suppression by thresholding of ultrasonic flaw signal and non destructive evaluation (NDE) of material degradation using wavelet analysis of ultrasonic echo waveform have been verified experimentally. Ultrasonic waves are one promising method for non-destructive method inspection of pipeline integrity. Discriminating between normal features (welds) and serious flaws (cracks or corrosion) can be facilitated by wavelet analysis (energy and entropy of wavelet coefficients at various scales) as it is shown by Tucker et al.[131] . Evaluation of degradation and damage of thermal sprayed coating can also be performed in a nondestructive way by ultrasonic testing. WT (DWT Daubechies of order 10) can be used to analyze the ultrasonic waveform for enhancing signal-to-noise ratio by keeping only scale 3[50] . In a close domain, speech enhancement is also an interesting challenge for wavelet users. Removing environmental noises by different approaches using DWT [45] and coefficient thresholding (wavelet shrinkage [30]) [114] or Wiener filtering in the wavelet domain [88] were both successfully tested. As was the blind equalization in wavelet transform domain, still for speech analysis[98] . The estimation of the subsoil characteristics and physical properties is a very important task in many various fields (geology, risk evaluation before a building construction, petroleum exploration). After propagation in the subsoil, the induced seismic disturbances are recorded by a set of sensors regularly placed on the ground. By analyzing the recorded signals, different waves can be identified (surface waves, reflected waves...). The estimation of the physical properties of these waves (delay, speed) leads to an estimation of the structure of the subsoil [108] . Processing and characterization of these 3D seismic data for petroleum industry for example by classical CW are proposed by Yin et al. [155] or, by using wavelets construction based on the acoustic wave equation (physical wavelets [64]), Wu et al. [149] . Numerous other references dealing with the same topic can be found in the Oil&Gas Journal.

3.2 Power production and power electronic

Power electronic, control of rotating machines and of other electric machines is invaded by WT[105] . M. Aller et al. propose a sensorless speed estimate using analytic wavelet [87] (constructed by modulating the frequency of a real symmetric window) transform -whose computations are performed in Fourier domain with FFT- of the stator current signal, the instantaneous frequency is determined from ridges detection in the scalogram [7] [83] [84] . Power quality monitoring consists mainly in detecting harmonic and voltage disturbances; if Fourier transform is currently used to analyze distorted waves in the frequency domain, Tsao has shown, in his Ph. D.[130] , how WT and probabilistic neural network can help to achieve such an analysis in real time. The application of wavelet analysis on power system transients has become increasingly popular in recent years due to its effectiveness in capturing short term transients. Power production (synchronous generators) and delivery disturbance survey are the main targets. High voltage insulation suffers from aging processes and failure can be sudden and catastrophic. On line monitoring and processing of electrical signals can provide useful diagnostic information. Transient detection, localization, identification and classification are the object of the processing. It applies on power transmission lines [40] [150] [154] [121] [116] but also on faulted phase current of generator. Example of transient detection and analysis aided by producing scalograms with a CWT using a pair of phase complimentary wavelets allowing phase information arising from the wavelet transform can be found in [26] ; there are many other papers on the same application [110] [107] . More generally speaking the paper [67] overviews recent developments in wavelet-based analysis of a number of physical processes of relevance to the Civil Engineering community. For example, the extension of wavelet transforms to the estimation of time-varying energy density permits the tracking of evolutionary characteristics in the signal using instantaneous wavelet spectra and the development of measures like wavelet-based coherence to capture intermittent correlated structures in signals.

3.3 Non destructive testing (NDT)

In the paper of Barat et al.[13] or in [14] [92] steel wire rope testing is performed. The diagnostic signal of steel wire rope by magnetic flux leakage (MFL) testing consists of impulses with different magnitude and duration, depending on depth and dimension of the wire defects. However, all such impulses have approximately the same form, which is caused by distribution of magnetic flux leakage around a broken wire. This particular feature allows to suppose that application of Wavelet transformation for the purpose of signal analysis can significantly increase sensibility and reliability of defect detection. Indeed, good result, in sense of diagnosis reliability, can be achieved using weighted summation of wavelet values for some chosen scales. In particular, the authors calculate a value that reflects relationship between useful impulse energy and interference energy for different wavelet types (namely, square root of this relation). This relation shows that Haar-wavelet gives dramatic improvement of SNR. Another NDT application is the processing of the signal given by MFL from a ferromagnetic material surface after magnetization as in magnetic flux leakage test of oil and gas pipelines. Yang-Li et al. use biorthogonal wavelet to decompose actual signals and result shows that the wavelet analysis has high performance in the feature extraction of flux leakage signals of pipeline [152] [156] . In a more general approach Kurz et al. in [75] proposes a brief review of the major wavelet algorithms involved in non destructive testing. Filtering and denoising by wavelet shrinkage are specially pointed out in this paper. Parts inspection is also invaded by wavelet analysis: tool wear monitoring can be performed by extraction of feature vectors from vibration signals measured during machining (DWT, energy of coefficients at each scale from orthogonal Daubechies of length 6 with 6 levels). Turning operation is selected by Wang et al.[140] as an example. Other authors have proposed similar approaches [43] [65] [77] [94] [56] [57] . Wu et al. [148] propose a method for real-time tool condition monitoring in transfer machining stations. This tool condition monitoring is obtained indirectly by on-line fine analysis of the spindle motor current. This fine analysis consists in calculating the wavelet packet transform of the signal and in selecting the principal components. The analysis of gas turbine vibration can be enhanced by the use of wavelet characterization and Wigner-Ville distribution as it is proposed by [49] , it is the ability to zoom on short lives high frequency phenomena that makes WT particularly attractive for the analysis of transients. The output of vibration sensors is digitized and fast transient features are characterized from the evolution of the wavelet transform coefficients across distinct scales. A neural network is used to extract the monitoring information. Computer simulation is an essential part of the design and development of jet engines for the aeropropulsion industry. Wavelet techniques are very suitable for analyzing the complex turbulent and transitional flows pervasive in jet engines. These flows are characterized by intermittency and a multitude of scales. Wavelet analysis results in information about these scales and their locations. Turbulent flows modelling in turbomachinery has been particularly developed by NASA Lewis Research Center [79] [48] . The control of process can make use of WT[118] . S. Parvez and Z. Gao[103] , for example, have proposed a PID-like controller based on a wavelet analysis of the error signal. This analysis allows high frequency and low frequency components to be extracted and used for optimally adapt control signal to nature of error. Two examples of control: motion and temperature are given. Symlets and Daubechies of order 4 were found to be reasonably good tools for control. Wavelet neural networks[42] have been found very effective for control of industrial process, for example in IC industry with localized modeling and compression of key process-relevant information, especially information pertaining to the detection of equipment and process faults [109] . A. Rying, in his Ph.D. dissertation presents also a novel application of the wavelet transform modulus maxima representation to help determine and prioritize the set of local features, signal for monitoring the film thickness during growth of silicon epitaxy coming from a quadrupole mass spectrometer sensor. Another application of these neural networks is proposed by Gao et al. [39] for flows measurement with a neural-wavelet based analysis of magnetic flowmeter (instruments for measuring the velocity of flow in many industrial applications) signal.

3.4 Chemical process

In chemical industry, signal processing and control is widely used and WT appears naturally as a useful tool[8] . For instance in [1] the authors investigate the validity of wavelet analysis as alternative procedure to process electrochemical noise records (ENR), especially those in which different signals are superposed. They practically measure the energy at different scales or separate two components of the signal (high coefficients for one component and the remaining for the other one) by the inverse wavelet transform. Chemical process survey by filtering of process variables as time series (cubic spline wavelets) is presented by T. Schrötter[113] . H. Briesen and W. Marquardt[18] present a chemical process modeling by adaptive multigrid method on the basis of a Wavelet-Galerkin discretization for the simulation and optimization of processes involving complex multicomponent mixtures in petroleum industry. Close to this domain of application one can notice an interesting attempt to use Radial Wavelet Networks [159] (variety of neural network using wavelet transform to determine the weights as the Gaussian functions are used in Radial Basis Functions, RBF) for modeling the relationship between chemical composition of steel and its hardness profile [24] [25] .

3.5 Stochastic signal analysis

The wavelet future shows great promise as a tool to redefine the probabilistic and statistical analysis of numerical series[104] . As in [99] where modelling wind speed at a target location from wind speed and direction known in a reference location (given by time series) is performed with a non-decimated wavelet packet transform to model the explanatory time series. The proposed technique transforms the explanatory time series into a wavelet packet representation and then uses standard statistical modeling methods to identify which wavelet packets are useful for modeling the given time series. Applications in economics and finance [41] [33] are another similar use of WT properties. In [41] , for example, wavelet multiscaling approach is there used to decompose a given time series on a scale-by-scale basis; at each scale the wavelet variance of the market return and the wavelet covariance between the market return and a portfolio are calculated to obtain an estimate of the systematic risk. WT is used as a key tool for unraveling the mysteries of computer traffic statistics and dynamics. Scale invariant properties such as long range dependence and self-similarity are estimated from squared wavelet coefficients averaged over time as in [4] [32] [112] . ”The impact of scale invariance extends to network management issues such as call admission control, congestion control, as well as policies for fairness and pricing” [3] . In this prospect a multifractal wavelet model has been proposed and applied to network traffic modeling and inference, the capability of WT for analysis and synthesis long-range dependence signals is used in [106] .

One can find a lot of other applications of wavelet transform and nearly every signal processing based device can be infected by WT. Wavelet-based communication systems, for example, are a promising design involving wavelet packet transform to obtain a given time-frequency partitioning[82] . Applications in bioinformatic have also a great potential, we will scan some of them in section 4.4. Many other examples could be cited.

4. IMAGE PROCESSING APPLICATIONS

4.1 Image compression

Image compression is the main application of WT in image processing. Wavelet compression algorithm provides better compression/quality than traditionally used JPEG algorithm. The current international standard for image compression (JPEG 2000) is largely based on scalar quantization of the coefficients of a DWT performed with Daubechies biorthogonal bases. Many authors have contributed to the field, one can find the forerunners and comprehensive papers amongst the following references: [10, 28, 81, 90, 115, 123, 133, 157, 158], (JPEG 2000 coverage from two of two members of the JPEG Committee has to be noticed [124]). Even multispectral images (from satellite imagery for instance) can be compressed with a wavelet based method, with multiwavelets bases for instance[63] . One of the earlier and most celebrated application is digital fingerprint image compression wavelet-based standard adopted by the FBI in 1993 (to store its 200 millions fingerprint records representing about 2000 terabytes) [23, 17] . It is based on a simple scalar quantization of the 64-subband wavelet coefficients (biorthogonal wavelets of Cohen-Daubechies-Fauveau, 1990) and leads to good quality images with a compression ratio of about 20:1 [19] . Video compression is a natural extension of the previous results [22, 122, 125] . Still imaging and video compression techniques based on WT are widely used in digital video recording and such commercial products are available for video monitoring or surveillance. These products make use of dedicated commercial software (see [58] for one example amongst numerous other) hardware (see for instance the PCI Bus-mastering wavelet video compression/decompression and capture board from XPress Plus: http://www.jknelectronics.com/xprspls1.htm) or even of integrated wavelet video codec which are now proposed by most of IC producers[158] . The implementation can also be performed with dedicated hardware based on the use of integrated digital signal processors [35] . Strongly linked to image compression and transmission, digital image watermarking is an important issue in which WT plays its part. Invisible and robust data hiding or embedding takes place in spatial as well as in frequency domain. Vandergheynst et al. show how directional wavelet frames can be used for computation of isotropic measure of local contrast, this measure being used as a masking model to facilitate the insertion of a watermark[135] .

4.2 Satellite imagery

As high-resolution imagery becomes commercially available, satellite imagery in geospatial applications is quickly spreading in civil industry. As pointed out by [96] wavelet technology is now the ”state of the art” for image compression that eliminates (or at least reduces drastically) the trade-off between size and quality. 3D wavelet transform is used for denoising and processing spatial and spectral data from Landsat images with application to surveillance of deforestation and crop detection [61, 62] . Geographic Information System (GIS) increasingly used as tool for topographical applications and research takes advantage of WT for modeling complex multivariate geographic relationships. Morehart et al. [93] have shown with examples from agricultural data that the redundant ”à trous” algorithm aids enormously in feature detection and exploration in the succession of resolution views of the data. Brunsell and Gillies say that ”recent research[74] suggests that wavelet decompositions are powerful tools in analyzing the scaling behaviour of geophysical variables (statistical variation of signal across different resolutions)”. Hu et al.[51] used multi-resolution to study the scale variation of soil moisture, average large-scale and detailed small-scale fluctuation components are extracted from WT.

4.3 Machine vision

Aspect inspection is one of the main industrial application issue of digital image processing[78] . In [66] the suggested solution focuses on detecting defects for manufacturing applications (in the design of robust quality control systems for the production of furniture, textile, integrated circuits, etc.) from their wavelet transformation and vector quantization related properties of the associated wavelet coefficients. More specifically, a novel methodology is investigated for discriminating defects by applying a supervised neural classification technique, namely Support Vector Machine, to innovative multidimensional wavelet based feature vectors. These vectors are extracted from the K-Level 2-D DWT (Discrete Wavelet). West et al. explain that the needs of industrial process tomography can be markedly different to those of other disciplines.

Some of these differences (far greater automation and quantification will be required) are illustrated in the hydrocyclone case study presented in [144] . They cite most of the authors using wavelets to fuse data at different levels. The technique of imaging Secondary Ion Mass Spectroscopy (SIMS) is largely used in chemistry for analyze and characterization of location and quantitative distributions of chemical components. Nikolov et al.[100] [147] propose to use the wavelet shrinkage algorithm to de-noise those images and improve their interpretation. Texture characterization is a well fitted problem for wavelet analysis[134] . Lumbreras et al.[85] propose, for instance, to combine color and texture information through a multiscale decomposition of each color channel in order to feed a classifier. Three algorithms are tested: multiresolution analysis with Mallat's algorithm, *à trous* algorithm[117] and wavelet packet transform. Two applications are presented, namely, the sorting of ceramic tiles and the recognition of metallic paints for car refinishing. Application of wavelets to processes and issues critical to semiconductor manufacturing is a promising challenge. Real time inspection in microelectronics manufacturing with multiresolution imaging is proposed by P. Bourgeat et al.[16] . Paper industry is also involved in using WT as it was shown by Y. Huawei[52] [53] who studied fibre flocculation (a disturbing phenomena for paper formation) and its parameters by processing stacks of images taken by high-speed video camera, images being treated by 2D-CWT Mexican hat Wavelet before correlation to the original ones. Another one of the few continuous wavelet transform applications in image processing using the Wavelet Transform Modulus Maxima method is proposed by Arneodo for analyzing the fractal properties of a textured image [11] . This method is used by Westra for printing defects identification and classification (applied to printed decoration, tampoprint images) with a template-invariant approach [145] [146] . It is to be noted that texture and feature analysis by WT are also used in image data base retrieval algorithms[59] [89] [55] . In [153] the authors propose an image browsing technique for infomediaries. Their system offers a dynamic mechanism of organizing product images by their features, in terms of colors and textures. The textural features are extracted from the luminance component of color images using the Gabor filters. It is shown that the retrieval accuracy of the Gabor features is higher than other textural features, such as the conventional pyramid-structured wavelet transform (PWT) features, tree-structured wavelet transform (TWT) features, and the multiresolution simultaneous autoregressive model (MR-SAR) features. In the paper of Addis et al. [5] an updated technical overview of an integrated content and metadata-based image retrieval system used by several major art galleries in Europe including the Louvre in Paris, the Victoria and Albert Museum in London, the Uffizi Gallery in Florence and the National Gallery in London is presented. Texture matching is based on energy coefficients in the pyramid wavelet transform using Daubechies wavelets. Other wavelet decompositions and basis functions are implemented and compared along with Gabor filter banks but the incorporated approach was chosen as the best compromise between retrieval accuracy and computational efficiency. Face recognition algorithms have now demonstrated their efficiency; in [68] a method for face recognition based on wavelet transform is developed. They use the ”symlet” wavelet because of its properties of symmetry and regularity. The wavelet coefficients are the features to be used for image classification. Fabric industry has room for quality control by artificial vision and wavelets, in their ability to characterize textured features are a precious processing tool[151] [60] . In the framework of textile industry Sarri-Saraf et al. present in [111] a device aiming at inspecting on-line the loom under construction. A specific class of the 2-D discrete wavelet transform called the multiscale wavelet representation is used as a preprocessing step with the objectives of attenuating the background texture and accentuating the defects. The non-subsampling properties guarantee the accuracy of detection and classification that follows. An application of WT in plastic manufacturing is proposed by Laligant [76] . Plastic caps are imaged and the screw thread, taking advantage of its periodical and localized features, is controlled in wavelet domain. Even applications in agriculture can be found; for weed detection from airborne imaging for instance in [137] or in [126] where an automatic herbicide sprayer is developed in order to reduce herbicide application amounts for corn and soybean fields. Detail wavelet coefficients corresponding to weed frequencies and orientations are selected in a discrete wavelet transform and thresholded.

4.4 Bioinformatic

Applications can be found in biology or what is called now by ”bioinformatic”: DNA sequence analysis is a huge challenge involving a lot of signal and image processing in which the ability of WT to perform good localization both in frequency and in space is of great interest. In [69] Kawagashira proposed a method called ”wavelet profile”, based on multiresolution analysis. Protein sequences represented numerically by different indices (polarity, accessible surface area, electron-ion integration potentials of the amino-acid) can be decomposed by WT and then up-sampled for similarity searching across scales and different proteins [73] . In [142] the gene array experiments involve a large number of error-prone steps which lead to a high level of noise in the resulting images. The authors use the shrinkage approach based on stationary wavelet transform for eliminating such noise source and to ensure better gene expression. More generally speaking, the stationary of the transform facilitates the identification of salient features, especially for recognizing the noises. The universal image quality index [143] highlights the superior results of the stationary transform compared to the downsampled one and gives performances in respect of the wavelets used (Haar, Daubechies, Biorthogonal, Coifman, ...). Even classifying images as objectionable or benign can be helped by wavelet transform (Daubechies) as it were shown by [141] . An original application in forensic science has been proposed in order to discriminate natural images from synthetic ones, it makes use of a statistical model built upon a multi-scale wavelet decomposition [34] .

4.5 Flow analysis

Image processing is also used to analyze turbulent flows and wavelets are again on the deck: in [80] the vector wavelet multi-resolution technique is applied to analyze the three-dimensional measurement results of a high-resolution dual-plane stereoscopic particle image velocimetry system for revealing a fundamental understanding of the multi-scale vortical structures in the near field of turbulent lobed jet. The authors choose the Daubechies wavelet basis for its smoothness and compact support. The instantaneous three-dimensional velocity is calculated and interpreted in multiscale velocity fields.

5. CONCLUSION

As it is shown in this -still largely incomplete- review, wavelet applications in industrial context are numerous and invade nearly every domain. However, if one considers only operational devices or software, very few can be really pointed out. And most of them deal with image compression. Presently one has to admit that wavelet transform stays essentially a laboratory technique, but with the development of dedicated IC and of efficient software tools the gap is being strode. Scale discrimination properties of WT are widely used for practical applications in algorithms of denoising (wavelet shrinkage), scale filtering, fractal analysis or scalogram visualization. Organizing and concentrating information is also one of the main reasons of WT success in numerous applications and particularly in image compression devices. To conclude, we would stress that wavelet cannot solve all the problems and that there are still a lot of limitations inherent to WT. We recall four of them. DWT, as any decimating algorithm, is not invariant by translation and this can induce artifacts and a lack of consistency in some transient detection algorithms and in signal or image enhancement approaches. Dyadic DWT has a very limited frequency resolution and sometime the searched feature is spred on two scales and cannot be clearly detected. CW or, in a more interesting way, rational wavelet analysis [12] [15] can overcome this withdrawing. Transposing 1D WT to two (and more) dimensional space is not easy and the classical separable approach[87] leads to a non isotropic behavior. Horizontal, vertical and diagonal directions are subject to special attention and if it can be of interest when processing is linked to human psychovisual system imitation[129] , on the contrary when the treatment aims at extracting exact physical information this anisotropy can be a serious source of errors. Some remedies have been studied and nonseparable wavelet basis, quincunx analysis[36] or steerable wavelet analysis [37] [9] are amongst the most known. Finally, it has been demonstrated that wavelets for orthogonal basis (in 1D) cannot be symetrical (zero-phase) if the corresponding filters are of finite impulse length. Daubechies, minimum length wavelets are, for instance, heavily asymetric. Signal and images to be treated are, most often, symetric and they need a zero-phase filtering for avoiding artifacts. Frequently used as a remedy to this problem biorthogonal wavelets can be of finite length but they lead to poor decorrelation between scales. Symlets or Coiflet are not of minimum length but they provide a quasi-symetrical analysis function.

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