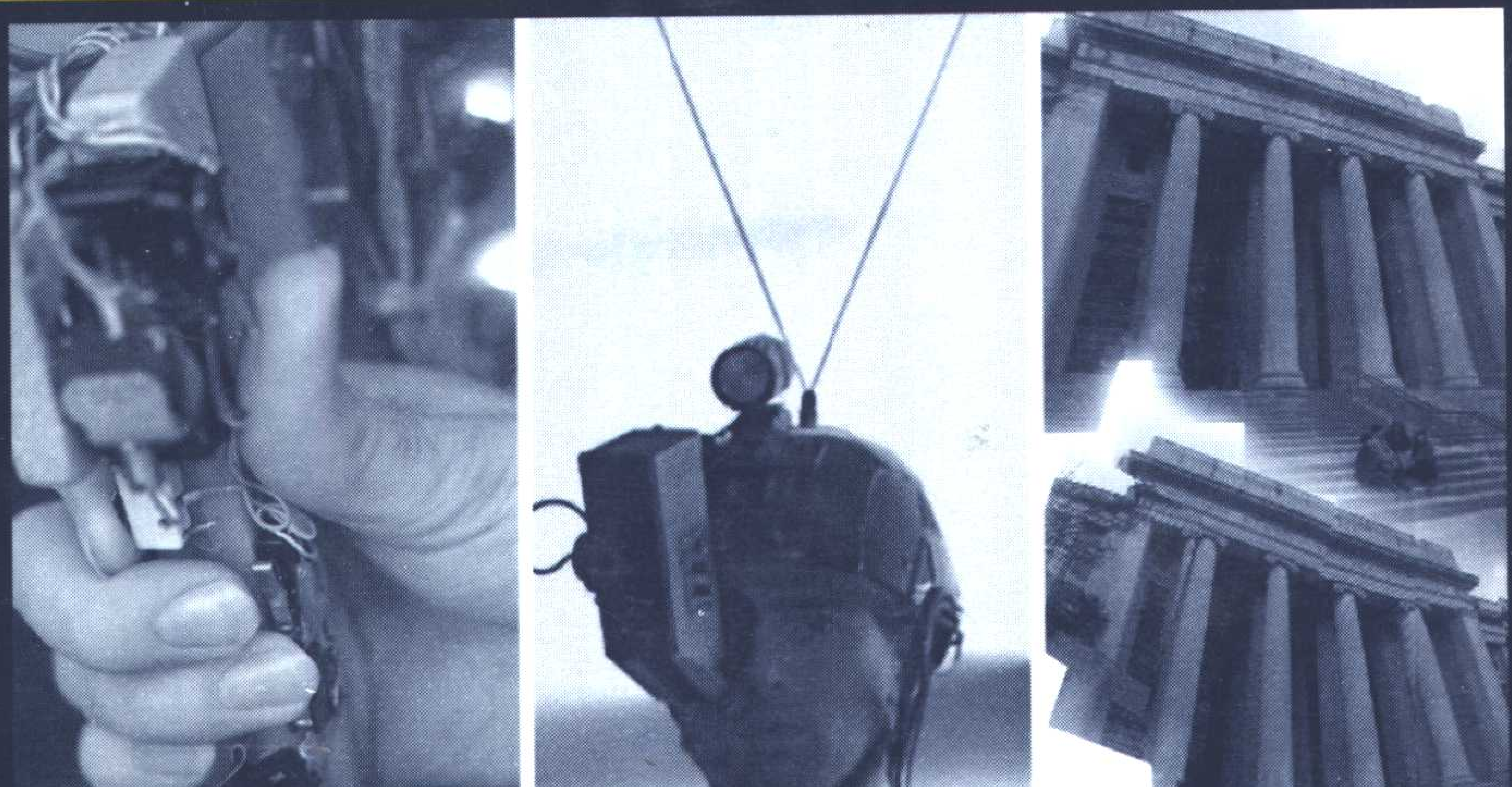
THE ELECTRICAL ENGINEERING AND SIGNAL PROCESSING SERIES

THE TRANSFORM AND DATA COMPRESSION HANDBOOK



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THE ELECTRICAL ENGINEERING AND SIGNAL PROCESSING SERIES

Edited by Alexander Poularikas and Richard C. Dorf

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Stergios Stergiopoulos

The Transform and Data Compression Handbook
K.R. Rao and P.C. Yip

The Encyclopedia of Signal Processing
Alexander Poularikas

Applications in Time Frequency Signal Processing
Antonia Papandreou-Suppappola

Preface

While this handbook is an exposition of different discrete transforms and their ever-expanding applications in the general area of signal processing, the overriding task is to maintain the continuity and connectivity among the chapters. This task is accomplished by the common theme of data compression. The handbook seeks to provide the reader with a wealth of information regarding the transforms (some have been widely used while others have great potential) as well as a demonstration of their power and practicality in data compression. Such compression is a necessary and desirable ingredient in today's world of massive data storage and data transmission. By providing a plethora of Web sites, ftp locations, and references to general review papers, the chapter authors have expanded the usefulness of this handbook for the common reader. The clear and concise presentations of the ideas and concepts, as well as the detailed descriptions of the algorithms, provide important insights into the applications and their limitations. With the understanding of these concepts, readers can apply the techniques presented in this handbook to their own areas of interest and improve on the performance by marrying this with their own expertise. We are confident that this handbook will be a valuable addition to the bookshelf of anyone actively engaged in or studying the art and science of signal processing.

The Transform and Data Compression Handbook is aimed at providing a description of various discrete transforms and their applications in different disciplines. In view of the proliferation of digital data (images, video, text, documents, audio, music, graphics, etc.), it is imperative that the data be mapped from the data domain (in which there are usually redundancies) to a different one (the transform domain) for efficient and economical storage and/or transmission. Transforms by themselves do not provide any compression. However, by reallocation of the energy in the data, transforms provide the possibilities for compression. Techniques such as adaptive quantization and entropy coding applied to the transform coefficients can result in significant reduction in bit rates. Depending on the quality levels required by the end user, other parameters such as human visual/acoustic sensitivity, adaptive scanning, statistical modeling, and variable length coding would further contribute to the bit rate reduction. Generally transforms, wavelet transforms in particular, are well suited for scalable coding (in spatial or temporal domains, or in SNR). This concept facilitates data transmission in embedded bit-stream format, providing for multi-resolution (spatial/temporal) and multiquality (SNR) end products, subject to bandwidth limitation, processing power, and cost constraints.

Many international standards relating to audio, video, and data, such as JPEG, H.261, H.262, MPEG-1, MPEG-2, MPEG-4, HDTV, and JPEG-2000, utilize transforms in their overall compression schemes. A number of consumer and commercial products, such as video-CD, DVD, videophone, set-top boxes, digital TV, and digital camera/VCR, have been made possible because of signal compression. Other electronic innovations, such as MP3, video-streaming, and wireless PCS, are completely dependent on the reduction of bit rates made possible by compression. It is not exaggerating to say that data compression is one of the main contributing factors in the explosive growth in information technology.

While different coding schemes can accomplish an amazing amount of compression, the cornerstone is still undoubtedly the underlying transform. It is for this reason that the definitions and properties for each of the transforms dealt with in this handbook are presented with such care and detail. The bibliography sections and Web sites provide further sources of information.

Outline of Chapters

Chapter 1 The Karhunen-Loève Transform

The first transform described in this handbook is the Karhunen-Loève transform (KLT). It takes its rightful place as the leadoff transform to be discussed. Dony does an excellent job of interpreting this statistically optimal transform. The simple and yet elegant explanation of rotation of axes in the data domain to achieve the "principal components" representation underscores the significant energy compaction provided by this transform. Other properties of the transform follow, and the chapter is rounded off with descriptions of applications in chest radiographs and other monochrome and color images. Web sites and software download locations are listed as well.

Chapter 2 The Discrete Fourier Transform

Discrete Fourier transform (DFT), the best known and arguably the most universally applied transform, is presented by Selesnick and Schuller. Following an exposition of the definitions and properties of the DFT, it is shown that by a symmetric extension of the sequence, the DFT can lead to the discrete cosine transform (DCT), another favorite transform described in Chapter 4. The authors then go on to develop the fast Fourier transform (FFT) algorithms, a catalyst for all DFT applications. A novel feature of this chapter is the linkage provided by the authors between DFT and filter-banks, which are used extensively in audio coders. Cosine-modulated filter-banks and complex DFT-based filter-banks are the byproducts of the DFT that are used in Moving Picture Expert Group (MPEG) audio coders. There is an extensive list of Web sites providing information for available software, algorithms, and applications, as well as other related links.

Chapter 3 Comparametric Transforms for Transmitting Eye Tap Video with Picture Transfer Protocol (PTP)

This is a unique, challenging, and provocative chapter written by Mann, the inventor of the wearable computer (WearComp), the Eye Tap camera, and reality mediator. This chapter takes us to the forefront of the multimedia revolution with a new computational/communications device that subsumes the functionality of the videophone, digital camera, and other wireless personal electronics innovations. Mann's invention functions as a true extension of the mind and body and causes the eye to function as if it were a camera. His invention has given rise to a whole new philosophical and mathematical approach to image compression and image storage, and it gives a refreshingly new definition of functionality in image transmission and processing. The new Eye Tap genre of video is best processed and compressed by comparametric equations, essentially equations representing projections and tone scale adjustments of images. Traditionally image compression has been directed to ensure a certain minimum quality or reliability (e.g., worst case scenario). The author instead makes a compelling argument in favour of "best case" scenario; Mann argues that being able to broadcast even intermittent still images to the Internet can provide a measure of security unmatched by conventional "robust" security systems. These arguments are based on a definition of "fear of functionality," a completely novel approach to the idea of security. The author has set up a Web site from which computer programs can be freely downloaded. Such a generous spirit is to be commended. It is also interesting to note that this chapter was typeset using LaTex running on a small wearable computer designed and built by the author.

Chapter 4 Discrete Cosine and Sine Transforms

Next to the DFT, discrete cosine transform (DCT) is probably the most used transform in digital signal processing work. DCT is one of a family of trigonometric transforms including the discrete sine transform (DST). In this chapter, Britanak presents a unified treatment of the family of DCTs and DSTs starting with the definitions, properties, and fast algorithms. This chapter is particularly relevant as the DCT has been adopted in several international standards for image/video coding. In modified form, both DCT and DST have been used in MDCT/MDST audio coding. Computer programs in C (listed in Sections 4.3 and 4.4) that can be implemented to perform the transforms are very useful in all signal processing applications. The chapter concludes with a specific application in a Joint Photographic Experts Group (JPEG) base line system (Fig. 4.3) using the standard test image of Lena.

Chapter 5 Lapped Transforms for Image Compression

Lapped transforms (LTs), developed originally to eliminate or reduce the blocking artifacts of block transforms such as DCT in low bit rate image/video coding, are presented by de Queiroz and Tran. Several versions of the LTs, such as orthogonal and nonorthogonal LTs, tree-structured hierarchical, symmetric, bi-orthogonal, and variable length LTs, are defined, and their properties and factorization schemes are described. Generalized versions of the lapped orthogonal transform (LOT), called GenLOT, are developed in Sections 5.6.3–4 while cosine-modulated LTs, otherwise known as MLT or ELT, are discussed in Section 5.8. To demonstrate the promise and potential for LTs in image coding, well known image compression algorithms are applied to standard test images, with DCT or the wavelet transform replaced by LTs. Comparative analysis shows the elimination of ringing and blocking artifacts that are characteristic of the DCT based coders and also performance rivaling that of the wavelet transforms.

Chapter 6 Wavelet-Based Image Compression

This is another highly valuable chapter as it addresses wavelet-based image compression. Wavelet-based transforms give a time-frequency decomposition of the signal, which has multi-resolution characteristics. The transforms have superior energy compaction and compatibility with Human Visual System (HVS). They make possible the embedded bit-stream coding corresponding to various subbands (the basis for fast browsing of images or databases over the Internet). Discrete wavelet transforms (DWT) and its variants have been adopted both by the FBI in the use of fingerprint image compression and the international standards groups (JPEG-2000 and MPEG-4 still frame image coding). It is highly possible that wavelets may eventually replace DCT in all the coders. Walker and Nguyen provide a clear explanation of the multiresolution aspects of DWT and its implementation using a 2-channel filter bank. Some of the recent enhancements of the basic DWT, such as EZW, SPIHT, WDR, and ASWDR, are enumerated, followed by their implementation in image coding and subsequent evaluation. Various Web sites that provide software, literature, simulation results, and innumerable other details further strengthen the chapter's utility.

Chapter 7 Fractal-Based Image and Video Compression

The concepts and techniques of fractal-based image/video compression are introduced in this chapter by Lu. The seminal work by Mandelbrot forms the basis of many treatises of fractal applications, made popular by movie scenes generated graphically by the use of fractals. Fractal-based signal analysis is currently at the forefront of research. Although compression techniques based on affine transforms or iterated function systems (IFS) may not have caught the attention of every researcher, their attractive properties making possible high compression ratios and asymmetric coding certainly deserve further study. With the advent of super HDTV, wireless cellular multimedia phones, and interactive services on the Internet, fractal transform and its variants such as IFS, QPIFS, and PIFS will find their rightful place in the compression arena. Starting with the basic properties of fractals, Lu demonstrates the compression property of fractals using the encoding/decoding procedures. The capabilities of fractals are illustrated using images and video. As with the other chapters, Web and ftp sites, mostly maintained by universities, provide access to software, literature, products, R&D, and applications to the interested readers.

Chapter 8 Compression of Wavelet Transform Coefficients

The concluding chapter presents a philosophical and thoughtful argument for the effectiveness of transforms in general and wavelets in particular for bandwidth reduction. The superiority of wavelet transform over others, including the widely used DCT, is clearly demonstrated by the characteristics of the DWT. From the chapter's title, the reader may get a wrong impression of duplication with Chapter 6. On the contrary, this chapter complements the topics in Chapter 6 by a clear exposition of the superior performance of the DWT over other transforms. The subband decomposition inherent in dyadic wavelet transform, preservation of spatial signal features in subbands of different scales, and self similarities among subbands of the spatial orientation are some of the reasons for this superiority. These self-similarities are conducive to statistical context modeling and adaptive entropy coding of wavelet coefficients. By a lucid presentation of these concepts aided by implementation on test images, Wu convincingly demonstrates the validity of the DWT adopted in JPEG-2000 and MPEG-4 and the bright future it has in other applications.

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The editors have been entrusted with the organizational and administrative process in compiling this handbook. Needless to say, without the expertise and efforts of the individual chapter authors, this handbook would never have seen the light of day. The editors sincerely acknowledge the energetic contributions from the chapter authors, whose uniform excellence has made this an outstanding volume. The editors thank the authors for their prompt and timely responses in spite of their heavy commitments in their daily academic or professional lives. It is hoped that the completion of this handbook will elicit a sense of pride and accomplishment, a well-earned and well-deserved reward for their efforts. The editors would also like to thank their families for the patience and perseverance they showed during the months of preparation of this handbook.

List of Acronyms

AFB	Analysis filter bank
ASPEC	Audio spectral perceptual entropy coding
ASWDR	Adaptively scanned wavelet difference reduction
bpp	Bits per pixel
CREW	Compression by reversible embedded wavelets
DCT	Discrete cosine transform
DFT	Discrete Fourier transform
DPCM	Differential pulse code modulation
DSP	Digital signal processing
DST	Discrete sine transform
DTFT	Discrete time Fourier transform
DWP	Discrete wavelet packet
DWT	Discrete wavelet transform
ECECOW	Embedded conditional entropy coding of wavelet
ECG	Electrocardiogram
ELT	Extended lapped transform
EZC	Embedded zerotree coding
EZW	Embedded zerotree wavelet
FAQ	Frequently asked questions
FFT	Fast Fourier transform
FIR	Finite impulse response
FLT	Fast lapped transform
FoF	Fear of functionality
FPGA	Field programmable gate array
GenLOT	Generalized LOT
GNU	GNU's Not Unix
GNUX	GNU-Linux
H.261	Standard for compression of videotelephony and teleconferencing
H.263	Standard for visual communication via telephone lines
HDTV	High definition TV
HLT	Hierarchical lapped transform
HSI	Hue, saturation, intensity
HV	Horizontal vertical
HVS	Human visual system
IDFT	Inverse discrete Fourier transform
IFS	Iterated function systems

ISO	International Standards Organization
ITU	International Telecommunication Union
JBIG	Joint Binary Image Group
JPEG	Joint Photographic Experts Group
JPEG-LS	JPEG-Lossless
KLT	Karhunen-Loève transform
LBT	Lapped bi-orthogonal transform
LOT	Lapped orthogonal transform
LT	Lapped transform
LZC	Layered zero coding
MC	Motion compensated
MDCT	Modified discrete cosine transform
MDST	Modified discrete sine transform
MIMO	Multi-input multi-output
MLT	Modulated lapped transform
MOS	Mean opinion score
MP3	MPEG-Layer 3
MPEG	Moving Pictures Expert Group
MPEG-AAC	MPEG advanced audio coder
MSE	Mean squares error
PAC	Perceptual audio coder
PCA	Principal component analysis
PIFS	Partitioned iterated function systems
PR	Perfect reconstruction
PSD	Personal safety device
PSNR	Peak signal to noise ratio
PTM	Polyphase transfer matrix
PTP	Picture transfer protocol
QCLS	Quadratic-constrained least squares
QM	Cute sound
QPIFS	Quadtree partitioned iterated function systems
RGB	Red, green, and blue
RLC	Run-length coding
RLD	Run-length decoder
ROI	Region of interest
RTT	Round trip time
SDF	Symmetric delay factorization
SFB	Synthesis filter bank
SPIHT	Set partitioning of hierarchical tree
STW	Spatial orientation tree wavelet
SVD	Singular value decomposition
TDAC	Time domain aliasing cancellation
TF	Time-frequency
VLC	Variable-length coding
VLD	Variable-length decoder
VQ	Vector quantization
WDR	Wavelet difference reduction
YIQ	Luminance, in-phase, and quadrature-phase chrominance

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