Multimedia Signals and Systems:

Basic and Advanced Algorithms for Signal Processing

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Content

Preface to the 2nd edition

Encouraged by a very positive response to the first edition of the book, we prepared the second edition. It is a modified version which intends to bring slightly different and deeper insight into certain areas of multimedia signals. In the first part of this new edition, special attention is given to the most relevant mathematical transformations used in multimedia signal processing. Some advanced robust signal processing concepts are included, with the aim to serve as an incentive for research in this area. Also, a unique relationship between different transformations is established, opening new perspectives for defining novel transforms in certain applications. Therefore, we consider some additional transformations that could be exploited to further improve the techniques for multimedia data processing. Another major modification is made in the area of Compressive sensing for multimedia signals. Beside the standard reconstruction algorithms, several new approaches are presented in this edition providing efficient applications to multimedia data. Moreover, the connection between the compressive sensing and robust estimation theory is considered. The Chapter Multimedia Communications is not included because it did not harmonize with the rest of the content in this edition, and will be a subject of a stand-alone publication. In order to enable a comprehensive analysis of images, audio and video data, more extensive and detailed descriptions of some filtering and compression algorithms are provided compared to the first edition.

This second edition of the book is composed of eight chapters: Chapter 1 - Mathematical transforms, Chapter 2 – Digital Audio, Chapter 3 - Digital data storage and compression, Chapter 4 – Digital image, Chapter 5 – Digital video, Chapter 6 - Compressive sensing, Chapter 7 - Digital watermarking and Chapter 8 – Telemedicine. As described above, the Chapter entitled Mathematical transforms (Chapter 1) and the Chapter entitled Compressive sensing (Chapter 6) have been significantly modified and supplemented by advanced approaches and algorithms. In order to facilitate the understanding of the concepts and algorithms, the authors have put in efforts to additionally enrich information in other chapters as well.

Each chapter ends with a section of examples and solved problems that may be useful for additional mastering and clarification of the presented material. Also, these examples are used to draw attention to certain interesting applications. Besides the examples from the previous editions, the second edition contains some advanced problems as a complement to the extended theoretical concepts. A considerable number of Matlab codes is included in the examples, so that the reader can easily reconstruct most of the presented techniques.

Regardless of the efforts that the authors made to correct errors and ambiguities from the first edition, the authors are aware that certain errors may appear in this second edition as well, since the content was changed and extended. Therefore, we appreciate any and all comments made by the readers.

Further, the authors gratefully acknowledge the constructive help of our colleagues during the preparation of this second edition, particularly to the help of Prof. Dr. Ljubiša Stanković and Dr. Milica Orlandić. Also, we are thankful to the PhD students Miloš Brajović, Andjela Draganić, Stefan Vujović and Maja Lakičević.

Finally, we would like to extend our gratitude to Prof. Dr. Moeness Amin whose help was instrumental together with the help of Prof. Dr. Sridhar Krishnan to publish the first edition of this book. Prof. Dr. Zdravko Uskoković and Prof. Dr. Victor Sucic also contributed to the success of the first edition.

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Authors

Introduction

Nowadays, there is an intention to merge different types of data into a single vivid presentation. By combining text, audio, images, video, graphics and animations we may achieve a more comprehensive description and better insight into areas, objects and events. In the past, different types of multimedia data were produced and presented by using a separate device. Consequently, integrating different data types was a demanding project by itself. The process of digitalization brings new perspectives and the possibility to make a universal data representation in binary (digital) format. Furthermore, this creates the possibility of computer-based multimedia data processing, and now we may observe computer as a multimedia device which is a basis of modern multimedia systems.

Thus, ***Multimedia*** is a frequently used word during the last decade and it is mainly related to the representation and processing of combined data types/media into a single package by using the computer technologies. Nevertheless, one should differentiate between the term multimedia used within certain creative art disciplines (assuming a combination of different data for the purpose of efficient presentation) and the engineering aspect of multimedia, where the focus is towards the algorithms for merging, processing and transmission of such a complex data structures.

When considering the word etymology, we may say that the term multimedia is derived from the Latin word *multus* meaning numerous (or several), and *medium* which means the middle or the center.

The fundamentals of multimedia systems imply creating, processing, compression, storing and transmission of multimedia data. Hence, the multimedia systems are multidisciplinary (they include certain parts from different fields, especially digital signal processing, hardware design, telecommunications and computer networking, etc.).

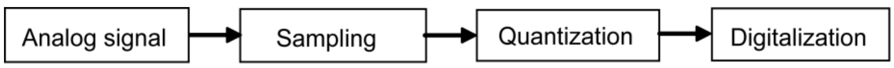
The fact that the multimedia data can be either time-dependent (audio, video and animations) or space-dependent (image, text and graphics) provides additional challenges in the analysis of multimedia signals.

Most of the algorithms in multimedia systems have been derived from the general signal processing algorithms. Hence, a significant attention should be paid to the signal processing theory and methods which are the key issues in further enhancing of multimedia applications. Finally, to keep up with the modern technologies, the multimedia systems should include advanced techniques related to digital data protection, compressive sensing, signal reconstruction, etc.

Since the multimedia systems are founded on the assumption of integrating the digital signals represented in the binary form, the process of digitalization and its effect on the signal quality will be briefly reviewed next.

Analog to digital signal conversion

The process of converting analog to digital signals is called the digitalization. It can be illustrated by using the following scheme:



The sampling of an analog signal is performed by using the sampling theorem which ensures the exact signal reconstruction from its digital samples. The Shannon-Nyquist sampling theorem defines the maximal sampling interval (the interval between successive samples) as follows:

$$T \le \frac{1}{2 f_{\max}},$$

where f_{max} represents the maximal signal frequency. According to the analog signal nature, the discrete signal samples may have any value from the set of real numbers. It means that, in order to represent the samples with high precision in the digital form, a large number of bits is required. Obviously, this is difficult to realize in practice, since the limited number of bits is available for representing signal samples. The number of bits per sample defines the number of quantization intervals, which further determines a set of possible values for digital samples. Hence, if the value of the sample is between two quantization levels, it is rounded to the closer quantization level. The original values of samples are changed and the changes are modelled as a quantization noise. The signal, represented by n bits, will have 2^n quantization levels. As illustrations, let us observe the examples of 8-bit and 16-bit format. In the first case the signal is represented by 256 quantization levels, while in the second case 65536 levels are available.

Working with digital signals brings several advantages. For instance, due to the same digital format, different types of data can be stored in the same storage media, transmitted using the same communication channels, processed and displayed by the same devices, which is inapplicable in the case of an analog data format. Also, an important property is robustness to noise. Namely, the digital values "0" and "1" are associated to the low (e.g., 0 V) and high voltages (e.g., 5V). Usually the threshold between the values 0 and 1 is set to the average between their corresponding voltage levels. During transmission, a digital signal can be corrupted by noise, but it does not affect the signal as long as the digital values are preserved, i.e., as long as the level of "1" does not become the level of "0" and vice versa.

However, the certain limitations and drawbacks of the digital format should be mentioned as well, such as: quantization noise and significant memory requirements, which further requires the development of sophisticated masking models and data compression algorithms.

In order to provide a better insight into the memory requirements of multimedia data, we can mention that text requires 1.28 Kb per line (80 characters per line, 2 bytes per character), stereo audio signal sampled at 44100 Hz with 16 bits per sample requires 1.41 Mb, a colour image of size 1024x768 requires 18.8 Mb (24 bits per pixel are used), while a video signal with the TV resolution requires 248.8 Mb (resolution 720x576, 24 bits per pixel, 25 frames per second).

CHAPTER 1

Mathematical transforms used for multimedia signal processing

Abstract

The algorithms for Multimedia data processing are mostly based and derived from the general signal processing techniques. They usually include standard transforms such as the Fourier transform, Discrete cosine transform, Wavelets transform, etc. Hence, in order to provide better understanding of algorithms in Multimedia systems, the fundamental concepts of commonly used mathematical transforms have been considered and explained using several illustrative examples. Beside the Fourier transform, Discrete cosine transform and Wavelets multiresolution analysis, this Chapter additionally includes transformations used in advanced multimedia applications, particularly, the time-frequency analysis and the Hermite functions expansion. For the signals in noisy environment, the concept of robust signal representations is derived in details, as well as the nonstationary time-varying filtering approach. Therefore, this Chapter provides both basic and advanced theoretical background on the mathematical transforms used in multimedia processing. Finally, an arbitrary time-frequency plane division using time-varying and frequency-varying windows is considered, together with the corresponding composite transformations.

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CHAPTER 2

Digital audio

Abstract

The audio signals as one of the basic types of Multimedia data have been considered in this Chapter. The basic properties of music and speech signals are presented, together with the concepts of human speech production and hearing system. The main focus is made on the algorithms for lossless (LZ-77, LZW, HUFFMAN) and lossy audio compression (MUSICAM, MPEG Layer I, II and III, ASPEC). The masking procedures based on the psychoacoustic model, the bit allocation and subbands coding are explained in details. The special purpose techniques for audio signals characterization are considered as well: voice activity indicators, word endpoints detector, time-frequency analysis of audio signals and singular value decomposition of audio signals.

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CHAPTER III

Storing and transmission of digital audio signals

Abstract

The storage and transmission possibilities for managing Multimedia data have been considered. Special attention has been devoted to the Compact Disc (CD) coding techniques including interleaving, Cyclic Redundancy Check, Reed-Solomon code and Eight-to-Fourteen Modulation. The Mini Disc (MD), Digital Versatile Disc (DVD) and Super Audio CD (SACD) have been discussed as well. Additionally, this Chapter presents and discusses QPSK modulation and OFDM principles and realization based on the Fourier transform. The theoretical considerations are illustrated on examples focusing on coding and modulation principles and applications.

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CHAPTER IV

Digital image

Abstract

Different aspects of digital image processing have been considered, explained and illustrated experimentally within this Chapter. For the beginners level in the image processing area, the basic digital image properties, color transformations and mathematical concepts behind the arithmetical and geometrical operations are explained in details. Several image filtering algorithms are presented and experimentally evaluated: arithmetic and geometric mean filter, median and alpha-trimmed median filter, frequency domain filtering, but also the advanced filtering approach based on the L-estimate space/spatial-frequency representation. The second part of this Chapter belongs to image compression algorithms including DCT-based JPEG, progressive and hierarchical JPEG, wavelet-based JPEG2000 algorithm, Fractal image compression. The quantization and coding procedures for JPEG and JPEG2000 algorithms are explained in details. Finally, some interesting edge detection, image segmentation and texture characterization algorithms are presented as well.

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CHAPTER V

Digital video

Abstract

Video signals require sophisticated processing algorithms due to their specific 3D nature. After introducing basic video standards, sampling schemes and video color models, the approaches for motion estimation and compensation are presented and discussed as an introduction for video compression and coding. Thereafter, we focus on the video compression algorithms from the MPEG (MPEG-1, MPEG-2 and MPEG-4) and VCEG (H.261, H.263 and H.264) groups. The MPEG algorithms are describing by addressing most of the coding elements in details. As one of the widely used standards nowadays, the H.264/MPEG-4 has been extensively elaborated: structure and role of frames, Intra coding and Inter coding prediction specifications, quarter pixel motion estimation precision, integer transform, content adaptive and variable length coding, etc). The second part of the Chapter is devoted to the QoS parameters and multimedia protocols (H.323 and SIP). The advanced level examples at the end of the Chapter considers some recently published video compression results based on the Hermite expansion method.

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CHAPTER VI

Compressive sensing

Abstract

In order to bring a new perspective into the Multimedia data acquisition, compression and reconstruction, the Compressive sensing theory and reconstruction algorithms have been considered. The compressive sensing represents an alternative signal acquisition and processing approach, where the signal under certain assumptions is reconstructed from a small number of randomly acquired samples far below the Nyquist-rate number. This Chapter presents a comprehensive theoretical background behind the Compressive sensing, including the sparsity property, incoherence, RIP property, and different minimization problems. Furthermore, numerous signal reconstruction algorithms, amenable to multimedia data applications, are elaborated and described. A special emphasis is given to: orthogonal matching pursuit, gradient-based reconstruction, interior point methods, threshold-based methods, generalized deviations-based method, total variation minimization, etc. It has been shown that these algorithms can be successfully applied to reconstruct 1D signals and images from a small number of random measurements. In order to provide a better insight into the compressive sensing theory, the concepts are explained on different examples. We believe that the content of this Chapter is structured in a way to be interesting and useful at both the beginner and the advanced level readers.

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CHAPTER VII

Digital Watermarking

Abstract

During the last decade digital watermarking has become an active research area focused on digital data protection. The modern multimedia systems require powerful data protection algorithms. Namely, due to the advances in the development of digital data and the modern way of communication, a number of watermarking procedure has been proposed. The watermarking purposes are classified as: ownership protection, protection and proof of copyrights, data authenticity protection, tracking of digital copies, copy and access control. This Chapter deals with the concepts of watermark embedding and watermark detection theory. Several interesting and commonly used algorithms for image and audio watermarking are presented. As an advanced level, the recently developed combined time-frequency watermarking approaches are also considered.

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CHAPTER VIII

Multimedia signals and systems in telemedicine

Abstract

Nowadays, the telemedicine has been considered as a new and perspective research area which uses the advantages of multimedia systems to provide efficient medical services at the distance. The future hospitals should provide health care services to patients all over the world using multimedia systems in the frame of telemedicine technologies. Signal and image acquisition, signal and image storage, signal and image display and processing are the major components of telemedicine. Aiming to promote the advantages of telemedicine to the multimedia signal processing community, this Chapter reviews different aspects of medical practice such as telenursing, teleradiology, telesurgery, telepharmacy, etc.

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