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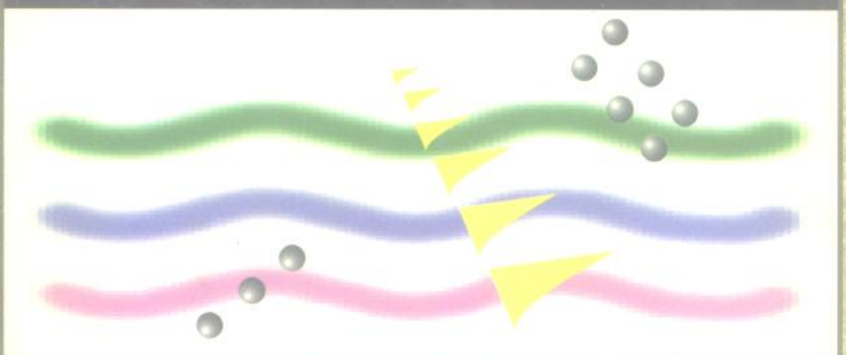

数字视频处理

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A. Murat Tekalp
University of Rochester

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出版前言

我们的大学生、研究生毕业后，面临的将是一个国际化的信息时代。他们将需要随时查阅大量的外文资料；会有更多的机会参加国际性学术交流活动；接待外国学者；走上国际会议的讲坛。作为科技工作者，他们不仅应有与国外同行进行口头和书面交流的能力，更为重要的是，他们必须具备极强的查阅外文资料获取信息的能力。有鉴于此，在国家教委所颁布的“大学英语教学大纲”中有一条规定：专业阅读应作为必修课程开设。同时，在大纲中还规定了这门课程的学时和教学要求。有些高校除开设“专业阅读”课之外，还在某些专业课拟进行英语授课。但教、学双方都苦于没有一定数量的合适的英文原版教材作为教学参考书。为满足这方面的需要，我们挑选了 7 本计算机科学方面最新版本的教材，进行影印出版。首批影印出版的 6 本书受到广大读者的热情欢迎，我们深受鼓舞，今后还将陆续推出新书。希望读者继续给予大力支持。Prentice Hall 公司和清华大学出版社这次合作将国际先进水平的教材引入我国高等学校，为师生们提供了教学用书，相信会对高校教材改革产生积极的影响。

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Digital Video Processing

Preface

At present, development of products and services offering full-motion digital video is undergoing remarkable progress, and it is almost certain that digital video will have a significant economic impact on the computer, telecommunications, and imaging industries in the next decade. Recent advances in digital video hardware and the emergence of international standards for digital video compression have already led to various desktop digital video products, which is a sign that the field is starting to mature. However, much more is yet to come in the form of digital TV, multimedia communication, and entertainment platforms in the next couple of years. There is no doubt that digital video processing, which began as a specialized research area in the 70s, has played a key role in these developments. Indeed, the advances in digital video hardware and processing algorithms are intimately related, in that it is the limitations of the hardware that set the possible level of processing in real time, and it is the advances in the compression algorithms that have made full-motion digital video a reality.

The goal of this book is to provide a comprehensive coverage of the principles of digital video processing, including leading algorithms for various applications, in a tutorial style. This book is an outcome of an advanced graduate level course in Digital Video Processing, which I offered for the first time at Bilkent University, Ankara, Turkey, in Fall 1992 during my sabbatical leave. I am now offering it at the University of Rochester. Because the subject is still an active research area, the underlying mathematical framework for the leading algorithms, as well as the new research directions as the field continues to evolve, are presented together as much as possible. The advanced results are presented in such a way that the application-oriented reader can skip them without affecting the continuity of the text.

The book is organized into six parts: i) *Representation of Digital Video*, including modeling of video image formation, spatio-temporal sampling, and sampling lattice conversion without using motion information; ii) *Two-Dimensional (2-D) Motion Estimation*; iii) *Three-Dimensional (3-D) Motion Estimation and Segmentation*; iv) *Video Filtering*; v) *Still Image Compression*; and vi) *Video Compression*, each of which is divided into four or five chapters. Detailed treatment of the mathematical principles behind representation of digital video as a form of computer data, and processing of this data for 2-D and 3-D motion estimation, digital video standards conversion, frame-rate conversion, de-interlacing, noise filtering, resolution enhancement, and motion-based segmentation are developed. The book also covers the fundamentals of image and video compression, and the emerging world standards for various image and video communication applications, including high-definition TV, multimedia workstations, videoconferencing, videophone, and mobile image communications. A more detailed description of the organization and the contents of each chapter is presented in Section 1.3.

As a textbook, it is well-suited to be used in a one-semester advanced graduate level course, where most of the chapters can be covered in one 75-minute lecture. A complete set of visual aids in the form of transparency masters is available from the author upon request. The instructor may skip Chapters 18-21 on still-image compression, if they have already been covered in another course. However, it is recommended that other chapters are followed in a sequential order, as most of them are closely linked to each other. For example, Section 8.1 provides background on various optimization methods which are later referred to in Chapter 11. Chapter 17 provides a unified framework to address all filtering problems discussed in Chapters 13-16. Chapter 24, "Model-Based Coding," relies on the discussion of 3-D motion estimation and segmentation techniques in Chapters 9-12. The book can also be used as a technical reference by research and development engineers and scientists, or for self-study after completing a standard textbook in image processing such as *Two-Dimensional Signal and Image Processing* by J. S. Lim. The reader is expected to have some background in linear system analysis, digital signal processing, and elementary probability theory. Prior exposure to still-frame image-processing concepts should be helpful but is not required. Upon completion, the reader should be equipped with an in-depth understanding of the fundamental concepts, able to follow the growing literature describing new research results in a timely fashion, and well-prepared to tackle many open problems in the field.

My interactions with several exceptional colleagues had significant impact on the development of this book. First, my long time collaboration with Dr. Ibrahim Sezan, Eastman Kodak Company, has shaped my understanding of the field. My collaboration with Prof. Levent Onural and Dr. Gozde Bozdagi, a Ph.D. student at the time, during my sabbatical stay at Bilkent University helped me catch up with very-low-bitrate and object-based coding. The research of several excellent graduate students with whom I have worked Dr. Gordana Pavlovic, Dr. Mehmet Ozkan, Michael Chang, Andrew Patti, and Yucel Altunbasak has made major contributions to this book. I am thankful to Dr. Tanju Erdem, Eastman Kodak Company, for many helpful discussions on video compression standards, and to Prof. Joel Trussell for his careful review of the manuscript. Finally, reading of the entire manuscript by Dr. Gozde Bozdagi, a visiting Research Associate at Rochester, and her help with the preparation of the pictures in this book are gratefully acknowledged. I would also like to extend my thanks to Dr. Michael Kriss, Carl Schauffele, and Gary Bottger from Eastman Kodak Company, and to several program directors at the National Science Foundation and the New York State Science and Technology Foundation for their continuing support of our research; Prof. Kevin Parker from the University of Rochester and Prof. Abdullah Atalar from Bilkent University for giving me the opportunity to offer this course; and Chip Blouin and John Youngquist from the George Washington University Continuing Education Center for their encouragement to offer the short-course version.

A. Murat Tekalp "tekalp@ee.rochester.edu"
Rochester, NY February 1995

About the Author

A. Murat Tekalp received B.S. degrees in electrical engineering and mathematics from Boğaziçi University, Istanbul, Turkey, in 1980, with the highest honors, and the M.S. and Ph.D. degrees in electrical, computer, and systems engineering from Rensselaer Polytechnic Institute (RPI), Troy, New York, in 1982 and 1984, respectively.

From December 1984 to August 1987, he was a research scientist and then a senior research scientist at Eastman Kodak Company, Rochester, New York. He joined the Electrical Engineering Department at the University of Rochester, Rochester, New York, as an assistant professor in September 1987, where he is currently a professor. His current research interests are in the area of digital image and video processing, including image restoration, motion and structure estimation, segmentation, object-based coding, content-based image retrieval, and magnetic resonance imaging.

Dr. Tekalp is a Senior Member of the IEEE and a member of Sigma Xi. He was a scholar of the Scientific and Technical Research Council of Turkey from 1978 to 1980. He received the NSF Research Initiation Award in 1988, and IEEE Rochester Section Awards in 1989 and 1992. He has served as an Associate Editor for IEEE Transactions on Signal Processing (1990-1992), and as the Chair of the Technical Program Committee for the 1991 MDSP Workshop sponsored by the IEEE Signal Processing Society. He was the organizer and first Chairman of the Rochester Chapter of the IEEE Signal Processing Society. At present he is the Vice Chair of the IEEE Signal Processing Society Technical Committee on Multidimensional Signal Processing, and an Associate Editor for IEEE Transactions on Image Processing, and Kluwer Journal on Multidimensional Systems and Signal Processing. He is also the Chair of the Rochester Section of IEEE.

About the Notation

Before we start, a few words about the notation used in this book are in order. Matrices are always denoted by capital bold letters, e.g., $\mathbf{R}$. Vectors, defined as column vectors, are represented by small or capital bold letters, e.g., $\mathbf{x}$ or $\mathbf{X}$. Small letters refer to vectors in the image plane or their lexicographic ordering, whereas capitals are used to represent vectors in the 3-D space. The distinction between matrices and 3-D vectors will be clear from the context. The symbols F and f are reserved to denote frequency. F (cycles/mm or cycles/sec) indicates the frequency variable associated with continuous signals, whereas f denotes the unitless normalized frequency variable.

In order to unify the presentation of the theory for both progressive and interlaced video, time-varying images are assumed to be sampled on 3-D lattices. Time-varying images of continuous variables are denoted by $s_c(x_1, x_2, t)$. Those sampled on a lattice can be considered as either functions of continuous variables with actual units, analogous to multiplication by an impulse train, or functions of discrete variables that are unitless. They are denoted by $s_p(x_1, x_2, t)$ and $s(n_1, n_2, k)$, respectively. Continuous or sampled still images will be represented by $s_k(x_1, x_2)$, where (x_1, x_2) denotes real numbers or all sites of the lattice that are associated with a given frame/field index k, respectively. The subscripts "c" and "p" may be added to distinguish between the former and the latter as need arises. Sampled still images will be represented by $s_k(n_1, n_2)$. We will drop the subscript k in $s_k(x_1, x_2)$ and $s_k(n_1, n_2)$ when possible to simplify the notation. Detailed definitions of these functions are provided in Chapter 3.

We let $\mathbf{d}(x_1, x_2, t; \ell\Delta t)$ denote the spatio-temporal displacement vector field between the frames/fields $s_p(x_1, x_2, t)$ and $s_p(x_1, x_2, t + \ell\Delta t)$, where ℓ is an integer, and Δt is the frame/field interval. The variables (x_1, x_2, t) are assumed to be either continuous-valued or evaluated on a 3-D lattice, which should be clear from the context. Similarly, we let $\mathbf{v}(x_1, x_2, t)$ denote either a continuous or sampled spatio-temporal velocity vector field, which should be apparent from the context. The displacement field between any two particular frames/fields k and $k + \ell$ will be represented by the vector $\mathbf{d}_{k,k+\ell}(x_1, x_2)$. Likewise, the velocity field at a given frame k will be denoted by the vector $\mathbf{v}_k(x_1, x_2)$. Once again, the subscripts on $\mathbf{d}_{k,k+\ell}(x_1, x_2)$ and $\mathbf{v}_k(x_1, x_2)$ will be dropped when possible to simplify the notation.

A quick summary of the notation is provided below, where $\mathbf{R}$ and $\mathbf{Z}$ denote the real numbers and integer numbers, respectively.

Time-varying images

Continuous spatio-temporal image:
$s_c(x_1, x_2, t) = s_c(\mathbf{x}, t), \quad (\mathbf{x}, t) \in \mathbf{R}^3 = \mathbf{R} \times \mathbf{R} \times \mathbf{R}$

Image sampled on a lattice - continuous coordinates:
$s_p(x_1, x_2, t) = s_p(\mathbf{x}, t), \quad \begin{bmatrix} \mathbf{x} \\ t \end{bmatrix} = \mathbf{V} \begin{bmatrix} \mathbf{n} \\ k \end{bmatrix} \in \Lambda^3$

Discrete spatio-temporal image:
$s(n_1, n_2, k) = s(\mathbf{n}, k), \quad (\mathbf{n}, k) \in \mathbf{Z}^3 = \mathbf{Z} \times \mathbf{Z} \times \mathbf{Z}.$

Still images

Continuous still image:
$s_k(x_1, x_2) = s_c(\mathbf{x}, t)|_{t=k\Delta t}, \quad \mathbf{x} \in R^2, \quad k$ fixed integer

Still image sampled on a lattice:
$s_k(x_1, x_2) = s_p(\mathbf{x}, t)|_{t=k\Delta t}, \quad k$ fixed integer
$\mathbf{x} = [v_{11}n_1 + v_{12}n_2 + v_{13}k, v_{21}n_1 + v_{22}n_2 + v_{23}k]^T$,
where v_{ij} denotes elements of the matrix $\mathbf{V}$,

Discrete still image:
$s_k(n_1, n_2) = s(\mathbf{n}, k), \quad \mathbf{n} \in Z^2, \quad k$ fixed integer

The subscript k may be dropped, and/or subscripts "c" and "p" may be added to $s(x_1, x_2)$ depending on the context.
$\mathbf{s}_k$ denotes lexicographic ordering of all pixels in $s_k(x_1, x_2)$.

Displacement field from time t to $t + \ell\Delta t$:

$\mathbf{d}(x_1, x_2, t; \ell\Delta t) = [d_1(x_1, x_2, t; \ell\Delta t), d_2(x_1, x_2, t; \ell\Delta t)]^T$,
$\ell \in \mathbf{Z}, \quad \Delta t \in R, \quad (x_1, x_2, t) \in \mathbf{R}^3$ or $(x_1, x_2, t) \in \Lambda^3$

$\mathbf{d}_{k,k+\ell}(x_1, x_2) = \mathbf{d}(x_1, x_2, t; \ell\Delta t)|_{t=k\Delta t}, \quad k, \ell$ fixed integers

$\mathbf{d}_1$ and $\mathbf{d}_2$ denote lexicographic ordering of the components of the motion vector field for a particular $(k, k+\ell)$ pair.

Instantaneous velocity field

$\mathbf{v}(x_1, x_2, t) = [v_1(x_1, x_2, t), v_2(x_1, x_2, t)]^T$,
$(x_1, x_2, t) \in \mathbf{R}^3$ or $(x_1, x_2, t) \in \Lambda^3$

$\mathbf{v}_k(x_1, x_2) = \mathbf{v}(x_1, x_2, t)|_{t=k\Delta t} \quad k$ fixed integer

$\mathbf{v}_1$ and $\mathbf{v}_2$ denote lexicographic ordering of the components of the motion vector field for a given k.

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