TELECONFERENCING

Edited by

K. Ramamohan Rao

and

Ram Srinivasan

TELECONFERENCING

Edited by

K. RAMAMOHAN RAO
University of Texas at Arlington

and

RAM SRINIVASAN
International Imaging Systems
Milpitas, California

A Hutchinson Ross Publication

VNR VAN NOSTRAND REINHOLD COMPANY
New York

Benchmark Papers in Electrical Engineering and Computer Science, Volume 30
Library of Congress Catalog Card Number: 85-6078
ISBN: 0-442-27826-8

Manufactured in the United States of America.

Published by Van Nostrand Reinhold Company Inc.
135 West 50th Street
New York, New York 10020

Van Nostrand Reinhold Company Limited
Molly Millars Lane
Wokingham, Berkshire RG11 2PY, England

Van Nostrand Reinhold
480 Latrobe Street
Melbourne, Victoria 3000, Australia

Macmillan of Canada
Division of Gage Publishing Limited
164 Commander Boulevard
Agincourt, Ontario MIS 3C7, Canada

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging in Publication Data
Main entry under title:
Teleconferencing.
"A Hutchinson Ross publication."
Includes indexes.
1. Teleconferencing—Addresses, essays, lectures.
I. Rao, K. Ramamohan (Kamisetty Ramamohan) II. Srinivasan, Ram.
TK5102.5.T424 1985 384.6'42 85-6078
ISBN 0-442-27826-8

Benchmark Papers in Electrical Engineering and Computer Science

Editor: John B. Thomas — Princeton University

A selection from the published volumes in this series

SYSTEM SENSITIVITY ANALYSIS / *José B. Cruz, Jr.*
RANDOM PROCESSES: Multiplicity Theory and Canonical Decompositions / *Anthony Ephremides and John B. Thomas*
ALGEBRAIC CODING THEORY: History and Development / *Ian F. Blake*
COMPUTER-AIDED CIRCUIT DESIGN: Simulation and Optimization / *S. W. Director*
ENVIRONMENTAL MODELING: Analysis and Management / *Douglas Daetz and Richard H. Pantell*
CIRCUIT THEORY: Foundations and Classical Contributions / *M. E. Van Valkenburg*
TWO-DIMENSIONAL DIGITAL SIGNAL PROCESSING / *Sanjit K. Mitra and Michael P. Ekstrom*
COMPUTER ARITHMETIC / *Earl E. Swartzlander, Jr.*
ARRAY PROCESSING: Applications to Radar / *Simon Haykin*
NONPARAMETRIC DETECTION: Theory and Applications / *Saleem A. Kassam and John B. Thomas*
DECONVOLUTION OF SEISMIC DATA / *V. K. Arya and J. K. Aggarwal*
REPRODUCING KERNEL HILBERT SPACES: Applications in Statistical Signal Processing / *Howard L. Weinert*
DISTRIBUTED PARAMETER SYSTEMS THEORY, PART I: Control / *Peter Stavroulakis*
DISTRIBUTED PARAMETER SYSTEMS THEORY, PART II: Estimation / *Peter Stavroulakis*
DISCRETE TRANSFORMS AND THEIR APPLICATIONS / *K. R. Rao*
QUANTIZATION / *Peter F. Swaszek*
WALSH FUNCTIONS IN SIGNAL AND SYSTEMS ANALYSIS AND DESIGN / *Spyros G. Tzafestas*

A complete listing of volumes in this series appears on page 251.

SERIES EDITOR'S FOREWORD

This Benchmark Series in Electrical Engineering and Computer Science is aimed at sifting, organizing, and making readily accessible to the reader the vast literature that has accumulated. Although the series is not intended as a complete substitute for a study of this literature, it will serve at least three major critical purposes. In the first place, it provides a practical point of entry into a given area of research. Each volume offers expert selection of the critical papers on a given topic as well as views on its structure, development, and present status. In the second place, the series provides a convenient and time-saving means for study in areas related to but not contiguous with one's principal interests. Last, but by no means least, the series allows the collection, in a particularly compact and convenient form, of the major works on which present research activities and interests are based.

Each volume in the series has been collected, organized, and edited by authorities in the area to which it pertains. In order to present a unified view of the area, the volume editors have prepared an introduction to the subject, have included comments on each article, and have provided a subject index to facilitate access to the papers.

We believe that this series will provide a manageable working library of the most important technical articles in electrical engineering and computer science. We hope that it will be equally valuable to students, teachers, and researchers.

Teleconferencing has been edited by K. R. Rao of the University of Texas at Arlington and R. Srinivasan of International Imaging Systems. It contains thirty-seven papers on teleconferencing, teleconferencing networks, pictured coding, and related technology. It should afford easy access to these new and exciting areas as well as provide an invaluable collected reference for active workers in the teleconferencing field.

JOHN B. THOMAS

PREFACE

Research on bandwidth compression for transmitting videoconferencing signals has come of age. It has turned from a subject of mere academic interest into an issue of practical importance. Handling the video component in teleconferencing has been a challenge to the researchers because of the problems posed. For the users, the excitement comes as a result of experiencing better communication. Over the past decade compression codecs and algorithms, which are inexpensive to implement and also render better quality pictures, have been brought to users. Recent developments in the videoconferencing field, its vicissitudes and its future, are of great importance for researchers as well as users. This volume presents papers of interest to academics, those employed in the videoconferencing industry, and the business community.

Papers in this volume have been divided into four categories: general interest review papers, motion compensation algorithms, 6.3-1.5 Mb/s bit rate codecs, and low bit rate codecs, mostly of 56 Kb/s and below. The work will enable researchers and developers to keep abreast of developments in compression methods for videoconferencing, and to direct their future efforts. Business managers and users will learn what this field has in store for them, its growth potential, and how they can utilize its developments.

The editors would like to express their gratitude to Dr. J. B. Thomas for his guidance during the preparation of this volume. K. R. Rao would like to thank the faculty, graduate students, and staff at the University of Texas at Arlington for their help. The understanding and encouragement of his wife, Karuna, and children, Ramesh and Sasirekha, also are deeply appreciated. Ram Srinivasan would like to acknowledge the help of Dr. Isaac Dukhovich, Mr. Michael Stauffer, and Mr. Kenneth Shaw of Picture Element Limited, Palo Alto, California. The enormous understanding of his wife, Sumathi, has enabled him to perform this work with extra enthusiasm. He would like to dedicate the book to his parents.

K. RAMAMOHAN RAO
RAM SRINIVASAN

CONTENTS BY AUTHOR

TELECONFERENCING

CONTENTS

PART II: MOTION COMPENSATION

PART III: TELECONFERENCING CODECS

PART IV: LOW BIT RATE CODECS

INTRODUCTION

Millard and Maunsell (1971) and Limb and co-workers (1977), scientists at Bell Labs, demonstrated a one-way, videotelephone between New York and Washington, D.C. on April 7, 1927. Then, on April 9, 1930, a two-way system between Bell Labs and AT&T headquarters in New York City was demonstrated. Thus the concept of videoconferencing systems was established. Graham (1958) demonstrated by computer simulation the feasibility of using 3-bit DPCM for the television transmission of still black and white pictures. Similar studies paved the way for the Picturephone® System of Bell Labs (1971). This system was introduced at a transmission bit rate of 6.312 Mb/s on a T-2 digital carrier. Videoconferencing is now coming into the limelight. With advances in semiconductor technology and their impact on the cost of telecommunication services, the concept of substituting video and audio transmission for travel is gaining acceptance (Paper 1). At present such substitution of videoconferencing for business travel amounts to only 0.003%, but this is expected to increase to 6% by 1990, as a study for NASA indicates (Paper 2).

Videoconferencing is international in nature. A wide variety of teleconferencing services is available in European countries (Thompson, 1981) under the umbrella of the European Telecommunication Satellite Organization (EUTELSAT), a consortium of 20 countries. The international videoconferencing services available by satellites and the implications of such services are discussed in Paper 3. The fundamental problem in providing video in teleconferencing is its enormous bandwidth and the associated cost. The bandwidth problem is most easily dealt with in the digital domain (Jain, 1981; Kaneko and Ishiguro, 1980; Netravali and Limb, 1980). The technological aspects and problems and prospects of digital videoconferencing codecs also are covered.

Digital image-data compression methods can be classified into two basically different categories; namely, predictive coding and transform coding. Another classification is intraframe, exploiting spatial redundancy, and interframe, exploiting both spatial and temporal redundancies. Since an 8-bit PCM transmission of TV images requires typically 90 Mb/s, much remains to be achieved in compressing information before digital videoconferencing can be economical for users. Fortunately, images from videoconferencing situations have large spatial and temporal redundancies. A variety of methods for bandwidth reduction (Haskell et al., 1972; Haskell et al., 1977), using predictive as well as transform coding, has been proposed. Interframe methods achieve higher compression than intraframe techniques, but interframe methods required storage of one or more frames. It is not yet clearly established which combination of methods best stands the test of motion and scene change. A technique called conditional replenishment (CR) (Candy et al., 1971; Mounts, 1969) uses the statistical fact that information is present in a scene only when motion occurs and only in selected areas of the frame. Several researchers have experimented with this technique. It is suitable for videoconference codecs where motion in the scene typically does not exceed 15% in a frame interval.

Research has been done in an attempt to achieve compression by estimating the motion taking place in a scene (Rocca and Zanoletti, 1972), and then compensating for it. Instead of simply transmitting interframe differences, motion is estimated for a pel or a block of pels, and differences are taken with respect to the displaced location. The entropy of the displaced frame difference (DFD) is much below that of frame differencing, indicating the higher quality of compression achieved by compensating for motion. Motion compensation improves the compression factor by 50 to 100% when compared to CR. Paper 10 stresses that motion compensation is the best way of coding.

There are two basic ways of estimating motion in coders, namely the method of differentials (Netravali and Robbins, 1979) or pel recursive algorithms (PRA), and the pattern matching or block matching algorithms (BMA). The PRA techniques start with an initial estimate of the motion parameters and revise these estimates at predetermined rates. For the most part the motion is estimated for every pel. The PRA proposed up to now are complex for videoconferencing implementation. On the other hand, BMA estimate motion vectors for a block of pels, say of size $(M \times N)$, in the current frame in relation to a reference (previous) frame. A spatially centered search area of size $(M + 2p) \times (N + 2p)$ is chosen in the reference frame. In this setup there are $(2p + 1)^2$ possible blocks in the search area that can be a match to the $(M \times N)$ block. The best match typically is sought by maximizing the cross-correlation or minimizing the mean square error. This simple pattern matching technique assumes translational motion for the blocks. BMA handled in this fashion still is expensive in computational terms, but the number of search points can be lower.

The papers in this volume are chosen so the reader gets both an overall view of the subject and an idea of the various algorithms implemented in the codecs operating at various bit rates, as low as 4.8 Kb/s. The papers are divided into four parts. Part I consists of review papers. Papers 1 and 2 focus on the acceptance of videoconferencing as a substitute for face-to-face meetings, and also on its economics. Papers 2, 3, and 4 also discuss the variety of videoconferencing services available, both national and international. In particular, Paper 4 discusses the short past of videoconferencing networks. Paper 5 deals with the cost aspect of full motion videoconferencing, while Paper 6 details how companies can have a successful system, citing some examples. Paper 7 discusses the technical problems in digital transmission of color televison signals. It also gives an idea of the system developed for teleconferencing, as well as for network quality TV. Papers 8 and 9 give an overview of the compression techniques, and are geared toward a final tilt on motion compensation methods.

Part II deals with various motion compensation algorithms. Papers in this group are mostly in the pattern matching category. The first approach to the pattern matching method for TV bandwidth compression was proposed by Taki and co-workers (1974). BMA leads to an adequate and uncomplicated means of estimating motion in videoconferencing scenes. Papers 10 and 11 emphasize that some sort of motion compensation is needed. Paper 11 also compares the prediction process based on translational and rotational motion. Papers 12 through 16 develop BMA algorithms that involve far less computational complexity. Paper 17 describes a technique for a very low bit-rate codec that measures displacement using significant points on an object. Paper 18 outlines a least mean square (LMS) adaptive algorithm that is significantly different from the rest of the papers. Paper 19 is about interpolation along the motion direction of missing frames. Interpolation like this has earlier been proven to provide better results than simple interpolation (Jain and Jain, 1979).

Part III consists of papers about codecs on the market, or which have been built and tested, transmitting in the range 6.3 to 1.5 Mb/s. A popular codec in the 6.3 Mb/s range is the TRIDEC 6.3 of NTT (Yasuda et al., 1977) using 4:1 dot interlace. Takikawa (Paper 20) of NTT later reported a better codec than this. Videocompression techniques have come up to such a level that full motion videoconferencing of good quality is possible at 1.5 Mb/s range, capable of transmission on a T-1 carrier. Dedicated T-1 carriers can be afforded only by big companies. A dedicated terrestrial T-1 carrier of AT&T still costs around $30,000 per month, which is a costly proposition for small companies. In the past two or three years, AT&T has expanded and popularized its own Picturephone® Meeting Service (PMS) (Papers 21 and 22). Its transmission rate is at 3 Mb/s using two DS-1 signals or 1.544 Mb/s each. The PMS cost per hour for one or two T-1 channels is also high. As a solution to this, ACTION/Honeywell of Dallas provides a switched network that can be used for audio, video, or data transmission, thus bringing down the cost (Paper 5).

Videoconferencing services in Europe are extensive, with participation by several countries (Thompson, 1982). A codec that is widely marketed is that of *GEC-Video Systems,* transmitting at 2 Mb/s and 1.5 Mb/s in their European and American versions (Papers 23 and 24), with a CR algorithm. A wide range of simulation and experimentation has gone into the develoment of the European codec. Each country has been developing its ideas on a specific part of the codec, for example, the movement detector (Paper 25). Papers 26, 27 and 28 bring out recent developments in Japan. NEC's codec is the first to incorporate a motion compensation (not just motion detection) technique. In the United

States, Compression Labs, Inc. of San Jose, California is a successful company in the development and commercialization of a codec at T-1 rate. The VTS 1.5 (Paper 29) is an intraframe system unlike other systems discussed.

Part IV consists of papers outlining codecs at 320 Kb/s and below up to 4.8 Kb/s. Paper 30 concerns a 320 Kb/s French codec with a segmentation procedure as its basis. The high cost of T-1 rate codecs has led small users to accept relatively lower quality and resolution pictures at affordable rates. Papers 31, 33, and 34 detail simulation experiments in the 56 Kb/s range. A codec developed with DARPA contract is Widcom's 56 Kb/s codec, costing only a fraction of a T-1 codec (Paper 32). Widcom is commercializing, and also is trying to improve the quality of reconstructed pictures. Transmission rates lower than this range are possible with a sketch coding concept (Papers 35 and 36) or freeze frame images (Paper 37).

The saying, "What you get is what you pay for," is very true with TV codecs. Depending on the application and economics a user can choose a T-1 rate codec or any of the very low bit-rate ones. Once the cost factor is established, quality comparison between codecs of the same transmission range is an easy task. It is believed that motion compensation is a feature that can be incorporated into currently available or future codecs with a significant improvement in performance and without a big cost increase. This should be easier for developers with more potential users.

The selection of papers in this volume has been made with an intent to focus not only on the technical aspects and problems of various compression algorithms, but also on economics and substitution ideologies. Inevitably, many other papers of interest have been omitted; some of them are referenced in various sections. It is hoped that this work will serve to stimulate not only researchers in the videoconferencing area, but also users, current and prospective.

REFERENCES

Bell Labs, 1971, The Picturephone® System, Special Issue, *Bell Syst. Tech. J.* **50:**219–665.

Candy, J. C., M. A. Franke, B. G. Haskell, and F. W. Mounts, 1972, Transmitting Television as Clusters of Frame-to-Frame Differences, *Bell Syst. Tech. J.* **50:**1889–1917.

Graham, R. E., 1958, *Predictive Quantizing of Television Signals,* IRE WESCON Convention Record, pp. 147–156.

Haskell, B. G., F. W. Mounts, and J. C. Candy, 1972, Interframe Coding of Videotelephone Pictures, *IEEE Proc.* **60:**792–800.

Haskell, B. G., R. L. Gordon, R. L. Schmidt, and J. V. Scattaglia, 1977, Interframe Coding of 525 Line, Monochrome Television at 1.5 Mbits/s, *IEEE Commun. Trans.* **COM-25:**1339–1348.

Jain, A. K., 1981, Image Data Compression: A Review, *IEEE Proc.* **69:**349–389.

Jain, J. R., and A. K. Jain, 1979, *Interframe Adaptive Data Compression Techniques for Images,* Signal and Image Processing Laboratory, University of California, Davis, Calif.

Kaneko, H., and T. Ishiguro, 1980, Digital Television Transmission Using Bandwidth Compression Techniques, *IEEE Commun. Mag.* **18:**14–22.

Limb, J. O., and J. A. Murphy, 1975, Estimating the Velocity of Moving Images in Television Signals, *Comput. Graphics Image Process.* **4:**311–327.

Limb, J. O., C. B. Rubinstein, and J. E. Thompson, 1977, Digital Encoding of Color Video Signal—A Review, *IEEE Commun. Trans.* **COM-25:**1349–1384.

Millard, J. B., and H. I. Maunsell, 1971, Digital Encoding of the Video Signal, *Bell Syst. Tech. J.* **50:**459–479.

Mounts, F. W., 1969, A Video Encoding System with Conditional Picture Element Replenishment, *Bell Syst. Tech. J.* **48:**2545–2554.

Netravali, A. N., and J. O. Limb, 1980, Picture Coding: A Review, *IEEE Proc.* **68:**366–406.

Netravali, A. N., and J. D. Robbins, 1979, Motion Compensated Television Coding, Part I, *Bell Syst. Tech. J.* **58:**631–670.

Rocca, F., and S. Zanoletti, 1972, Bandwidth Reduction Via Movement Compensation on a Model of the Random Video Process, *Commun. Trans. IEEE* **COM-20:**960–965.

Taki, Y., M. Hatori, and S. Tanaka, 1974, Interframe Image Coding with Movement Tracking, *Inst. Electron. Commun. Eng. Conf. Rec.* p. 1260. (In Japanese.)

Thompson, J. E., 1981, European Collaboration on Picture Coding Research at 2Mbits/s Transmission, *IEEE Commun. Trans.* **COM-29:**2003–2004.

Thompson, J. E., 1982, Objectives and Results of Project Cost-211, *GLOBECOM Proc.* **82:**802–804.

Yasuda, H., H. Kawanishi, T. Matsuoka, and F. Kanaya, 1977, TRIDEC System Design, *Electron. Commun. Lab. Rev. (Japan)* **25:**1337–1346.