Volume 6, No. 4, August 1994

ISSN 0923-5965
6(4) 281–378 (1994)

SIGNAL PROCESSING

IMAGE COMMUNICATION

CONTENTS

Papers

Theory, Techniques & Applications

A publication of the European Association for Signal Processing (EURASIP)

SIGNAL PROCESSING

IMAGE COMMUNICATION

Theory, Techniques & Applications

A publication of the European Association for Signal Processing (EURASIP)

Editorial Policy. SIGNAL PROCESSING: IMAGE COMMUNICATION is an international journal for the development of the theory and practice of image communication. Its primary objectives are the following:

- To present a forum for the advancement of the theory and practice of image communication.
- To stimulate cross-fertilization between areas similar in nature which have traditionally been separated, for example, various aspects of visual communications and information systems.
- To contribute to a rapid information exchange between the industrial and academic environments.

The editorial policy and the technical content of the journal are the responsibility of the Editor-in-Chief and the Editorial Board. The Journal is self-supporting from subscription income and contains a minimum amount of advertisements. Advertisements are subject to the prior approval of the Editor-in-Chief. The journal welcomes contributions from every country in the world.

Scope. SIGNAL PROCESSING: IMAGE COMMUNICATION publishes articles relating to aspects of the design, implementation and use of image communication systems.
SIGNAL PROCESSING: IMAGE COMMUNICATION features original research work, tutorial and review articles, and accounts of practical developments.

Subjects. Subject areas covered by the journal include:

TV, HDTV and 3D-TV systems
Visual Science
Image Coding
Image Transmission
Interactive Image Communication
TV and Advanced TV Broadcasting
Image Storage and Retrieval
Graphic Arts
Electronic Printing
Imaging Technology
Display Technology
VLSI Processors for Image Communications

Membership and Subscription Information.
SIGNAL PROCESSING: IMAGE COMMUNICATION (ISBN 0923-5965) is published in one volume (six issues) a year. For 1994 Volume 6 is scheduled for publication. Subscription prices are available upon request from the publisher. Subscriptions are accepted on a prepaid basis only and are entered on a calendar year basis. Issues are sent by surface mail except to the following countries, where air delivery (S.A.L. – Surface Air Lifted) is ensured: Argentina, Australia, Brazil, Canada, Hong Kong, India, Israel, Japan, Malaysia, Mexico, New Zealand, Pakistan, People's Republic of China, Singapore, South Africa, South Korea, Taiwan, Thailand, USA. For the rest of the world, airmail charges are available upon request. Claims for missing issues will be honoured free of charge if made within six months after the publication date of the issues. Mail orders and inquiries to: Elsevier Science B.V., Journals Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands. For full membership information of the Association, possibly combined with a subscription at a reduced rate, please contact: EURASIP, P.O. Box 134, CH-1000 Lausanne 13, Switzerland.

Signal Processing: IMAGE COMMUNICATION
Volume 6, No. 4, August 1994

CONTENTS

Papers

ANNOUNCEMENT

Authors may now accompany their manuscripts with texts in electronic form

Please see the notes on the inside back cover and the guide at the back of the issue. Authors are requested to submit a complete checklist with each diskette. Additional copies of the guide and the checklist are available from the publisher.

ELSEVIER

Signal Processing: *Image Communication* 6 (1994) 303–317

SIGNAL PROCESSING: IMAGE COMMUNICATION

Inter-block filtering and downsampling in DCT domain[1]

A. Neri[a], G. Russo[b], P. Talone[b,*]

[a] *University of 'Rome III', Rome, Italy*
[b] *Fondazione Ugo Bordoni, Via B. Castiglione 59, 00142 Rome, Italy*

Received 16 December 1992

Abstract

The extensive use of discrete cosine transform (DCT) techniques in image coding suggests the investigation on filtering and downsampling methods directly acting on the DCT domain. As DCT image transforms usually operate on blocks, it is useful that the DCT filtering techniques preserve the block dimension. In this context the present paper first revises the intra-block filtering techniques to enlighten the limitations implied by small block dimensions. To overcome the artefacts introduced by this method and to satisfy the filtering design constraints which are usually defined in the Fourier domain, inter-block techniques are developed starting from the implementation of FIR filtering. Inter-block schemes do not exhibit any limitation but their computational cost has to be taken into account. In addition, hybrid techniques, using variable length FIR filters after the discard of low order DCT coefficients, are introduced to increase the computational efficiency; in this case, the introduced aliasing has to be kept at tolerable values. The amount of the tolerable aliasing strictly depends on the subsequent operations applied to the filtered and downsampled image. The numerical examples reported could form a basis for error estimation and evaluation of trade-off between performance and computational complexity.

Key words: Discrete cosine transform; Block operation; Filtering; Downsampling

1. Introduction

Filtering and downsampling of image signals are basic operations normally performed in image processing.

This is, for instance, the case of spatial scalability (e.g. MPEG High $1440 \times 1152 \Rightarrow$ CCIR 601 $720 \times 576 \Rightarrow$ MPEG SIF 352×288 [2, 6] and JPEG Progressive Hierarchical Mode [7]) as well as of chrominance downsampling (e.g. CCIR 4:4:4 $\Rightarrow$ CIR 4:2:2 $\Rightarrow$ MPEG 4:2:0 [2, 6]).

Filtering and downsampling are usually carried out in the space domain by means of FIR filters.

However, the extensive use of DCT techniques in image coding suggested the investigation on filtering and downsampling directly in the transformed (DCT) domain. As DCT image transforms usually

* Corresponding author. Tel: +39-6-54803460, Fax +39-6-54804404.

[1] This work has been carried out in the framework of the agreement between Fondazione Bordoni and the Italian PT Administration.

SSDI 0923-5965(93)00017-D

operate on square blocks of small dimension (8, 16), DCT operations are usually intra-block oriented. In particular, the above mentioned operations can be realized as matrix products [1, 5, 8–10, 12, 13].

The possibility to combine into a unique operator (acting on spatial or transformed blocks) a series of block operations such as direct and inverse transforms, intra-block filtering and downsampling was demonstrated in [1].

The matrix based operations allow to directly produce
- the DCT transform of a filtered or downsampled image from the original image,
- the DCT transform of a filtered or downsampled image from its DCT,
- a filtered or downsampled image from its DCT.

This paper presents a brief review of the intra-block filtering methods in DCT domain and discusses their performance.

Then, in order to overcome the intra-block technique drawbacks, an inter-block filtering method and some hybrid techniques are presented and discussed. The use of an inter-block technique is necessary to satisfy the filtering design constraints which are usually defined in the Fourier domain.

All the above-mentioned techniques are presented in a context that aims at preserving the transformed block dimension; this means that, manipulating image blocks of $N \times N$ pixels, a transformed $kN \times hN$ macroblock is considered as a set of (hk) transformed blocks of dimension $N \times N$ and not as a single $kN \times hN$ transformed block.

The paper is organized as follows. Sections 2 and 3 report a concise review of some basic concepts and definitions regarding spatial filtering, downsampling and DCT transform. Moreover, notation used in the following description is introduced. In Section 4 a method to perform spatial downsampling in DCT domain is presented. Section 5 presents a review of the intra-block filtering techniques in DCT domain and illustrates their performance. In Section 6, an inter-block filtering technique is proposed and its properties are discussed. Finally, in Section 7, hybrid methods to increase the computational efficiency of the inter-block technique are suggested and their performance are directly derived from the results illustrated in Sections 5 and 6.

2. Spatial filtering and downsampling

Image filtering is usually carried out in the space domain by means of FIR filters. Simple methods based on pixel averaging are reported in [6, 7].

The well established FIR design techniques allow to easily satisfy the frequency filtering constraints. As a matter of fact, these constraints are usually given in terms of templates in the Fourier domain. For instance, the template for insertion loss/frequency characteristic of the CCIR recommended low-pass filter for the $4:4:4 \Rightarrow 4:2:2$ format conversion is reported in [2].

A usual method to perform spatial bidimensional 2:1 downsampling on an image is to serially operate on columns and on rows.

Executing a 2:1 column downsampling on a $N \times 2N$ block $[g]$ means essentially to assemble an $N \times N$ matrix with the odd columns of $[g]$.

The assembly must be preceded by a low-pass filter on $[g]$ rows to reduce aliasing effects on the downsampled image.

Similarly, a 2:1 row downsampling on a $2N \times N$ block $[g]$ means to assemble an $N \times N$ matrix with the odd rows of $[g]$.

Obviously the choice of odd columns or rows is a conventional matter; the operations on the even components are totally equivalent.

3. DCT operator

Let g_{ij} be the ij-element of the $N \times N$ image block $[g]$ and G_{uv} the uv-element of the $N \times N$ two-dimensional DCT $[G]$.

As well known, G_{uv} has the following expression [11]:

$$G_{uv} = 2\frac{c(u)c(v)}{N}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} g_{ij}\cos\frac{(2i+1)u\pi}{2N} \times \cos\frac{(2j+1)v\pi}{2N}, \qquad (1)$$

where

$$c(u), c(v) = \begin{cases} 1/\sqrt{2}, & \text{if } u, v = 0, \\ 1, & \text{otherwise,} \end{cases}$$

$$u, v = 0, \ldots, N-1.$$

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.