UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD

INTEL CORPORATION
Petitioner

v.

TELEFONAKTIEBOLAGET LM ERICSSON,
Patent Owner

INTER PARTES REVIEW OF U.S. PATENT NO. 10,142,659

DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.

2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.

3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in

Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item's MARC record indicates the date of an item's public availability.

5. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library's collection, it is my experience that an item's 008 field accurately indicates the date of an item's public availability.

6. I have reviewed Exhibit 1020, *Digital Image Processing* by Rafael C. Gonzalez and Richard E. Woods, 2008 edition.

7. Attached hereto as Appendix GONZALEZ01 is a true and correct copy of the MARC record for *Digital Image Processing* as held by the University of Pittsburgh library. I secured this record myself from the library's public catalog. The

MARC record contained within Appendix GONZALEZ01 accurately describes the title, author, publisher, and ISBN number of *Digital Image Processing.*

8. Attached hereto as Appendix GONZALEZ02 is a true and correct copy of GONZALEZ02 as held by the University of Pittsburgh library. I secured these scans myself from the library's collection. In comparing Exhibit 1020 to Appendix GONZALEZ02, it is my determination that Exhibit 1020 is a true and correct copy of *Digital Image Processing* by Rafael C. Gonzalez and Richard E. Woods.

9. The 008 field of the MARC record in Appendix GONZALEZ01 indicates the date of record creation. The 008 field of Appendix GONZALEZ01 indicates University of Pittsburgh library first acquired this book as of June 9, 2009. Considering this information, it is my determination that *Digital Image Processing* was made available to the public through at least the University of Pittsburg library shortly after its initial acquisition by the library as of June 9, 2009.

10. The public availability of Gonzalez as of June 9, 2009 is further confirmed by similar entries in the Library of Congress. Attached hereto as Appendix GONZALEZ03 is a true and correct copy of the MARC record for *Digital Image Processing* as held by the Library of Congress. I secured this record myself from the library's public catalog. The MARC record contained within Appendix GONZALEZ03 accurately describes the title, author, publisher, and ISBN number of *Digital Image Processing*, and, like the University of Pittsburg library's MARC

record, the 008 field of the Library of Congress's MARC record in Appendix GONZALEZ03 indicates the date of record creation was also June 9, 2009.

11. I have reviewed Exhibit 1024, "Adaptive Deblocking Filter" by Peter List, et. al as published in *IEEE Transactions on Circuits and Systems for Video Technology*, July 2003.

12. Attached hereto as Appendix LIST01 is a true and correct copy of the MARC record for *IEEE Transactions on Circuits and Systems for Video Technology* as held by the Carnegie Library of Pittsburgh. I secured this record myself from the library's public catalog. The MARC record contained within Appendix LIST01 accurately describes the title, author, publisher, and ISSN number of *IEEE Transactions on Circuits and Systems for Video Technology.* The 'Lib Has' field of this record visible on page # indicates this collection includes the July 2003 edition of *IEEE Transactions on Circuits and Systems for Video Technology* containing "Adaptive Deblocking Filter".

13. Attached hereto as Appendix LIST02 is a true and correct copy of "Adaptive Deblocking Filter" as published in *IEEE Transactions on Circuits and Systems for Video Technology* as held by the Carnegie Library of Pittsburgh. I secured these scans myself from the library's collection. In comparing Exhibit 1024 to Appendix LIST02, it is my determination that Exhibit 1024 is a true and correct

copy of "Adaptive Deblocking Filter" by Peter List, et. al as published in *IEEE Transactions on Circuits and Systems for Video Technology* July 2003.

14. The 008 field of the MARC record in Appendix LIST01 indicates the date of record creation. The 008 field of Appendix LIST01 indicates the Carnegie Library of Pittsburgh first acquired a subscription to this journal as of July 24, 1990 and held that subscription until 2009. Considering this information, it is my determination that the Carnegie Library of Pittsburgh received the July 2003 edition of *IEEE Transactions on Circuits and Systems for Video Technology* shortly after its release around July 2003 and therefore "Adaptive Deblocking Filter" was made available to the public through the Carnegie Library of Pittsburgh's subscription shortly after its initial release in July 2003.

15. However, I also understand that a copy of "Adaptive Deblocking Filter" by Peter List, et. al is also available through the Institute of Electrical and Electronics Engineers ("IEEE") Xplore website. According to the IEEE Xplore Website, this copy was published within Volume 13 of the *IEEE Transactions on Circuits and Systems for Video Technology*, Issue 7 in July 2003, consistent with the Carnegie Library of Pittsburgh's records.

16. Based on my own personal experience in the library field, IEEE is a reputable organization that has, among other things, hosted and published full-text technical articles for over two decades through a platform called "IEEE Xplore."

IEEE expressly states that the "Date of Publication for Journals and Standards on IEEE Xplore represents the very first instance of public dissemination" through IEEE. https://ieeexplore.ieee.org/Xplorehelp/working-with-documents/publication-dates. Based on my own experiences with IEEE Xplore, I have never had a reason to doubt the date of publication listed on IEEE Xplore and consider those dates accurate.

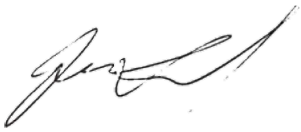
17. Based on the totality of the circumstances, it is my determination that a copy of "Adaptive Deblocking Filter" by Peter List, et. al was publicly available and accessible via IEEE Xplore by at least July 2003, as listed on the IEEE Xplore website, a printout of which is provided as Appendix LIST03 and available at https://ieeexplore.ieee.org/document/1218194. This is also consistent with IEEE Xplore's standard policies of announcing the first date of publication.

18. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of $200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

19. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and

that all statements made on information and belief are believed to be true; and further that these statements were made the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 6/10/2024



June Ann Munford

Appendix
CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.

- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.

- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in

Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over $400,000 and total assets of approximately $1,300,000.

● Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.

● Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.

● Led the organization and digitization of the library's archival records.

● Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.

● Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013
Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

● Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.

● Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.

● Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013
Library Assistant, Hart Area Public Library
Hart, MI

● Responsible for verifying imported MARC records and original MARC

cataloging for the local-level collection as well as the Michigan Electronic Library.

● Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter
- Treasurer, 2012

Library Of Michigan
- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014
- New Directors Conference Panel Member

Southwest Michigan Library Cooperative
- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008
Petoskey, MI
- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011
Nashville, TN
- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012
Fairbanks, AK
- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Civil Action No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Cases IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

2023 ● Pillsbury Winthrop Shaw Whitman LLP

Gravel Rating Systems v. Costco Wholesale Corp. (Civil Action No. 4:21-cv-149-ALM)

Limited Case and Clientele History

Alston & Bird

- Ericsson

  v. Collision Communications (IPR2022-01233)

- Nokia

  v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

- Universal Electronics Inc

  v. Roku Inc (IPR2022-00818)

Arnold & Porter

- Ivantis

  v. Glaukos (Case No. 8:18-cv-00620)

- Samsung

  v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis

  v. Cathx (Case No. 5:21-cv-00077-RWS)

Erise I.P.

- Apple
  - v. Ericsson Inc. (IPR2022-00715)
  - v. Future Link Systems (IPRs 6317804, 6622108, 6807505, and 7917680)
  - v. INVT (Case No. 20-1881)
  - v. Navblazer LLC (IPR2020-01253)
  - v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)
  - v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)
  - v. Telefonaktiebolaget LM Ericsson (IPR2022-00275)
- Fanduel
  - v. CGT (Case No. 19-1393)
- Garmin
  - v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)
- Netscout
  - v. Longhorn HD LLC (Case No. 2:20-cv-00349)
  - v. Implicit, LLC (Civil Action No. 2:18-cv-53-JRG)
- Sony Interactive Entertainment LLC
  - v. Bot M8 LLC (IPR2020-01288)
  - v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)
- Unified Patents

v. GE Video Compression (Civil Action No. 2:19-cv-248)

Fish & Richardson

- Apple
  - v. AliveCor (3:21-cv-03958)
  - v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)
  - v. Koss Corporation (IPR2021-00305)
  - v. Masimo (IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)
  - v. Neonode (Case No. 21-cv-08872-EMC)
  - v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)
- Dell
  - v. Neo Wireless (IPR2022-00616)
- Dish Network
  - v. Entropic Communications, LLC (Case No. 2:2023-CV-01043)
  - v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)
  - v. TQ Delta LLC (Case No. 18-1798)
- Evapco Dry Cooling
  - v. SPG Dry Cooling (IPR2021-00688)
- Genetec
  - v. Sensormatic Electronics (Case No. 1:20-CV-00760)
- Huawei

v. Bell Northern Research LLC (IPR2019-01174)

- Kianxis

  v. Blue Yonder (Case No. 3:20-cv-03636)

- LG Electronics

  v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)

- Metaswitch

  v. Sonus Networks (IPR2018-01719)

- Microsoft

  v. Throughputer Inc (IPR2022-00757)

- Mom Enterprises

  v. Ddrops Company (Case No. 1:22-cv-00332)

- MLC Intellectual Property

  v. MicronTech (Case No. 3:14-cv-03657-SI)

- Nearmap Inc

  v. EagleView Technologies (IPR2022-01009)

- Neuroderm Ltd.

  v. Abbvie, Inc (Case No. PGR2022-00040)

- Realtek Semiconductor

v. Future Link (IPR2021-01182)

- Quectel
  - v. Koninklijke Philips (Case No. 1:20-cv-01710)

- Samsung
  - v. Aire Technology (IPR2022-00877)
  - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
  - v. Communication Technologies Inc (IPR2022-01221)
  - v. Jawbone Innovations (IPR2022-00865)
  - v. MemoryWeb LLC (IPR2022-00885)
  - v. Dodots Licensing Solutions (IPR2023-00701)
  - v. Telefonaktiebolaget LM Ericsson (IPR2021-00615)

- Texas Instruments
  - v. Vantage Micro LLC (IPR2020-01261)

- Xilinx
  - v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Irell & Manella

- Curium

O'Melveny & Myers

- Apple
  - v. Maxell (Case No. 5:19-cv-00036-RWS)

- Micron Technology Inc.

  v. Besang Inc (IPR2023-00900)

- Samsung

  v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Heru Industries

  v. The UAB Research Foundation (IPR2022-01148)

- Intel Corporation

  v. BitMICRO (Case No. 5:23-cv-00625)

- Realtek Semiconductor

  v. Future Link (IPR2021-01182)

- Twitter Inc

  v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)

- TCL Industries

  v. Koninklijke Philips NV (IPR2021-00495, IPR2021-00496 and IPR2021-00497)

Pillsbury Winthrop Shaw Pittman

- Intel

  v. FG SRC LLC (Case No. 6:20-cv-00315)

- Gravel Rating Systems

v. Costco (Case No. 4:21-cv-149)
v. Lowe's Home Centers (Case No. 4:21-cv-150)
v. T-Mobile USA (Case No. 4:21-cv-152)
v. Kohl's Inc. (Case No. 4:21-cv-258)
v. Under Armor (Case No. 4:21-cv-356)

Quinn Emanuel

- Wolfspeed

    v. The Trustees of Purdue University (Case No. 1:2021-cv-00840)

Stern, Kessler, Goldstein & Fox

- Preliminary Research

Sheppard, Mullin, Richter & Hampton LLP

- Cadence Design Systems Inc.

    v. Semiconductor Design Technologies (Case No. 3:23-cv-01001)

Appendix
GONZALEZ01

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100     1#$aGonzalez, Rafael C.
245     10$aDigital image processing / $cRafael C. Gonzalez, Richard E. Woods.
250     ##$a3rd ed.
260     ##$aUpper Saddle River, N.J. : $bPrentice Hall, $cc2008.
300     ##$axxii, 954 p. : $bill. (some col.) ; $c25 cm.
504     ##$aIncludes bibliographical references (p. 915-942) and index.
505     0#$aIntroduction -- Digital image fundamentals -- Intensity transformations and spatial filtering -- Filtering the frequency domain -- Image
520     ##$aCompletely self-contained-and heavily illustrated-this introduction to basic concepts and methodologies for digital image processing is w
650     #0$aImage processing $xDigital techniques.
650     17$aBeeldverwerking. $2gtt
650     17$aDigitale technieken. $2gtt
650     17$aComputers. $2gtt
650     #6$aTraitement d'images $xTechniques numériques.
650     07$aWahrscheinlichkeitsrechnung. $2swd
650     07$aInferenzstatistik. $2swd
650     07$aBildverarbeitung. $2swd
650     07$aData Mining. $2swd
650     07$aMustererkennung. $2swd
700     1#$aWoods, Richard E. $q(Richard Eugene), $d1954-
906     ##$aULS
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TOP
SEND TO
GET IT
DETAILS
VIRTUAL BROW...

MULTIPLE VERSIONS

Digital image processing

Gonzalez, Rafael C.; Woods, Richard E. (Richard Eugene), 1954-

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Available , General Collection ; TA1632 .G66 2008
(1 copy, 1 available, 0 requests)

Item in place
Loanable

Details

Title	Digital image processing
Creator	Gonzalez, Rafael C. >
Contributor	Woods, Richard E. (Richard Eugene), 1954- >
Language	English
Edition	3rd ed.
Publisher	Upper Saddle River, N.J. : Prentice Hall
Date	c2008
Type	Book
Description	xxii, 954 p. : ill. (some col.) ; 25 cm.
Notes	Includes bibliographical references (p. 915-942) and index.
Summary	Completely self-contained-and heavily illustrated-this introduction to basic concepts and methodologies for digital image processing is written at a level that truly is suitable for seniors and first-year graduate students in almost any technical discipline. The leading textbook in its field for more than twenty years, it continues its cutting-edge focus on contemporary developments in all mainstream areas of image processing-e.g., image fundamentals, image enhancement in the spatial and frequency domains, restoration, color image processing, wavelets, image compression, morphology, segmentation, image description, and the fundamentals of object recognition. It focuses on material that is fundamental and has a broad scope of application.

Related reading

Recommended items that are related to the record



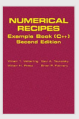
Introduction to algorithms
Cormen, Thomas H.
ISBN 9780262033848
suggested by



Computer graphics : ...
Hughes, John F.
ISBN 9780321399526
suggested by



Digital signal processing : ...
Proakis, John G.
ISBN 9780023968150
suggested by



Numerical recipes example ...
Vetterling, William T.
ISBN 9780521750349
suggested by

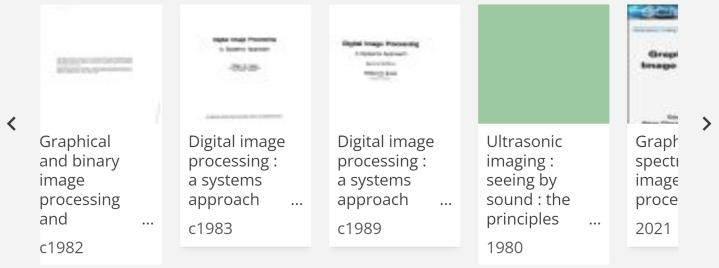


Discrete-time signal processing
Oppenheim, Alan V.
ISBN 9780137549207
suggested by

More

Contents	Introduction -- Digital image fundamentals -- Intensity transformations and spatial filtering -- Filtering the frequency domain -- Image restoration and reconstruction -- Color image processing -- Wavelets and multiresolution processing -- Image compression -- Morphological image processing -- Image segmentation -- Representation and description -- Object recongnition.
Subject	Image processing -- Digital techniques › Beeldverwerking › Digitale technieken › Computers › Traitement d'images -- Techniques numériques › Wahrscheinlichkeitsrechnung › Inferenzstatistik › Bildverarbeitung › Data Mining › Mustererkennung ›
Identifier	LC : 2009289249 OCLC : (OCoLC)ocn137312858 ISBN : 9780131687288 ISBN : 013168728X ISBN : 9780135052679 (pbk.) ISBN : 013505267X (pbk.)
Source	Library Catalog

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Reader Reviews | Also Available As | Tags
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SUMMARY

For courses in Image Processing and Computer Vision.
Completely self-contained--and heavily illustrated--this introduction to basic concepts and methodologies for digital image processing is written at a level that *truly* is suitable for seniors and first-year graduate students in almost any technical discipline. The leading textbook in its field for more than twenty years, it continues (read more)

ABOUT THE AUTHOR

Rafael C. Gonzalez

Rafael C. Gonzalez received the B.S.E.E. degree from the University of Miami in 1965 and the M.E. and Ph.D. degrees in electrical engineering from the University of Florida, Gainesville, in 1967 and 1970, respectively. He joined the Electrical and Computer Engineering Department at University of Tennessee, Knoxville (UTK) in 1970, where he became Associate Professor in 1973, Professor (read more)

More by Rafael C. Gonzalez



LOOK INSIDE

1 Introduction

What Is Digital Image Processing? The Origins of Digital Image Processing

Examples of Fields that Use Digital Image Processing

SEE FULL TABLE OF CONTENTS COVER

READER REVIEWS

★★★★★ Reviewed by one person **What do you think?** Write your own review

This is *the* best book on digital image processing I have ever read. It is the only book of its kind that I have ever read like a novel, spending one entire Christmas holiday curled up on the couch, devouring it. I like it because I can immediately turn its ideas into IDL code. That never really happened with the Russ book, for example.

Review by co_coyote (LibraryThing) ★★★★★

ALSO AVAILABLE AS



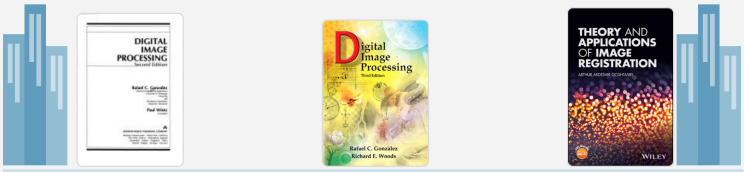
Paper Book

TAGS

images | wavelets | clinic | GIS | electrical | electronics | compression | informatica | optics | jacket | remote sensing | processing | digital imaging | calculus | image processing | imaging

BROWSE TAGS

BROWSE SHELF



TA1632 .G66 1987 TA1632 .G73 2021

SEE FULL SHELF

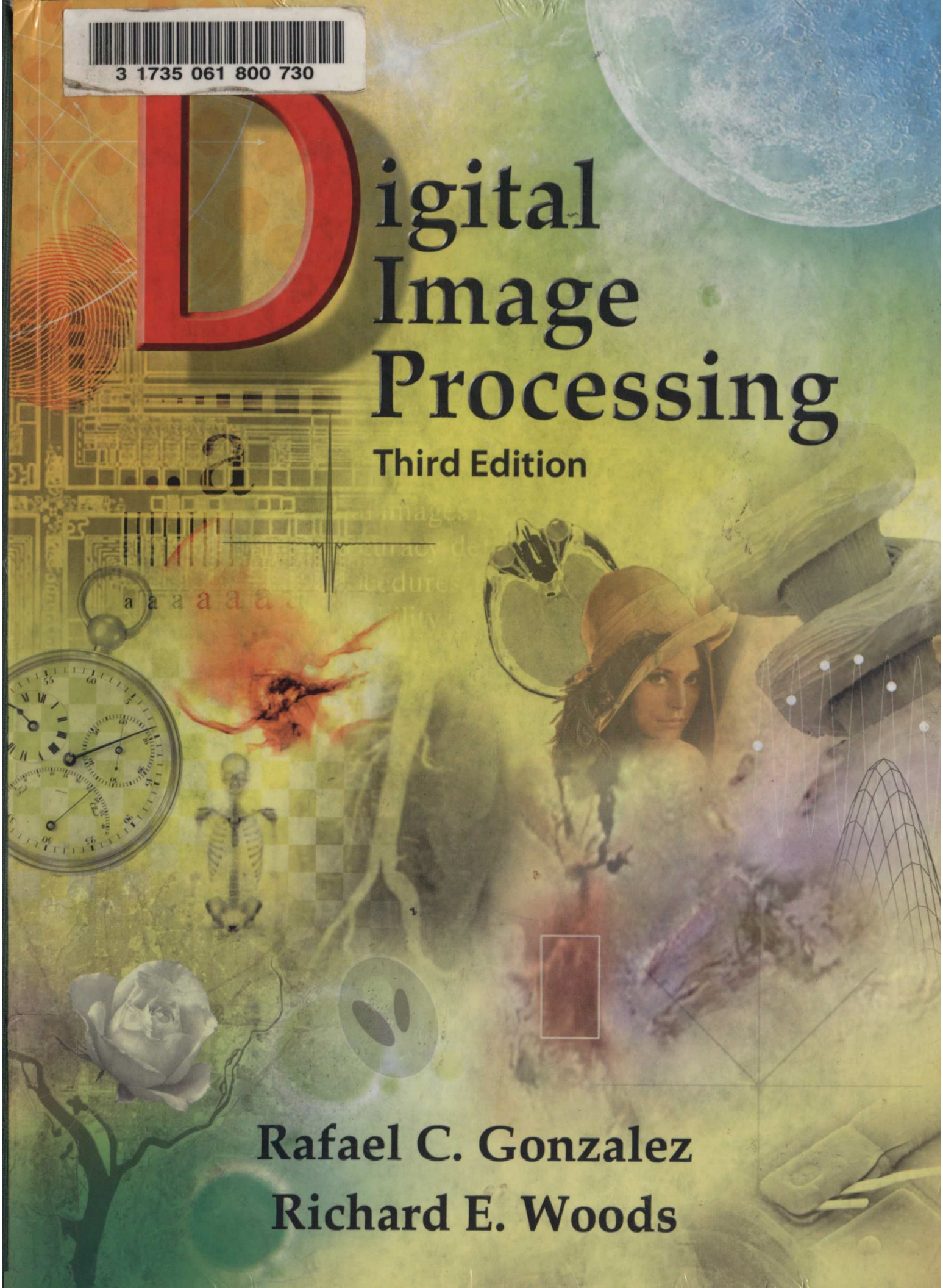
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Appendix
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Digital Image Processing

Third Edition



Rafael C. Gonzalez
Richard E. Woods

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Digital Image Processing

Third Edition

Rafael C. Gonzalez **Richard E. Woods**

Digital Image Processing has been the leading textbook in its field for more than thirty years. As the 1977 and 1987 editions by Gonzalez and Wintz, and the 1992 and 2002 editions by Gonzalez and Woods, the present edition was prepared with students and instructors in mind. The changes and upgrades resulting in this edition are based on a survey involving faculty, students, and independent readers of the book in 134 institutions from 32 countries. The new material is timely, highly readable, and illustrated with numerous examples of practical significance. Areas of image processing covered include intensity transformations and spatial filtering, the Fourier transform and filtering in the frequency domain, image enhancement, image restoration, computed tomography, fuzzy sets, color image processing, wavelets, image and video compression, morphological processing, image segmentation, and image description. Coverage concludes with a discussion on the fundamentals of object recognition.

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- A revision of introductory concepts that provides readers with foundation material much earlier in the book than before.
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Richard E. Woods

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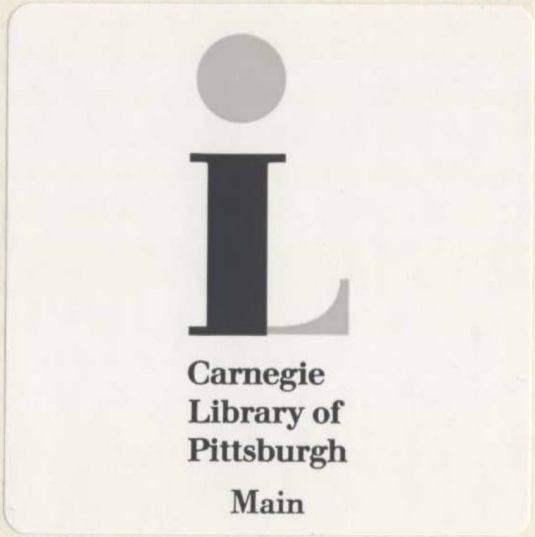
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SPECIAL ISSUE ON THE H.264/AVC VIDEO CODING STANDARD

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Adaptive Deblocking Filter

Peter List, Anthony Joch, Jani Lainema, Gisle Bjøntegaard, and Marta Karczewicz

***Abstract*—This paper describes the adaptive deblocking filter used in the H.264/MPEG-4 AVC video coding standard. The filter performs simple operations to detect and analyze artifacts on coded block boundaries and attenuates those by applying a selected filter.**

***Index Terms*—Block-based coding, video coding, video filtering, video signal processing.**

I. Introduction

THERE are two building blocks within the architecture of the H.264/MPEG-4 AVC video coding standard [1] which can be a source of blocking artifacts. The most significant one is the block-based integer discrete cosine transforms (DCTs) in intra and inter frame prediction error coding. Coarse quantization of the transform coefficients can cause visually disturbing discontinuities at the block boundaries [2]–[4]. The second source of blocking artifacts is motion compensated prediction. Motion compensated blocks are generated by copying interpolated pixel data from different locations of possibly different reference frames. Since there is almost never a perfect fit for this data, discontinuities on the edges of the copied blocks of data typically arise. Additionally, in the copying process, existing edge discontinuities in reference frames are carried into the interior of the block to be compensated. Although the small 4×4 sample transform size used in H.264/MPEG-4 AVC somewhat reduces the problem, a deblocking filter is still an advantageous tool to maximize coding performance.

There are two main approaches in integrating deblocking filters into video codecs. Deblocking filters can be used either as post filters or loop filters. Post filters only operate on the display buffer outside of the coding loop, and thus are not normative in the standardization process. Because their use is optional, post-filters offer maximum freedom for decoder implementations. On the contrary, loop filters operate within the coding loop. That is, the filtered frames are used as reference frames for motion compensation of subsequent coded frames. This forces all standard conformant decoders to perform identical filtering in order to stay in synchronization with the encoder. Naturally, a decoder can still perform post filtering in addition to the loop filtering if found necessary in a specific application.

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P. List is with Deutsche Telekom, T-Systems, 64295 Darmstadt, Germany (e-mail: Peter.List@t-systems.com).

A. Joch is with UB Video Inc., Vancouver, BC V6B 2R9, Canada (e-mail: anthony@ubvideo.com).

J. Lainema and M. Karczewicz are with the Nokia Research Center, Irving, TX 75039 USA (e-mail: jani.lainema@nokia.com; marta.karczewicz@nokia.com).

G. Bjøntegaard is with TANDBERG, N-1324 Lysaker, Norway (e-mail: gbj@tandberg.no).

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Performing the filtering inside the coding loop has several advantages over post filtering. Firstly, the requirement of a loop filter *guarantees* a certain level of quality. This is especially important in modern communications systems where decoders of several manufacturers are used to decode distributed video material. With a loop filter in the codec design, content providers can safely assume that their material is processed by proper deblocking filters, guaranteeing the quality level expected by the producer.

Secondly, there is no need for an extra frame buffer in the decoder. In the post-filtering approach, the frame is typically decoded into a reference frame buffer. An additional frame buffer may be needed to store the filtered frame to be passed to the display device. In the loop-filtering approach, however, filtering can be carried out macroblock-wise during the decoding process, and the filtered output stored directly to the reference frame buffers.

Thirdly, empirical tests have shown that loop filtering typically improves both objective and subjective quality of video streams with significant reduction in decoder complexity compared to post filtering [3], [5]. Quality improvements are mainly due to the fact that filtered reference frames offer higher quality prediction for motion compensation. Reductions in computational complexity can be achieved by taking into account the fact that the image area in past frames is already filtered, and thereby optimizing the filtering process accordingly. Fig. 1 shows the reconstructed frame in a loop-filter (left) and a post-filter (right) based TML 8.5[1] system before loop/post filtering. It can be seen that the main coding artifact in the loop-filter case is the blockiness on the 4×4 grid caused by prediction error coding. This artifact can be efficiently compensated by the deblocking filter described in this paper. In the post-filter case, the blockiness does not follow the grid boundaries but is spread inside the 4×4 blocks due to blocky reference images that were used for motion compensation [4]. This additionally results in an increased amount of residual coding to remove artificially created high frequency edges and possible ringing effects at low bit rates.

Despite all of these advantages, the requirement of a normative loop filter was extensively debated during the development of the H.264/MPEG-4 AVC standard. A critical factor in the debate was the comparatively high complexity of the loop filter. Even after a tremendous effort in speed optimization of the filtering algorithms, the filter can easily account for one-third of the computational complexity of a decoder. This is true even

[1]While this paper describes the deblocking filter design in the final draft of the H.264/MPEG-4 AVC standard [1], results and figures have been generated using the TML 8.5 software, which corresponds to an earlier draft specification [6]. Some parts of the deblocking filter design have been modified in the interim between these drafts (primarily for complexity reduction). However, the major properties and the performance of the filter have remained unchanged.

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(a) (b)

Fig. 1. Detail of luminance input to the deblocking filter in the case of (a) loop-filtering and (b) post-filtering based system.

though the loop filter can be implemented without any multiplication or division operations.

The complexity is mainly based on the high adaptivity of the filter, which requires conditional processing on the block edge and sample levels. As a consequence, conditional branches almost inevitably appear in the inner most loops of the algorithm. These are known to be very time consuming and are also quite a challenge for parallel processing in DSP hardware or SIMD code on general-purpose processors.

Another reason for the high complexity is the small block size employed for residual coding in the H.264 coding algorithm. With the 4×4 blocks and a typical filter length of 2 samples in each direction, almost every sample in a picture must be loaded from memory, either to be modified or to determine if neighboring samples will be modified. This was not the case for the H.263 loop filter or any MPEG-4/H.263 post filters, which operate on an 8×8 block structure.

In Sections II–IV, we provide an overview of the design of the H.264/MPEG-4 AVC adaptive deblocking filter. For a complete and detailed description of the filtering process, see [1]. Further information on the evolution of the filter design is available in the many contributions to the H.264/MPEG-4 AVC standardization effort that influenced the final filter design, including [7]–[19].

II. Boundary Analysis

A. Error Distribution in a 4×4 Block

When using a block transform for residual coding, it is well known that the coding errors are larger near the block boundaries than in the middle of the block. The numbers below show an example of the square error distribution over a 4×4 block

122	107	106	111
103	102	101	112
106	100	98	108
118	105	106	120

A heuristic argument for this effect is that an interior sample has several surrounding samples which add "weight" to a good reconstruction—whereas an edge sample has less such weight and thereby obtains a poorer reconstruction. As a result of this uneven error distribution, there is a potential for *objective* quality improvement by block edge filtering. This potential was kept in mind when designing the filter.

The H.264/MPEG-4 AVC deblocking filter is adaptive on several levels.

TABLE I
Filter Strength Parameter as a Function of Coding Mode

Block modes and conditions	Bs
One of the blocks is Intra *and* the edge is a macroblock edge	4
One of the blocks is Intra	3
One of the blocks has coded residuals	2
Difference of block motion $\geq$ 1 luma sample distance	1
Motion compensation from different reference frames	1
Else	0

- On the slice level, the global filtering strength can be adjusted to the individual characteristics of the video sequence.
- On the block-edge level, filtering strength is made dependent on the inter/intra prediction decision, motion differences, and the presence of coded residuals in the two participating blocks. Special strong filtering is applied for macroblocks with very flat characteristics to remove "tiling artifacts".
- On the sample level, sample values and quantizer-dependent thresholds can turn off filtering for each individual sample.

Sections II-B and II-C describe in detail how this adaptivity is designed into the H.264/MPEG-4 AVC deblocking filter.

B. Edge Level Adaptivity of the Filter

To every edge between two 4×4 luminance sample blocks, a *Boundary-Strength* (Bs) parameter is assigned an integer value from 0 to 4. Table I shows how the value of Bs depends on the modes and coding conditions of the two adjacent blocks. In this table, conditions are evaluated from top to bottom, until one of the conditions holds true, and the corresponding value is assigned to Bs.

In the actual filtering algorithm, Bs determines the strength of the filtering performed on the edge, including a selection between the two primary filtering modes. A value of 4 means a special mode of the filter is applied, which allows for the strongest filtering, whereas a value of 0 means no filtering is applied on this specific edge. In the standard mode of filtering which is applied for edges with Bs from 1 to 3, the value of Bs affects the maximum modification of the sample values that can be caused by filtering. The gradation of Bs reflects that the strongest blocking artifacts are mainly due to intra and prediction error coding and are to a somewhat smaller extent caused by block motion compensation.

The Bs values for filtering of chrominance block edges are not calculated independently, but instead copied from the values calculated for their corresponding luminance edges.

In the case of macroblock adaptive frame/field coding (MBAFF), the conditions in Table I get somewhat more complex because any of the two adjacent blocks might belong to a frame- or a field-coded macroblock. The principle of varying filter strength remains the same in any case. To avoid excessive blurring, special consideration is made to prevent very strong

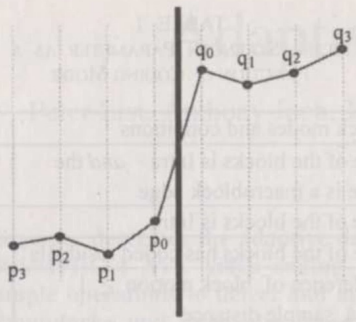


Fig. 2. One-dimensional visualization of a block edge in a typical situation where the filter would be turned on.

filtering of horizontal edges of field-coded macroblocks, since the spatial extent of the vertical filtering is doubled for such macroblocks.

C. Sample-Level Adaptivity of the Filter

In deblocking filtering, it is crucially important to be able to distinguish between true edges in the image and those created by quantization of the DCT coefficients. To preserve image sharpness, the true edges should be left unfiltered as much as possible while filtering artificial edges to reduce their visibility.

In order to separate these two cases, the sample values across every edge to be filtered are analyzed. Let us denote one line of sample values inside two neighboring 4×4 blocks by $p_3, p_2, p_1, p_0, q_0, q_1, q_2, q_3$, with the actual boundary between p_0 and q_0, as shown in Fig. 2. Up to three sample values for luminance and one for chrominance on each side of the edge may be modified by the filtering process.

As stated in Section II-B, filtering does not take place for edges with Bs equal to zero. For edges with nonzero Bs values, a pair of quantization-dependent parameters, referred to as α and β, are used in the content activity check that determines whether each set of samples is filtered. Filtering on a line of samples only takes place if the three conditions

$$|p_0 - q_0| < \alpha(\text{Index}_A) \quad (1)$$

$$|p_1 - p_0| < \beta(\text{Index}_B) \quad (2)$$

$$|q_1 - q_0| < \beta(\text{Index}_B) \quad (3)$$

all hold. In these conditions, both table-derived thresholds α and β are dependant on the average quantization parameter (QP) employed over the edge, as well as encoder selected offset values that can be used to control the properties of the deblocking filter on the slice level. These table index values are calculated as

$$\text{Index}_A = \text{Min}(\text{Max}(0, \text{QP} + \text{Offset}_A), 51) \quad (4)$$

$$\text{Index}_B = \text{Min}(\text{Max}(0, \text{QP} + \text{Offset}_B), 51) \quad (5)$$

where 0–51 represents the range of valid QP values.

The values of α and β are defined approximately according to the following relationships:

$$\alpha(x) = 0.8(2^{x/6} - 1) \quad (6)$$

$$\beta(x) = 0.5x - 7. \quad (7)$$

Thus, in general, $\beta(x)$ is considerably smaller than $\alpha(x)$. To define the actual tables, variations from this basic relationship have been made based on empirical tests to produce visually pleasing results for a variety of content. In particular, at the low end of the table, values are clipped to zero so that for values of $\text{Index}_A < 16$ or $\text{Index}_B < 16$, one or both of α and β become 0 and filtering is effectively turned off.

The dependency of α and β on QP links the strength of filtering to the general quality of the reconstructed picture prior to filtering. Since the thresholds values increase with QP, boundaries that contain higher content activity are filtered when QP is larger, since the coding error (size of artifacts) increases with QP. The exponential nature of α reflects the dependency on QP of the size of an expected blocking artifact, since the quantization step size doubles every time QP is increased by 6.

D. Slice-Level Adaptivity of the Filter

On the slice level, encoder-selectable offsets—referred to as Offset_A and Offset_B—may be used to adjust the values of α and β used in filtering and thereby increase or decrease the amount of filtering that takes place compared to filtering with the default zero offsets. The offset values are transmitted in the slice header syntax and are applied to the QP-based addressing of the α and β tables.

The ability to control the properties of deblocking filter by transmitting nonzero offsets provides the encoder designer with the ability to optimize the subjective quality of the decoded video beyond that provided by use of the default tables. For example, reducing the amount of filtering by transmitting negative offsets can help to maintain the sharpness of small spatial details, particularly with high-resolution video content, in which small blocking artifacts tend to be less apparent. On the other hand, using positive offsets to increase the amount of filtering can improve subjective quality on content where visible blocking artifacts remain if the default values are used. This is beneficial for lower resolution content with smooth brightness transitions and to remove additional artifacts that might be introduced by sub-optimal motion estimation, mode decisions, or residual coding.

III. Filtering

A. Overview of Filtering Operations

In order to ensure a perfect match in the filtering process between encoders and decoders, filtering operations must be conducted in a specific order throughout each coded picture. Filtering is conducted "in-place," so that the modified sample values after featuring each line of samples across an edge are used as input values to subsequent operations.

Filtering occurs on a macroblock basis, with horizontal filtering of the vertical edges performed first, followed by vertical filtering (of the horizontal edges). Both directions of filtering on each macroblock must be conducted before moving on to the next macroblock. The macroblocks are filtered in raster-scan order throughout the picture. For MBAFF coded frames, in which pairs of vertically adjacent macroblocks are grouped together, the filtering order is based on these macroblock pairs, with the pairs being filtered in raster-scan order throughout the frame, and the top macroblocks being filtered first within each pair.

For each luminance macroblock, the left-most edge of the macroblock is filtered first, followed from left to right by the three vertical edges that are internal to the macroblock. Similarly, the top edge of the macroblock is filtered first in the horizontal filtering pass, followed by the three internal horizontal edges from top to bottom. Chrominance filtering follows a similar order, with one external edge and one internal edge in each direction for each 8×8 chrominance macroblock.

Two filtering modes are defined and are selected based on the Bs parameter for a set of samples. A special mode of filtering that allows for stronger filtering is applied when Bs is equal to 4; the more common mode of filtering is applied otherwise (Bs = 1, 2, or 3).

For both filtering modes, the β threshold value is used to evaluate two additional spatial activity conditions that are used to determine the extent of the filtering in the case of luminance samples

$$|p_2 - p_0| < \beta(\text{Index}_B) \tag{8}$$

$$|q_2 - q_0| < \beta(\text{Index}_B). \tag{9}$$

When these conditions hold true, which occurs in the case of small changes in intensity on either side of the edge, the strength of the filtering is greater.

B. Filtering for Edges With Bs From 1 to 3

For clarity, the filter operations are divided into basic filter operation and clipping.

1) Basic Filter Operation: We first describe the basic filtering operation for luminance. In this mode of filtering, the filtered values p_0' and q_0' are calculated as

$$p_0' = p_0 + \Delta_0 \text{ and} \tag{10}$$

$$q_0' = q_0 - \Delta_0 \tag{11}$$

where the value of Δ_0 is calculated in a two-step process, with the calculation of an initial Δ_{0i} value, followed by clipping of this value before it is applied in the above equations.

The initial value, Δ_{0i} is computed based on the sample values across the edge

$$\Delta_{0i} = (4(q_0 - p_0) + (p_1 - q_1) + 4) \gg 3. \tag{12}$$

The impulse response of these operations for calculating p_0' is $(1, 4, 4, -1)/8$.

The values of p_1 and q_1 are only modified if the corresponding condition (8) or (9) is true. Otherwise, the values are not modified. That is, if condition (8) is true, then the filtered value of p_1' is calculated as

$$p_1' = p_1 + \Delta_{p1}. \tag{13}$$

Similarly, if condition (9) is true, the filtered value of q_1' is calculated as

$$q_1' = q_1 + \Delta_{q1}. \tag{14}$$

These values are also calculated in a two-step process. The initial Δ value for computing p_1' is computed as

$$\Delta_{p1i} = (p_2 + ((p_0 + q_0 + 1) \gg 1) - 2p_1) \gg 1. \tag{15}$$

The value Δ_{q1i} is obtained accordingly, substituting q_2 and q_1 for p_2 and p_1, respectively. The corresponding impulse response $(1, 0, 0.5, 0.5)/2$ has a very strong low-pass characteristic.

2) Clipping: If these intermediate values Δ_{0i}, Δ_{p1i}, and Δ_{q1i} were used directly in the filtering equations, it would result in far too much low-pass filtering (blurring). A significant part of the adaptivity of the filter is obtained by limiting these Δ values. This process is called clipping. Different procedures for clipping are applied for the interior and edge samples.

The Δ values that are used in filtering the interior samples are clipped the range $-c_1$ to c_1, where c_1 is a parameter that is determined based on a table that is indexed in two dimensions, with the value of Index_A as computed for determining α used in one dimension, and the Bs value used in the other. The value of c_1 increases allowing stronger filtering, as the values of Index_A and Bs increase. The final clipping values for filtering of p_1 and q_1 are calculated as

$$\Delta_{p1} = \text{Min}(\text{Max}(-c_1, \Delta_{p1i}), c_1) \tag{16}$$

$$\Delta_{q1} = \text{Min}(\text{Max}(-c_1, \Delta_{q1i}), c_1). \tag{17}$$

For filtering of the edge samples p_0 and q_0, the clipping range that is applied to Δ_{0i} is determined based on the value of c_1 and the evaluation of the conditions (8) and (9). The clipping value c_0 is first set equal to c_1, and then incremented by 1 for each of conditions (8) and (9) that holds true. Then, the amount of modification that will be applied to each of the edge samples is computed as

$$\Delta_0 = \text{Min}(\text{Max}(-c_0, \Delta_{0i}), c_0). \tag{18}$$

Thus, stronger filtering is applied to the edge samples when the changes in intensity on each side of the edge are smaller than the β threshold (and the p_1 and/or q_1 sample values were also modified).

For chrominance filtering, only the p_0 and q_0 values may be modified. These are filtered in the same way as for luminance, except that the clipping value, c_0 is set equal to c_1 plus 1. In this way, there is no need to evaluate conditions (8) and (9) for chrominance on edges with Bs less than 4, and therefore no need to access sample values p_2 and q_2.

C. Filtering for Edges With Bs Equal to 4

Intra coding in H.264/MPEG-4 AVC tends to use 16×16 luma sample prediction modes when coding nearly uniform image areas. This causes small amplitude blocking artifacts at the macroblock boundaries. However, due to the Mach band effect [20], even very small differences in the intensity values are perceived as abrupt steps in these cases. To compensate for this tiling effect, stronger filtering is applied on boundaries between two macroblocks with smooth image content.

For luminance filtering, a decision is made based on the image content between a very strong 4- and 5-tap filter that modifies the edge sample and two interior samples on each side, or a weaker 3-tap filter modifies only to the edge sample. The stronger filter is only applied when the following constraint on the difference across the edge holds true:

$$|p_0 - q_0| < (a \gg 2) + 2. \tag{19}$$

TABLE II
AVERAGE BIT RATE SAVINGS FOR ALIGNED PSNRS OBTAINED WITH TML 8.5 LOOP FILTER

Sequence	Type	Bitrate saving [%]
Container	10 Hz, QCIF	8.9
Foreman	10 Hz, QCIF	4.8
News	10 Hz, QCIF	8.1
Silent Voice	15 Hz, QCIF	9.4
Paris	15 Hz, CIF	7.6
Foreman	15 Hz, CIF	6.9

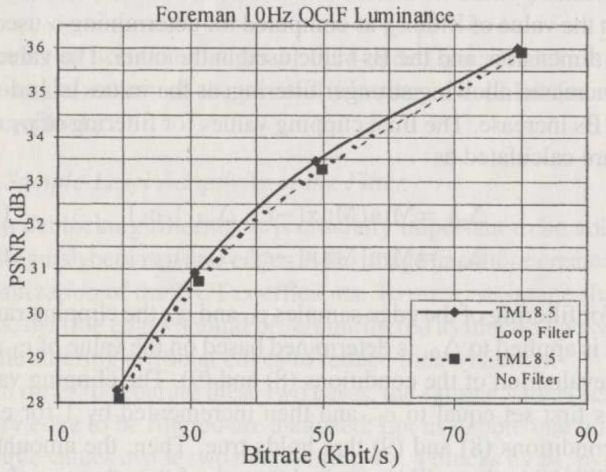


Fig. 3. Luminance PSNR curve for Foreman with and without a loop filter in TML 8.5.

Notice that (19) is a similar condition to (1), with a tighter constraint on the maximum sample value difference across the edge.

For luminance filtering, when the smoothness conditions (8) and (19) hold true, the filtered values are calculated according to the following equations:

$$p_0' = (p_2 + 2p_1 + 2p_0 + 2q_0 + q_1 + 4) \gg 3 \quad (20)$$

$$p_1' = (p_2 + p_1 + p_0 + q_0 + 2) \gg 2 \quad (21)$$

$$p_2' = (2p_3 + 3p_2 + p_1 + p_0 + q_0 + 4) \gg 3. \quad (22)$$

Otherwise, for chrominance filtering, or if either (8) or (19) is false, only p_0 is modified according to the following equation:

$$p_0' = (2p_1 + p_0 + q_1 + 2) \gg 2 \quad (23)$$

and p_1 and p_2 are left unchanged.

The q values are modified in a similar manner, substituting condition (9) for condition (8) when selecting the filter for luminance.

IV. RESULTS

Table II lists examples of bitrate savings on aligned luminance and chrominance PSNRs [21], [22] achieved with the TML 8.5 loop filter against the same H.264/MPEG-4 AVC codec without a deblocking filter.

More specific PSNR curves for Foreman and Silent Voice sequences are given in Figs. 3–6. Even more remarkable are the improvements in subjective picture quality illustrated in Figs. 7 and 8, which compare loop-filter output images to unfiltered output images at two different bit rates and resolutions.

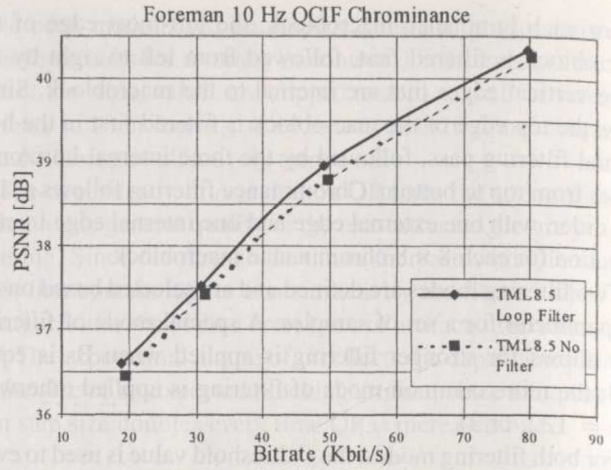


Fig. 4. Chrominance PSNR curve for Foreman with and without a loop filter in TML 8.5.

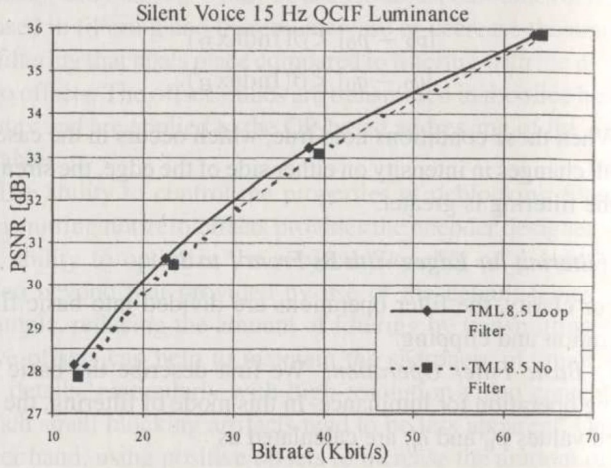


Fig. 5. Luminance PSNR curve for Silent Voice with and without a loop filter in TML 8.5.

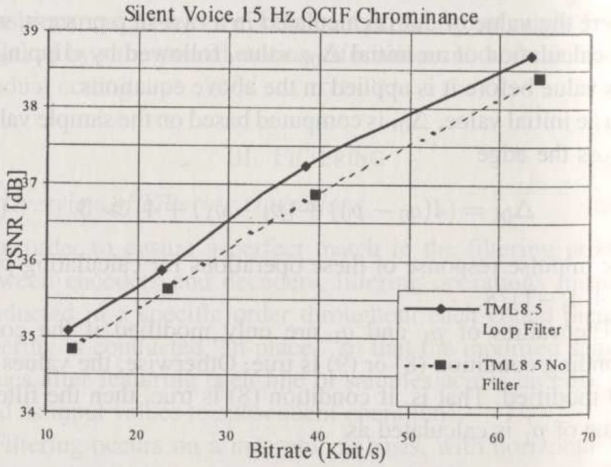
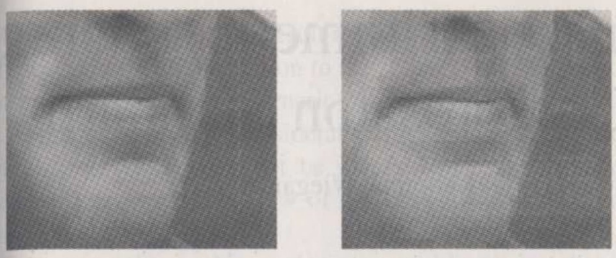


Fig. 6. Chrominance PSNR curve for Silent Voice with and without a loop filter in TML 8.5.

V. CONCLUSIONS

The adaptive deblocking filter described in this paper achieves substantial objective and subjective quality im-



(a) (b)

Fig. 7. Detail of the luminance output in the case of (a) loop filtering and (b) no filtering. CIF sequence was coded at 200 kbps and 15 fps.



(a) (b)

Fig. 8. Detail of the luminance output in the case of (a) loop filtering and (b) no filtering. QCIF sequence was coded at 30 kbps and 10 fps.

provements with a reasonably simple algorithm. The good performance is based on reliable detection of real and artificially created edges and efficient filtering of the latter ones. Bit-rate savings exceeding 9% are observed with equal PSNR levels together with significantly improved visual quality.

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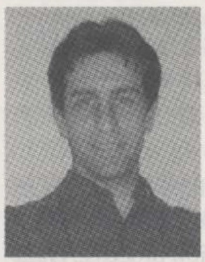
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Peter List was born in 1957. He graduated in physics in 1985 and received the Ph.D. degree in applied physics in 1989, both from the University of Frankfurt/Main, Germany.

He is project manager at T-Systems Nova, Darmstadt, Germany, a reserach and development company of Deutsche Telekom. Since 1990, he has been with Deutsche Telekom, and has actively followed the international standardization of video compression in ISO, ITU, and several European projects for more than ten years.



Anthony Joch received the B.Eng. degree in computer engineering from McMaster University, Hamilton, ON, Canada, in 1999, and the M.A.Sc. degree in electrical engineering from the University of British Columbia, Vancouver, BC, Canada, in 2002.

In 2000, he joined UB Video Inc., Vancouver, BC, where he is currently a Senior Engineer involved in the development of software codecs for the H.264/MPEG-4 AVC standard. His research interests include reduced-complexity algorithms for video encoding, video pre- and post-processing, and multimedia systems. He has been an active contributor to the H.264/MPEG-4 AVC standardization effort, particularly in the area of deblocking filtering and as a co-chair of the ad-hoc group for bitstream exchange.

Jani Lainema received the M.Sc. degree in computer engineering from Tampere University of Technology, Tampere, Finland, in 1996.

He joined the Visual Communications Laboratory of Nokia Research Center, Irving, TX, in 1996, where he is currently a Project Manager and Senior Research Scientist. His research interests include video, image and graphics coding and communications.

Gisle Bjøntegaard received the Dr. Phil.degree in physics from the University of Oslo, Oslo, Norway, in 1974.

From 1974 to 1996, he was a Senior Scientist with Telenor Research and Development, Oslo, Norway. His areas of research included radio link network design, reflector antenna design and construction, digital signal procession, and development of video compression methods. From 1996 to 2002, he was a Group Manager at Telenor Broadband Services, Oslo, Norway, where his areas of work included the design of point-to-point satellite communication and development of satellite digital TV platform. Since 2002, he has been a Principal Scientist at Tandberg Telecom, Lysaker, Norway, working with video-coding development and implementation. He has contributed actively to the development of the ITU video standards H.261, H.262, H.263, and H.264, as well as to ISO/IEC MPEG2 and MPEG4.

Marta Karczewicz received the M.S. degree in electrical engineering in 1994 and Dr. Technol. degree in 1997, both from Tampere University of Technology, Tampere, Finland.

During 1994–1996, she was Researcher in the Signal Processing Laboratory, Tampere University of Technology. Since 1996, she has been with the Visual Communication Laboratory, Nokia Research Center, Iriving, TX, where she is currently a Senior Research Manager. Her research interests include image compression, communication and computer graphics.

Appendix
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Abstract:
This paper describes the adaptive deblocking filter used in the H.264/MPEG-4 AVC video coding standard. The filter performs simple operations to detect and analyze artifacts on coded block boundaries and attenuates those by applying a selected filter.

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Contents

I. Introduction
There are two building blocks within the architecture of the H.264/MPEG-4 AVC video coding standard [1] which can be a source of blocking artifacts. The most significant one is the block-based integer discrete cosine transforms (DCTs) in intra and inter frame prediction error coding. Coarse quantization of the transform coefficients can cause visually disturbing discontinuities at the block boundaries [2]–[4]. The second source of blocking artifacts is motion compensated prediction.

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Motion compensated blocks are generated by copying interpolated pixel data from different locations of possibly different reference frames. Since there is almost never a perfect fit for this data, discontinuities on the edges of the copied blocks of data typically arise. Additionally, in the copying process, existing edge discontinuities in reference frames are carried into the interior of the block to be compensated. Although the small 4×4 sample transform size used in H.264/MPEG-4 AVC somewhat reduces the problem, a deblocking filter is still an advantageous tool to maximize coding performance.

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