

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. 9,641,841

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 Pittsburgh 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 Pittsburgh 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

A handwritten signature in black ink, appearing to read 'June Ann Munford', with a stylized flourish at the end.

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

- Wolfsped
 - 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

```

leader 02770cam a2200517 a 4500
001 9962615733406236
005 20130215194539.0
008 090609s2008 njua b 001 0 eng
010 ##$a 2009289249
035 ##$a(OCOLC)ocn137312858
035 ##$a6261573
035 ##$a(ppiu)6261573-pittdb
035 ##$a(pittdb)6261573-pittdb
040 ##$aDLC $beng $cDLC $dUKM $dBTCTA $dBAKER $dTXA $dYDXCP $dUMC $dNLGGC $dVP@ $dCDX $dU9S $dYHM $dHEBIS $dIL4I7 $dDEBBG $dOCL
015 ##$aGBA740765 $2bnb
015 ##$aGBA897139 $2bnb
016 7#$a013755574 $2Uk
016 7#$a014686701 $2Uk
020 ##$a9780131687288
020 ##$a013168728X
020 ##$a9780135052679 (pbk.)
020 ##$a013505267X (pbk.)
050 00$aTA1632 $b.G66 2008
082 00$a621.36/7 $222
084 ##$a54.74 $2bcl
084 ##$aDAT 760f $2stub
084 ##$aST 330 $2rvk
084 ##$aZN 6050 $2rvk
049 ##$aPITT
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 v
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

```



Search anything

Books, Articles, and More



ADVANCED SEARCH



MULTIPLE VERSIONS

Digital image processing

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

Available at Science and Engineering Library (Benedum Hall) General Collection (TA1632 .G66 2008) >

Report a Problem

5 versions found. See all versions >

TOP

SEND TO

GET IT

DETAILS

VIRTUAL BROW...

Send to



CITATION



EMAIL



ENDNOTE/ZOTER



PRINT



PERMALINK

Get It

Please sign in to check if there are any request options. Sign in

BACK TO LOCATIONS

LOCATION ITEMS

Science and Engineering Library (Benedum Hall)

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



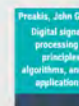
Introduction to algorithms

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



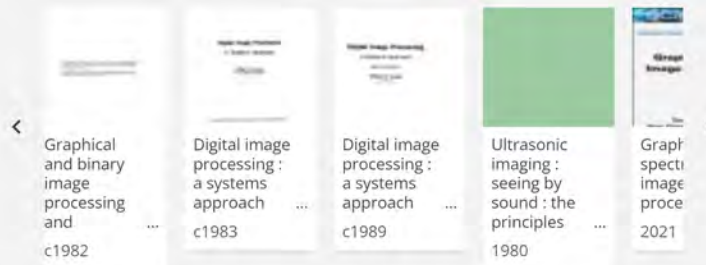
Discrete-time signal processing

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 recognition.
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

Virtual Browse



Links

Find this Item in Google Books [🔗](#) >
Display Source Record [🔗](#) >

Syndetics Unbound

Summary About The Author Look Inside
Reader Reviews Also Available As Tags
Browse Shelf

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

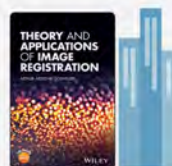


[BROWSE TAGS](#)

BROWSE SHELF



TA1632 .G66 1987



TA1632 .G73 2021

[SEE FULL SHELF](#)

Appendix
GONZALEZ02



3 1735 061 800 730



igital Image Processing

Third Edition

Rafael C. Gonzalez
Richard E. Woods

**Gonzalez
Woods**



**igital
Image Processing**

**Third
Edition**

ENG
TA1632
G66
2008

8359300344



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.

New Features

- A revision of introductory concepts that provides readers with foundation material much earlier in the book than before.
- A revised and updated discussion of intensity transformation, spatial correlation, convolution, and their application to spatial filtering.
- New discussion of fuzzy sets and their application to image processing.
- A new chapter on the discrete Fourier transform and frequency domain processing.
- New coverage of computerized tomography.
- A major revision of the wavelets chapter.
- A new chapter on data compression, including new compression techniques, digital video compression, standards, and watermarking.
- New coverage of morphological reconstruction, gray-scale morphology, and advanced morphological algorithms.
- New coverage of the Marr-Hildreth and Canny edge detection algorithms.
- Expanded coverage of image thresholding.
- New examples and illustrations involving over 400 new images and more than 200 new drawings and tables.
- Expanded homework sets, including over 80 new problems.
- Updated bibliography.

Book Web Site: www.prenhall.com/gonzalezwoods

Although the book is completely self-contained, a newly redesigned companion web site provides additional support in the form of review material, answers to selected problems, laboratory project suggestions, classroom presentation slides, tutorials, and a score of other features. An Instructor's Manual is available to instructors who have adopted the book for classroom use.

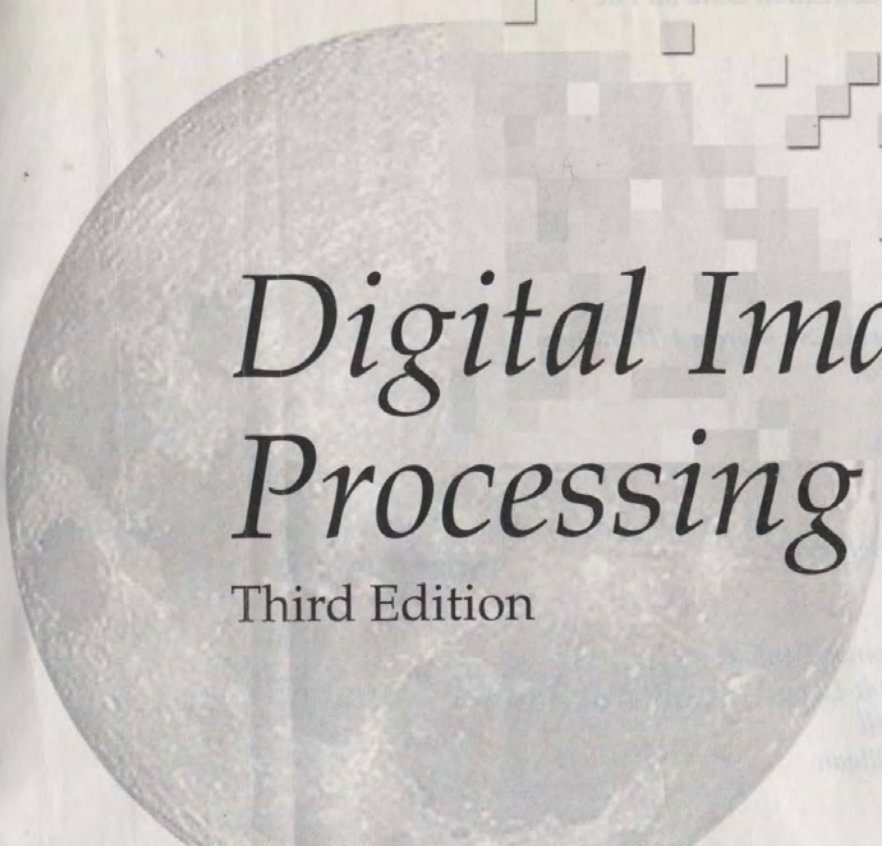
PEARSON

Prentice
HallUpper Saddle River, New Jersey 07458
www.prenhall.comISBN-13: 978-0-13-168728-8
ISBN-10: 0-13-168728-X

UNIVERSITY
OF PITTSBURGH
LIBRARIES



THIS BOOK PRESENTED BY



Digital Image Processing

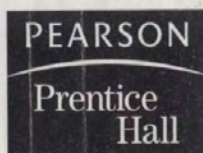
Third Edition

Rafael C. Gonzalez

University of Tennessee

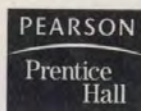
Richard E. Woods

MedData Interactive



Upper Saddle River, NJ 07458

Vice President and Editorial Director, ECS: *Marcia J. Horton*
Executive Editor: *Michael McDonald*
Associate Editor: *Alice Dworkin*
Editorial Assistant: *William Opaluch*
Managing Editor: *Scott Disanno*
Production Editor: *Rose Kernan*
Director of Creative Services: *Paul Belfanti*
Creative Director: *Juan Lopez*
Art Director: *Heather Scott*
Art Editors: *Gregory Dulles* and *Thomas Benfatti*
Manufacturing Manager: *Alexis Heydt-Long*
Manufacturing Buyer: *Lisa McDowell*
Senior Marketing Manager: *Tim Galligan*



© 2008 by Pearson Education, Inc.
Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form, or by any means, without permission in writing from the publisher.

Pearson Prentice Hall® is a trademark of Pearson Education, Inc.

The authors and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The authors and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The authors and publisher shall not be liable in any event for incidental or consequential damages with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America.

10 9 8 7 6 5 4

ISBN 0-13-168728-x
978-0-13-168728-8

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte., Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
Pearson Educación de México, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd.
Pearson Education, Inc., *Upper Saddle River, New Jersey*

Contents

<i>Preface</i>	<i>xv</i>
<i>Acknowledgments</i>	<i>xix</i>
<i>The Book Web Site</i>	<i>xx</i>
<i>About the Authors</i>	<i>xxi</i>

1 Introduction 1

1.1	What Is Digital Image Processing?	1
1.2	The Origins of Digital Image Processing	3
1.3	Examples of Fields that Use Digital Image Processing	7
1.3.1	Gamma-Ray Imaging	8
1.3.2	X-Ray Imaging	9
1.3.3	Imaging in the Ultraviolet Band	11
1.3.4	Imaging in the Visible and Infrared Bands	12
1.3.5	Imaging in the Microwave Band	18
1.3.6	Imaging in the Radio Band	20
1.3.7	Examples in which Other Imaging Modalities Are Used	20
1.4	Fundamental Steps in Digital Image Processing	25
1.5	Components of an Image Processing System	28
	Summary	31
	References and Further Reading	31

2 Digital Image Fundamentals 35

2.1	Elements of Visual Perception	36
2.1.1	Structure of the Human Eye	36
2.1.2	Image Formation in the Eye	38
2.1.3	Brightness Adaptation and Discrimination	39
2.2	Light and the Electromagnetic Spectrum	43
2.3	Image Sensing and Acquisition	46
2.3.1	Image Acquisition Using a Single Sensor	48
2.3.2	Image Acquisition Using Sensor Strips	48
2.3.3	Image Acquisition Using Sensor Arrays	50
2.3.4	A Simple Image Formation Model	50
2.4	Image Sampling and Quantization	52
2.4.1	Basic Concepts in Sampling and Quantization	52
2.4.2	Representing Digital Images	55
2.4.3	Spatial and Intensity Resolution	59
2.4.4	Image Interpolation	65

2.5	Some Basic Relationships between Pixels	68
2.5.1	Neighbors of a Pixel	68
2.5.2	Adjacency, Connectivity, Regions, and Boundaries	68
2.5.3	Distance Measures	71
2.6	An Introduction to the Mathematical Tools Used in Digital Image Processing	72
2.6.1	Array versus Matrix Operations	72
2.6.2	Linear versus Nonlinear Operations	73
2.6.3	Arithmetic Operations	74
2.6.4	Set and Logical Operations	80
2.6.5	Spatial Operations	85
2.6.6	Vector and Matrix Operations	92
2.6.7	Image Transforms	93
2.6.8	Probabilistic Methods	96
	Summary	98
	References and Further Reading	98
	Problems	99
3	<i>Intensity Transformations and Spatial Filtering</i>	104
3.1	Background	105
3.1.1	The Basics of Intensity Transformations and Spatial Filtering	105
3.1.2	About the Examples in This Chapter	107
3.2	Some Basic Intensity Transformation Functions	107
3.2.1	Image Negatives	108
3.2.2	Log Transformations	109
3.2.3	Power-Law (Gamma) Transformations	110
3.2.4	Piecewise-Linear Transformation Functions	115
3.3	Histogram Processing	120
3.3.1	Histogram Equalization	122
3.3.2	Histogram Matching (Specification)	128
3.3.3	Local Histogram Processing	139
3.3.4	Using Histogram Statistics for Image Enhancement	139
3.4	Fundamentals of Spatial Filtering	144
3.4.1	The Mechanics of Spatial Filtering	145
3.4.2	Spatial Correlation and Convolution	146
3.4.3	Vector Representation of Linear Filtering	150
3.4.4	Generating Spatial Filter Masks	151
3.5	Smoothing Spatial Filters	152
3.5.1	Smoothing Linear Filters	152
3.5.2	Order-Statistic (Nonlinear) Filters	156
3.6	Sharpening Spatial Filters	157
3.6.1	Foundation	158
3.6.2	Using the Second Derivative for Image Sharpening—The Laplacian	160

- 3.6.3 Unsharp Masking and Highboost Filtering 162
- 3.6.4 Using First-Order Derivatives for (Nonlinear) Image Sharpening—The Gradient 165
- 3.7 Combining Spatial Enhancement Methods 169
- 3.8 Using Fuzzy Techniques for Intensity Transformations and Spatial Filtering 173
 - 3.8.1 Introduction 173
 - 3.8.2 Principles of Fuzzy Set Theory 174
 - 3.8.3 Using Fuzzy Sets 178
 - 3.8.4 Using Fuzzy Sets for Intensity Transformations 186
 - 3.8.5 Using Fuzzy Sets for Spatial Filtering 189
- Summary 192
- References and Further Reading 192
- Problems 193

4 *Filtering in the Frequency Domain* 199

- 4.1 Background 200
 - 4.1.1 A Brief History of the Fourier Series and Transform 200
 - 4.1.2 About the Examples in this Chapter 201
- 4.2 Preliminary Concepts 202
 - 4.2.1 Complex Numbers 202
 - 4.2.2 Fourier Series 203
 - 4.2.3 Impulses and Their Sifting Property 203
 - 4.2.4 The Fourier Transform of Functions of One Continuous Variable 205
 - 4.2.5 Convolution 209
- 4.3 Sampling and the Fourier Transform of Sampled Functions 211
 - 4.3.1 Sampling 211
 - 4.3.2 The Fourier Transform of Sampled Functions 212
 - 4.3.3 The Sampling Theorem 213
 - 4.3.4 Aliasing 217
 - 4.3.5 Function Reconstruction (Recovery) from Sampled Data 219
- 4.4 The Discrete Fourier Transform (DFT) of One Variable 220
 - 4.4.1 Obtaining the DFT from the Continuous Transform of a Sampled Function 221
 - 4.4.2 Relationship Between the Sampling and Frequency Intervals 223
- 4.5 Extension to Functions of Two Variables 225
 - 4.5.1 The 2-D Impulse and Its Sifting Property 225
 - 4.5.2 The 2-D Continuous Fourier Transform Pair 226
 - 4.5.3 Two-Dimensional Sampling and the 2-D Sampling Theorem 227
 - 4.5.4 Aliasing in Images 228
 - 4.5.5 The 2-D Discrete Fourier Transform and Its Inverse 235

4.6	Some Properties of the 2-D Discrete Fourier Transform	236
4.6.1	Relationships Between Spatial and Frequency Intervals	236
4.6.2	Translation and Rotation	236
4.6.3	Periodicity	237
4.6.4	Symmetry Properties	239
4.6.5	Fourier Spectrum and Phase Angle	245
4.6.6	The 2-D Convolution Theorem	249
4.6.7	Summary of 2-D Discrete Fourier Transform Properties	253
4.7	The Basics of Filtering in the Frequency Domain	255
4.7.1	Additional Characteristics of the Frequency Domain	255
4.7.2	Frequency Domain Filtering Fundamentals	257
4.7.3	Summary of Steps for Filtering in the Frequency Domain	263
4.7.4	Correspondence Between Filtering in the Spatial and Frequency Domains	263
4.8	Image Smoothing Using Frequency Domain Filters	269
4.8.1	Ideal Lowpass Filters	269
4.8.2	Butterworth Lowpass Filters	273
4.8.3	Gaussian Lowpass Filters	276
4.8.4	Additional Examples of Lowpass Filtering	277
4.9	Image Sharpening Using Frequency Domain Filters	280
4.9.1	Ideal Highpass Filters	281
4.9.2	Butterworth Highpass Filters	284
4.9.3	Gaussian Highpass Filters	285
4.9.4	The Laplacian in the Frequency Domain	286
4.9.5	Unsharp Masking, Highboost Filtering, and High-Frequency-Emphasis Filtering	288
4.9.6	Homomorphic Filtering	289
4.10	Selective Filtering	294
4.10.1	Bandreject and Bandpass Filters	294
4.10.2	Notch Filters	294
4.11	Implementation	298
4.11.1	Separability of the 2-D DFT	298
4.11.2	Computing the IDFT Using a DFT Algorithm	299
4.11.3	The Fast Fourier Transform (FFT)	299
4.11.4	Some Comments on Filter Design	303
	Summary	303
	References and Further Reading	304
	Problems	304

5 *Image Restoration and Reconstruction* 311

5.1	A Model of the Image Degradation/Restoration Process	312
5.2	Noise Models	313
5.2.1	Spatial and Frequency Properties of Noise	313
5.2.2	Some Important Noise Probability Density Functions	314

5.2.3	Periodic Noise	318
5.2.4	Estimation of Noise Parameters	319
5.3	Restoration in the Presence of Noise Only—Spatial Filtering	322
5.3.1	Mean Filters	322
5.3.2	Order-Statistic Filters	325
5.3.3	Adaptive Filters	330
5.4	Periodic Noise Reduction by Frequency Domain Filtering	335
5.4.1	Bandreject Filters	335
5.4.2	Bandpass Filters	336
5.4.3	Notch Filters	337
5.4.4	Optimum Notch Filtering	338
5.5	Linear, Position-Invariant Degradations	343
5.6	Estimating the Degradation Function	346
5.6.1	Estimation by Image Observation	346
5.6.2	Estimation by Experimentation	347
5.6.3	Estimation by Modeling	347
5.7	Inverse Filtering	351
5.8	Minimum Mean Square Error (Wiener) Filtering	352
5.9	Constrained Least Squares Filtering	357
5.10	Geometric Mean Filter	361
5.11	Image Reconstruction from Projections	362
5.11.1	Introduction	362
5.11.2	Principles of Computed Tomography (CT)	365
5.11.3	Projections and the Radon Transform	368
5.11.4	The Fourier-Slice Theorem	374
5.11.5	Reconstruction Using Parallel-Beam Filtered Backprojections	375
5.11.6	Reconstruction Using Fan-Beam Filtered Backprojections	381
	Summary	387
	References and Further Reading	388
	Problems	389

6 *Color Image Processing* 394

6.1	Color Fundamentals	395
6.2	Color Models	401
6.2.1	The RGB Color Model	402
6.2.2	The CMY and CMYK Color Models	406
6.2.3	The HSI Color Model	407
6.3	Pseudocolor Image Processing	414
6.3.1	Intensity Slicing	415
6.3.2	Intensity to Color Transformations	418
6.4	Basics of Full-Color Image Processing	424
6.5	Color Transformations	426
6.5.1	Formulation	426
6.5.2	Color Complements	430

- 6.5.3 Color Slicing 431
- 6.5.4 Tone and Color Corrections 433
- 6.5.5 Histogram Processing 438
- 6.6 **Smoothing and Sharpening** 439
 - 6.6.1 Color Image Smoothing 439
 - 6.6.2 Color Image Sharpening 442
- 6.7 **Image Segmentation Based on Color** 443
 - 6.7.1 Segmentation in HSI Color Space 443
 - 6.7.2 Segmentation in RGB Vector Space 445
 - 6.7.3 Color Edge Detection 447
- 6.8 **Noise in Color Images** 451
- 6.9 **Color Image Compression** 454
 - Summary 455
 - References and Further Reading 456
 - Problems 456

7 *Wavelets and Multiresolution Processing* 461

- 7.1 **Background** 462
 - 7.1.1 Image Pyramids 463
 - 7.1.2 Subband Coding 466
 - 7.1.3 The Haar Transform 474
- 7.2 **Multiresolution Expansions** 477
 - 7.2.1 Series Expansions 477
 - 7.2.2 Scaling Functions 479
 - 7.2.3 Wavelet Functions 483
- 7.3 **Wavelet Transforms in One Dimension** 486
 - 7.3.1 The Wavelet Series Expansions 486
 - 7.3.2 The Discrete Wavelet Transform 488
 - 7.3.3 The Continuous Wavelet Transform 491
- 7.4 **The Fast Wavelet Transform** 493
- 7.5 **Wavelet Transforms in Two Dimensions** 501
- 7.6 **Wavelet Packets** 510
 - Summary 520
 - References and Further Reading 520
 - Problems 521

8 *Image Compression* 525

- 8.1 **Fundamentals** 526
 - 8.1.1 Coding Redundancy 528
 - 8.1.2 Spatial and Temporal Redundancy 529
 - 8.1.3 Irrelevant Information 530
 - 8.1.4 Measuring Image Information 531
 - 8.1.5 Fidelity Criteria 534

- 8.1.6 Image Compression Models 536
- 8.1.7 Image Formats, Containers, and Compression Standards 538
- 8.2 **Some Basic Compression Methods** 542
 - 8.2.1 Huffman Coding 542
 - 8.2.2 Golomb Coding 544
 - 8.2.3 Arithmetic Coding 548
 - 8.2.4 LZW Coding 551
 - 8.2.5 Run-Length Coding 553
 - 8.2.6 Symbol-Based Coding 559
 - 8.2.7 Bit-Plane Coding 562
 - 8.2.8 Block Transform Coding 566
 - 8.2.9 Predictive Coding 584
 - 8.2.10 Wavelet Coding 604
- 8.3 **Digital Image Watermarking** 614
 - Summary 621
 - References and Further Reading 622
 - Problems 623

9 *Morphological Image Processing* 627

- 9.1 Preliminaries 628
- 9.2 **Erosion and Dilation** 630
 - 9.2.1 Erosion 631
 - 9.2.2 Dilation 633
 - 9.2.3 Duality 635
- 9.3 **Opening and Closing** 635
- 9.4 **The Hit-or-Miss Transformation** 640
- 9.5 **Some Basic Morphological Algorithms** 642
 - 9.5.1 Boundary Extraction 642
 - 9.5.2 Hole Filling 643
 - 9.5.3 Extraction of Connected Components 645
 - 9.5.4 Convex Hull 647
 - 9.5.5 Thinning 649
 - 9.5.6 Thickening 650
 - 9.5.7 Skeletons 651
 - 9.5.8 Pruning 654
 - 9.5.9 Morphological Reconstruction 656
 - 9.5.10 Summary of Morphological Operations on Binary Images 664
- 9.6 **Gray-Scale Morphology** 665
 - 9.6.1 Erosion and Dilation 666
 - 9.6.2 Opening and Closing 668
 - 9.6.3 Some Basic Gray-Scale Morphological Algorithms 670
 - 9.6.4 Gray-Scale Morphological Reconstruction 676
 - Summary 679
 - References and Further Reading 679
 - Problems 680

10 *Image Segmentation* 689

- 10.1 **Fundamentals** 690
- 10.2 **Point, Line, and Edge Detection** 692
 - 10.2.1 Background 692
 - 10.2.2 Detection of Isolated Points 696
 - 10.2.3 Line Detection 697
 - 10.2.4 Edge Models 700
 - 10.2.5 Basic Edge Detection 706
 - 10.2.6 More Advanced Techniques for Edge Detection 714
 - 10.2.7 Edge Linking and Boundary Detection 725
- 10.3 **Thresholding** 738
 - 10.3.1 Foundation 738
 - 10.3.2 Basic Global Thresholding 741
 - 10.3.3 Optimum Global Thresholding Using Otsu's Method 742
 - 10.3.4 Using Image Smoothing to Improve Global Thresholding 747
 - 10.3.5 Using Edges to Improve Global Thresholding 749
 - 10.3.6 Multiple Thresholds 752
 - 10.3.7 Variable Thresholding 756
 - 10.3.8 Multivariable Thresholding 761
- 10.4 **Region-Based Segmentation** 763
 - 10.4.1 Region Growing 763
 - 10.4.2 Region Splitting and Merging 766
- 10.5 **Segmentation Using Morphological Watersheds** 769
 - 10.5.1 Background 769
 - 10.5.2 Dam Construction 772
 - 10.5.3 Watershed Segmentation Algorithm 774
 - 10.5.4 The Use of Markers 776
- 10.6 **The Use of Motion in Segmentation** 778
 - 10.6.1 Spatial Techniques 778
 - 10.6.2 Frequency Domain Techniques 782
- Summary** 785
- References and Further Reading** 785
- Problems** 787

11 *Representation and Description* 795

- 11.1 **Representation** 796
 - 11.1.1 Boundary (Border) Following 796
 - 11.1.2 Chain Codes 798
 - 11.1.3 Polygonal Approximations Using Minimum-Perimeter Polygons 801
 - 11.1.4 Other Polygonal Approximation Approaches 807
 - 11.1.5 Signatures 808

11.1.6	Boundary Segments	810
11.1.7	Skeletons	812
11.2	Boundary Descriptors	815
11.2.1	Some Simple Descriptors	815
11.2.2	Shape Numbers	816
11.2.3	Fourier Descriptors	818
11.2.4	Statistical Moments	821
11.3	Regional Descriptors	822
11.3.1	Some Simple Descriptors	822
11.3.2	Topological Descriptors	823
11.3.3	Texture	827
11.3.4	Moment Invariants	839
11.4	Use of Principal Components for Description	842
11.5	Relational Descriptors	852
	Summary	856
	References and Further Reading	856
	Problems	857

12 *Object Recognition* 861

12.1	Patterns and Pattern Classes	861
12.2	Recognition Based on Decision-Theoretic Methods	866
12.2.1	Matching	866
12.2.2	Optimum Statistical Classifiers	872
12.2.3	Neural Networks	882
12.3	Structural Methods	903
12.3.1	Matching Shape Numbers	903
12.3.2	String Matching	904
	Summary	906
	References and Further Reading	906
	Problems	907

Appendix A 910

Bibliography 915

Index 943

TA1632

6261573

eng ✓

66

2008

DATE DUE		
MAY 10 2011		
JUL 08 2011		
JAN 11 2012		
MAY 11 2016		
GAYLORD		PRINTED IN U.S.A.

Appendix
GONZALEZ03



CATALOG

1. Digital image processing

LCCN 2009289249
Type of material Book
Personal name Gonzalez, Rafael C.
Main title Digital image processing / Rafael C. Gonzalez, Richard E. Woods.
Edition 3rd ed.
Published/Created Upper Saddle River, N.J. : Prentice Hall, c2008.
Description xxii, 954 p. : ill. (some col.) ; 25 cm.
Links Table of contents <http://www.loc.gov/catdir/toc/fy031/2002276271.html>
ISBN 9780131687288
 013168728X
LC classification TA1632 .G66 2008
Related names Woods, Richard E. (Richard Eugene), 1954-
LC Subjects Image processing--Digital techniques.
Notes Includes bibliographical references (p. 915-942) and index.
Dewey class no. 621.36/7

CALL NUMBER TA1632 .G66 2008
 Copy 1
Request in Jefferson or Adams Building Reading Rooms

CALL NUMBER TA1632 .G66 2008 FT MEADE
 Copy 2
Request in Jefferson or Adams Building Reading Rooms - STORED OFFSITE

LC CATALOG
 Library of Congress
 101 Independence Ave., SE
 Washington, DC 20540

Questions? Ask a Librarian:
<https://ask.loc.gov/>

LIBRARY

CATALOG



1 of 1



BOOK

Digital image processing

[Full Record](#)[MARC Tags](#)

000	01041cam a2200277 a 4500
001	15769456
005	20180410102012.0
008	090609s2008 njua b 001 0 eng
906	— a 7 b cbc c orignew d 2 e ncip f 20 g y-gencatlg
925	0_ a acquire b 2 shelf copies x policy default
955	— b xh11 2009-06-09 i xh11 2009-06-09 to Dewey w rd11 2009-06-18
010	— a 2009289249
020	— a 9780131687288
020	— a 013168728X
040	— a DLC c DLC d DLC
050	00 a TA1632 b .G66 2008
082	00 a 621.36/7 2 22
100	1_ a Gonzalez, Rafael C.
245	10 a Digital image processing / c Rafael C. Gonzalez, Richard E. Woods.
250	— a 3rd ed.
260	— a Upper Saddle River, N.J. : b Prentice Hall, c c2008.
300	— a xxii, 954 p. : b ill. (some col.) ; c 25 cm.
504	— a Includes bibliographical references (p. 915-942) and index.
650	_0 a Image processing x Digital techniques.
700	1_ a Woods, Richard E. q (Richard Eugene), d 1954-
856	41 3 Table of contents u http://www.loc.gov/catdir/toc/fy031/2002276271.html

[Request this Item](#)

 [LC Find It](#)

Item Availability



CALL NUMBER	TA1632 .G66 2008 Copy 1
Request in	Jefferson or Adams Building Reading Rooms
Status	Not Charged

CALL NUMBER	TA1632 .G66 2008 FT MEADE Copy 2
Request in	Jefferson or Adams Building Reading Rooms - STORED OFFSITE
Status	c.2 Charged - Due - (Internal Loan)

Appendix

LIST01

The CATALOG

Connecting Public Libraries in Allegheny County, PA

Your Library	Tips & Resources	Find Articles	Interlibrary Loan	Get a Library Card
--------------	------------------	---------------	-------------------	--------------------

Start Over

Add to Wish List

Regular Display

Return to List

Limit/Sort Search

Another Search

(Search History)

LEADER 00000cas 22000005a 4500
001 22134460
003 OCoLC
005 20150414135429.0
008 900724c1991999nyuqr p 0 a0eng d
010 91642188 |zsn 90001281
022 0 1051-8215
030 ITCTEM
032 006329|bUSPS
037 |bIEEE Service Center, 445 Hoes Lane, P.O. Box 1331,
Piscataway, NJ 08855-1331
040 NSD|cNSD|dNYG|dMYG|dHUL|dNSD|dDLC|dNSD|dDLC|dCAS|dWAU|dOCL
|dNSD|dELM|dNST|dNSD|dDLC|dWaoLN|dUtoRBLW
042 nsdp|alc
050 00 IN PROCESS
050 14 TK6630.A1|bI4
082 10 621|212
210 0 IEEE trans. circuits syst. video technol.
222 0 IEEE transactions on circuits and systems for video
technology
245 00 IEEE transactions on circuits and systems for video
technology :|ba publication of the Circuits and Systems
Society.
246 10 Circuits and systems for video technology
246 23 Institute of Electrical and Electronics Engineers
transactions on circuits and systems for video technology
260 New York, NY :|bInstitute of Electrical and Electronics
Engineers,|c1991-
300 volumes :|billustrations ;|c28 cm
310 Quarterly
336 text|btxt|2rdacontent
337 unmediated|bn|2rdamedia
338 volume|bnc|2rdacarrier
362 0 Vol. 1, no. 1 (Mar. 1991)-
500 Title from cover.
510 1 Computer & control abstracts|x0036-8113|bMarch 1991-
510 1 Electrical & electronics abstracts|x0036-8105|bMarch 1991-
510 1 Physics abstracts|x0036-8091|bMarch 1991-
650 0 Television|xEquipment and supplies|vPeriodicals.
650 0 Television circuits|vPeriodicals.
650 0 Image processing|vPeriodicals.
650 0 Signal processing|vPeriodicals.
710 2 IEEE Circuits and Systems Society.
850 AAP|aAU|aArU|aAzTeS|aCCC|aCPT|aCSt|aCU-A|aCU-RivP|aCU-SB
|aCoFS|aCoU|aDgW|aDLC|aGAT|aICarBS|aIaU|aInLP|aKyU|aMBU
|aMCM|aMH-GM|aMdBj|aMmet|aMiEM|aMiU|aMoKL|aMoU|aMsSM|aN
|aNn|aNNC|aNru|aNsyU|aNcD|aNcRS|aNjP|aNjR|aNmu|aOCU|aOU
|aOrCS|aPPD|aPPiC|aPU|aRPB-S|aTU|aTxCM|aTxHR|aViB1bV|aWM
|aWaU
890 IEEE transactions on circuits and systems for video
technology.
901 |cSer
935 ADO-0676
936 Vol. 1, no. 2 (June 1991) LIC

Location	CLP Main (Oakland) Second Floor - Magazines
Lib Has	Volume 1 (1991) to Volume 19, no. 2 (2009).

The CATALOG

Connecting Public Libraries in Allegheny County, PA

Your Library

Tips & Resources

Find Articles

Interlibrary Loan

Get a Library Card

[Start Over](#)

[Add to
Wish List](#)

[Add to
Book Cart](#)

[MARC Display](#)

[Return to
List](#)

[Limit/Sort
Search](#)

[More Information](#)

[Another Search](#)

TITLE

ieee transactions on circuits and syst

All Libraries

System Sorted

[Search](#)

☐ Show available items only

(Search History)

Record:

[Previous](#)

[Next](#)

Title IEEE transactions on circuits and systems for video technology : a publication of the Circuits and Systems Society.

Publisher New York, NY : Institute of Electrical and Electronics Engineers, 1991-

Description volumes : illustrations ; 28 cm

Frequency Quarterly

Pub Date Vol. 1, no. 1 (Mar. 1991)-

Location [CLP Main \(Oakland\) Second Floor - Magazines](#)

Lib Has Volume 1 (1991) to Volume 19, no. 2 (2009).

Details

Note Title from cover.

Indexed In: Computer & control abstracts 0036-8113 March 1991-
Electrical & electronics abstracts 0036-8105 March 1991-
Physics abstracts 0036-8091 March 1991-

Subject [Television -- Equipment and supplies -- Periodicals.](#)

[Show similar items](#)

[Television circuits -- Periodicals.](#)

[Image processing -- Periodicals.](#)

[Signal processing -- Periodicals.](#)

Add'l Author [IEEE Circuits and Systems Society.](#)

Key Title [IEEE trans. circuits syst. video technol.](#)

IEEE transactions on circuits and systems for video technology

Add'l Title Institute of Electrical and Electronics Engineers transactions on circuits and systems for video technology

ISSN 1051-8215



[New Library Catalog](#)

[Suggest a Purchase](#)

[Questions](#)

[Site Requirement](#)

The eNetwork is a collaboration of the [Allegheny County Library Association](#) and [Carnegie Library of Pittsburgh](#)



Appendix LIST02

IEEE
TRANSACTIONS
ON
CIRCUITS
AND
SYSTEMS
FOR
VIDEO
TECHNOLOGY

13
2003



**Carnegie
Library of
Pittsburgh**

Main

IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY

A PUBLICATION OF THE IEEE CIRCUITS AND SYSTEMS SOCIETY

WWW.IEEE-CAS.ORG



JULY 2003

VOLUME 13

NUMBER 7

ITCTEM

(ISSN 1051-8215)

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

GUEST EDITORIAL

Introduction to the Special Issue on the H.264/AVC Video Coding Standard . . . A. Luthra, G. J. Sullivan, and T. Wiegand 557

PAPERS

- Overview of the H.264/AVC Video Coding Standard T. Wiegand, G. J. Sullivan, G. Bjøntegaard, and A. Luthra 560
- Motion- and Aliasing-Compensated Prediction for Hybrid Video Coding T. Wedi and H. G. Musmann 577
- Generalized B Pictures and the Draft H.264/AVC Video-Compression Standard M. Flierl and B. Girod 587
- Low-Complexity Transform and Quantization in H.264/AVC H. S. Malvar, A. Hallapuro, M. Karczewicz, and L. Kerofsky 598
- Variable Block-Size Transforms for H.264/AVC M. Wien 604
- Adaptive Deblocking Filter P. List, A. Joch, J. Lainema, G. Bjøntegaard, and M. Karczewicz 614
- Context-Based Adaptive Binary Arithmetic Coding in the H.264/AVC Video Compression Standard D. Marpe, H. Schwarz, and T. Wiegand 620
- The SP- and SI-Frames Design for H.264/AVC M. Karczewicz and R. Kurceren 637
- H.264/AVC Over IP S. Wenger 645
- H.264/AVC in Wireless Environments T. Stockhammer, M. M. Hannuksela, and T. Wiegand 657
- A Generalized Hypothetical Reference Decoder for H.264/AVC . . . J. Ribas-Corbera, P. A. Chou, and S. L. Regunathan 674
- Rate-Constrained Coder Control and Comparison of Video Coding Standards T. Wiegand, H. Schwarz, A. Joch, F. Kossentini, and G. J. Sullivan 688
- H.264/AVC Baseline Profile Decoder Complexity Analysis M. Horowitz, A. Joch, F. Kossentini, and A. Hallapuro 704
- Complexity of Optimized H.26L Video Decoder Implementation . . . V. Lappalainen, A. Hallapuro, and T. D. Härmäläinen 717

COMMENTS AND CORRECTIONS

Corrections to "Genetic Algorithm Optimization of Multidimensional Grayscale Soft Morphological Filters With Applications in Film Archive Restoration M. S. Hamid, N. R. Harvey, and S. Marshall 726

CALLS FOR PAPERS

ISCAS 2004 727

Special Issue on Integrated Multimedia Platforms 728

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.

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 8.5¹ 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

Manuscript received May 2, 2003.

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).

Digital Object Identifier 10.1109/TCSVT.2003.815175

¹While 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.

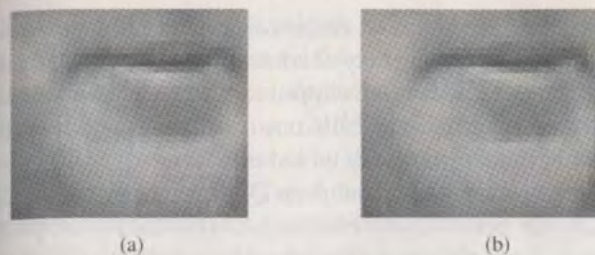


Fig. 1. Detail of luminance input to the deblocking filter in the case of (a) loop-filtering and (b) post-filtering based system.

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 luma sample distance ≥ 1	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

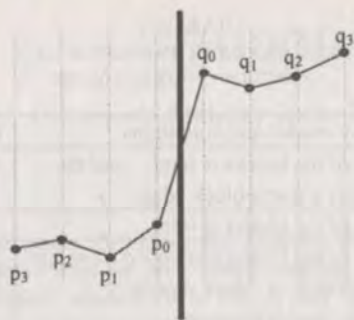


Fig. 2. One-dimensional visualization of a block edge in a typical situation where the filter would be turned on.

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 B_s equal to zero. For edges with nonzero B_s 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

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

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

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

$$p'_0 = p_0 + \Delta_0 \text{ and} \quad (10)$$

$$q'_0 = q_0 - \Delta_0 \quad (11)$$

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

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

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

$$p'_1 = p_1 + \Delta_{p1}. \quad (13)$$

Similarly, if condition (9) is true, the filtered value of q'_1 is calculated as

$$q'_1 = q_1 + \Delta_{q1}. \quad (14)$$

These values are also calculated in a two-step process. The initial Δ value for computing p'_1 is computed as

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

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

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

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

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

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

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:

$$|p_0 - q_0| < (a \gg 2) + 2. \quad (19)$$

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

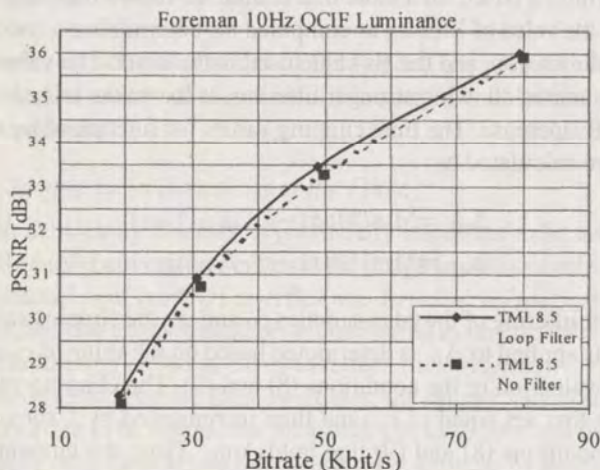


Fig. 3. Luminance PSNR curve for Foreman with and without a loop filter in TML 8.5.

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

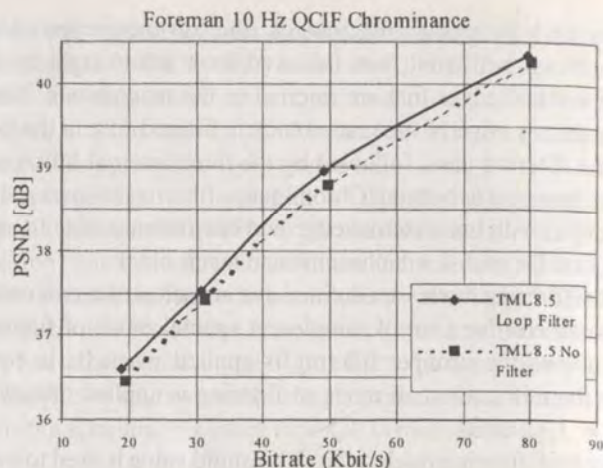


Fig. 4. Chrominance PSNR curve for Foreman with and without a loop filter in TML 8.5.

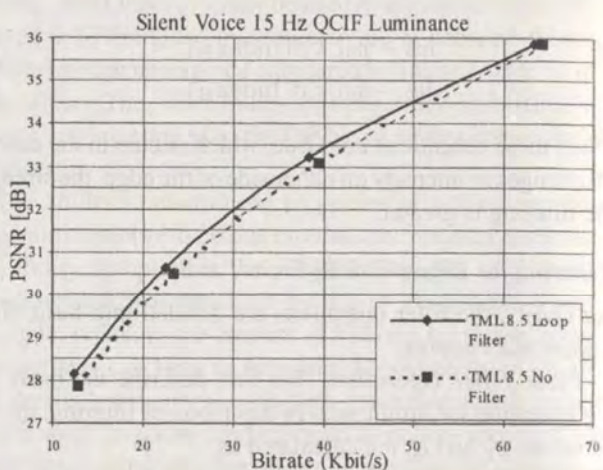


Fig. 5. Luminance PSNR curve for Silent Voice with and without a loop filter in TML 8.5.

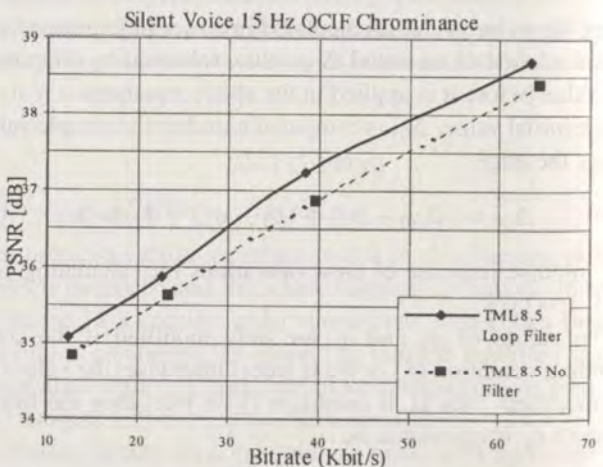


Fig. 6. Chrominance PSNR curve for Silent Voice with and without a loop filter in TML 8.5.

and 8, which compare loop-filter output images to unfiltered output images at two different bit rates and resolutions.

V. CONCLUSIONS

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

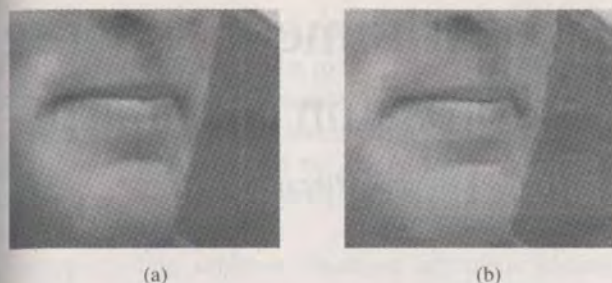


Fig. 7. Detail of the luminance output in the case of (a) loop filtering and (b) no filtering. CIF sequence was coded at 200 kbps and 15 fps.



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.

REFERENCES

- [1] Draft ITU-T Recommendation and Final Draft International Standard of Joint Video Specification (ITU-T Rec. H.264/ISO/IEC 14496-10 AVC), Mar. 2003.
- [2] K. K. Pang and T. K. Tan, "Optimum loop filter in hybrid coders," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 4, pp. 158–167, Apr. 1994.
- [3] Y.-L. Lee and H. W. Park, "Loop filtering and post-filtering for low-bit-rates moving picture coding," *Signal Processing: Image Commun.*, vol. 16, pp. 871–890, 2001.
- [4] S. D. Kim, J. Yi, H. M. Kim, and J. B. Ra, "A deblocking filter with two separate modes in block-based video coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 9, pp. 156–160, Feb. 1999.
- [5] J. Lainema and M. Karczewicz, "TML 8.4 Loop Filter Analysis," ITU-T SG16 Doc. VCEG-N29, 2001.
- [6] (2001) H.26L Test Model Long Term Number 8 (TML-8). [Online]. Available: <http://standard.pictel.com/video-site/h26L/>
- [7] J. Lainema and M. Karczewicz, "Core Experiment Results on Low Complexity Loop Filtering," ITU-T SG16 Doc. VCEG-M21, 2001.
- [8] —, "Further Improvements on TML Loop Filtering," ITU-T SG16 Doc. VCEG-M22, 2001.
- [9] G. Bjøntegaard and I. Lille-Langoy, "Possible Simplifications of the Present Deblocking Filter in TML 5.9," ITU-T SG16 Doc. VCEG-M30, 2001.
- [10] P. List, "Proposal for a Simplification of the H.26L Loopfilter," ITU-T SG16 Doc. VCEG-M48, 2001.
- [11] —, "Report of the Ad Hoc Committee on Loop Filter Improvement," ITU-T SG16 Doc. VCEG-N08r1, 2001.
- [12] S. Sun and S. Lei, "Improved TML Loop Filter With Lower Complexity," ITU-T SG16 Doc. VCEG-N17, 2001.
- [13] G. Côté, L. Winger, and M. Gallant, "Lower Complexity Deblocking Filter With In-Place Filtering," Doc. VCEG-O39, 2001.
- [14] P. List, "AHG Report: Loop Filter," Doc. JVT-B011r2, 2002.
- [15] J. Au, B. Lin, A. Joch, and F. Kossentini, "Complexity Reduction and Analysis for Deblocking Filter," Doc. JVT-C094, 2002.
- [16] A. Joch, "Improved Loop-Filter Tables and Variable-Shift Table Indexing," Doc. JVT-D038, 2002.
- [17] —, "Loop Filter Simplification and Improvement," Doc. JVT-D037, 2002.

- [18] C. Gomila and A. Joch, "Simplified Chroma Deblocking (Revisited)," Doc. JVT-E089, 2002.
- [19] A. MacInnis and S. Zhong, "Corrections to Loop Filter in the Case of MB-AFF," Doc. JVT-F027, 2002.
- [20] A. K. Jain, *Fundamentals of Digital Image Processing*. New York: Prentice-Hall, 1989.
- [21] G. Bjøntegaard, "Calculation of Average PSNR Differences Between RD-Curves," ITU-T SG16 Doc. VCEG-M33, 2001.
- [22] —, "Recommended Simulation Conditions for H.26L," ITU-T SG16 Doc. VCEG-M75, 2001.



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 research 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 processing, 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, Irving, TX, where she is currently a Senior Research Manager. Her research interests include image compression, communication and computer graphics.

Appendix LIST03



Browse ▾

My Settings ▾

Help ▾

Institutional Sign In

Institutional Sign In

All



ADVANCED SEARCH

Journals & Magazines > IEEE Transactions on Circuits... > Volume: 13 Issue: 7 ?

Adaptive deblocking filter

Publisher: IEEE

Cite This

PDF

P. List ; A. Joch ; J. Lainema ; G. Bjontegaard ; M. Karczewicz All Authors ...

509
Cites in
Papers260
Cites in
Patents3098
Full
Text Views

Alerts

Manage Content Alerts

Add to Citation Alerts

Abstract



Downl

PDF

Document Sections

- I. Introduction
- II. Boundary Analysis
- III. Filtering
- IV. Results
- V. Conclusions

Authors

Figures

References

Citations

Keywords

Metrics

More Like This

Footnotes

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 artifa... [View more](#)

▼ Metadata

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.

Published in: IEEE Transactions on Circuits and Systems for Video Technology (Volume: 13 , Issue: 7, July 2003)

Page(s): 614 - 619

DOI: 10.1109/TCSVT.2003.815175

Date of Publication: July 2003 ?

Publisher: IEEE

▼ ISSN Information:

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.



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.

Authors	▼
Figures	▼
References	▼
Citations	▼
Keywords	▼
Metrics	▼
Footnotes	▼

More Like This

Picture-level adaptive filter for asymmetric stereoscopic video
2008 15th IEEE International Conference on Image Processing
Published: 2008

Adaptive interpolation filters and high-resolution displacements for video coding
IEEE Transactions on Circuits and Systems for Video Technology
Published: 2006

Show More

IEEE Personal Account

CHANGE
USERNAME/PASSWORD

Purchase Details

PAYMENT OPTIONS
VIEW PURCHASED
DOCUMENTS

Profile Information

COMMUNICATIONS
PREFERENCES
PROFESSION AND
EDUCATION
TECHNICAL INTERESTS

Need Help?

US & CANADA: +1 800
678 4333
WORLDWIDE: +1 732
981 0060
CONTACT & SUPPORT

Follow



About IEEE *Xplore* | Contact Us | Help | Accessibility | Terms of Use | Nondiscrimination Policy | IEEE Ethics Reporting  | Sitemap | IEEE Privacy Policy

A not-for-profit organization, IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity.

© Copyright 2024 IEEE - All rights reserved, including rights for text and data mining and training of artificial intelligence and similar technologies.

IEEE Account

- » Change Username/Password
- » Update Address

Purchase Details

- » Payment Options
- » Order History
- » View Purchased Documents

Profile Information

- » Communications Preferences
- » Profession and Education

» Technical Interests

Need Help?

» **US & Canada:** +1 800 678 4333

» **Worldwide:** +1 732 981 0060

» Contact & Support

[About IEEE Xplore](#) | [Contact Us](#) | [Help](#) | [Accessibility](#) | [Terms of Use](#) | [Nondiscrimination Policy](#) | [Sitemap](#) | [Privacy & Opting Out of Cookies](#)

A not-for-profit organization, IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity.
© Copyright 2024 IEEE - All rights reserved. Use of this web site signifies your agreement to the terms and conditions.