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**13. ABSTRACT (Maximum 200 words)**

The two VAX 3100 workstations and softwares arrived by mid December and were installed in a room designated as Advanced Communications Laboratory. The full color Targa 24 board arrived in January 1990. Both VAX operating systems have been loaded, and the BOSS and SPW softwares will be loaded soon by the two paid graduate students recently assigned to this lab. Their priorities are learning the VMS operating system, and the usage of the two software systems.

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FINAL TECHNICAL REPORT

ON

COMMUNICATION SYSTEM SIMULATION WORKSTATION

Grant # AFOSR-89-0117

Submitted to: DEPARTMENT OF AIR FORCE

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

BOLLING AIR FORCE BASE, DC 20332-6448

By: Dr. Hamed Parsiani
Associate Prof. Elect./Computer Engr., UPR

Dr. Jorge Cruz-Emeric
Prof. Elect./Computer Engr., UPR

Date: Jan. 30, 1990

Rec'd 2/7/90 updated/rec'd #3

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INTRODUCTION

The two VAX 3100 workstations and softwares arrived by mid Dicember and were installed in a room designated as Advanced Communications Laboratory. The full color Targa 24 board arrived in January 1990. Both VAX operating systems have been loaded, and the BOSS and SPW softwares will be loaded soon by the two paid graduate students recently assigned to this lab. Their priorities are learning the VMS operating system, and the usage of the two software systems.

An IBM compatible PC with 640K RAM and 20 MB hard disk is assigned to this lab in which the full color image board is installed. Therefore, any full color image data processed by the VAX workstations will be displayed by the full color board.

EQUIPMENT IDENTIFICATION:

1. The two VAX 3100 are manufactured by DEC company. The cost of the equipment considering all the needed peripherals was $41749.75, as delivered to the Univ. of Puerto Rico . The quotation is included in the Appendix A.

2. The full color image board, Targa 24, is manufactured by Truevision Inc., and was sold by their representation in New Jersey. The cost of the board with a cable was $3700.57, as delivered to the Univ. of Puerto Rico. A copy of the purchase order is included in the Appendix A.

SOFTWARE IDENTIFICATION:

BOSS simulator for VAX/VMS , SPW workstation for VAX/VMS, optical communications library, and 12 months of software subscription services for both BOSS and SPW were purchased from COMDISCO Systems Inc. The full cost of the software was $4050.8, as delivered to the University of puerto Rico. A copy of the quotation is included in the Appendix A.

SUMMARY OF RESEARCH PROJECTS:

1) Assigned Thesis projects:

Two graduate students will be using the VAX 3100 workstations, the softwares and the full color image board in the development of their thesis projects . Their thesis proposals were recently approved and the topics are:

a) SUB-BAND DECOMPOSITION/RECONSTRUCTION OF COLOR IMAGES USING QUADRATURE MIRROR FILTERS, POLYPHASE FILTERS, AND THEIR PSYCHOVISUAL IMPACT.

b) COLOR IMAGE ISOLATED-NOISE DETECTION AND REDUCTION

Copies of these proposals are made available in the Appendix B, Dr. Hamed Parsiani will supervise both research efforts.

2) Pending Research proposal by Dr. Hamed Parsiani:

The research pre-proposal by Dr. Hamed Parsiani with the title of

DETERMINATION AND TEST OF THE TRANSFER EQUATIONS FOR ERROR STATISTICAL PARAMETERS OF AN EMBEDED CHANNEL FROM HIGH BIT RATE (OPTICAL FIBER) TDM WITH SPECIFIED INTERLEAVING FORMAT.

which appeared in the AFOSR # 890117 is presently being completed for submission, the intentions are to submit the completed proposal to the Air Force , or any other appropriate US Department. This research will also require the use of the VAX 3100 simmulation laboratory.

3) Dr. Robert Kerr who was another member of this grant has returned to the mainland USA. His proposal is therefore discontinued.

4) Dr. Jorge Cruz-Emeric is still interested to submit his proposal, "STUDY OF ADAPTIVE FILTERS WITH REDUCED WORD-LENGTH COEFFICIENTS" for a research grant, as soon as it is completed.

APPENDIX A

# QUOTATION

DIGITAL EQUIPMENT CARIBBEAN, INC.
P.O. BOX 11038, FDEZ. JUNCOS STATION
SANTURCE, PUERTO RICO 00910

PHONE (809) 754-7575 • (809) 754-7596 CABLE DIGITAL SAN JUAN TELEX 385-7056

QUOTATION NUMBER PR89 399(C)
DATE MAY 24, 1989

PLEASE REFER TO THE QUOTATION NO. IN ALL CORRESPONDENCE AND ORDERS

REFERENCE
VOLUME AGREEMENT NO. 32064
NEAREST DIGITAL SALES OFFICE

TO
UNIVERSITY OF PUERTO RICO
MAYAGUEZ CAMPUS
MAYAGUEZ, PR 00708

ATT: DR. HAMED PARSIANI

DIGITAL EQUIPMENT CARIBBEAN, INC.
MERCANTIL PLAZA BUILDING
FOURTH FLOOR - SUITE 401
HATO REY PR 00918

THANK YOU FOR YOUR INQUIRY, WE ARE PLEASED TO QUOTE AS FOLLOWS

| ITEM | QTY. | MODEL NO. | DESCRIPTION | MONTHLY MAINT | ADD-ON INST CHG | DISC % | UNIT PRICE | NET AMOUNT |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | PV014-BW | VAXSTATION 3100 INCLUDING:<br>- 8MB MEMORY<br>- 8 PLANE 19" COLOR MONITOR<br>- 2x104 MB DISK DRIVE<br>- RX23 1.4 MB FLOPPY DRIVE<br>- RRD40 COMPACT DISK DRIVE<br>- KEYBOARD AND MOUSE<br>- ETHERNET CONTROLLER<br>- VMS SINGLE USER LICENSE<br>- VWS WORKSTATION SW LICENSE<br>- DECWINDOWS SOFTWARE LICENSE<br>- DECNET SOFTWARE LICENSE<br>- LAVC SOFTWARE LICENSE<br>- BUILT IN IMAGE CAPABILITIES | | | 34 | $21,630.00 | $28,552.00 |
| 2 | 2 | VR10X-AA | VR100/260 TILT SWIVEL BASE | | | 34 | 295.00 | 389.00 |
| 3 | 1 | TK50Z-GA | 95 MB TAPE BACKUP | | | 34 | 5,105.00 | 3,369.00 |
| 4 | 1 | LN03-AA | 8 PPM LASER PRINTER | | | 34 | 3,042.00 | 2,008.00 |
| 5 | 1 | LN03X-CR | LN03 RAM CARTRIDGE | | | 34 | 504.00 | 333.00 |
| 6 | 1 | QA-VV8AA-H5 | DESKTOP VMS MEDIA AND DOC. | | | 34 | 1,607.00 | 1,061.00 |
| 7 | 1 | QA-001AN-GZ | VMS V5.0 DECNET NETWORKING DOC. | | | 34 | 112.00 | 74.00 |
| 8 | 1 | QA-A96AA-H5 | WORKSTATION SW MEDIA AND DOC. | | | 34 | 612.00 | 404.00 |
| 9 | 2 | QL-100AC-AA | VAX FORTRAN LICENSE | | | 25 | 835.00 | 1,253.00 |
| 10 | 1 | QA-100AA-H5 | VAX FORTRAN MEDIA & DOC. | | | 34 | 587.00 | 387.00 |

SERVICE TYPE:
CALL WINDOW:
PAYMENT TERMS

- [ ] Irrevocable/Confirmed Letter of Credit
- [x] Net 30 Days
- [ ] Other

SALES TERMS

- [x] FOB Digital Plant

| | |
|---|---|
| SUB TOTAL | SEE PAGE 2 |
| INSTALLATION | |
| EXCISE TAX | |
| INSURANCE | |
| ESTIMATED FREIGHT | |
| NET TOTAL AMOUNT | |

This quotation shall remain firm for 60 days from the date hereof, unless modified in writing by Digital Equipment Caribbean, Inc. prior to our acceptance of your contract offer. This quotation is subject to credit approval and is governed by the Digital Equipment Caribbean, Inc. standard terms and conditions attached hereto and/or the volume agreement as noted above.
Any contract resulting from the quotation must be accepted by a duly authorized representative of Digital Equipment Caribbean Inc. Insurance will be provided on property while in transit and a charge of $.50 per $100.00 of equipment valuation will be made unless instructions to the contrary are clearly stated.

STIMATED PRODUCT DELIVERY SCHEDULE/SERVICE COMMENCEMENT DATE (SUBJECT TO MODIFICATION BY DIGITAL) 30-60 DAYS
ROM ORDER ACCEPTANCE

QUOTATION PREPARED BY: LUIS PRINCIPE Luis C. Principe



DELIVERY DATES WILL BE CONFIRMED UPON ACCEPTANCE
OF YOUR CONTRACT OFFER

digital

**QUOTATION**

DIGITAL EQUIPMENT CARIBBEAN, INC.
P.O. BOX 11038, FDEZ. JUNCOS STATION
SANTURCE, PUERTO RICO 00910

QUOTATION NUMBER: PR89/399(C)
DATE: MAY 24, 1989
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PHONE (809) 754-7575 • (809) 754-7598 CABLE DIGITAL SAN JUAN TELEX 305-7056

REFERENCE
VOLUME AGREEMENT NO
NEAREST DIGITAL SALES OFFICE

TO
UNIVERSITY OF PUERTO RICO
MAYAGUEZ CAMPUS
MAYAGUEZ, PR 00708

ATT: DR. HAMED PARSIANI

DIGITAL EQUIPMENT CARIBBEAN, INC.
MERCANTIL PLAZA BUILDING
FOURTH FLOOR - SUITE 401
HATO REY PR 00918

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| ITEM | QTY | MODEL NO | DESCRIPTION | MONTHLY MAINT | ADD ON INST CHG | DISC % | UNIT PRICE | NET AMOUNT |
|---|---|---|---|---|---|---|---|---|
| 11 | 1 | QL-015AC-AA | VAX C LANGUAGE LICENSE | | | 25 | 760.00 | 570.00 |
| 12 | 1 | QA-015AA-H5 | VAX C MEDIA & DOC. | | | 34 | 913.00 | 603.00 |
| 13 | 1 | H8224-00 | THINWIRE BARREL CONNECTOR | | | 34 | 11.00 | 11.00 |

NOTES:

* TERMS AND CONDITIONS ATTACHED.
* PLEASE REFER TO OUR QUOTATION NO. ON YOUR PURCHASE ORDER.
* IN ORDER TO USE VAXSTATIONS IMAGE CABALITIES SOFTWARE HAS TO BE WRITTEN OR PURCHASED BY CUSTOMER.

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CALL WINDOW:
PAYMENT TERMS

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[ ] Net 30 Days
[ ] Other

SALES TERMS

[X] FOB Digital Plant

| | |
|---|---|
| SUB TOTAL | $39,010.00 |
| INSTALLATION | N/A |
| EXCISE TAX | 2,255.50 |
| INSURANCE | 284.25 |
| ESTIMATED FREIGHT | 200.00 |
| NET TOTAL AMOUNT | $41,749.75 |

[illegible] shall remain firm for [illegible] days from the date hereof unless modified in writing by Digital Equipment Caribbean Inc. prior to our acceptance of your contract offer. This quotation is subject to credit approval and is governed [by] the Digital Equipment Caribbean Inc. standard terms and conditions attached hereto and/or the volume agreement noted above.

[Any] contract resulting from the quotation must be accepted by a duly authorized representative of Digital Equipment Caribbean Inc. Insurance will be provided on property while in transit and a charge of $.50 per $100.00 of equipment [illegible] will be made unless instructions to the contrary are clearly stated.

ESTIMATED PRODUCT DELIVERY SCHEDULE/SERVICE COMMENCEMENT DATE (SUBJECT TO MODIFICATION BY DIGITAL) FROM ORDER ACCEPTANCE 30-45 DAYS

QUOTATION PREPARED BY: LUIS PRINCIPE



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DESCUENTO PRONTO PAGO
VEASE ORDEN
RECOGERAN PERSONALMENTE

PAGO POR ANTICIPADO

OTRO

| CO | SEC | CLAVE |
|---|---|---|
| LP | dr | |

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# PURCHASE ORDER

| FECHA DE ORDEN / ORDER DATE | FECHA REQUERIDA / DATE REQUESTED | NUMERO / NUMBER |
|---|---|---|
| 7 7 89 (DD MM YY) | DD MM YY | NO. P-000025 |

EL NUMERO DE ORDEN DEBERA APARECER EN TODA CORRESPONDENCIA, PAQUETES, CONDUCE, FACTURA, Y CONOCIMIENTO DE EMBARQUES. THIS PURCHASE ORDER NO. MUST APPEAR ON ALL CORRESPONDENCE, PACKAGES, PACKING LIST, INVOICES, AND BILL OF LADING.

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A / TO

COMDISCO SYSTEMS, INC.
919 E. HILLSDALE BLVD.
FOSTER CITY, CALIFORNIA 94404

ATTEN. ANNE PURVIS

CODIFICACION / ACCOUNT CODE

FONDO | UNI | PART | FONC | OBJ | SUB

5-35750 Código de Gastos 3254

SUBDIVISION

| PAGINA / PAGE | CONTRATO / CONTRACT | SUBASTA / BID | NUM. REQUISICION / REQUISITION NO. |
|---|---|---|---|
| 1 de 1 | | | CII-#2983 |

| F.O.B. | TERMINOS / TERMS |
|---|---|
| DESTINATION | NET: 30 days |
| DELIVERY: 2 WEEKS | |

DEPTO. ING. ELECTRICA Y COMPUTADORAS
DR. HAMED PARSIANI

| RENGLON | CANTIDAD ORDENADA | UNIDAD | BALANCE PENDIENTE | (✓) | DESCRIPCION | PRECIO UNITARIO / UNIT PRICE | EXTENSION |
|---|---|---|---|---|---|---|---|
| 1 | 2 | | | | BOX 1000-V Block Oriented System Simulater (BOSS) for VAX/VMS Workstations.<br>Includes: Boss Software<br>Boss Documentation Set<br>90 Days SSS & S/W Maintenance | $ 200.00 | $ 400.00 |
| 2 | 1 | | | | BOS1001-V 12-Months Software Subscription Service (SSS) and S/W Maintenance for BOSS | 2,250.00 | 2,250.00 |
| 3 | 1 | | | | BOS1001-V 12-Months Software Subscription Service (SSS) and S/W Maintenance for BOSS for each copy 2 thru 10. | 250.00 | 250.00 |
| 4 | 1 | | | | BOS1050-V Optical Communications Library | N/C | N/C |
| 5 | 2 | | | | SPW1000-V Signal Processing WorkSystem (SPW) for VAX/VMS Workstations<br>Includes: SPW Software<br>SPW Documentation Set<br>90 days SSS & S/W Maintenance | 200.00 | 400.00 |

| | |
|---|---|
| IMPORTE TOTAL / TOTAL AMOUNT | $ 3,800.00 |
| ESTIMADO TRANSPORTACION | $ 250.00 |
| TOTAL A OBLIGARSE | $ 4,050.00 |

COTIZADO CON / QUOTED WITH: ROBERT M. GROSSMAN

FECHA / DATE: DD MM YY

| FECHA DE CARTA | CONTESTACION | COMENTARIOS |
|---|---|---|
| | | |

| FECHA DE LLAMADA | PERSONA CON QUIEN HABLO | NUM. DE TELEFONO |
|---|---|---|
| | | |

Modelo 105
Rev Julio 1979

# UNIVERSIDAD DE PUERTO RICO

RUM

1. Unidad Institucional

CII-3329

2. REQUISICION NUM. ______

FECHA: 3 de nov. 1989

## REQUISICION DE SUMINISTROS

| 3 Oficina Solicitante | 4 Lugar de Entrega |
|---|---|
| Depto. Ing. Eléctrica y Computadoras | Depto. Ing. Eléctrica y Computadoras |
| 5 Titulo de la Cuenta<br>Communication System Simulation Work-Station | 6. Número de Cuenta<br>5-35750 |

| 7 Renglón | 8. Descripción Articulos | 9. Cantidad Solicitada | 10. Unidad de Medida | 11. Precio Unitario | 12. Importe Estimado | 13. Código de Gastos |
|---|---|---|---|---|---|---|
| 1 | True Vision Targa 24 | 1 | | $3,373 | $ 3,373.00 | |
| 2 | Cable for Targa 24 and Mitsubishi Diamond Scan 14" | 1 | | 75 | 75.00 | |
| | SubTotal | | | | $ 3,448.00 | |
| | UPS Shipment | | | | 25.00 | |
| | 6.6% Tax | | | | 227.57 | |
| | TOTAL | | | | $ 3,700.57 | |
| | SUPLIDOR:<br>EDWARD T. MAHOOD<br>2101 US ROUTE 206<br>BELLE MEAD, NJ 08502-0000 | | | | | |

Solicitado por Prof. Hamed Parsiani

Certifico que los artículos solicitados son necesarios para llevar a cabo las labores encomendadas

Ing. José Gil-Borges

14. Funcionario Autorizado

15 Director Oficina Solicitante

# APPENDIX B

SUB-BAND DECOMPOSITION/RECONSTRUCTION OF COLOR IMAGES USING
QUADRATURE MIRROR FILTERS, POLYPHASE FILTERS, AND
THEIR PSYCHOVISUAL IMPACT

by

Homar Rivera

A thesis proposal submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

in

ELECTRICAL ENGINEERING

UNIVERSITY OF PUERTO RICO
MAYAGÜEZ CAMPUS
1989

Approved by:

| | |
|---|---|
| Member, Graduate Committee | 12/14/89<br>Date |
| Member, Graduate Committee | 12/15/89<br>Date |
| President, Graduate Committee | 12/14/89<br>Date |
| Chairperson of the Department | 19-Dic-89<br>Date |
| Director of Graduate Studies | Jan. 17/90<br>Date |

## 1. Justification

Sub-band coding is a coding technique where a parallel set of filters or analysis filter bank, is applied to the input signal in order to decompose it into several frequency bands. The bands are decimated and coded, not necessarily with the same type of code (i.e., to match the statistics of the particular sub-band), before they are transmitted. On the synthesis or reconstruction side, the signals are decoded, interpolated, and filtered before being added to reproduce the original image. This coding technique offers several advantages, among the most important ones are:

1) The quantization noise generated in a particular band is limited largely to that band, and does not influence other bands,
2) offers the means of transmitting good quality pictures at high transmission rates, and
3) the error in coding of a particular sub-band is limited to that sub-band.

Quadrature Mirror Filtering (QMF) provides an answer to the perfect analysis and synthesis problem. Nevertheless, an ideal QMF bank is too complex to determine. In addition, if N greater than 2 is used, perfect band splitting is not assured thus creating bands that are wasted due to undesired overlaps with other bands [1]. Recently, a symmetric short kernel filter design technique was developed [2], reducing its design complexity only to some extent (i.e., a non-algorithmic design), and has the constraint that the number of channels (N), is limited to powers of 2 if a tree type structure is used.

As an alternative to the aforementioned problems, a parallel band-pass filter structure has been developed [3,4], called Pseudo Quadrature Mirror Filtering (PQMF), which uses shifted versions of a prototype low-pass filter or a polyphase filter bank. This technique uses N equally spaced bands, and subsamples each band at 1/N the original rate, where N is not restricted to powers of 2. The reconstruction is done by inserting N-1 zeroes between successive samples of the subbands. The resulting sequences are then passed through a synthesis filter bank, and added to reproduce the original signal. Notice that this technique is somewhat similar to the classical QMF, with the added flexibility of any N, and a well defined algorithmic method to design both the analysis and synthesis filter banks. For N subbands, the filter bank is formed by [3,4,5]:

1) designing a low-pass FIR symmetric prototype filter satisfying certain design requirements, and

2) modulating the low-pass prototype filter by a sinusoid with center frequencies at odd multiples of pi/2N.

In summary, PQMF offers a versatile and flexible alternative for image transmission, but unlike QMF which offers perfect reconstruction, PQMF offers near-perfect reconstruction because ideal band-pass filters are impossible to obtain. However, the human visual perception is very tolerable to small and smooth amplitude distortions [6]. Therefore, it is the hope of this research to demonstrate that the PQMF method produces distortions which will not affect the perceived visual quality of the reconstructed images as compared to the already proven method of QMF [7,8,9] for image decomposition.

## 2. Previous Work

A review of pertinent previous work on sub-band coding using QMF and PQMF has been accomplished. QMF was originally introduced by Esteban and Galand [10,11], for speech compression. A QMF filter design by linear programming was introduced by F. Grenez [12] in order to minimize aliasing and amplitude distortions. QMF was extended to n-dimension by M. Vetterli [13], thus allowing the possibility of its use in image compression. Vetterli [1], also derived QMF methodology of n-dimension and N channels for perfect reconstruction but without regard for perfect band splitting. Later, the first applications of QMF for images came about [7,8,9], yielding high compression and good quality reconstruction. Still, up to this point, the filters were fairly long tap, requiring a large number of multiplications and additions. A filter design technique developing short kernel filters was introduced by D. LeGall [2,14], thus eliminating the problem of filter design (to some extent) and mathematical complexity, but remaining with the limitation that the number of channels must be a power of 2 because of the tree type structure.

Another technique of sub-band decomposition was developed, PQMF, based on the modulation of a single prototype filter. This technique was introduced first by Nassbaumer and Vetterli [3,4] and allowed for N channel decomposition of the signal and computational reduction.

With the original PQMF design, the length of the prototype filter was a function of the number of channels, until Masson and Picel [5] developed a similar PQMF design where the length of the prototype filter was no longer a function of the number of channels. PQMF was extended to n-dimension by Vetterli [13] and Tabatabai [15], therefore allowing the possibility of its use in image transmission. To my knowledge, no actual implementation of PQMF for image transmission has been effected.

## 3. Objective

The objective of this work is to implement a set of QMF and PQMF filter banks to allow for the psychovisual and mean square error comparison of reconstructed images (faces and sceneries) using both methods of band splitting. It is also intended to develop software that will determine the optimum low-pass prototype filter for the use in the PQMF method, given a set of specifications.

## 4. Procedure

The first step is to develop a program that will give the optimum PQMF filter bank, given a set of specifications. This program will take into consideration the effect of all filters in the bank. This program will be written in FORTRAN and C languages, and will use available subroutines when possible.

The second step is to develop computer programs for the analysis and synthesis of images using QMF and PQMF. These programs will be written in C language. The images that will be analyzed are a set of

RGB image files (256x256) which are available and will be displayed using a full color Truevision Targa 24 image board. The support software for the image display using Targa 24 board are also available.

The third and final step is to conduct a psychovisual and mean square error comparison of both methods. The psychovisual comparison will be accomplished by a group of individuals with some knowledge of image features and another group of individuals without the knowledge of image features. The results of all comparisons will be compiled to allow for possible improvements and to reach the conclusions.

5. Bibliography

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[11] Esteban, D., and C. Galand, "Applications of quadrature mirror filters to split band voice coding schemes," IBM Laboratory, pp.191-195, 1977.

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[15] Tabatabai, A., "Some results on two-dimensional pseudo quadrature mirror filters," IEEE Trans. on Circuits and Systems, Vol. CAS-34, No. 8, August 1987.

COLOR IMAGE ISOLATED-NOISE DETECTION AND REDUCTION

by

Sigfredo Peña

**A thesis proposal submitted in partial fulfillment**

**of the requirements for the degree of**

MASTER OF SCIENCE

in

ELECTRICAL ENGINEERING

UNIVERSITY OF PUERTO RICO

MAYAGUEZ CAMPUS

1989

Approved by:

| | |
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| Member, Graduate Committee | 15 de diciembre de 1989<br>Date |
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## 1 JUSTIFICATION

Most of the work done in digital enhancement and image restoration has been limited to application in monochrome images. But the increasing applications of color images [1,2] demand the development of restoration and enhancement techniques for color processing.

Use of color in image displays is not only more pleasing, but it also enables us to receive more visual information. While we can perceive only a few dozens of gray levels, we have the ability to distinguish between thousands of colors [3]. The problem of color processing is the amount of data to be processed. A typical color image consist of three files (red,green and blue (RGB)) 256 by 256 pixels each, 8 bits per pixel giving a total of 1536 Kbits. This amount of data is not easy to manipulate, store or transmit. It will take too much processing time and a large amount of memory.

Many techniques have been developed in order to compress the image, reducing the number of bits required to represent each pixel, resulting in a net reduction of data [3]. However, these techniques use irreversible processes such as quantization-dequantization, resulting in a degradation of the image. Also, if the image is transmitted, some bit loss can occur due to transmission channel errors. These errors appear on image as isolated spots or lines, called isolated noise [4].

There are many available techniques for noise reduction, which yield good results removing isolated noise [5,6,7]. But these methods, which are applied to the entire image, cause smoothing of the image. The result is noise reduction at the cost of degradation or blurring of the noise-free areas of the image.

It is highly desirable to develop a technique to only remove the isolated noise of the image and leave the noise-free areas unchanged. Such a technique requires the detection of the noisy areas. This can be achieved by combining edge detection and noise smoothing techniques.

## 2 PREVIOUS WORK

Image noise is any unwanted signal or disturbance in an image. In order to effectively apply a noise suppression algorithm, a preliminary analysis of the image noise structure is usually necessary. Periodic noise is a spurious repetitive pattern that has consistent characteristics throughout an image. A typical source for such noise may be electronic interference from data transmission or reception equipment. It is relatively easy to diagnose and characterize from the imagery, so it can be easily removed. Random noise is considerably more difficult to separate from valid data. It is characterized by statistical variation in gray levels from pixel to pixel. It may originate in the atmosphere, or electronic components, such as detector or amplifiers, or it may be an inherent part of the image transmission-reception processing techniques applied, such as errors introduced by quantization-dequantization procesess [5].

A variety of techniques have been proposed to remove or reduce noise in digital images. These techniques are called filters and can be classified in two groups: a) linear filtering and b) nonlinear filtering.

Linear filtering techniques apply linear system theory to develop image restoration models [6]. One basic approach has been the application of Wiener filtering. Other approaches include least square filter, optimal recursive filter, and variations and extensions of these filters. All these techniques required that the image restoration models have available a priori knowledge of the statistics of the degradation or noise. In addition to its dependence on detailed models, linear filtering has another drawback in that introduces signal degradation, usually in the form of edge distortion.

Nonlinear filtering techniques have been proposed as alternatives to linear filtering methods. Most of them operate in the spatial domain and involve some type of local operation, such as averaging, using a masking window moving over an image. The focus of these approaches is on the reduction of noise and preservation of important features such as edges. These nonlinear methods are not based on detailed knowledge of the image noise, consequently, they are simple to implement. They are sometimes referred to as edge-preserving smoothing methods or noise cleaning methods.

An introduction to the subject of smoothing noisy images using nonlinear methods is presented in [7]. A complete study of the most used techniques is presented by Chin and Yeh [8] and Mastin [9]. From the methods studied, the K-nearest neighbors method, proposed by Davis and Rosenfeld

[10], shows the best performance; it gives good noise reduction and good edge preservation. But this method is computationally intensive. Median filters [5] also show good performance and seem to be a good alternative. Originally, median filters required a lot of computations, but a fast median filter algorithm developed by Huang [11] eliminated that problem. Another method considered was the unweighted neighbor averaging. This is the simplest smoothing method, but also the one with the worst performance.

All of the aforementioned methods are applied to the entire image, so image is completely smoothened. In the case of an image corrupted by isolated noise, not only noisy areas are smoothened, but noise-free areas are also affected contributing to a general degradation of the image. An optimal filter for this case will be one in which only noisy areas are filtered, leaving noise-free areas intact. Such a technique will require the detection of those noisy areas in order to selectively apply filtering to them. One approach is the use of edge detection techniques.

Edge detection, which is the detection of changes in gray levels in neighbor pixels, is a widely studied field in image processing. Edge detection techniques can be used to detect isolated noise because most isolated spots and lines are interpreted by the detector as small edges.

A variety of edge detection algorithms have been developed [11,12,13], which extends from the simple gradient detectors to the more complex ones including zero-crossing [14], stochastic detectors [3], others based on Kalman filtering techniques [15], and Hilbert transforms [16]. Gradient detectors are a preferred technique for their simplicity and good edge detection ability.

All the aforementioned methods for filtering and edge detection have been developed for monochrome images, in which each pixel represents a single level of gray. In color images each pixel is obtained by a combination of three primary colors: red, green and blue (RGB). Those three color components are highly correlated, so we cannot apply monochrome techniques indepently to each one of the colors. In order to apply those monochrome techniques for color processing a color conversion must be performed.

There are many color conversions available in order to process a color image. These conversions allow us to change an image from the highly correlated RGB system to another system in which color components are uncorrelated, so monochrome techniques can be individually applied to each of the components. The most used conversions are YIQ (or the European version $YC_rC_b$) and, the HSI color systems.

Strickland [1] and Westerink [2] suggest the conversion of the image from RGB to the YIQ model, where Y, the luminance, can be considered as the monochrome version of the color image. Filtering and edge detection are then applied only to the Y component, leaving I and Q, the chrominances unchange. Once image is processed, it is converted back to the original RGB format. Penney [17] and Kay [18] suggest the conversion of RGB image to HSI model. HSI model characterize the attributes of visual perception which are hue, saturation and intensity. In this model the intensity component (I) is considered the monochrome version of color image, so the same procedure as YIQ is performed. Both methods provided good results, although HSI requires more computational effort since the conversion from RGB is nonlinear, while YIQ is a simple linear conversion.

## 3 OBJECTIVE

The objective of this work is to develop a noise reduction algorithm for color images degraded by isolated noise, based on edge detection techniques, in which only the noisy areas are filtered, leaving the noise-free areas unchanged.

## 4 PROCEDURE

It is proposed to develop a noise reduction algorithm which consists of two parts: a) detection of the noisy areas, and b) reduction of the noise in those areas.

An edge detection algorithm will be applied to the noisy image in order to detect edges and isolated noise. Next an edge preserving noise smoothing filter will be applied to those detected areas. The expected result will be reduction of noise and preservation of edges, while noise free areas will remain unchanged.

Color images will be processed using the $YC_rC_b$ system since the noisy image data is available in this system. The proposed noise reduction algorithm will be applied to the Y (luminance) component as suggested in [1] and [2]. However, the possibility of applying the algorithm to the $C_r$ and $C_b$ components, in order to increase the performance, will be studied.

In order to achieve the desired results the following procedure will be adopted:

First, an appropriate edge detection method will be selected. Among various methods, gradient and zero-crossing detectors are possible candidates. The selected method must provide good edge and isolated noise detection at low computational cost.

Next, an appropriate filtering algorithm will be selected. Only spatial nonlinear filtering will be considered, discarding Fourier and linear filtering due to their computational complexity and poor edge preserving ability. The selected algorithm must provide good noise reduction and edge preservation at low computational cost.

Next, programs will be written to implement the complete algorithm. All such programs will be written in C language running under UNIX operating system on AT&T 3B2. Programs will be tested with simulated data, and the final test will be performed using a real 256 by 256 color image corrupted by isolated noise produced by quantization errors. Such an image is already available in the $YC_rC_b$ format.

In order to compare the performance of the proposed algorithm, two classical smoothing methods will also be implemented: unweigthed neighbor averaging and median filtering. These two methods are widely used for their simplicity and performance. The proposed method will be compared with these two methods in terms of:

a) psychovisual quality

b) mean square error

c) computational cost

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