Image Processing and DSP Technology Applied to Remote Activity Monitoring

A thesis is presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Technology at Massey University.

by

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Integrated Research and Teaching in the Fields of:

Statistics & Applied Statistics

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TO WHOM IT MAY CONCERN

This is to state that the research carried out for my Doctoral thesis entitled "Image Processing and DSP Technology Applied to Remote Activity" in the Institute of Information Sciences and Technology, Massey University, Turitea, New Zealand is all my own work.

This is also to certify that the thesis material has not been used for any other degree.

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Abstract

This thesis describes the development of image processing algorithms to achieve industrial remote activity monitoring. The design of such algorithms is constrained by the requirement that they must be implemented in real-time on a cost effective digital signal processor (DSP). A review of the literature revealed that two viable alternatives were available. These are JPEG, a well established lossy block-based image compression algorithm and methods using wavelets. A suitable family of wavelets was identified as the biorthogonal-7.9, the coefficients indicating the number of taps in the quadrature mirror filters at the heart of the transform. Data compression is then achieved through the construction of zerotrees followed by sequential baseline coding. The two candidate algorithms were then systematically compared for recovered image quality and implementation cost at high compression ratios in the range of 16:1 to 64:1. On this basis the wavelet approach was selected and its implementation on a DSP studied. The architectural features of the Motorola 56303 DSP are presented and analysed. It is shown that the various components required for the wavelet based algorithm can be efficiently mapped onto the DSP architecture. Motion detection and image watermarking algorithms were designed and co-operatively implemented with the compression algorithm. A new method of watermarking highly compressed images was developed and this algorithm has been named the Image Authentication Watermark. A new way of representing optimal Huffman code tables has been developed to enable Huffman entropy coding to perform competitively with the more complex arithmetic coding. A product of this research is a smart digital camera that has been integrated into an automated video surveillance system now in industrial production.

Keywords:

image processing, compression, watermarking, digital camera, digital signal processor.

Contents

Preface

It was in 1983 that I first became interested in computers and electronics, I was eleven years old. My school had recently acquired a Sinclair ZX-81 (with a 16 kbyte RAM expansion pack). Not many of my peers seemed interested in the chunky graphics that could be produced by this home computer, but I was hooked. After some bargaining with my parents, I was soon to be the owner of a series of home computers, each one boasting more RAM and better (even coloured) graphics.

It was not until the final year of my undergraduate degree in 1993 that I did any serious image processing or digital signal processor (DSP) work. Dr Wyatt Page, later one of my supervisors, challenged the class to develop an image compression algorithm in Matlab using many of the techniques described in this thesis (less wavelets). I remember enjoying this programming challenge immensely. I suspect that is why I ended up spending over three years of my working career back at Massey University trying for the extra bonus marks in that assignment! I also enjoyed the DSP related projects I worked on in my final year. The challenge of writing complex algorithms in raw assembler language appealed to my sense of detail especially when there were many demanding memory and processing constraints.

I worked as a software engineer for two and a half years and then jumped at the chance to return to university to work on a project that would involve both DSPs and image processing. The company I worked for gave me three years of "study leave" and sponsored the project (and me). As I write this last part of this thesis, I am back at work with the same company and I find it gratifying to know that the smart digital camera is in commercial production. I guess it has the potential to make the owner of the company rich (or richer) and that alone should keep me and my peers employed for some time to come.

Nick Body, 9th October 2000

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- My second supervisors Dr Wyatt Page and Dr Jamil Khan both offered support and encouragement as well as a wealth of technical knowledge about image processing and DSPs. Wyatt proved to be a great person to bounce ideas off and to help guide me in designing the image processing algorithms.
- Dr Don Bailey was my colleague who occupied the office next to me for the three years I worked on this research. Don was the head of the Image Analysis Unit at Massey and what he doesn't know about image processing is probably not worth knowing about! Your constant "availability" to answer my questions or to listen to my ramblings was much appreciated. Our joint research into "stuff that hadn't yet been done with Huffman coding" proved to be most amusing!
- My employer (Cardax International) and FRST (Foundation for Research, Science and Technology) for financing the project to make it look appealing to my need to be paid well whilst returning to be a student. The funding of the trip to Chicago to present a conference paper at ICIP-98 was also provided by the project and was the experience of a lifetime.
- My colleagues at Cardax International for supporting the development of the commercial smart digital camera. Felix Collins and Charles Oram integrated my image processing code into the commercial system. Tony Smith designed and constructed the test-rig hardware for the prototype camera. Grant Allen provided the used of his flat bed scanner to assist with some of the illustrations in this thesis.

- My wife, Melicia, for being ever so patient as the time to write up my thesis seemed to drag on forever! I suspect you will see more of me now and I will no longer talk about DSPs in my sleep...
- My parents for assisting with the proofreading of the final copy of the thesis. Not a task I would normally wish on anyone, but they were kind of handy!
- And finally I would like to thank God, not just a person but a complete *tuple* of [Father, Son, Holy Spirit]. Many times when debugging the complexity of the assembly language code, the quiet reassuring voice of God would point me in the right direction. Your assistance in what must seem like a trivial exercise is much appreciated.

List of Figures

Publications

Papers 4, 5, 6 & 7 were published in internationally refereed conference proceedings.

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2. **Body, N. B.; Page, W. H., and Hodgson, R. M.,** *"Application of the Wavelet Packet Transform to Very Low Bit Rate Coding of Images,"* The NZ Communication Research Workshop 1997, Wellington Town Hall, Wellington, New Zealand, 1997.

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Glossary of Acronyms

ADC – Analogue to Digital Converter

AGU – Address Generation Unit

ALU – Arithmetic Logic Unit

AVS – Automated Video Surveillance

CCD – Charge Coupled Device

CCTV – Closed Circuit Television

CODEC – Coder-Decoder

CWT – Continuous Wavelet Transform

DCT – Discrete Cosine Transform

DFG – Data Flow Graph

DFT – Discrete Fourier Transform

DLL – Dynamic Link Library

DMA – Direct Memory Access

DPCM – Differential Pulse Code Modulation

DSP – Digital Signal Processor

DWT – Discrete Wavelet Transform

EZW – Embedded Zerotree Wavelet

FIR – Finite Impulse Response

GPP – General Purpose Processor

HVS – Human Visual System

IAW – Image Authentication Watermark

IIR – Infinite Impulse Response

JND – Just Noticeable Distortion

JPEG – Joint Photographic Expert Group

JTAG – Joint Test Action Group

KL – Karhunen-Loève

LAN – Local Area Network

LSB – Least Significant Bit

MMX – Multimedia Extensions

MOS – Mean Observer Score

MPEG – Motion Pictures Expert Group

MSE – Mean Square Error

PIR – Passive Infra-Red

PSNR – Peak-to-peak Signal to Noise Ratio

QMF – Quadrature Mirror Filter

RMSE – Root Mean Square Error

SAD – Sum of Absolute Differences

SBC – Sequential Baseline Coding

SCI – Synchronous Communications Interface

SIMD – Single Instruction, Multiple Data

SPIHT – Set Partitioning In Hierarchical Trees

SPL – Signal Processing Library

SRAM – Static Random Access Memory

SSE – Sum of Squared Error

STFT – Short-Time Fourier Transform

SWT – Symmetric Wavelet Transform

TCP – Transmission Control Protocol

UDP – User Datagram Protocol

WSQ – Wavelet/Scalar Quantisation