Three Dimensional T-Ray Inspection Systems

by

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B.E. (Electrical & Electronic, First Class Honours),
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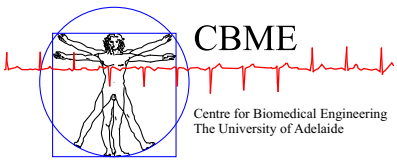
Thesis submitted for the degree of

Doctor of Philosophy

in

School of Electrical and Electronic Engineering,
Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide, Australia

December, 2004



Contents

Abstract

Pulsed terahertz (THz) systems are an emergent technology, finding diverse applications as they approach maturity. From their birth in the late 1980's to the wealth of alternate sources and imaging modalities now available, the rise has been fuelled by the expectation that this will prove a world changing technology. This Thesis takes an application focused approach and seeks to provide enabling systems and algorithms for the development of *functional* imaging systems with broad potential application in security inspection, non-destructive testing and biomedical imaging.

Three dimensional pulsed THz imaging systems were first introduced in 1996 using a reflection-mode ultrasound-like configuration. This Thesis builds upon this former work by focusing on *transmission* mode tomography systems using pulsed THz radiation. Several novel 3D imaging modalities are introduced. The hardware architectures, based on optoelectronic generation and detection of THz radiation are described. Approximations to the wave equation are derived, allowing linear reconstruction algorithms to recover 3D structural information from the transmitted THz field. Finally the systems are demonstrated and the achievable resolution and image quality are investigated. Three imaging architectures are developed herein:

1. T-ray holography allows the 3D distribution of point scatters to be resolved based on a single projection image utilising a novel reconstruction algorithm based on the windowed Fourier transform and back-propagation of the Fresnel-Kirchhoff diffraction equation.

2. T-ray diffraction tomography utilises the diffracted THz field to allow a Helmholtz equation based, frequency-dependent reconstruction to be performed and the THz spectrum at each pixel to be calculated.

3. T-ray Computed Tomography (CT) uses analogous techniques to X-ray CT, based on the Radon transform, to provide 3D T-ray reconstructions of unprecedented fidelity.

These techniques have important applications in material identification, which is investigated in the second part of this Thesis.

Pulsed THz spectroscopy has been widely acclaimed for its potential to identify different materials based on their spectral properties. The second part of this Thesis presents algorithms towards this goal. Three case studies are performed focusing on biomaterial classification, anthrax detection and *in vitro* osteosarcoma cell differentiation. A classification framework is developed to process the THz spectral data and identify specific materials. A linear filter model is introduced to describe the system response of different materials, and the filter taps are utilised for feature extraction. This technique is demonstrated for biomaterial and anthrax classification. For cell differentiation a genetic algorithm is used to select deconvolved frequency components to train a classifier. In each case a high classification accuracy is demonstrated, highlighting the promise and potential of three dimensional T-ray inspection systems.

Statement of Originality

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published written by another person, except where due reference has been made in the text.

I give consent to this copy of the thesis, when deposited in the University Library, being available for loan, photocopying and dissemination through the digital thesis collection.

29th December, 2004

Signed

Date

Acknowledgments

A great number of people have collaborated to make this Ph.D. an exceptionally rewarding and memorable experience. I extend my sincerest thanks to my family, friends, colleagues and supervisors for their support and encouragement.

I thank my supervisor Associate Professor Derek Abbott for introducing me to the world of terahertz imaging and for the continuous flow of ideas that he provided. I also thank him for his encouragement and tireless work in reviewing journal publications and this Thesis. My co-supervisor Professor Doug Gray provided welcome advice and contributed significantly to the development of linear filter models for THz classification.

I had the pleasure of working with one of the true pioneers of THz imaging, Professor X.-C. Zhang (Rensselaer Polytechnic Institute, USA). I hold him in the highest esteem for captivating me with his vision of the potential of THz research and for his inspiration and guidance.

While a Ph.D. is, by nature, a solitary experience, I have benefitted greatly from interaction with colleagues at the University of Adelaide and at Rensselaer Polytechnic Institute. I wish to acknowledge Dr Samuel Mickan, Dr Greg Harmer, Leonard Hall, Hua Zhong, Haibo Liu and Jingqun Xi. A special debt of gratitude is also owed to Dr Shaohong Wang from Rensselaer Polytechnic Institute. Much of the work in this Thesis is a result of our fruitful collaboration.

Thanks are due to Matthew Berryman and Gretel M. Png for proof-reading this Thesis, and to Dr Greg Harmer for gracious provision of the LaTeX template. Thanks also to Dr David Findlay and Shelly Hay from the Royal Adelaide Hospital for supplying cancer cell samples for THz spectroscopy studies.

I thank my parents for their love and for teaching me that *"... the* LORD *gives wisdom, from His mouth come knowledge and understanding." – Proverbs 2:6.* I also thank the rest of my family: Daniel, Cameron, Mark, Amanda and Rebecca, for memories and support.

I gratefully acknowledge the many funding agencies whose generous grants facilitated this research. This work was enabled by the Mutual Community Travel Award,

the D.R. Stranks Scholarship, the Optical Society of America and New Focus Award, the International Society for Optical Engineering, the AFUW, the SA Premier's Department and the Australian Research Council. This work was also supported in part by the Center for Subsurface Sensing and Imaging Systems, under the Engineering Research Centers Program of the National Science Foundation (award number EEC-9986821), and the Cooperative Research Centre for Sensor, Signal and Information Processing (CSSIP). Support was also provided by the University of Adelaide B3 medical funding scheme and the University of Adelaide Small Grants Funding Scheme. Special thanks are due to the Australian-American Fulbright Commission for funding and for the opportunity of a lifetime in the form of a two-year educational exchange to Rensselaer Polytechnic Institute in New York.

Finally, I owe everlasting gratitude to my wife Tennille, who has given me everything, at great cost, and with great love.

"Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else – if you ran very fast for a long time, as we've been doing."

"A slow sort of country!" said the Queen. "Now here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that."

- Lewis Carroll (Carroll 1936)

"There are only two ways to live your life. One is as though nothing is a miracle. The other is as though everything is a miracle."

- Albert Einstein

Thesis Conventions

Typesetting. This Thesis is typeset using the LaTeX2e software. Processed plots and images were generated using Matlab 6.1 (Mathworks Inc.). CorelDRAW 8.4 (Corel Corporation) was used to produce schematic diagrams and other drawings. Pixotec Slicer Dicer (Pixotec Inc.) was used to generate 3D rendered images.

Spelling. Australian English spelling has been adopted throughout, as defined by the Macquarie English Dictionary (A. Delbridge, Ed., Macquarie Library, North Ryde, NSW, Australia, 2001). Where more than one spelling variant is permitted such as 'biassing' or 'biasing' and 'infra-red' or 'infrared' the option with the fewest characters has been chosen.

Referencing. The Harvard style is used for referencing and citation in this Thesis.

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