Microwave Signal Processing for Foreign Object Identification

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Acknowledgements

This thesis builds upon the well-known solutions of the wave equation in different coordinate systems, in particular those of Helmholtz's equation. The original work presented in this thesis is the use of an inverse method of determining unknown properties (size, position and dielectric properties) of an embedded object in a host medium using the scattering of microwave signals. Using well-established solutions for the forward and backward electromagnetic fields and matching these with experimentally determined values of the reflection coefficients we verified the method worked for simple pre-determined shapes. Chapters 2, 3 and 4 use some of these solutions with appropriate references in order to proceed for developing the microwave application system. Chapters 6 and 7 are related to experimental work which was carried out at the premises of Keam Holdem Associates in Auckland, New Zealand.

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Abstract

This thesis presents a novel approach for detecting an internal object using non-invasive surface measurements of the reflection coefficients. The low cost and safety of the low power microwave detection system may be practically suited to first level breast cancer screening with further development. The significant difference in the dielectric properties of a malignant tumour compared to healthy breast tissue makes it possible to estimate the size and position of a tumour using microwave frequencies.

Incident and backscattered electromagnetic waves are analysed using three coordinate systems. Starting from a plane wave reflection model, this approach advances to obtain mathematical solutions to the nonlinear scattering problems of cylindrically and spherically-shaped objects. The solution to the inverse problem for finding the position, size and electrical properties of the unknown microwave scatterer is determined using Newton's iterative method. Both of the forward and inverse algorithms are tested using simulations before proceedings to an experimental application.

List of publications

1. G. G. Senaratne, R. B. Keam, W. L. Sweatman, G. C. Wake and R. Simpkin, *An inverse method for detection of a foreign object using microwave measurements*, IET Journal on Science, Measurements and Technology (in press), (2008).

2. G. G. Senaratne, R. B. Keam, W. L. Sweatman and G. C. Wake, *Solutions to the inverse problem with potential application for breast tumour detection using microwave measurements*, Journal on Computational and Mathematical Methods in Medicine, **8**, no. 4, 245-61, (2007).

3. —, *Solutions to the inverse problem in a two-dimensional model for microwave breast tumour detection*, Journal of Intelligent System Technologies and Applications, IJISTA, **3**, no. 1/2, 133-48, (2007).

4. —, *Solutions to the two-dimensional boundary value problem for microwave breast tumour detection*, IEEE Microwave and Wireless Component Letters, **16**, no. 10, 525-27, (2006).

5. —, *An investigation based on the electrical properties in normal and malignant human breast tissues for tumour detection*, proceedings of the IIMS PG Conference, Massey University, New Zealand, October, 74-79, (2006).

6. —, *Microwave scattering at malignant tissue boundaries: A new method for breast screening*, proceedings of the International Conference SICE-ICCAS, Bussan, Korea, TA 07, (2006).

7. G. G. Senaratne, R. B. Keam, W. L. Sweatman and G. C. Wake, *Solutions to the two-dimensional microwave scattering problem: A new approach for breast tumour detection*, proceedings of the IIMS PG Conference, Massey University, New Zealand, 156-164, (2005).

8. G. G. Senaratne, R. B. Keam, W. L. Sweatman and G. C. Wake, *A new approach to breast tumour detection using microwave frequencies: A two-dimensional model*, proceedings of the First International Conference on Sensing Technology, ICST, Massey University, New Zealand, 460-65, (2005).

9. —, *Inverse methods for the detection of internal objects using microwave technology: With potential for breast screening*, proceedings of the Fifth International Conference on Inverse Problems in Engineering: Theory and Practice, Cambridge University, UK, Leeds University Press, Leeds, UK, Vol III, Chapter **S01**, 1-10, (2005).

10. R. B. Keam, G. G. Senaratne and R. Pochin, *One-dimensional propagation difference between tumour and healthy breast tissue at 2 GHz*, proceedings of the New Zealand National Conference on Non Destructive Testing, 21-25, (2004).

11. G. Senaratne and S. C. Mukhopadhyay, *Investigation of the interaction of planar electromagnetic sensor with dielectric materials at radio frequencies*, proceedings of the Fifth ISEMA Conference on Wave Interaction with Water and Moisture Substances, New Zealand, 95-99, (2003).

12. S. C. Mukhopadhyay, J. D. Woolley, G. Senaratne, G. Sengupta and S.Yamada, *Experimental observation of the effect of dielectric materials on the transfer impedance of planar electromagnetic sensors*, proceedings of the ENDE conference, 21-23, (2003).

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