PhD Thesis Title: "Wideband Microwave Imaging System for Brain Injury Diagnosis"

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ABSTRACT:

Brain injury is a major cause of disability and mortality worldwide. This medical emergency occurs when the brain is damaged as a result of various traumatic and non-traumatic incidences, including accidents, strokes, drug abuses, tumours, infections and various diseases. As the devastating disorder of brain injury deteriorates rapidly, fast diagnosis and management is critically important for the treatment and recovery of the affected patient. Therefore, on-the-spot accurate detection by means of head imaging is the governing factor of the timely medication to ensure complete recovery of the injured patient. Although some existing imaging technologies, like CT and MRI, are capable for brain injury diagnosis, they are time-consuming, expensive, bulky and mostly stationary. Thus, they cannot be carried by first response paramedic teams for the diagnosis purpose or be used for monitoring the patient to observe concurrent brain injury over periods of time without moving the patient. A compact and mobile technology that can be applied to monitor the patient continuously in real time, either at the bedside or in emergency room, would be a significant advantage in comparison to the existing imaging techniques. This thesis aims to develop wideband microwave imaging systems for brain injury diagnosis. In doing so, it makes seven main contributions to the field of microwave imaging systems:

1. As the efficacy of the microwave imaging systems relies on the sensing antennas, emphasize is given in the developments of compact, wideband antennas with directional radiation patterns for low microwave frequencies. This is the first contribution of the present PhD thesis. Three-dimensional (3D) antennas are proposed, relying on multiple folding and slot-loading techniques. Nevertheless, a novel generalized miniaturization technique is proposed for compact antennas. The antennas are found to be efficient in both near- and far-fields for both frequency- and time-domain characterizations.

2. The second contribution is the development of artificial human head phantom with realistic heterogeneous tissue distributions and actual wideband frequency-dispersive dielectric properties. The phantom is fabricated from artificial tissue emulating materials which are contained and structured by using 3D printed structures and castes. This realistic 3D human head phantom significantly improves the reliability of the experimental validation process of wideband microwave imaging compared to the reported validations with existing simple and stylized head phantoms.

3. The third contribution is the performance comparison of directional and omni-directional antennas for wideband microwave head imaging systems. A novel near-field time-domain characterization technique is proposed that enables the comparative analysis of antennas for near-field applications. Application of this technique demonstrates that for microwave imaging systems, directional antennas are more effective than omni-directional antennas. In terms of imaging performance, it is observed that directional antennas yield better images with higher accuracy compared

to the omni-directional antennas. This conclusive evidence significantly assists the decision making of practical wideband microwave imaging solutions.

4. The fourth contribution is the development of microwave imaging system for brain injury diagnosis, which is made portable by using a compact unidirectional antenna and a wideband transceiver. The system is prototyped and the imaging performance is validated by using a realistic 3D human head phantom. The developed confocal imaging algorithm is seen to successfully locate the position of brain injuries.

5. The fifth contribution is the improved back-projection algorithm relying on a novel approach of effective head permittivity model, which overcomes the limitations of constant permittivity based existing imaging algorithms. The efficacy of the algorithm is verified in realistic brain injury scenarios in both simulation and measurement environments.

6. The sixth contribution is the design and experimental evaluation of an automated head imaging system, which utilizes a single miniaturized wideband antenna with directional radiations. Based on the determinations of the numerical results, the imaging performances of the system are improved by considering the surface waves for both forward and scattered wave propagations. The experimental results positively validate the applicability of the imaging system for brain injury diagnosis.

7. The last, but not least, contribution is the array-based portable wideband microwave imaging system with multi-level scanning capabilities. The system, developed from 3D printing parts and custom made components, is flexible to be adjusted for different head shapes and sizes. The fast data acquisition technique and imaging algorithm rely on the threshold normalization approach that efficiently performs 3D localization of the position of brain injuries when applied on a realistic head phantom. The system meets the safety requirements of electromagnetic devices. The reliability of the imaging performance of pilot volunteer tests demonstrates the potential of this system for preclinical trials for brain injury diagnosis.

The developed devices, techniques, systems and other advances reported in this thesis positively contribute to microwave imaging domain. They are expected to encourage a low-cost, compact and portable wideband microwave head imaging system in near future. This can proceed for mass production and significantly reduce human sufferings due to brain injuries.

References to author publications that relate specifically to the dissertation:

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