

New Electromagnetic-Thermal Imaging Method with Multi-frequency Microwave Imaging System

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Microwave imaging (MWI) techniques demonstrate significant improvements in medical imaging relative to traditional imaging methods. For example, MWI systems are more cost-effective and portable than most magnetic resonance imaging (MRI) equipment. Due to its non-ionizing nature, MWI does not suffer from the safety issues associated with X-ray and positron emission tomography (PET). Consequently, several MWI prototype systems have been effectively used for medical imaging applications, encompassing medical diagnosis and therapy assessment.

Thermal therapy techniques, including thermal ablation and hyperthermia, have garnered increasing attention in laboratory and clinical cancer treatment studies. In thermal therapy techniques, it is essential to monitor the administered thermal dose in the malignant area during treatment to prevent thermal overdose or undertreatment. The prevailing protocol of utilizing MRI/PET for monitoring thermal treatment may necessitate several interruptions to transfer the patient from the treatment room to the imaging room. On the contrary, MWI systems can effectively prevent interruptions and produce near-real-time intra-operative data on the administered thermal dose, as they can be integrated with the thermal administration system. Nonetheless, monitoring the thermal treatment process in target areas within substantial human organs (such as the liver, brain, and breast) remains challenging. For example, based on the authors' knowledge, currently, no direct mathematical function is built to directly utilize microwave signals for temperature mapping. Furthermore, no appropriate preconditioner is proposed to relax the ill-posedness, ill-conditioning, and underdetermined nature of three-dimensional (3D) imaging for hyperthermia and thermal ablation operations on biological tissues.

In this study, we present a new electromagnetic-thermal imaging method to monitor thermal therapy in near-real-time. For the first time, a new electromagnetic-thermal cost function is proposed to map 3D temperature distribution using electromagnetic signals. Using the differential Born approximation method for the inverse scattering purposes, our MWI system can reconstruct dielectric map variances caused by temperature changes, thus capturing the temperature changes throughout the treatment. Moreover, the MRI T_2 -weighted scans were applied to generate accurate preconditioned maps for thermal monitoring. Multiple actual thermal ablation operations on Sprague-Dawley rats were conducted, and excellent 3D thermal mapping results on different organs validate the accuracy of the proposed electromagnetic-thermal imaging method.