Potential Point-of-Care Biomonitoring Enabled by EM Technology

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Abstract

The aging population urgently demands innovation in healthcare and rehabilitation. More affordable routine biomonitoring is needed with tissue contrast for the early detection of dementia and other diseases. Emerging electromagnetics (EM) technologies could be the source of the innovative facilitators. In this paper, we report the R&D progress of electromagnetics (EM) technology in healthcare and rehabilitation for the aging population. The progress on a portable MRI head imager for a more affordable routine scan, artificial intelligence (AI) driven magnet resonance electrical property tomography (MREPT). A prospective view on their future trends will be given.

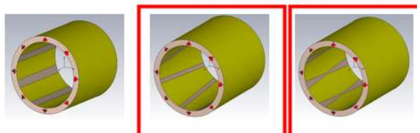
1 Introduction

The size of aging population is increasing quickly, which raises big challenges to healthcare and rehabilitation. The devices that could enable routine monitoring of older people at home and in the community are urgently needed. Electromagnetic waves, which are transparent energy yet can interact with substances have become popular in this sector. Although shallow penetration depth prevents most existing available affordable healthcare devices from reaching the deep targeted site, exploring in a wider spectrum of different EM parameters introduces possibility of solving the problem. Intensive research for applying EM to healthcare and rehabilitation has been carrying out from the past decade. In this paper, examples on monitoring will be presented.

2 Portable MRI for daily body-dedicated MR scan

Further development on permanent magnet array (PMA)-based portable MRI [1, 2, 3, 4] was conducted. Due to the nature of the magnetic field a PMA supplies, it is less homogeneous and it requires RF coils working at a wider frequency band. Recently, wideband transversal electromagnetic (TEM) coils arrays were proposed for a 1.5T system [5]. Fig. 1 shows the designs of the proposed single tapered and double tapered TEM (2nd column and 3rd column) and a comparison of performance to a traditional design (1st column). As can be seen, an increase of 11.25% and 10.62% in bandwidth were obtained, respectively, while the sensitivity was maintained comparable. More flexible printing technology using aerosol jet printing on paper substrate [6, 7] were proposed to afford more conformal configuration for receive coils.

Moreover, further analysis on encoding using non-linear gradients were conducted and documented in [8, 9]. Based on the analysis, a Transmit Array Spatial Encoding (TRASE) coil was designed to further encode the signal using the transmit coil sensitivity [10]. Fig. 2 (a) shows the situation before the application of a TRACE coil using local k-space [8]. Fig. 2 (b) shows the design of the TRACE coil, its homogeneous field strength, linear phase, and the corresponding pulse sequence. The right-hand corner of Fig. 2 (b) shows the local k-space after applying the TRACE coil design. As can be seen, the coverage of the local k-space has been improved dramatically, which lead to a significant improvement of image quality as shown in Fig. 2 (c).



	Non-tapered TEM coil			Single tapered TEM coil			Dual tapered TEM c		
Frequency (MHz)	f_L	f_r	f_H	f_L	f_r	f_H	f_L	f_r	f_H
	61.2	64	66.8	60.4	64	67.6	60.6	64	67.
FWHM Bandwidth	5.6 MHz			7.2 MHz			6.8 MHz		
Fractional Bandwidth	8.75%			11.25%			10.62%		
$\Delta B_1^+ \times 10^{-7}$ (T/√W)	6.95	13.6	7.19	7.26	14.6	7.19	8.64	17.5	8.7
$B^+_{1\,av(Norm)} \times 10^{-7}$ (T/√W)	5.26	10.5	5.38	4.45	8.81	4.44	4.30	8.69	4.4

Figure 1. Comparison of performances of traditional TEM, and single tapered and double tapered TEM [5]

3 Machine Learning for MR electrical property tomography (MREPT)

For tissue impedance, i.e. electrical properties (permittivity ε_r and conductivity σ), magnetic resonance imaging (MRI) contrast, MR electrical property tomography (MREPT) [11], offers a promising approach to measure them in vivo. This approach is based on data from MRI measurement (B1-). Machine learning that was initially proposed in [12] shed the light to solve the existing problems of MREPT, namely noise sensitivity and boundary inaccuracy.

In this work, we propose to address the analytical reconstruction limitations of MREPT, i.e. noise amplification and boundary errors, by combining a currently used analytical method for MREPT reconstruction convection-reaction MREPT (cr-MREPT)

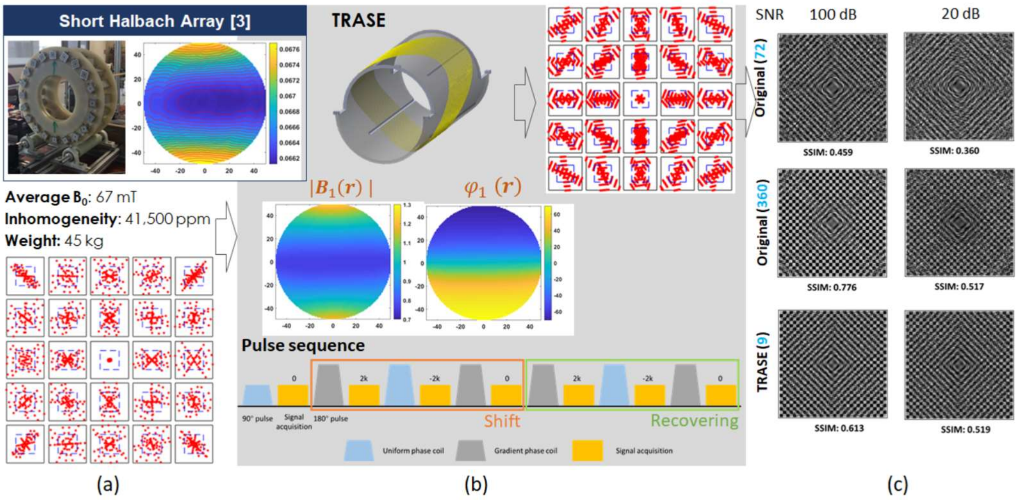


Figure 2. (a) local k-space without a TRACE coil [10] (b) the design of a TRACE coil and the local k-space after applying it (c) the effect of applying TRACE coil.

[11] with ML optimization, which is helpful to generalize ML-MREPT methods.

The cr-MREPT method to reconstruct EPs works by solving a convection reaction partial differential equation (pde) [11].

$$-i\omega B_1^+ = -\gamma\nabla^2 B_1^+ + \nabla\gamma \cdot \begin{bmatrix} -\frac{\partial B_1^+}{\partial x} + i\frac{\partial B_1^+}{\partial y}, \\ -\frac{\partial B_1^+}{\partial x} - i\frac{\partial B_1^+}{\partial y}, \\ -\frac{\partial B_1^+}{\partial z} \end{bmatrix} \quad (1)$$

where ω is the angular frequency of the electromagnetic fields, $B_1^+ = \frac{(B_x+iB_y)}{2}$, is the positive circularly polarized magnetic field, $\gamma = (\frac{1}{\sigma+i\omega\varepsilon_r})$ is the inverse of the complex permittivity. The pde is solved in a finite differences' method [11]. However, the method still suffers from instabilities on the solution. Hence an artificial diffusion term, $\rho\nabla^2\gamma$, is added to the pde to provide a more stable solution [13]. The governing equation after adding the diffusion term is shown as follows

$$-i\omega B_1^+ = \boldsymbol{\rho\nabla^2\gamma} - \gamma\nabla^2 B_1^+ + \nabla\gamma \cdot \begin{bmatrix} -\frac{\partial B_1^+}{\partial x} + i\frac{\partial B_1^+}{\partial y}, \\ -\frac{\partial B_1^+}{\partial x} - i\frac{\partial B_1^+}{\partial y}, \\ -\frac{\partial B_1^+}{\partial z} \end{bmatrix} \quad (2)$$

In our previous work, ρ, was set to be constant in the field of view (FoV) [12]. However, different regions in the FoV will improve or deteriorate according to the selection of the diffusion coefficient, hence by using local diffusion coefficients on the FoV, the reconstruction accuracy can be improved [13], still the selection of the spatial varying coefficient is difficult and increases the complexity of the problem.

The spatial distribution of the coefficient of the diffusion term, ρ, is controlled by a ML algorithm, to provide a local diffusion term to perform accurate reconstructions by further stabilizing the equation and providing boundary artifact reduced reconstructions. The input to the model is the real part of the complex B1+ field, related to the conductivity reconstruction [13], which is the focus of this work.

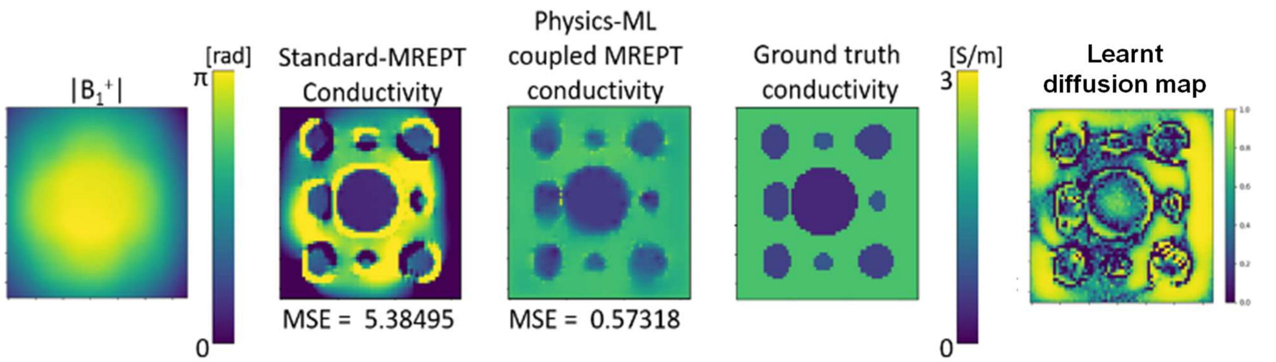


Figure 3. Models for investigating the variation of dielectric properties of biological tissues [9]

Fig. 3. Shows the conductivity reconstruction of two test samples for all the tested algorithms and the expected conductivity values (ground truth values). For cr-EPT without artificial diffusion coefficient the reconstruction shows a very unstable solution for both samples, for cr-EPT with a FoV constant diffusion coefficient shows a very undershoot solution for the second row sample and for cr-EPT with a spatially optimized diffusion coefficient where the undershooting of the previous samples is reduced, the applied directional diffusion coefficients for each sample is also shown.

4 Discussion

Besides the early detection of dementia and the other diseases, such as cancer, MREPT provides information of the electrical properties of human tissue as well as the associated anatomy in general. It can further facilitate efficient pain monitoring and pain relief in terms of guiding where and how electrical stimuli can be applied based on ion channel modelling [14, 15] and the associated close loop pain investigations [16, 17].

5 Conclusion

This paper presents the further research and development of emerging EM technologies for healthcare and rehabilitation. For the daily routine biomonitoring for early detection of dementia and other diseases, the research and development of portable MRI head imager is reported in terms of wideband RF coil design and the design of TRACE coil. Meanwhile, the latest development of AI-driven MREPT is detailed which increase the accuracy of image reconstruction through mitigating the boundary inaccuracy and lowering the noise sensitivity. The importance of the role of EM technologies to healthcare and rehabilitation is illustrated.

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