EM Technology for Healthcare & Rehabilitation Applications

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Chiba (Japan): Four Seasons

cherry blossoms at Chiba Castle

fireworks festival

autumn foliage

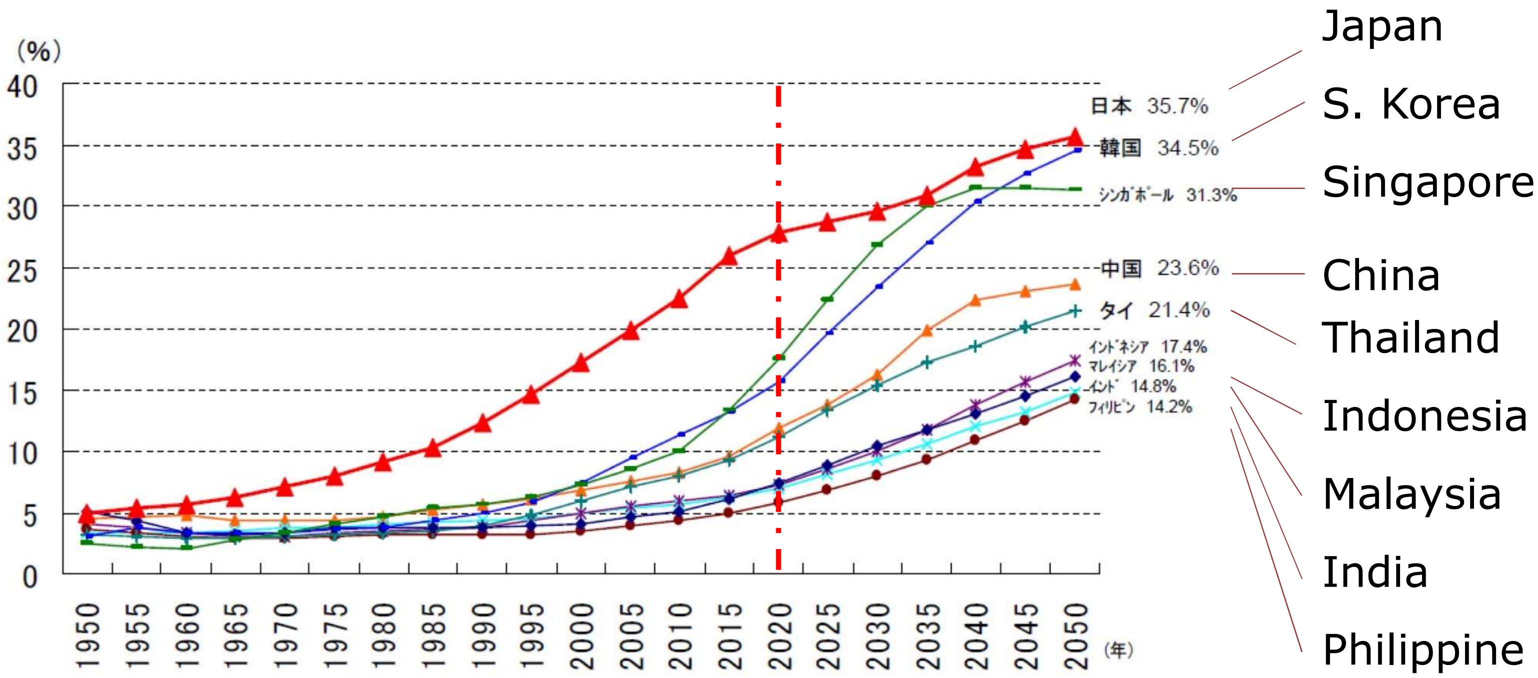
Naritasan Sinshoji Temple

Outlines

- Introduction
- EM for Monitoring Human Functions
- EM as Driving Mechanisms for Human Functions
- Conclusions & Remarks

Introduction

A Global Phenomenon: Population Ageing



Japan is the Top Runner: 26.7% aged 65 or over

Japanese Ministry of Internal Affairs and Communications

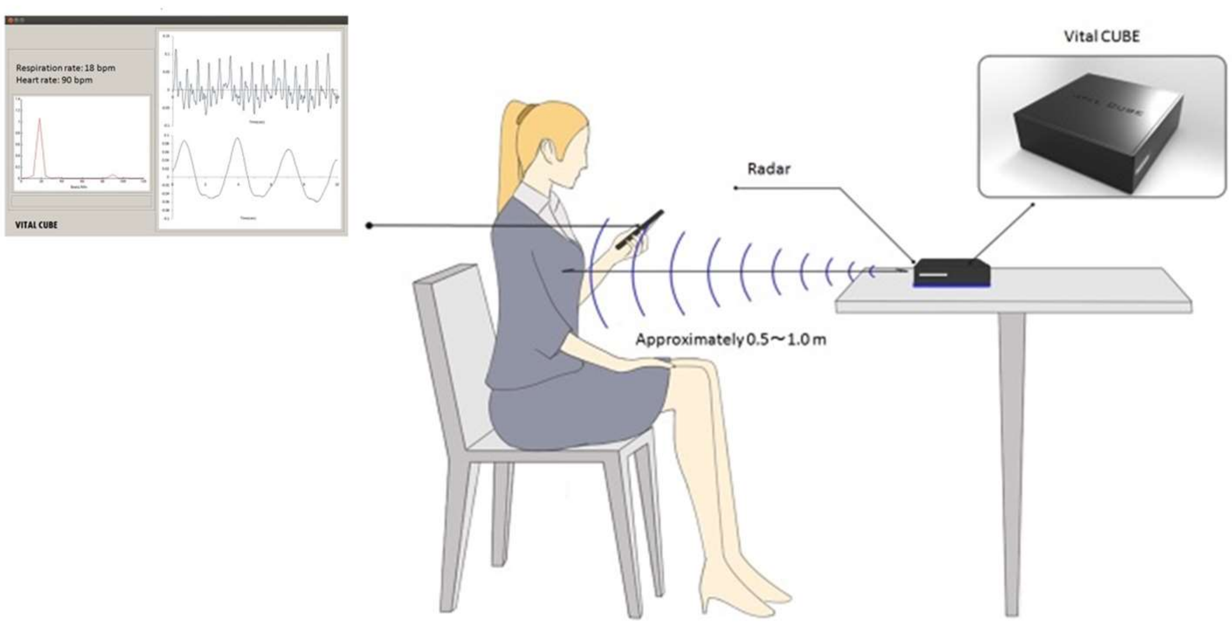
Introduction

- Big challenges to healthcare and rehabilitation caused by population aging.
- One of the challenges: the lack of caregiving personnel, especially, monitoring and guiding older people at home, urgently needs technology aid.
- Electromagnetic waves, which are “transparent energy” yet can interact with substances, have become popular in this sector.
- Although short penetration depth makes it difficult for EM to reach the targeted sites, 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

EM for Monitoring Human Functions

Far-field Applications

Millimeter-wave radar system to monitor respiration and heartbeat signals [1]



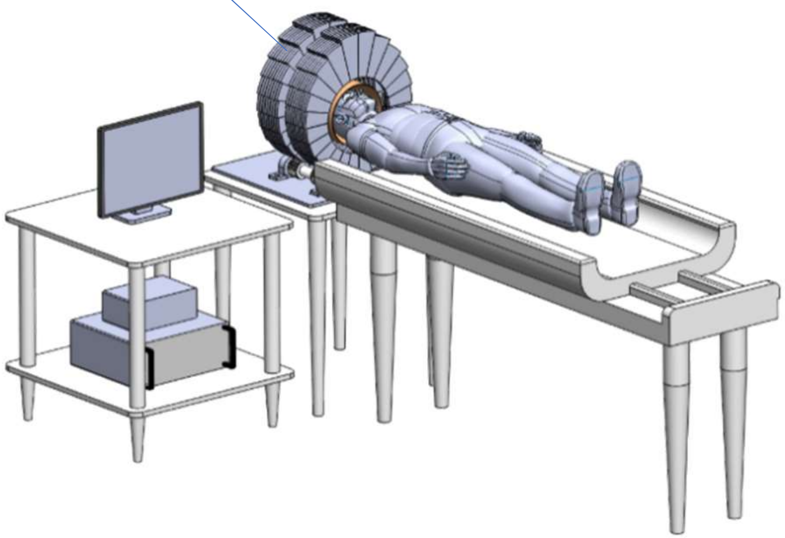
[1] Guanghao Sun, Shinji Gotoh, Zijun Zhao, Seokjin Kim,Satoshi Suzuki, Nevrez Imamoglu, Wenwei Yu, and Takemi Matsui, “Vital-CUBE: A Non-contact Vital Sign Monitoring System Using Medical Radar for Ubiquitous Home Healthcare”, Journal of Medical Imaging and Health Informatics, 4, 863-867 (2014)

EM for Monitoring Human Functions

Near-field Applications

Permanent-Magnet-Array-based portable MRI system [1, 2, 3]

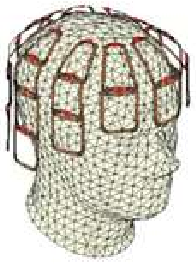
Inward-outward ring permanent magnet array [2, 3]



Tx Coils

A solenoid transmit (Tx) coil with irregular pitches that has strong and homogeneous fields [4]

Rx Coils



Surface receive coils (Rx) that are conformal and designed to be close to the head as much as possible

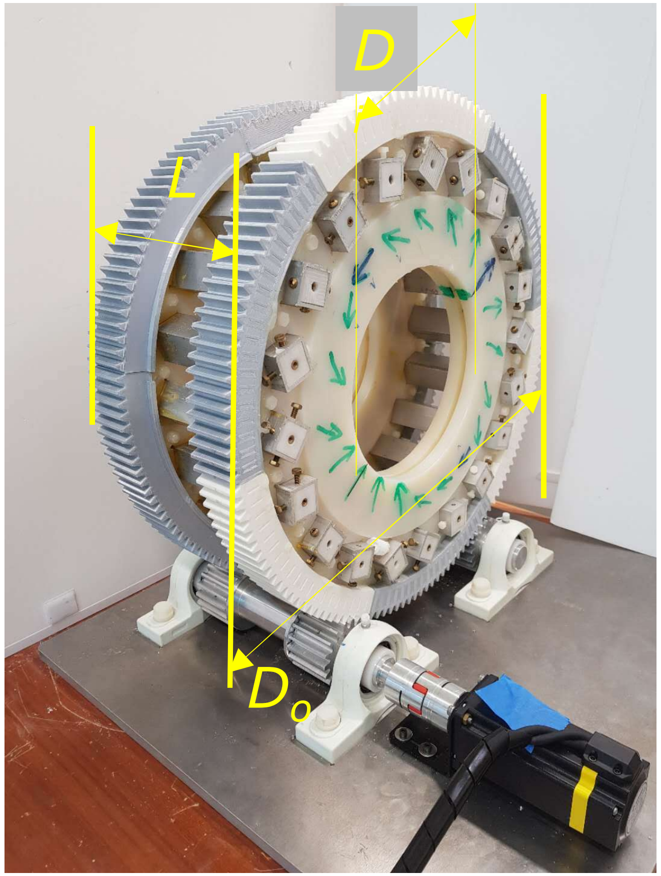
[1] Z. H. Ren, et al, "A Low-field Portable Magnetic Resonance Imaging System for Head Imaging", Progress in Electromagnetics Research Symposium 2017 in Singapore, 19-22 Nov. 2017

[2] Z. H. Ren, et al, "Design and Optimization of a Ring-Pair Permanent Magnet Array for Head Imaging in a Low-field Portable MRI System", IEEE Transactions on Magnetics, Volume 55, Issue 1, Jan. 2019

[3] Z. H. Ren, et al, "An Irregular-shaped Ring-Pair Magnet Array with a Linear Field Gradient for 2D Head Imaging in Low-field Portable MRI", IEEE Access 7, 48715-48724, 2019

[4] Z. H. Ren, et al, "The Design of A Short Solenoid with Homogeneous B1 for A Low-field Portable MRI Scanner Using Genetic Algorithm", poster, ISMRM 26th Annual Meeting & Exhibition, 2018

Short Solenoid for a Short Halbach Array



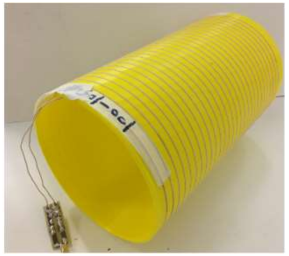
Outer diameter: D_o	450mm
inner diameter: D_i	210mm
The length of the array: L	190mm

Tx coils

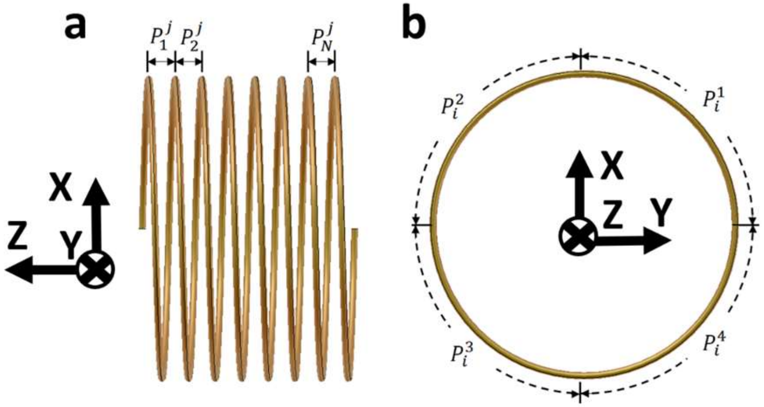
- Homogeneous field
- Compact size, especially short to fit in the magnet
- Low input inductance
  > Easy to match
  > Easy to detune

Solenoid with variable pitches

Problems for standard solenoid:
- High input inductance
- Long ring-down time
- Long

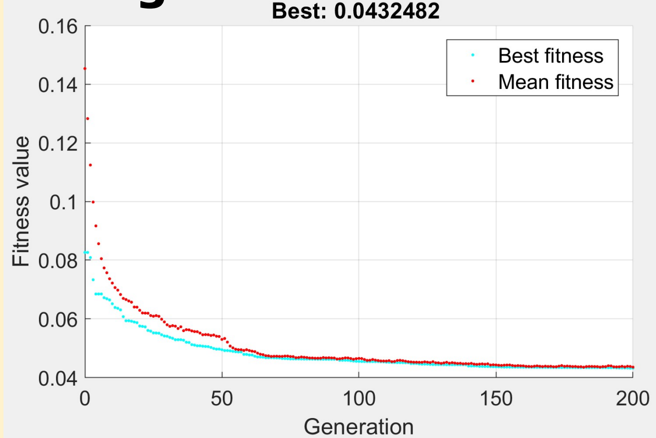


Solution:
A shorter solenoid with variable pitches.

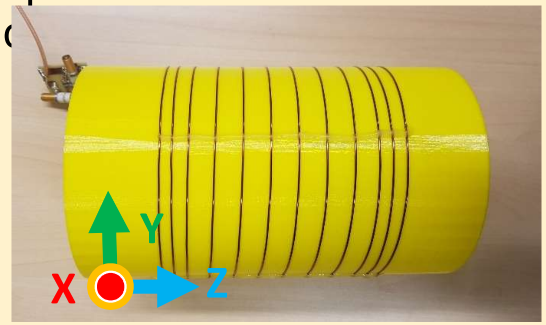


Schematic for optimized solenoid

Variable-pitch solenoid using GA

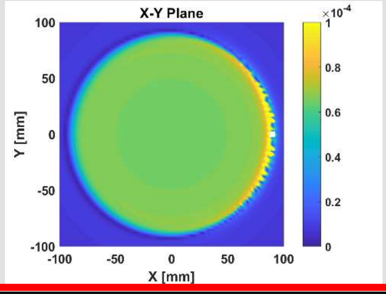
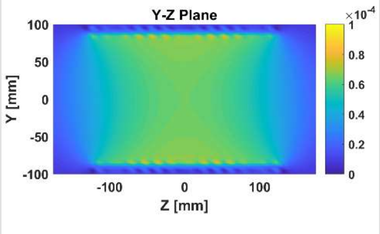
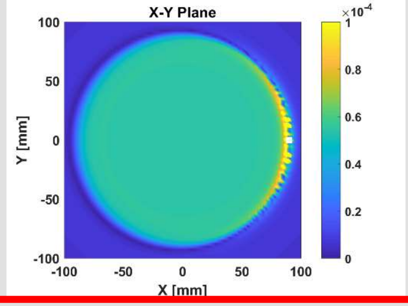
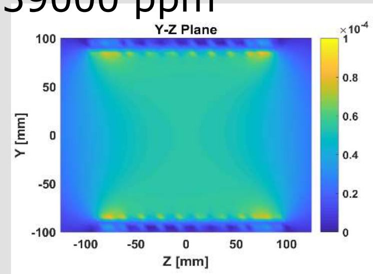
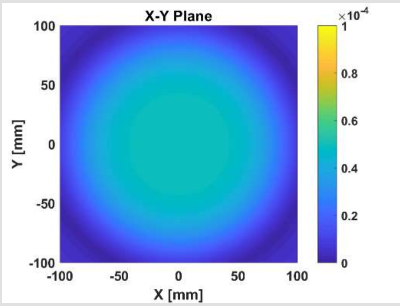
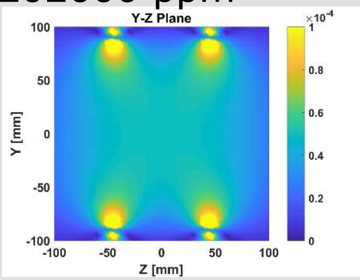


Optimization results for one l



The built optimized solenoid

Comparison of three types of Tx coil

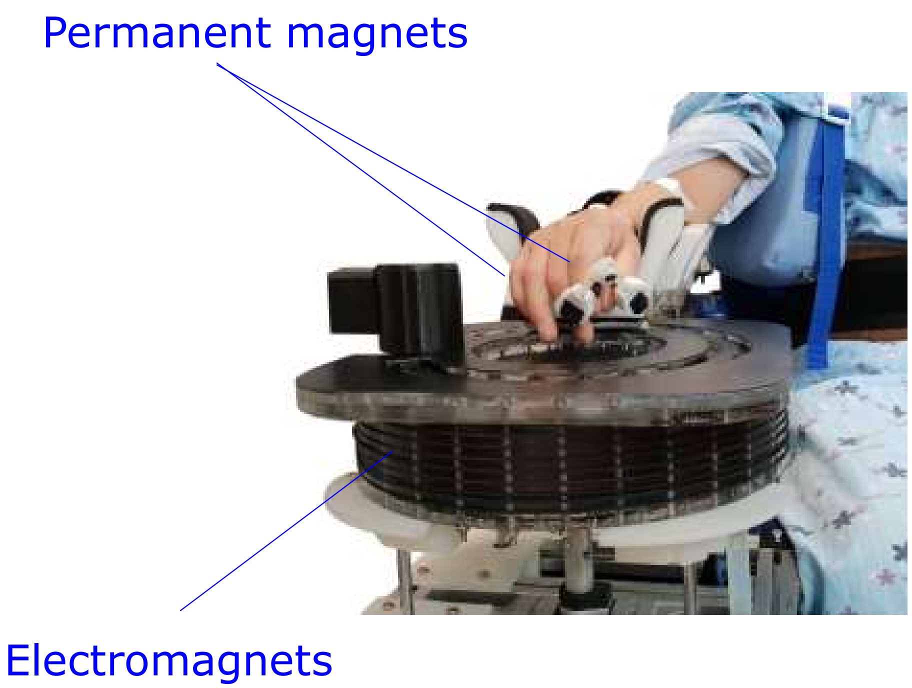
Coil	B_1 in x-y plane	B_1 in y-z plane	L, length
Standard solenoid 		39000 ppm 	L: 32.2 uH Length: 288 mm
Optimized solenoid 		39000 ppm 	L: 12.5 uH Length: 192 mm
Helmholtz Coil 		202000 ppm 	L: 21.2 uH Length: 100 mm

- Homogeneous field
- Compact size
- Low input inductance
  - > Easy to match
  - > Easy to detune

Note: Filed of view is a cylindrical volume with a diameter of 120 mm and a length of 50 mm in the center of the coil.

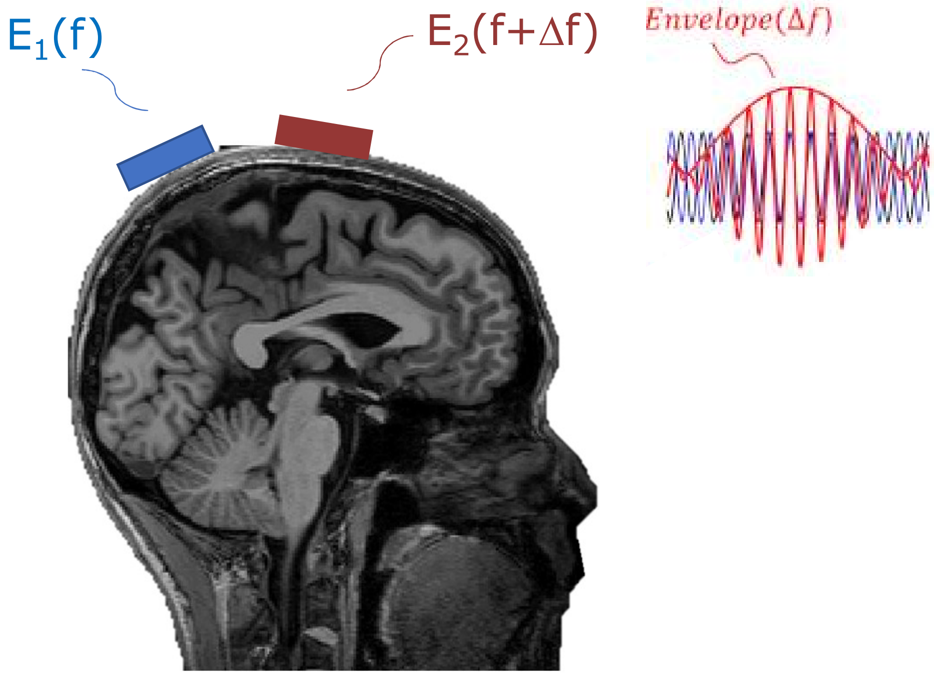
EM as Driving Mechanisms for Human Functions

Magnet-based device has been proposed for hand rehabilitation [1]



[1] I. C. Baek, et al, "A Novel Non-mechanical Finger Rehabilitation System Based on Magnetic Force Control," Journal of Magnetics, vol. 22, no. 1, pp. 155–161, 2017.

Non-invasive Deep Brain Stimulation applying Temporally Interfering Electric Fields [2]

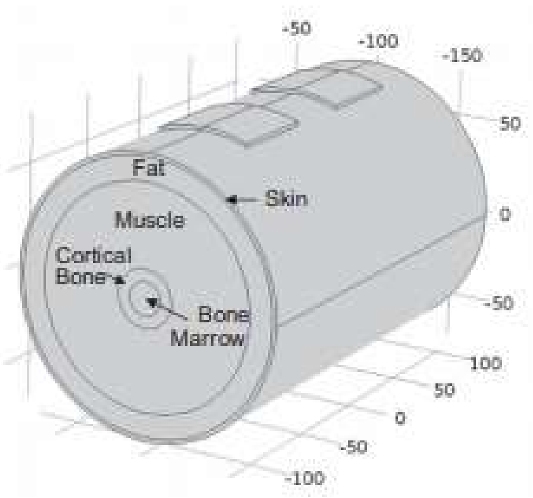


[2] N. Grossman, et al, "Noninvasive Deep Brain Stimulation via Temporally Interfering Electric Fields", Cell 169, 1029–1041, June 1, 2017

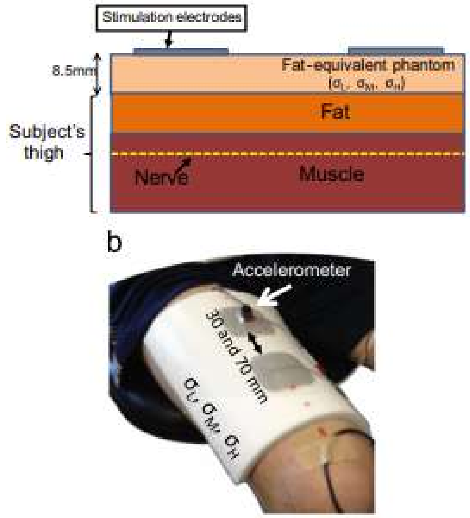
EM as Driving Mechanisms for Human Functions

Penetration depth of stimulation to the nerve in a leg [1]

Cylindrical model



Experimental setup of human-phantom coupling



Finding: Reducing tissue impedance is a possible mechanism to generate muscle activation with less energy to increase the penetration depth

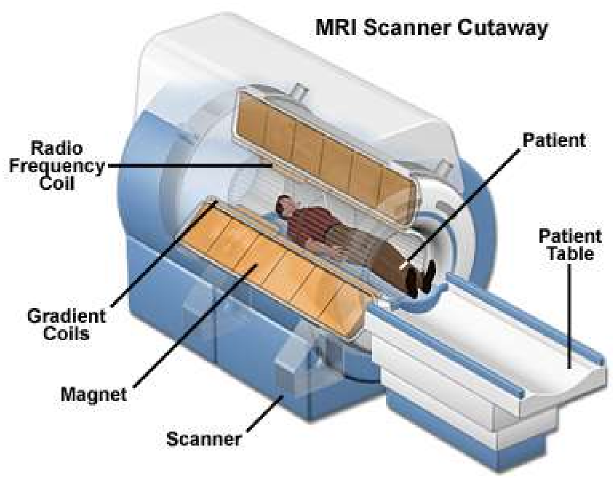
[1] J. Gomez-Tames et al, "A human-phantom coupling experiment and a dispersive simulation model for investigating the variation of dielectric properties of biological tissues", Computers in Biology and Medicine, pp. 144–149, 61, 2015

EM as Driving Mechanisms for Human Functions

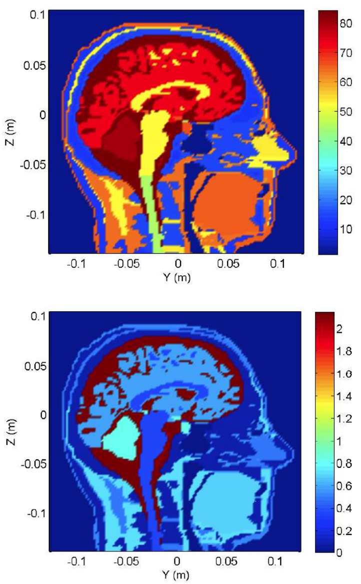
Region-specific regularization of convection-reaction Magnetic Resonance Electrical Property Tomography (MREPT) [1]

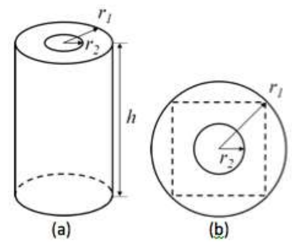
$$\rho \nabla_{xy}^2 \gamma + \mathcal{L}_{xy} \cdot \nabla_{xy} \gamma - \gamma \nabla^2 H_1^+ + i\omega\mu H_1^+ = 0$$

Data from an MRI scanner



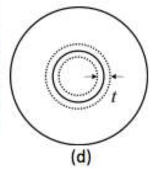
Electrical Properties



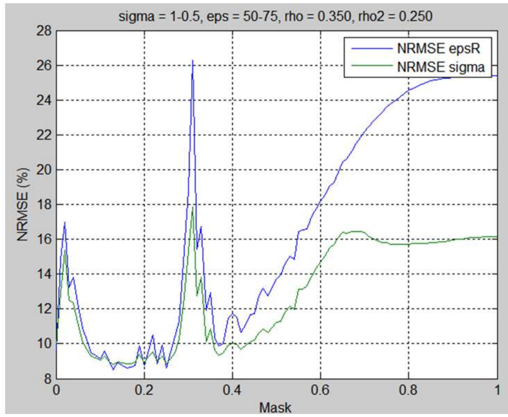


Material	ε	σ [S/m]
gray matter	73.56	0.58
white matter	52.56	0.34
bone	14.72	0.06
cerebellum	79.81	0.82
CSF	84.07	2.14
high contrast	100.00	2.00

(c)



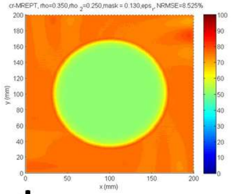
a



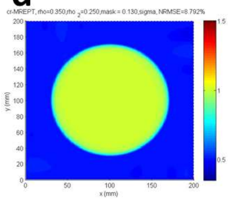
b

t	NRMSE, ε	NRMSE, σ
0.09	9.355384	9.170086
0.1	9.142261	9.06551
0.11	9.566394	9.290357
0.12	9.045113	8.999645
0.13	8.525078	8.79184
0.14	8.886735	8.965873
0.15	8.739544	8.904112
0.16	8.589783	8.842088

c



d



[1] A. J. Garcia, W. Yu, and S. Y. Huang, "Region-specific regularization of convection-reaction Magnetic Resonance Electrical Property Tomography (MREPT) for improving the accuracy and noise-tolerance of EP reconstruction", 26th ISMRM 2018

Conclusions & Remarks

- Innovative applications of EM to monitoring and rehabilitation are highlighted.
- Owing to the nature of EM waves, the contact of human-machine interaction can be removed, bringing people convenience.
- Re-designs by exploring different spectrum of frequency/electrical properties have proven to revolutionize the corresponding applications.
- Because of the wide spectrum and invisible power EM offers, more EM-related applications are expected in the near future to tackle the difficulties of aging-related problems.

Thank you

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