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Magnetic Induction Tomography for Brain Tissue Imaging Based on Conductivity Distribution for Parkinson's disease Diagnosis

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ABSTRACT

Parkinson's disease is a prevalent neurodegenerative complication defined by the accumulation of alpha synuclein lewy bodies in the brain. Misdiagnosis results widespread of Parkinson's disease because clinical diagnosis is challenging, underlining a need of a better detection technique, such as non-invasive magnetic induction tomography (MIT) technique. Non-invasive techniques for biological tissues imaging are becoming popular in biomedical engineering field. Therefore, MIT technology as a non-invasive technique has been encouraged in a medical field due to its advancement of technology in diagnosing diseases. The measurement parameters in MIT are passive electromagnetic properties (conductivity, permittivity, permeability) for biological tissue and the most dominant parameter in MIT is conductivity properties. It is uses a phase shift between a primary magnetic field and an induced field caused by a target object's conductivity. As a function of conductivity, the phase shift between the applied and secondary fields is expressed. Thus, the phase shift can be used to characterize the conductivity of a target object. The phase shift between the excitation and induced magnetic fields (EMF and IMF) reflects the change in conductivity in biological tissues. This paper focuses on the virtual simulation by using COMSOL Multi-physics for the design and development of MIT system that emphasizes on single channel magnetic induction tomography for biological tissue (bran tissue) imaging based on conductivity distribution for Parkinson's disease diagnosis. The develop system employs the use of excitation coils to induce an electromagnetic field (e.m.f) in the brain tissue, which is then measured at the receiving side by sensors. The proposed system is capable of indicating Parkinson's disease based on conductivity distribution. This method provides the valuable information of the brain abnormality based on differences of conductivities of normal brain and Parkinson's disease brain tissues.

Keywords: Parkinson's disease, Magnetic Induction Tomography, COMSOL Multiphysics

1. INTRODUCTION

Parkinson's disease is serious disease caused by abnormal accumulation of alpha synuclein in the brain, which leads to movement disorder or even death [1]. To reduce mortality, various medical screening methods such as computed tomography (CT), chest radiography, magnetic resonance imaging (MRI), ultrasound, and x-ray have been intensively investigated [2]. However, most of them are expensive and not sensitive enough for detecting early stage of Parkinson's disease. CT detects more early stage of brain disease than conventional radiography, but it is relatively expensive [3]. Device with improved sensitivity and low cost is needed as the best device for detecting Parkinson's disease earlier. Therefore, the objective of this project is to determine the feasibility of MIT for the detection of Parkinson's disease by using single channel magnetic induction tomography based on conductivity distribution [4].

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MIT is a low-cost, non-invasive and does not emit ionizing radiation and therefore it is a harmless modality for the application in biomedical [5]. MIT is a new technique, which consists of primary magnetic fields that are produced by the transmitter coils to induce eddy currents in the object. This eddy currents will produce secondary magnetic field that will be measured by receiver coils. Thus, the weak signal produced by eddy current can be measured by the presence of noise and large signals resulting from direct excitation-detection coil coupling [6]. In spite of that, MIT is preferred for imaging biological tissue since the conductivity is dominant property compared to other properties of passive electromagnetic properties which are permittivity and permeability.

2. MATERIAL AND METHODS

This section provides a summary of the methodology, including sample preparation and simulation with circular and square coils. The project begins with a review of previous research on Parkinson's disease and magnetic induction tomography, followed by a study of the parameters that can be used in this study. Following that, research on COMSOL Multiphasic software version 5.0 and its simulation is discussed. After knowing the parameter, the simulation can be done, and the data can be collected from the simulation result. The flowchart of the methodology includes the simulation and the hardware experiment (Figure 1). Based on the relationship between the phase shift and the conductivity range for 10 MHz, the four coils' performance will be compared and chose the best one for further analysis.

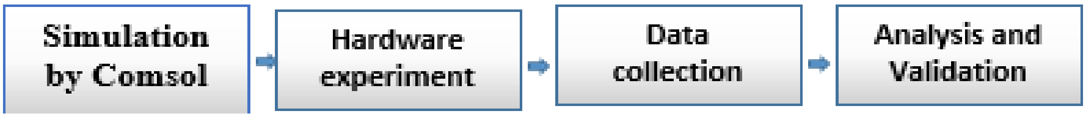

Figure 1. Flowchart of the experiment

2.1 Simulation by using COMSOL Multiphasic 5.0

The designing of magnetic induction tomography (MIT) system with brain 2D model is to show the flow pattern of the eddy current. It has been made by using two coils placed at both sides of the brain area (Figure 2). This section discusses the use of a single channel MIT system for simulating 2D models for imaging brain tissues for Parkinson's disease identification. The simulation system is obtained by using COMSOL Multi-physics software based on finite element analysis method (FEM), simulated by using numerical method in order to validate analytical solution. The simulation was performed based on the locations, depth and diameter of the material used in the COMSOL Multi-physics software. Using COMSOL multiphysics, simulation was carried based on magnetic induction tomography by the excitation of the transmitter coil (Figure 2). The study of the output result was analyzed to get the information of the single channel magnetic induction for biological tissue. FEM is a numerical technique used to perform finite element analysis (FEA) of any given physical phenomenon. 10 MHz frequency was used in the simulation process and β scattering region was chosen because this is where mostly the pathological changes occur. The simulation workstation used was a Dell Inspiron PC with an i5 processor and 8GB RAM. A triangular cross section with a linear and iterative solver was used in CONSOL, with a default solver relative resilience of 0.01 [11]. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

2.1.1 Samples preparation

The brain blood was represented by sodium chloride in six sample solutions, prepared using a conductivity meter. The samples were added to distilled water to measure conductivity. A 2D model of the brain-magnetic system was created, with the transmitter coil excited to induce simulation (Figure 2). The results are shown in Table 1. The study used sodium chloride as a representative of the blood of the brain due to its similar conductivity properties. The conductivity of sodium chloride closely resembles that of blood, making it a suitable surrogate for investigating the electrical properties of brain tissue. Six samples were prepared for the experiment, each with a different conductivity range. The conductivity meter was used to measure the conductivity during the process of adding sodium chloride to distilled water. The 2D model of the brain-magnetic system was depicted on the left side, while the transmitter coil was excited to induce simulation on the right side. The choice of sodium chloride as a surrogate for the blood of the brain was determined based on previous studies that demonstrated the comparable conductivity effects of sodium chloride on biological tissues. The experiment aimed to understand the electrical properties of brain tissue in the brain.

Table 1 Conductivity range values for the samples prepared

Number of sample	Conductivity value (ms/cm)
1	10.92
2	15.95
3	20.99
4	25.94
5	30.93
6	35.97

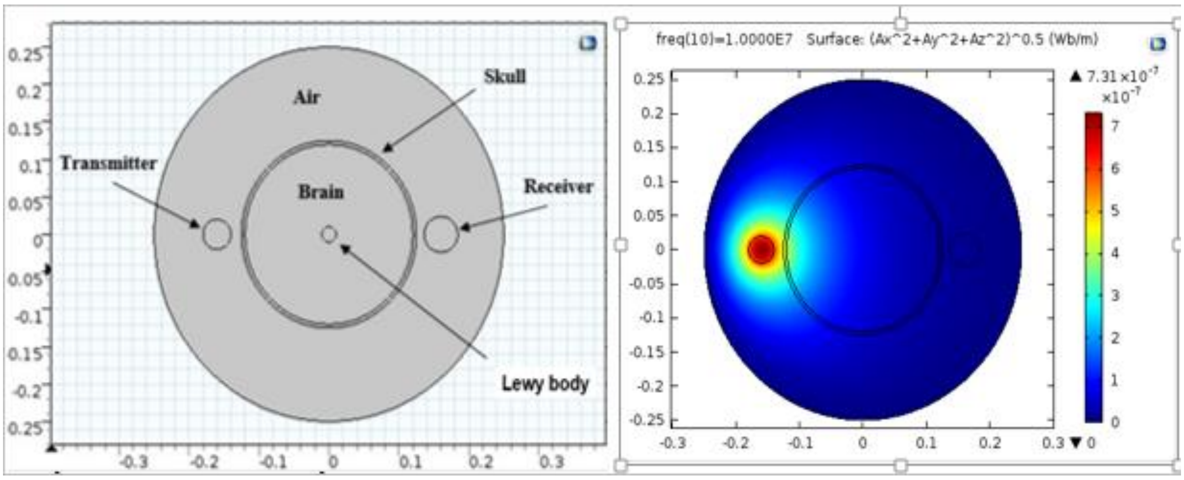

Figure 2. 2D model of the brain-magnetic system (left). The excitation for the transmitter coil to induce simulation (Right)

2.1.2 Hardware experiment and data Collection with MIT system

Magnetic Induction Tomography is a system used to study the conductivity distribution within the human body. It involves conducting hardware experiments and collecting data to evaluate its performance and feasibility. Induction coils are used to detect eddy currents in conductors exposed to a magnetic field, obtaining images of the conductivity distribution. This method is preferred over Hall sensors due to its higher signal-to-noise ratio. Various transmission methods are being developed for magnetic induction tomography, analyzing the amplitude and phase distortion of magnetic force lines passing through the test medium. The hardware experiment and data collection phase are crucial for evaluating the system's performance and feasibility. Careful control and monitoring of various factors are necessary for reliable and accurate data collection.

Table 2 Parameters used for the comparison of 4 coils performance channel MIT model of simulation

Parameter	Value
Number of turns of coils	5
Applied current into the coils	Transmitting coil: 1 A Receiving coils: 0 A
Coils configuration	5TX-12RX
Type of coil	Circular and square
Coils material	Copper
Coils diameter	0.015 m
Thickness of skin tissue	0.0051 m
Insulator size	0.4 m * 0.4 m
Frequency used	10 MHz
Di-electrical properties of the normal brain tissue	Conductivity: 1.0968 S/m Permittivity: 7.8933
Di-electrical properties of skin (dry)	Conductivity: 0.197323 S/m Permittivity: 361.670349
Di-electrical properties of the brain affected tissue	Conductivity: 8.2 mS/m Permittivity: 300

3. RESULTS AND DISCUSSION

The developed system for Parkinson's disease identification based on conductivity requires the identification of the most suitable frequency transceiver pair. This can be achieved through simulations using COMSOL Multiphysics 5.0 and MATLAB2010a, as well as hardware testing using a single channel MIT system. Comparing the performance of different frequency transceiver pairs can help determine the optimal pair for detecting Parkinson's disease based on conductivity. Analyzing conductivity data from different pairs can help identify the pair with the highest accuracy and reliability. This analysis aims to verify the system's performance and accuracy in detecting Parkinson's disease based on conductivity measurements.

3.1. *Phase shift with varying frequency for normal brain tissue with different coils and number of turns*

The phase shift increases with increasing the frequency for the normal brain tissue conductivity (Figure 3.1). The phase shift in normal brain tissue is influenced by the frequency of magnetic induction, which can be observed using various coils and turns. Ultra-high field gradient-echo imaging has shown that the spatial variation of magnetic susceptibility in brain tissues generates a unique phase contrast between gray and white matter, providing a superior contrast-to-noise ratio compared to the corresponding magnitude image. This frequency-dependent phase shift is significant in the field of magnetic induction tomography, providing insights into the electrical conductivity properties of the brain. The phase shift increases with increasing frequency for normal brain tissue conductivity, making it useful for detecting Parkinson's disease -induced changes in magnetic susceptibility and assessing alpha synuclein concentration in brain tissues.

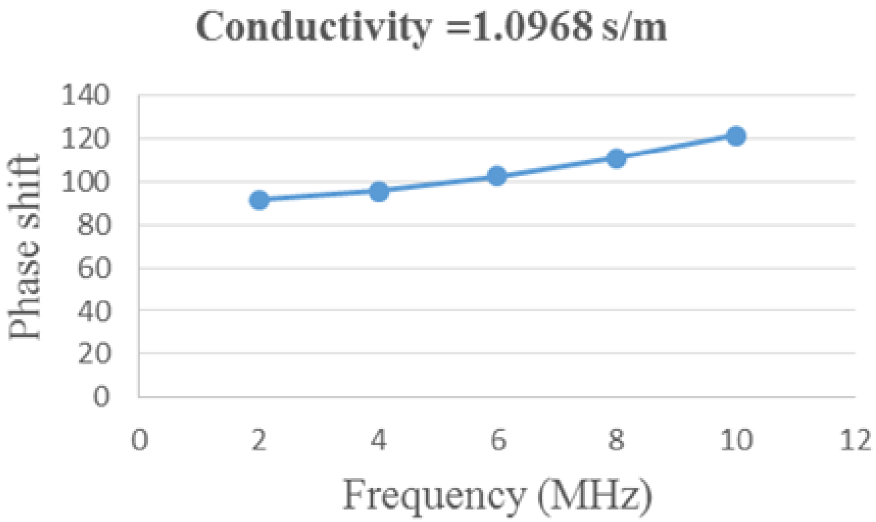

Figure 3.1. Phase shift for normal brain tissue conductivity

3.2. *Comparison between the performance of the four coils*

Based on the relationship between the phase shift and the conductivity range for 10 MHz, the four coils' performance was compared. The graph shows that, when compared to the other three coils, the square coil with the most coils (5Tx-12Rx), five transmitter to twelve receiver (TX-RX) during the magnetic induction tomographic measurement system, has the best overall performance (Figure 3.2). As a result, this coil has been chosen for use in the section on data accuracy analysis.

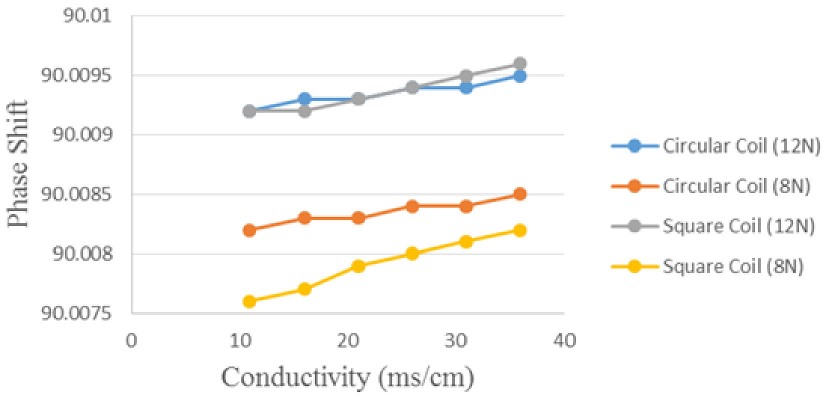

Figure 3.2. Performances of the four coils with 10MHz

3.3. *Phase shift with varying frequency and varying conductivity*

The phase shift analysis technique is a method that uses high precision in phase shift measurement to detect and quantify tissue lesions, including those associated with Parkinson's disease. This technique involves a phase shift between the primary and secondary magnetic fields generated by induced eddy currents in cerebral tissues. The inductive phase shift, generated by changes in electrical conductivity, can be detected as a composite magnetic field using sensor coils. The study found that the phase shift increases with increasing frequency, suggesting that the conductivity of brain tissue and the varying conductivity of Parkinson's disease may contribute to the increase in phase shift with higher frequencies (Figure 3.3). This technique can be a valuable tool for detecting Parkinson's disease and distinguishing it from normal brain tissue. Magnetic induction tomography imaging is a non-invasive technique that uses eddy currents to detect and analyze changes in the electrical conductivity of biological tissues. The phase shift, a key parameter in this technique, is the difference in phase between the excitation and detection signals. This shift can be caused by factors such as differences in tissue conductivity, abnormalities in tissue structure, or lesions or diseases within the tissues. The Magnetic Inductive Phase Shift technique is used to detect this phase shift, which helps reconstruct the electrical conductivity distribution within the human body. The main purpose of phase shift in magnetic induction tomography imaging is to detect and analyze changes in the electrical conductivity of biological tissues. The phase shift information obtained through this technique is crucial for understanding the electrical conductivity distribution within the human body.

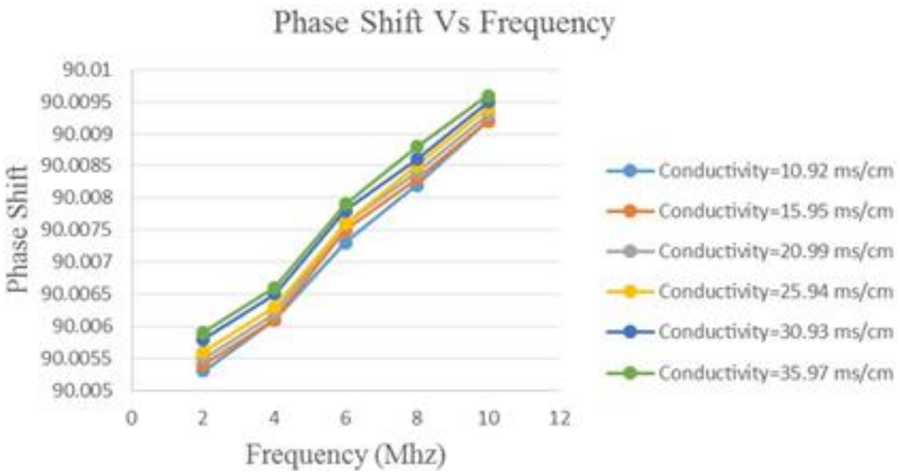

Figure 3.3. Phase shift for 5Tx-12Rx of square coil

Table 3.1 The calculated value of the phase shift with varying frequencies and conductivity values

Conductivity (ms/cm)	Frequency (MHz)				
Range	**2**	**4**	**6**	**8**	**10**
10.92	90.0053	90.0061	90.0073	90.0082	90.0092
15,95	90.0054	90.0061	90.0073	90.0083	90.0092
20.99	90.0055	90.0062	90.0076	90.0084	90.0093
25.94	90.0056	90.0063	90.0076	90.0085	90.0094
30.93	90.0058	90.0065	90.00738	90.0086	90.0095
35.97	90.0059	90.0066	90.0079	90.0088	90.0096

3.4. Data Accuracy

The phase shift for the 10MHz frequency with varying conductivity of the normal and abnormal brain tissues for the square coil (5Tx-12Rx) are increasing with increasing the conductivity (Table 3.2). The percentage error between the actual and the estimate value was estimated. The actual values and the estimated values increase with increasing the conductivity and the errors also increases (Table 3.3). The purpose of calculating the actual and estimated values is to determine the differences in each conductivity, and Table 3.2 shows that the higher the conductivity, the higher the actual and estimated value. The actual and estimated values were were determined to be 90.0096 and 90.0098 with a percentage error of less than 0.03%, respectively, based on the observation during magnetic induction tomography measurement, demonstrating the efficiency and reliability of magnetic induction tomography as a measuring method (Table 3.2). Magnetic induction tomography measurements were used to evaluate the accuracy of conductivity values. This demonstrates the reliability and effectiveness of magnetic induction tomography as a measuring method for conductivity. The high accuracy and low percentage error in conductivity values indicate the precision and accuracy of this technique in measuring electrical properties. This high accuracy and low percentage error demonstrate the potential of magnetic induction tomography to provide accurate and reliable information about the electrical properties of materials. Data accuracy is crucial in magnetic induction tomography with COMSOL Multiphysics, as it allows for reliable and precise measurements of electromagnetic properties within a system. In medical imaging, the accuracy of data becomes even more critical. A study by Chen, Lee, and Liu found that due to the low conductivity of biological tissue, a high accuracy phase measurement system is necessary [7]. Gradiometer coils, consisting of two detection coils and an excitation coil, are often used to achieve this high accuracy. Another study supports the use of gradiometer coils to increase phase accuracy in magnetic induction tomography [8]. Additionally, magnetic induction tomography can be used to reconstruct the conductivity of a given object or system through relative measurements, where the conductivity distribution is determined relative to a reference point. Data accuracy is crucial in scientific reports, particularly in fields like medicine and dentistry, where misuse of statistics and data misinterpretation can negatively impact patient care and treatment outcomes. This analysis examines the data accuracy of a linear regression graph plotting the relationship between phase shift and conductivity. The methodology used is a linear regression analysis, represented by the equation y = 90.009 + 1.7124E-05X, where y represents conductivity and X represents phase shift (Figure 3.5). To further analyze data accuracy, it is recommended to increase the sample size to obtain a larger and more representative data set. Previous studies on the accuracy of diagnosis in insurance claims data reported an accuracy rate of 80%. To ensure high analytical data accuracy, a strong correlation between measured electrical conductivity and calculated electrical conductivity from ion concentrations is essential.

Table 3.2 Phase shift for the 10MHz frequency and square coil (5Tx-12Rx)

Conductivity (ms/cm)	Phase shift (actual value)	Estimate value	Error %
10.92	90.0092	90.0093	0.001 %
15.95	90.0092	90.0093	0.001 %
20.99	90.0093	90.0094	0.001 %
25.94	90.0093	90.0096	0.002 %
30.93	90.0095	90.0097	0.002 %
35.97	90.0096	90.0098	0.002 %

Table 3.3 Actual and the estimated values increase with increasing the conductivity

Conductivity (ms/cm)	Phase shift
10.92	90.0091
15.95	90.0092
20.99	90.0093
25.94	90.0093
30.93	90.0095
35.97	90.0096

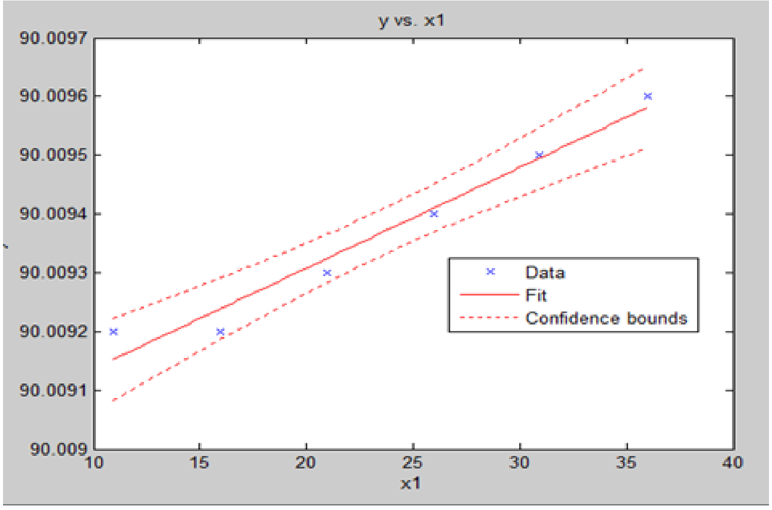

Figure 3.5. The linear regression graph of different phase shift and conductivity (y = 90.009 + 1.7124E-05X.)

4. CONCLUSION

This project aims to assess the effectiveness of different frequency transceiver pairs for accurate detection of Parkinson's disease using magnetic induction tomography using COMSOL Multiphysics software. A low-power embedded computer is used for data mining and analysis on wearable sensors for telehealth applications. A simulation model is built to determine the optimal frequency transceiver pair for detecting Parkinson's disease, considering the dielectric properties of normal and Parkinson's disease brain tissues. Data is collected for each coil with a frequency range of 1-10MHz using four circular and square coils. The phase shift is calculated, and graphs are plotted to compare the performance of different coils for normal and Parkinson's disease brain tissues. The results will provide valuable insights into the performance of different frequency transceiver pairs for detecting Parkinson's disease using magnetic induction tomography. The proposed architecture aims to improve the effectiveness of telehealth applications in Parkinson's disease monitoring.

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REFERENCES

1. Xu L, Pu J. Alpha-Synuclein in Parkinson’s Disease: From Pathogenetic Dysfunction to Potential Clinical Application. Parkinson’s Disease 2016;2016.
2. Brogi E, Bignami E, Sidoti A, Shawar M, Gargani L, Vetrugno L, et al. Could the use of bedside lung ultrasound reduce the number of chest x-rays in the intensive care unit? Cardiovascular Ultrasound 2017;15(1):1–5.
3. Ogawa T, Fujii S, Kuya K, Kitao SI, Shinohara Y, Ishibashi M, et al. Role of neuroimaging on differentiation of Parkinson’s disease and its related diseases. Yonago Acta Medica 2018;61(3):145–55.
4. Meijer FJA, Goraj B, Bloem BR, Esselink RAJ. How i do it: Clinical application of brain mri in the diagnostic work-up of parkinsonism. Journal of Parkinson’s Disease 2017;7(2):211–7.
5. Park CS, Jeon J, Oh B, Chae HY, Park K, Son H, et al. A portable phase-domain magnetic induction tomography transceiver with phase-band auto-tracking and frequency-sweep capabilities. Sensors (Switzerland) 2018;18(11).
6. Saiful M, Mansor B, Jumaah MF, Zakaria Z, Rahim RA, Nor NM, et al. Sensors & Transducers Magnetic Induction Tomography Modeling in Biological Tissue Imaging Using Two-Port Network Technique. 2013;150(3):112–9.
7. Chen J, Ke L, Du Q, Zu W, Ding X. Sector sensor array technique for high conductivity materials imaging in magnetic induction tomography. BioMedical Engineering Online 2019;18(1):1–16.
8. Amran M, Daud R, Ali Hassan MK, Zakaria Z, Omar MI, Mat F. Effect of electromagnetic induction spectroscopy of femur bone on electromagnetic signal strength. IOP Conference Series: Materials Science and Engineering 2019;705(1).
9. Ma L, McCann D, Hunt A. Combining Magnetic Induction Tomography and Electromagnetic Velocity Tomography for Water Continuous Multiphase Flows. IEEE Sensors Journal 2017;17(24):8271–81.
10. Bakshi S, Chelliah V, Chen C, van der Graaf PH. Mathematical Biology Models of Parkinson’s Disease. CPT: Pharmacometrics and Systems Pharmacology 2019;8(2):77–86.
11. Driscoll M. The Impact of the Finite Element Method on Medical Device Design. Journal of Medical and Biological Engineering [Internet] 2019;39(2):171–2.