URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

Detection of Alzheimer's Disease in Human Brain using Microwave Sensor

Namrata Mendiratta [(1)], Komal Kumari [(1)] , Gopi Shrikanth Reddy[(1)] and Anirban Sarkar [(1)]
[(1)] School of Computing and Electrical Engineering, The Indian Institute of Technology Mandi, Himachal Pradesh 175005, India

Abstract

This research presents an innovative concept for an EM bio-sensor, validated through a realistic human head voxel model for detecting Alzheimer's disease of three different stages (mild, moderate and severe) in the human brain. The sensor was simulated using CST Studio. The key finding is that the EM bio-sensor can easily detect Alzheimer's disease. With its realistic approach for clinical applications, this method is suitable for non-invasive RF sensing in biomedical applications, offering benefits such as low cost, highly sensitive and compact.

1. Introduction

Alzheimer's disease is a progressive brain disorder marked by the buildup of specific proteins in the brain. This condition leads to brain shrinkage and the gradual death of brain tissue. As the leading cause of dementia, Alzheimer's results in a steady deterioration of memory, cognitive abilities, behavior, and social skills, significantly impairing a person's capacity to function [1-2]. Recently, more than 55 million people worldwide are having dementia, with over 60% of them living in developing countries. New cases around 10 million are diagnosed each year [3-6]. Microwave sensing is increasingly recognized as a promising technique for medical screening due to its numerous benefits [7]. These include lower power consumption, low consumption, low price, reliability, security, and adequate depth of propagation in deep-tissue monitoring. In particular, lower frequency bands (1-4 GHz) allow for superior propagation depth compared to other methods. This makes microwaves ideal for applications requiring deeper penetration, such as all over brain screening, breast health surveillance, and implant communications like capsule endoscopy [8-11].

This paper proposes a microwave sensor designed for detection of Alzheimer's disease of different stages by examining changes in frequency response due to variations in the brain tissue's relative permittivity. Early detection of these diseases allows for more effective treatment since the conditions are identified in their initial stages. This detection method is cost-effective compared to the techniques currently in use.

2. Design of Proposed Microwave Sensor

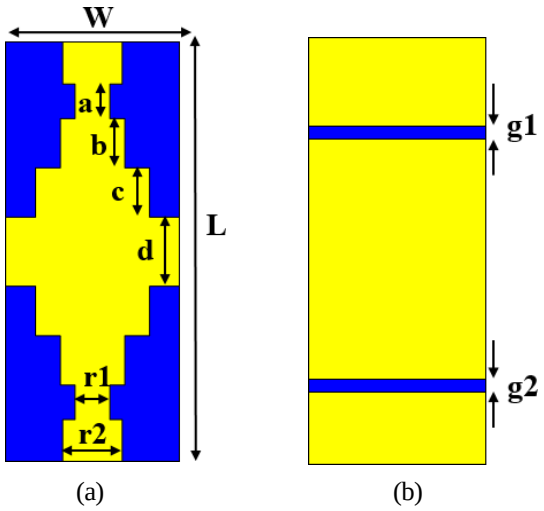


Figure 1. Proposed EM sensor (a) front view (b) Back view

The proposed microwave sensor, depicted in Figure. 1, generates a single resonant frequency within the 1 GHz to 3 GHz range. This resonant frequency is employed to detect Alzheimer's disease. The resonant frequency is specifically observed at 2.24 GHz for S_{11} and 2.23 GHz for S_{22} as shown in Figure.2. A microstrip transmission line is employed to convey power between two ports. A ground plane is situated beneath the substrate. The designed sensor is constructed on Rogers 5880 substrate, which has a relative permittivity (ε_r) of 2.2 and a thickness (h) of 3.175 mm.

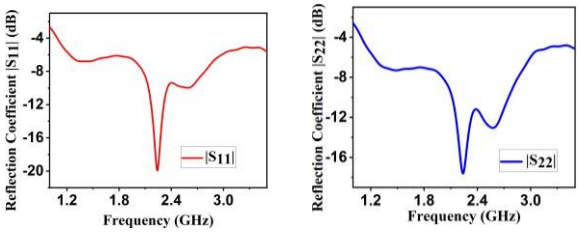
TABLE I. STRUCTURAL PARAMETERS OF THE PROPOSED EM SENSOR (IN MM)

Variables	***W***	***L***	***a***	***b***	***c***
Size	35 *mm*	85 *mm*	7 *mm*	10 *mm*	10 *mm*
Variables	***d***	***r1***	***r2***	***g1***	***g2***
Size	14 *mm*	7 *mm*	12 *mm*	3.50 *mm*	2.50 *mm*

3. Operating Principle

RF sensors continuously emit electromagnetic fields into their surroundings. These fields interact with nearby

objects and reflect back to the sensor. By analyzing the frequency shifts of these reflected waves, the sensor detects



(a) (b)

Figure 2. Reflection Coefficient of the proposed sensor (a) S_{11} (b) S_{22}

the changes in the biological environment. When any changes in brain occur due to Alzheimer's disease, it can alter the relative permittivity of the healthy brain. Therefore, as the dielectric constant of the brain changes, the resonance frequency of the RF sensor also shifts, altering the S_{11} and S_{22} parameters from their original positions.

The area of the proposed sensor where the electromagnetic fields are most focused is utilized for purposes of detection. When brain is placed in this region of highest field concentration, the sensor shows a prominent response in terms of complex permittivity and permeability. The red portion in Figure 3. determines the region of high electric field concentration.

4. Results and Discussions

The proposed sensor is placed outside the head voxel model as shown in Figure 4. (b) . the interaction between the brain and sensor is observed. The head voxel model Figure 3**.** Electric field concentration of the proposed sensor

includes shapes and materials representing various regions, tissues, and ventricles of the brain. It provided a realistic depiction of the human head, featuring different layers such as skull, cerebrospinal fluid (CSF), gray matter, skin, and white matter shown in Figure 4. (a).

The dielectric properties of specific regions and tissues were adjusted to align with the measurements obtained from dielectric assessments of the tissues. The dielectric properties of the brain are changed in accordance with the Alzheimer's disease. Different parts of brain affected in case of Alzheimer's disease (AD) for different stages are represented in Figure 5. Table II. lists the specific region of brain that were affected during Alzheimer's Disease due to formation of plaque and tau protein.

A shift in amplitude of reflection coefficient (S_{11}) is of around 0.3 dB in mild stage AD while 1 dB shift is seen in moderate stage AD and a shift of 7 dB in amplitude of the resonant frequency is observed in case of severe AD when

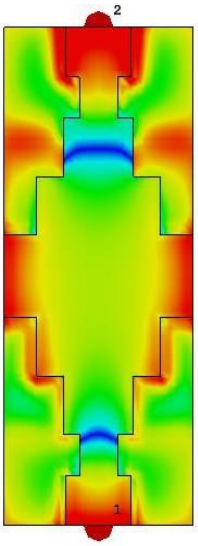


Figure 3. Electric Field distribution of the proposed sensor

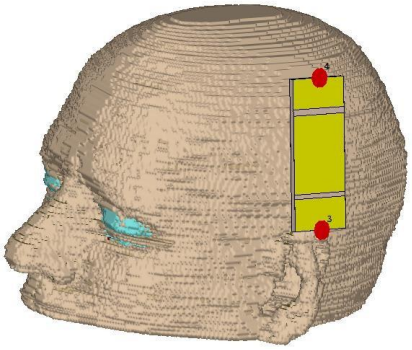
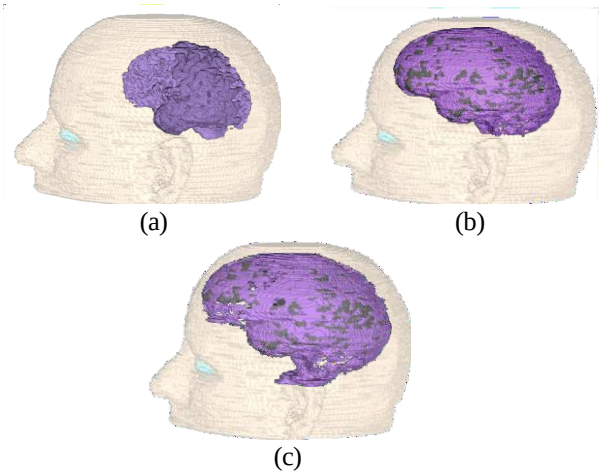


Figure 4. (a) Cross-sectional view of human head voxel model and proposed sensor interaction.



(a) (b)

(c)

Figure 5. Regions of brain affected in different Stages of Alzheimer's disease (a) Mild Stage (b) Moderate stage (c) Severe Stage

compared with resonant frequency obtained for healthy brain as shown in Figure 6(a), Figure 6(b) and Figure 6(c). between healthy brain and brain having Alzheimer's

disease when the proposed is placed near the head voxel model. The dielectric properties of healthy brain and Alzheimer's disease are shown in Table III. and Table IV. Therefore, this difference in the magnitude of S_{11} parameters determines whether the person is having Alzheimer's disease.

TABLE II. REGIONS OF BRAIN AFFECTED DURING DIFFERENT STAGES

Stages	*Brain region affected*
Mild Alzheimer's Disease	1) Medial Temporal lobe (White matter) 2) Temporal Lobe (white matter and gray matter) 3) Parietal Lobe (white matter and gray matter)
Moderate Alzheimer's Disease	1) Medial Temporal lobe (White matter) 2) Temporal Lobe (white matter and gray matter) 3) Parietal Lobe (white matter and gray matter) 4) Frontal Lobe (white matter and gray matter)
Severe Alzheimer's Disease	1) Medial Temporal lobe (White matter) 2) Temporal Lobe (white matter and gray matter) 3) Parietal Lobe (white matter and gray matter) 4) Frontal Lobe (white matter and gray matter) 5) Occipital Lobe (white matter and gray matter)

TABLE III. RELATIVE PERMITTIVITY OF HEALTHY BRAIN

Layer	*Gray Matter*	*White Matter*	*CSF*
Relative Permittivity (ε_r)	54.2	37	66
Conductivity(σ)(S/m)	1.789	1.194	2.45

TABLE IV. RELATIVE PERMITTIVITY OF ALZHEIMER'S DISEASE IN BRAIN

Layer	*Gray Matter*	*White Matter*	*CSF*
Relative Permittivity (ε_r)	42	31	34
Conductivity(σ)(S/m)	3.969	1.945	3.64

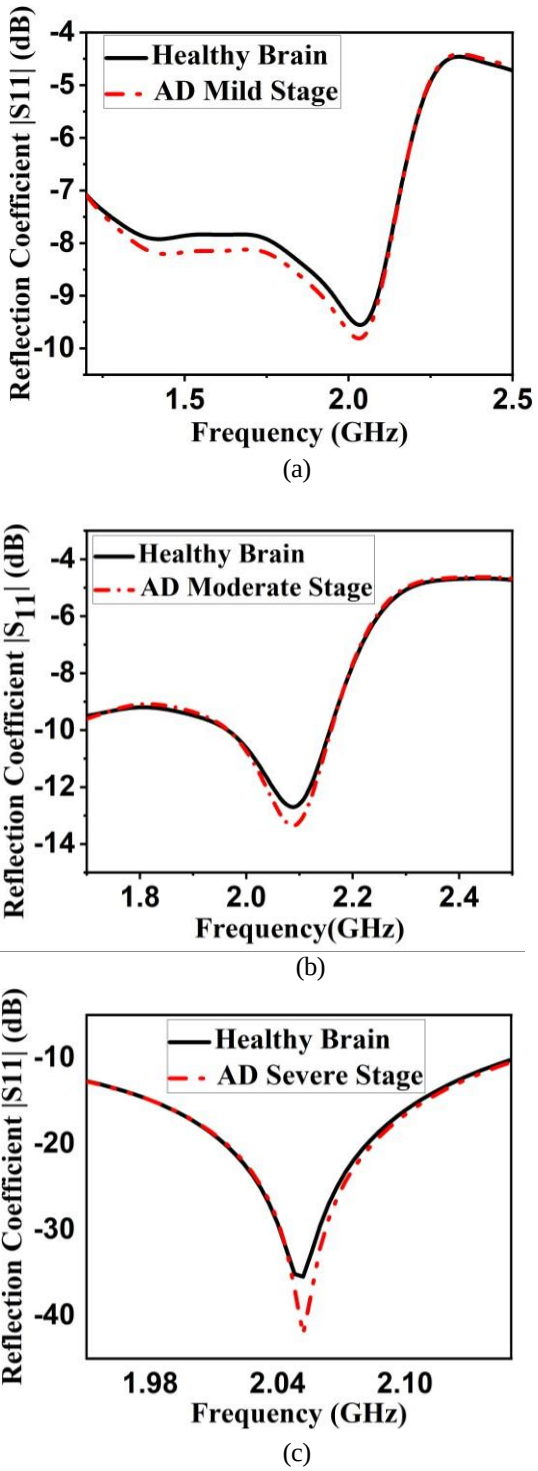


Figure 6. Shift in S_{11} between health brain and Alzheimer's disease (a) Mild Stage AD (b) Moderate Stage AD (c) Severe Stage AD

5. Conclusion

This research introduces a novel concept of developing a EM bio-sensor, which has been validated through human head realistic bead model for Alzheimer's disease in the

human brain. The sensor was simulated in CST Studio. The key conclusion is that the EM bio-sensor can easily detect the Alzheimer's Disease of three different stages i.e. mild AD, moderate AD and severe AD. Given its realistic approach for clinical applications, this method is suitable for next-generation non-invasive microwave sensing in biomedical applications, offering advantages such as low cost and miniaturized size. This portable sensor also holds potential for smart healthcare applications, especially if integrated with a self-powered module.

6. Acknowledgements

I would like to thank IIT Mandi iHUB and HCI Foundation for Financial support and I would also like to thank Dr. Anirban Sarkar and Dr. Gopi Srikanth Reddy for their expert advice and encouragement.

7. References

1. L. C. Walker and H. LeVine, "The cerebral proteopathies," Neurobiol. Aging, vol. 21, no. 4, pp. 559–561, Jul. 2000.

2. C. A. Taylor, S. F. Greenlund, L. C. McGuire, H. Lu, and J. B. Croft, "Deaths from Alzheimer's disease—United States, 1999–2014,"MMWR Morb Mortal Weekly Rep., vol. 66, no. 20, pp. 521–526, 2017.

3. Alzheimer's Association, "2019 Alzheimer's disease facts andfigures," Alzheimer's Dementia, vol. 15, no. 3, pp. 321–387, Mar. 2019.

4. What is Alzheimer's disease: Factsheet 401LP July 2014. Alzheimer'sSociety. Accessed: Nov. 25, 2019. [Online]. Available: https://www.alzheimers.org.uk /sites/ default/files/migrate/downloads/what_is_alzheimers_dise ase.pdf

5. C. Reitz and R. Mayeux, "Alzheimer disease: Epidemiology, diagnostic criteria, risk factors and biomarkers," Biochem. Pharmacol., vol. 88, no. 4, pp. 640–651, 2014.

6. C. R. Harrington, "The molecular pathology of Alzheimer's disease," Imag. Alzheimer's Disease Other Demantias, Neuroimaging Clinics North Amer., vol. 22, no. 1, pp. 11–22, 2012.

7. I. Saied, T . Arslan, S. chandran, C.Smith, T.Jones and S. Pal," NonInvasive RF Technique for Detecting Different Stages of Alzheimer's Disease and Imaging Beta-Amyloid Plaques and Tau Tangles in the Brain"IEEE Transactions,vol 39,no.12,pp. 4060-4069.2020.

8. M Akhtari M et al. "Conductivities of three-layer live human skull Brain" Topogr., vol. 14, pp. 151–67,2002.

9. R. H. Takahashi, T. Nagao, and G. K. Gouras, "Plaque formation and the intraneuronal accumulation of β-amyloid in Alzheimer's disease," Pathol. Int., vol. 67, no. 4, pp. 185–193, Apr. 2017.

10. R. Michael, A. Lenferink, G. Vrensen, E. Gelpi, R. Barraquer, and C. Otto, "Hyperspectral Raman imaging of neuritic plaques and neurofibrillary tangles in brain tissue from Alzheimer's disease patients," Sci. Rep., vol. 7, no. 1, pp. 1–11, 2017.

11. C. Ballatore, V. Lee, and J. Trojanowski, "Tau-mediated neurodegeneration in Alzheimer's disease and related disorders," Nature Rev. Neurosci., vol. 8, no. 9, pp. 663–672, 2007