Developments of Tomography and Radar-based Head Imaging Systems

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***Abstract*—Microwave-based diagnostic systems are increasingly attracting huge attention due to their low-cost, non-ionizing and non-invasive characteristics. This paper reviews the recent developments of head imaging systems reported for applications in medical emergencies. The reviewed systems include tomography and radar systems. It is shown that although microwave systems for head imaging have reached a mature stage, they still need a preclinical validation.**

Keywords—Head imaging, microwave imaging, intracranial hemorrhage, brain stroke.

I. Introduction

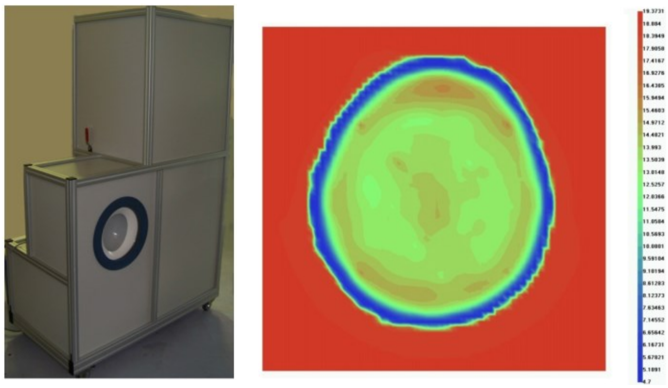
Microwave-based imaging refers to the image reconstruction process of an object using microwave frequencies (1-30 GHz) [1]. Recently, numerous researchers have been involved in investigating different microwave techniques for head imaging due to its low-cost, fast, non-invasive, non-ionizing and portable features compared to the existing imaging systems like computerized tomography (CT) scan, magnetic resonance imaging (MRI) etc. In microwave-based head imaging system, a low-level of electromagnetic energy is emitted towards the head using an antenna array and the scattered signals are collected and processed to image the interior of the human head. The image reconstruction and the principle of detection mostly depend on the contrast of scattering or electrical properties (conductivity and/or permittivity) between normal and abnormal tissues of the human head at the band of operation. The scope of microwave head imaging extends to a diverse range of fields including antennas to capture the backscattered signals, digital signal processing to locate the target and for the image computation and software engineering for the collection of data and image output [2]. However, this type of microwave systems was underdeveloped due to its unique hardware component requirements and limitation in data processing speed. Recent advancements of wireless communication and computing have opened new doors for further research and development of this technology towards various applications pertaining human head [3].

The head imaging systems can be applied on the detection of brain tumour [4]. However, among the numerous identified applications of the head imaging systems, researchers have concentrated more on the applications that are defined as life-threatening medical emergencies, which require rapid detection and medication for complete recovery. The detection of brain stroke, intracranial hemorrhage, subdural hematoma and so on [2, 3], occurring from various traumatic and non-traumatic causes are some of the examples of such applications. In order to take a rapid medication procedure, the diagnosis is required to be on-site and fast. Microwave-based sensing system relying on a supervised learning-based classification algorithm using data from an antenna array was presented to be clinically applicable for stroke classification [5]. However, imaging provides more information regarding the position and size of the brain injury.

Owing to the combination of multiple technologies, the challenges of head imaging systems are multifold. Firstly, the detecting antennas are placed in close proximity of the human head where the lossy high permittivity head's tissues prevent the transmitted low powered signal from penetrating inside the head. The radiation and thermal safety of the human subject is one of the prime reasons restricting the transmission power, which is typically 1 mW or 0 dBm [6]. Low-microwave frequencies are less susceptible in lossy tissues and provide better penetration with the amount of utilized power, but may result in low resolution images due to the increased wavelength [7]. Attaining wide bandwidth can improve the image quality in this regard [8]. Most of the reported head imaging systems utilize frequencies between 0.5-4 GHz in narrowband or wideband manner, as a compromise between the image resolution and signal penetration [9-20]. The size of the antenna is the major design concern at these low frequencies, especially when wideband is demanded. Utilizing matching liquid in front of the antennas can reduce the relative size and improve matching with the head [2]; however, it may increase physical discomfort of the patient when applied. It is obvious that compact designs enable more elements in the sensing array within the available specific volume. This paper reviews the recent developments in the microwave-based head imaging systems reported for diagnostic applications.

II. Microwave-based Head Imaging Systems

The two major approaches that have become prevalent in microwave imaging literature are microwave tomography (MT) and ultra-wideband (UWB) radar techniques. Both of them have advantages over each other. In MT technique the head is surrounded by an array of antennas operating at a single or multiple frequencies. Comparing the measured data from these antennas, MT approach seeks to estimate the complex dielectric profiles of the imaged domain (the head) by solving a non-linear inverse scattering problem. On the other hand, UWB radar method directly looks for the location of the significant scatterers (bleeding or clot target) by processing the scattered signals across a wide span of microwave frequencies. UWB radar imaging is well preferred in microwave imaging due to its fast image processing in ill-conditioned non-linear problems, such as head imaging. However, due to the use of wide bandwidth the microwave hardware (transceiver, antenna) design, and signal acquisition and processing are more challenging.

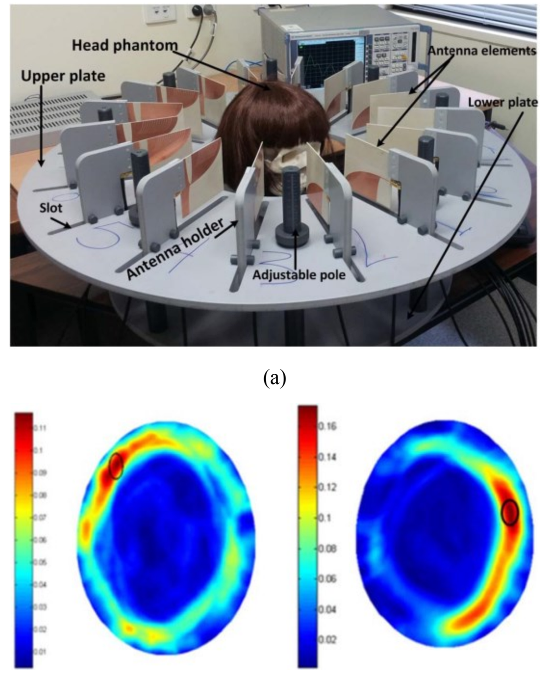


(a) (b)

Fig. 1 (a) Overall view of the EMTensor Brain Imaging System Generation 1 (EMT BRIM G1) and (b) MT image of a volunteer's head using the imaging system [12].

A. *Microwave Tomography Imaging*

MT is a form of quantitative imaging technique. The reconstructed image using MT illustrates the distribution of different tissues inside the human head. Typically, narrowband or multiband antennas are utilized in the imaging system which usually uses homogeneous matching medium to couple the transmitted energy and reduces reflections occurring at the skin layer. Among different reported MT studies for head imaging, variations of processing techniques, operating frequencies and utilized models are found. An MT system using 32 × 32 transmitters-receivers with simple inhomogeneous head model was proposed in [7]. Presuming high (40-60 dB) signal to noise ratio (SNR), the system attains good detection capability using multi-frequency approach at 0.5, 1 and 2 GHz. Images of virtual brain with ischemic stroke and edema was also detected using similar approach at 1 GHz [9]. Another study presents MT of realistic head models based on the Born iterative method [10]. It exhibits the feasibility of microwave imaging using 36 point sources operating at 850 GHz requiring lower SNR of 20 dB. The detection of ischemic strokes was performed through head imaging of 2D realistic head model using 24 ideal sources at 1 GHz using the nonlinear iterative Gauss–Newton algorithm [11]. All these studies promise the detection of stroke affected region through images. However, they are performed in simulation environment with transverse slices of the head. Recently, an MT system was manufactured (Fig. 1) (EMTensor Brain Imaging System Generation 1 (EMT BRIM G1)) with 160 antennas operating from 0.9 to 1.1 GHz located in 5 rings [12]. Images of healthy volunteers have demonstrated the detection of exterior layers of the head tissues. Although the interior portion of the head cannot be prominently layered and thus improvements of hardware and imaging algorithm are required, this is a significant milestone towards the practical implementation of MT for head imaging.



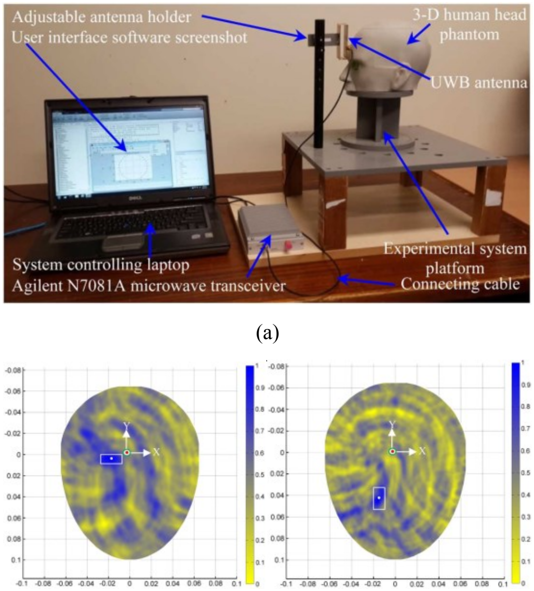
(a)

(b)

Fig. 2 (a) Configuration of the microwave imaging system and (b) reconstructed images with two different locations of a hemorrhagic stroke in a realistic head phantom [17].

B. *Ultra-wideband radar Imaging*

UWB head imaging systems utilize the modality of qualitative imaging. In this case, the system transmits a wideband signal. The scattered signals are captured and processed to form a microwave image. The reconstructed image does not present the dielectric properties of the imaged domain or the targeted region. However, it shows any significant scatterer within the imaged domain. Depending on the number of antennas used in the system, UWB radar imaging method can be utilized in three different approaches: mono static, bi-static and multi-static. Various numerical simulations of the head imaging systems are found using 2D head slices [13], 3D simple head model [14] as well as 3D realistic head model [15]. Although for microwave imaging, the properties of human tissues are fixed, in UWB scenario, the dispersive properties of the head has to be considered for realistic assumption. With the improvement of human tissue emulating materials and manufacturing techniques, phantoms are manufactured with anatomically and electrically realistic properties [16]. These phantoms play a vital role in the design, validation and safety precautions of head imaging systems. A complete microwave system (Fig. 2) was constructed using 16 antipodal antennas covering 1-4 GHz [17]. The system was experimentally verified by using a realistic human head phantom with hemorrhagic stroke. Another experimental measurement system using antennas covering relatively smaller bandwidth (1.2-2.8 GHz) demonstrates the efficacy of the UWB imaging in detecting hemorrhagic stroke inside a realistic human head [18]. However, none of these systems is easily portable. Among the other limitations of these systems, the bulky vector network analyser and high profile antennas are vital for their operation [19]. Recently, a portable UWB imaging system (Fig. 3) has been reported using a compact unidirectional antenna and a small wideband transceiver for head imaging [2]. The system was validated using realistic head phantom [20] and found efficient in detecting traumatic brain injuries which is expected to continue for preclinical tests in the near future.



(a)

(b)

Fig. 3 (a) Experimental setup of the head imaging system and (b) measured reconstructed images of a realistic head phantom with traumatic brain injury in different locations [2].

III. Conclusions

This paper has reviewed the recently developed head imaging systems that pose potential for preclinical or clinical implementation. The imaging of the head interior provides vital information about the location and impact of brain injury. In this manuscript, most frequent microwave-based head imaging, namely MT and UWB systems are discussed. Although numerous imaging techniques are examined for other applications, like breast cancer detection, synthetic aperture radar (SAR) applications and so on, many of these techniques are not valid, inefficient or unexplored for head imaging application. Nevertheless, more studies are yet to be reported for a practically applicable and clinically approved microwave-based head imaging system intended to the diagnosis of life-threatening medical emergencies.

References

[1] M. Pastorino, Microwave Imaging, John Wiley & Sons, Inc., Hoboken, NJ, USA. 2010.

[2] Mobashsher, A.T.; Abbosh, A.M.; Wang, Y., "Microwave System to Detect Traumatic Brain Injuries Using Compact Unidirectional Antenna and Wideband Transceiver With Verification on Realistic Head Phantom," Microwave Theory and Techniques, IEEE Transactions on , vol.62, no.9, pp.1826,1836, Sept. 2014

[3] S. Semenov, "Microwave tomography: review of the progress towards clinical applications," Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 367, pp. 3021-3042, 2009.

[4] Haoyu Zhang; Flynn, B.; Erdogan, A.T.; Arslan, T., "Microwave imaging for brain tumour detection using an UWB Vivaldi Antenna array," Antennas and Propagation Conference (LAPC), 2012 Loughborough , vol., no., pp.1,4, 12-13 Nov. 2012

[5] Persson, M.; Fhager, A.; Trefna, H.D.; Yinan Yu; McKelvey, T.; Pegenius, G.; Karlsson, J.-E.; Elam, M., "Microwave-Based Stroke Diagnosis Making Global Prehospital Thrombolytic Treatment Possible," Biomedical Engineering, IEEE Transactions on , vol.61, no.11, pp.2806,2817, Nov. 2014.

[6] Mobashsher, A.T.; Abbosh, A., "Development of compact directional antenna utilising plane of symmetry for wideband brain stroke detection systems," Electronics Letters , vol.50, no.12, pp.850,851, June 5 2014

[7] S. Y. Semenov and D. R. Corfield, "Microwave tomography for brain imaging: Feasibility assessment for stroke detection," Int. J. Antennas Propag., vol. 2008, pp. 254830-1–254830-8, 2008

[8] Fhager, A.; Hashemzadeh, P.; Persson, M., "Reconstruction Quality and Spectral Content of an Electromagnetic Time-Domain Inversion Algorithm," Biomedical Engineering, IEEE Transactions on , vol.53, no.8, pp.1594,1604, Aug. 2006

[9] Semenov, S., "Electromagnetic sensing and imaging for medical applications," Antenna Measurements & Applications (CAMA), 2014 IEEE Conference on , vol., no., pp.1,4, 16-19 Nov. 2014.

[10] Ireland, D.; Bialkowski, K.; Abbosh, A., "Microwave imaging for brain stroke detection using Born iterative method," Microwaves, Antennas & Propagation, IET , vol.7, no.11, pp.909,915, August 20 2013

[11] Jalilvand, M.; Chuanren Wu; Schmid, J.; Zwick, T., "Quantitative imaging of numerically realistic human head model using microwave tomography," Electronics Letters , vol.50, no.4, pp.255,256, February 13 2014

[12] Semenov, S.; Seiser, B.; Stoegmann, E.; Auff, E., "Electromagnetic tomography for brain imaging: From virtual to human brain," Antenna Measurements & Applications (CAMA), 2014 IEEE Conference on , vol., no., pp.1,4, 16-19 Nov. 2014.

[13] Ireland, D.; Abbosh, A., "Modeling Human Head at Microwave Frequencies Using Optimized Debye Models and FDTD Method," Antennas and Propagation, IEEE Transactions on , vol.61, no.4, pp.2352,2355, April 2013

[14] Jalilvand, M.; Zwick, T.; Wiesbeck, W.; Pancera, E., "UWB synthetic aperture-based radar system for hemorrhagic head-stroke detection," Radar Conference (RADAR), 2011 IEEE , vol., no., pp.956,959, 23-27 May 2011

[15] Mobashsher, A.T.; Nguyen, P.T.; Abbosh, A., "Detection and localization of brain strokes in realistic 3-D human head phantom," Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO), 2013 IEEE MTT-S International , vol., no., pp.1,3, 9-11 Dec. 2013

[16] Mobashsher, A.T.; Abbosh, A.M., "Artificial Human Phantoms: Human Proxy in Testing Microwave Apparatuses That Have Electromagnetic Interaction with the Human Body," Microwave Magazine, IEEE , vol.16, no.6, pp.42,62, July 2015

[17] Mohammed, B.J.; Abbosh, A.M.; Mustafa, S.; Ireland, D., "Microwave System for Head Imaging," Instrumentation and Measurement, IEEE Transactions on , vol.63, no.1, pp.117,123, Jan. 2014

[18] Mobashsher, A.T.; Mohammed, B.J.; Mustafa, S.; Abbosh, A., "Ultra wideband antenna for portable brain stroke diagnostic system," Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO), 2013 IEEE MTT-S International , vol., no., pp.1,3, 9-11 Dec. 2013

[19] Marimuthu, J.; Bialkowski, K.S.; Abbosh, A.M., "Stepped frequency continuous wave software defined radar for medical imaging," Antennas and Propagation Society International Symposium (APSURSI), 2014 IEEE , vol., no., pp.1909,1910, 6-11 July 2014

[20] Mobashsher, A.T.; Abbosh, A.M., "Three-Dimensional Human Head Phantom With Realistic Electrical Properties and Anatomy," Antennas and Wireless Propagation Letters, IEEE , vol.13, no., pp.1401,1404, 2014.