Jurnal Kejuruteraan 32(1) 2020: 39-49
https://doi.org/10.17576/jkukm-2020-32(1)-06

Development of Microwave Brain Stroke Imaging System using Multiple Antipodal Vivaldi Antennas Based on Raspberry Pi Technology

Azahari Salleh[a,b*], Ching Chiou Yang[a], Touhidul Alam[a], Mandeep Singh Jit Singh[a], Md. Samsuzzaman[c], Mohammad Tariqul Islam[a*]
[a]Department of Electrical, Electronics and Systems Engineering,
Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Malaysia
[b]Centre for Telecommunication Research & Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka, Malaysia
[c]Faculty of Computer Science and Engineering, Patuakhali Science and Technology University, Bangladesh
**Corresponding author: azahari@utem.edu.my, tariqul@ukm.edu.my*

Received 15 April 2019, Received in revised form 17 November 2019
Accepted 18 December 2019, Available online 28 February 2020

ABSTRACT

This paper proposes a Microwave Imaging System (MIS) for brain stroke detection. In the MIS, the primary challenge is to improve in terms of cost, size, and stroke image quality. Thus, the main contribution of this work is the economy and the compact rotation platform integrated with an array of nine antipodal Vivaldi antenna in circular arrangement and single computer board, Raspberry Pi Module (RPM) as microcontroller developed. The design and fabrication of wideband antenna based on Computer Simulation Technology (CST) software and Rogers RO4350B substrate, which operated from 2.06 GHz to 2.61 GHz. In the RPM, the Python programming language used for regulating the angle of rotation and antenna switching process. The process of receiving reflection signals from the head phantom for each antenna supervised by Single-Pole 8-Throw (SP8T) Radio Frequency (RF) switch. The fabricated head phantom based on the primary tissues of the brain, white matter using inexpensive materials, and located in the middle of the platform. Platform rotation is a combination of wood-based platform with the size 0.36m^2 and material Perspex. Then, through an interfacing process between Python script and Vector Network Analyzer (VNA), the raw data in S-Parameters transferred to the MATLAB software for analysis. The fabricated antenna able to realize high directivity, 86.92% efficiency, and 2.45 dBi gain. Overall, the proposed system offers the cost-effective, compact, and able to collect the data effectively around the head phantom that consist of a target clot and without a target clot at 50 different positions. It successfully tracked the presence of stroke clots through color differences in color plots.

Keywords: Microwave Imaging System; brain stroke; antipodal vivaldi antenna; Raspberry Pi

ABSTRAK

Artikel ini mencadangkan Sistem Pengimejan Gelombang Mikro (MIS) untuk mengesan strok otak, Dalam MIS, cabaran yang paling utama adalah untuk memperbaiki dari segi kos, saiz dan kualiti gambar strok. Oleh itu, sumbangan utama dalam kerja ini ialah pelantar putaran berkos rendah dan padat disepadukan dengan sembilan antena Vivaldi antipod dalam susunan bulat dan papan komputer tunggal, Modul Raspberi Pi (RPM) sebagai mikropengwal telah dibangunkan. Rekabentuk dan fabrikasi antenna jalur lebar adalah berdasarkan perisian Teknologi Simulasi Komputer (CST) dan substrat Roger RO4350B yang mana beroperasi dari 2.06 GHz hingga 2.61 GHz. Dalam RPM, bahasa pengaturcaraan Python telah digunakan untuk mengawal sudut putaran dan proses pensuisan antenna. Proses menerima isyarat pantulan dari fantom kepala diselia oleh suis RF SP8T. Fantom kepala telah difabrikasi berdasarkan tisu utama otak, bahan putih menggunakan bahan yang murah dan diletakkan di tengah-tengah pelantar. Pelantar putaran adalah kombinasi antara tapak pelantar berasaskan kayu dengan saiz 0.36m^2 dan bahan perspek Kemudian, melalui proses pengantaramuka antara skrip Python dan Penganalisis Rangkaian Vektor (VNA), data mentah dalam parameter S telah dipindahkan ke perisian Matlab untuk dianalisis. Antena yang difabrikasi mampu merealisasikan keterarahan yang tinggi, 86.92% kecekapan purata dan 2.45 dBi gandaan. Keseluruhannya, sistem yang telah dicadangkan menawarkan kos yang berkesan, padat dan mampu memungut data dengan berkesan mengelilingi fantom kepala yang terdiri dari gumpalan sasaran dan tanpa gumpalan sasaran pada 50 kedudukan berbeza. Ia berjaya mengesan kehadiran gumpalan strok melalui perbezaan warna dalam plot warna.

Kata kunci: Sistem Pengimejan Gelombang Mikro; strok otak; Antena Vivaldi Antipod; Raspberry Pi

INTRODUCTION

Generally, brain stroke is a disease that occurs suddenly due to a blockage in the blood vessels of the brain or the rupture of blood vessels in the brain. This condition causes the oxygen supply will decrease until the brain is no longer functioning. (Powers et al. 2018). The main effect of this problem is paralysis, coma, and the worst can be life-threatening. (Munawar et al. 2016; Wu, et al. 2016) In terms of statistics, the disease has become the third-largest cause of death in Malaysia, with a total of 50,000 new cases reported each year (Kooi et al. 2016). Meanwhile, 15 million cases detected worldwide each year, where every six seconds, a person will die from stroke regardless of age and gender (Benjamin et al. 2019; Stroke Association 2015). Ischemic stroke is a blood clot, or fatty deposits block a type of stroke that occurs at most about 85% as a result of blood flow to the brain (Tournier et al. 2017; Kanchana & Menaka, 2015). Intra-cerebral hemorrhage is the most common type of hemorrhagic stroke caused by an artery in the brain bursts and flooded the brain tissue in the blood (Mobashsher & Abbosh, 2015; Mobashsher et al. 2016; Mobashsher et al. 2016). However, in the case of a minor stroke or Transient Ischemic Attack (TIA), it is happening in a very short and does not lead to permanent brain damage. During a TIA, the blood supply dropped dramatically in less than five minutes, and it is only temporary. Then, recognizing and treating immediately possible to reduce the risk of an actual stroke or other more severe complications. (Maasland et al. 2011; Brazzelli et al. 2014; Li, et al. 2015). Therefore, the fast and effective detection plays an essential role in ensuring that stroke patients can receive further treatment after identifying the type of stroke.

At the hospital, existing technologies such as Magnetic Resonance Imaging (MRI) and Computer Tomography (CT) scans often used for stroke detection due to high resolution and image accuracy (Salleh et al. 2019; Qureshi & Mustansar, 2018; Chowdhury & Bandyopadhyay, 2017; Ali et al. 2015). It can simultaneously facilitate the doctor to make the right decisions in identifying the defect areas of the brain, type of stroke, and avoid unnecessary surgery. CT scan is an X-ray procedure that combines many x-ray images with the aid of a computer to produce cross-sectional view of the image, including three-dimensional internal organs images and structures of the body. Radiation levels are higher than standard X-ray procedures but does not lead to pain. The effects of radiation from CT scans can also be an adverse effect in the long term. (Hubert et al. 2014; Yu, et al. 2016) Then, MRI uses magnetic fields and radio waves to create detailed images of organs and tissues in the body of a human. Unlike X-rays and Computed Tomography (CT scan), MRI is a non-invasive imaging method that is safe and does not involve X-ray radiation. The resulting image is more detailed than CT scans, especially in describing the soft tissue. However, this equipment does not offer a mobile system that can be moved easily and only can operate in a particular room. The price is too high to cause this facility is only available at established hospitals. Due to the large size, it's hard to bring during an emergency (Qureshi & Mustansar, 2018; Bialkowski, et al. 2015; Gupta & Mishra 2014; Ayrum & Hyoungsuk 2015). Along these lines, there is a requirement for an alternate imaging method which can give a sheltered, ease, versatile and quick imaging results for brain stroke identification. At the same time, the device will use in all hospitals and be used either in an ambulance or patient room. Based on these factors, stroke detection research was conducted using MWI. It also taken into consideration the success of breast cancer research using this method (Elahi et al. 2018; Islam et al. 2017; Chouiti et al. 2016; Islam et al. 2019; Samsuzzaman et al. 2019; Loughlin et al. 2017; Glavin et al. 2018).

Microwave Brain Stroke Imaging (MBSI) offers every one of these favorable circumstances alongside non-ionizing and non-obtrusive highlights (Ramadhan et al. 2018; Rezaeieh, et al. 2015; Bisio et al. 2016). Through this method, the microwave signal from the antenna is used to penetrate the tissues of the human body. The signal in the recurrence scope of 0.5 – 4.5 GHz and a power level between 0 and 20 dBm, give a sensible bargain between the spatial determination of brain images and the entrance of signs into the human head (Mobashsher, et al. 2016; Jamlos & Mustafa, 2019; Mobashsher, et al. 2013; Kuzuoglu & Ozgun, 2016). In principle, the transmitted and reflected signs from the object of interest are estimated and prepared to build a solid image of the target based on differences between the dielectric properties of the target and its surroundings. The point of MBSI is to distinguish and find the region of the harmed brain tissues, either ischemic or hemorrhagic stroke condition.

The existing type of active microwave imaging techniques is Microwave Tomography (MWT) and UWB radar imaging. MWT or established inverse scattering decides the detail dielectric profile, including area, size, shape, and electromagnetic qualities, i.e., permittivity, conductivity, and magnetic permeability of any unusual inspected tissue (Shukla 2015; Guo 2017; Tournier et al. 2017; Azghani et al. 2015). In the MWT strategy, the head is using an array of antennas working at solitary or various frequencies. In numerical studies MWT has reached a good level by modeling complex human heads. However, rarely researchers are involved in practical MWT studies that need much further improvement of the required system. Ordinarily, tomography based effective image construction estimations consistently takes long time (in the span of hours for image getting ready, despite the data acquiring time (10-15 minutes for chest) (Mahmood et al. 2015; Meaney et al. 2000). UWB radar-based utilize the modality of qualitative imaging. The localization of main scatterer can determine by differentiating the dielectric properties of background and stroke spot (Paulson et al. 2005). From the backscattered signals of the antenna array, the entry times and amplitudes of backscattered signals are handled to find the interest point. In a mono-static configuration, an antenna is used to transmit the signal to the head model and consider as simple system. If using two antennas, it is known as bi-static mode, where the second antenna will receive a reflection signal from the head. For multi-static systems, more than two antennas are used to receive reflection signals. This method will increase the system complexity and give high error factor for the detection of stroke image. However, the image quality is more precise than the mono-static (Mobashsher et al. 2014a, 2014b; Porter et al. 2016; Jalilvand et al. 2011).

The critical element in the MBSI is a rotating platform which used to fix the model of a human head or antenna and determine the method of data collection as a whole. In (Mohammed et al. 2016; Mohammed et al. 2014), PVC materials used to build a platform that consists of two plates to fix the head phantom and adjust the position of the 16 antennas. While in (Mobashsher, et al. 2014a; Mobashsher et al. 2016), only one plate is used to fix the antenna and rotate the model human head. The process of developing this rotation platform is simple and easy and low cost. However, it cannot adapt to the diversity of size and configuration is not realistic because the phantom head is moving. Then some improvements have been made in the system to address the issue of practicality with a phantom head is fixed and using only one antenna. However, the resolution of the stroke image was low (Mobashsher & Abbosh 2016a).

The microcontroller is used to control the platform in the MWI. In breast imaging, breast model will rotate using Arduino Uno microcontroller boards, and the stepper motor that controls the rotation will rotate clockwise from 0° to 360° (Kibria et al. 2019; Islam et al. 2017; Islam et al. 2019). Method of collecting data for the angle of rotation will affect the quality of imaging. The collected data will be imported into an imaging algorithm for generating images of two dimensional or three dimensional. Therefore, the angle of rotation is critical in the microwave imaging system. In (Mobashsher et al. 2014a; Mobashsher & Abbosh 2014), the angle of rotation at 11.25° with 32 positions applied around the model of a human head. However, some studied use rotational angle at 3.6°. Bleeding is detected more clearly and accurately. By adding the position of rotation rate, the resolution of the image also increases. Nevertheless, the position that many rounds will take more time to make a full rotation (Mobashsher et al. 2016).

The lower microwave frequency range suitable for use in the MWI system. Imaging for a vital organ in the human body, such as the head, requires sufficient signal penetration for maximum signal reflections. Microwave frequencies lower than 1 GHz will increase penetration, but this will degrade the resolution of the image resulting in a blurred image. Therefore, the lower frequency of 1 GHz is not suitable for use in imaging systems

model human head (Zhuge et al. 2008). The effectiveness of the microwave imaging system is dependent on the efficiency of the antenna design. Therefore the antenna with proper impedance matching at the appropriate frequency and operates at a wide bandwidth is crucial for comprehensive imaging systems. The compact size and high directivity antenna need to consider for MBSI. The unidirectional antenna provided higher performance compared to omnidirectional antenna. It due to the less power bounced back from the head and lowering the effect of the surrounding interference. However, in terms of complexity of design, the directional antenna is more complicated than omnidirectional antenna (Zamani et al. 2016; Abbosh & Mobashsher 2014; Inum et al. 2017; Mobashsher & Abbosh 2016b).

In this work, the development of microwave head imaging systems or MBSI consists of imaging platform, the antenna, and the head phantom. Platform rotation serves to rotate the antenna in a specific rotation angle around the phantom head. Nine antipodal Vivaldi antennas used to transmit and receive the reflected signal. The movement of the antennas fully controlled by the Raspberry Pi Module and Phyton programming. Matlab software is responsible for analyzing the imaging result.

METHODOLOGY

The development of MIS consists of rotation platform, antenna design, head phantom, and data acquisition. The block diagram of the imaging system shown in Figure 1. The system consists of nine antipodal Vivaldi antenna installed on a rotating platform, RPM as a microcontroller, stepper motor, stepper motor driver, RF switch, VNA, and laptop (central processing unit). The function of the head imaging rotation platform was used to rotate the platform in a specific rotation angle during the experiment. The development of the rotating platform divided into two parts, which are software and hardware. Python programming language is used to interface with different parts of the system, such as to rotate the platform and control the switching of the RF switch to capture the backscattered signal sequentially. The RPM, which functions as a microcontroller, will be connected to the stepper motor, driver and RF switch.

Besides that, four wire-leads of the unipolar stepper motor connected to the stepper motor pin at the L298N motor driver. The half-step switching sequence is used to control the rotation of the stepper motor. This switching sequence consists of eight-step in one sequence, which able to provide smoother operation due to the increased resolution of the angle. The RF switch consists of the input control that used to switch the antenna sequentially to receive the backscattered signal. A flowchart of the Python coding shown in Figure 2. First, set the step of rotation to 7.2°. Then, the antenna will start capturing the backscattered signal from the head phantom. After that, the step or the rotation angle will increase until one full cycle (360°) or 50 steps. Every time the stepper motor increases one step, the antennas will capture all signals around the head phantom.

The platform is fabricated using Perspex and wood as shown in Figure 3. The radius of the platform is 20 cm and mounted with nine poles of the antenna holder with a height of 25 cm. The antenna will be installed in the holder

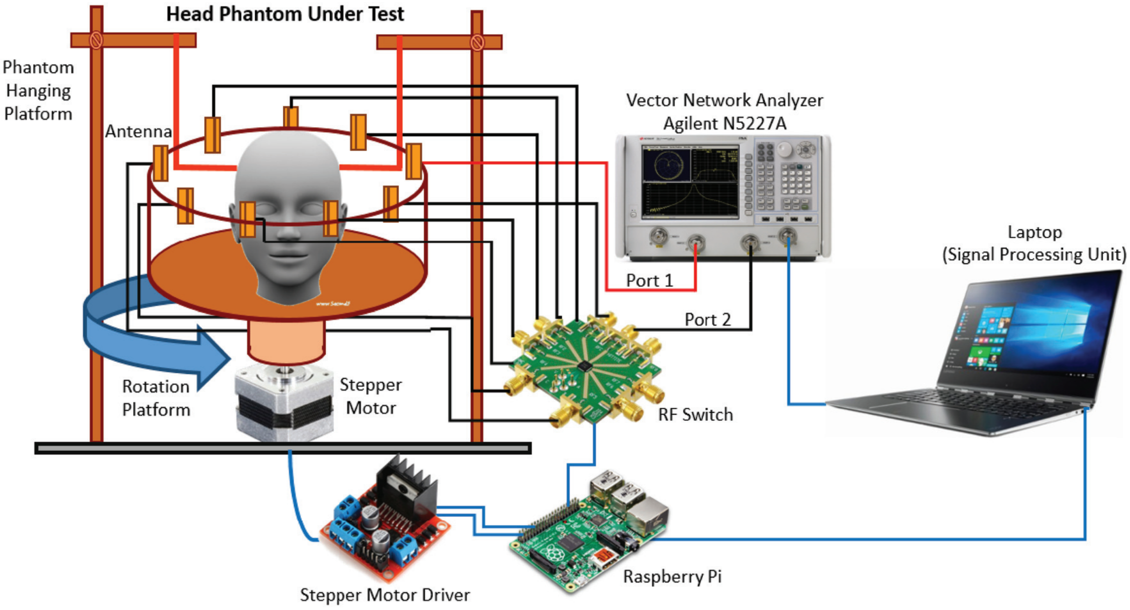


FIGURE 1. Block diagram of MIS

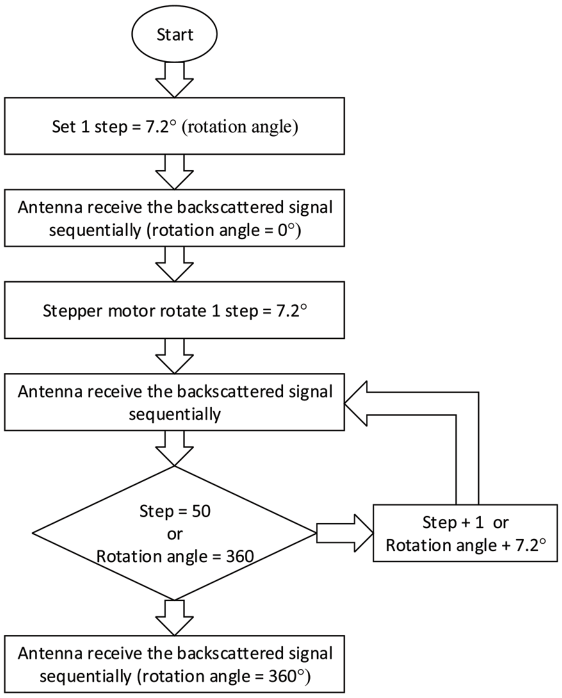
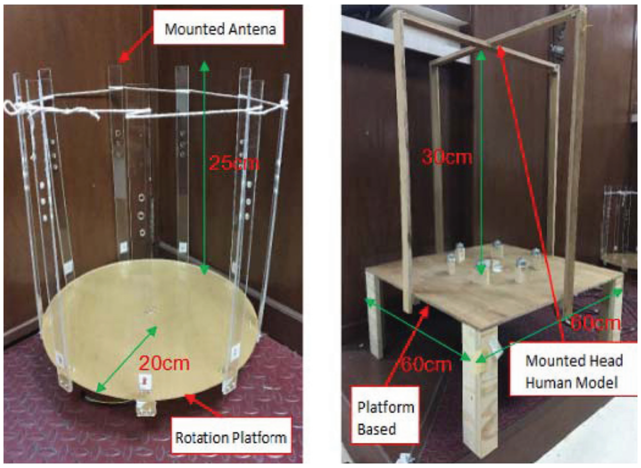
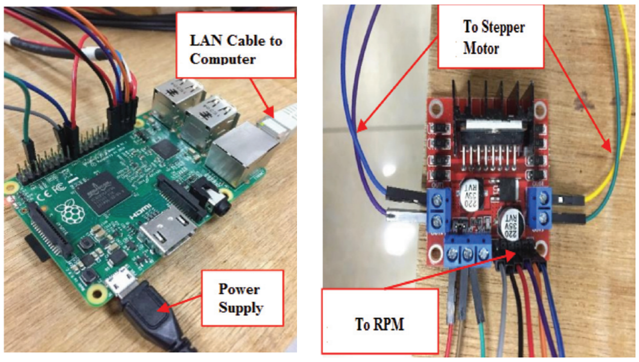


FIGURE 2. Flowchart of Python coding



(a) (b)

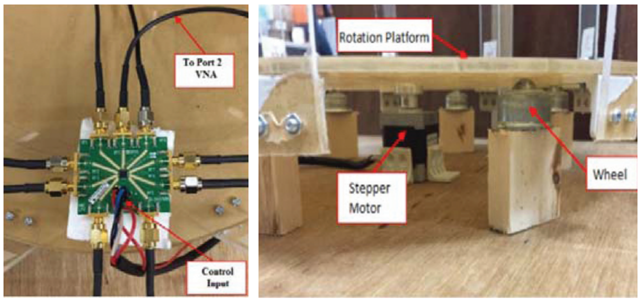
FIGURE 3. (a) Rotation platform (Perspex) (b) Platform based (wood)



(a) (b)

FIGURE 4. (a) Connection of RPM (b) Connection of Stepper motor driver to stepper motor and RPM

then connected using the RF cable with the characteristic impedance of 50 Ω to the RF switch. The leading hardware used to build a platform of rotation is RPM (Raspberry Pi 2 Model B), which serves as a microcontroller. The RPM connected to a stepper motor, stepper motor driver and RF switch. The function of the RPM is used to control the movement of the stepper motor and RF switch. Programming has been written using the Python programming language organized into the RPM. An external power supply of 12 V and 2 A are used to supply power to the stepper motor driver, but RF switch can continue to power supply 3.3 V of RPM. Figure 4 shows the overview of RPM and stepper motor driver. Platform rotation installed on top of a stepper motor and is locked using a metal hub. The stepper motor is a direct current motor that divides the full rotation into some of the same steps. Besides, the stepper motor driver is used to control the magnitude and direction of electrical current flow to the motor windings. Stepper motor driver receives a voltage of RPM and supply energy to the windings and motor shaft. RF switch is used to receive the reflected signals in sequence and directs the reflected signal to the VNA. RF switch has nine ports where SMA connectors with eight input ports (RF1 - RF8 / J1 - J8 connected to the antenna, and the output port (RFC / J9) connected to the second port VNA as shown in Figure 5(a). RF cable was used to connect the antenna to the RF switch. SMA connector port and the RF cable have a characteristic impedance of 50 Ω. RF switch has been placed on a round platform to reduce the use of RF cables and does not give any distractions while rotating. The components like stepper motor, stepper motor driver, RPM, and RF switch placed on the platform based. There are six wheels has been added to the platform to increase the wheel during rotation of platform stability and can reduce the load on the motor as shown in Figure 5(b).



(a) (b)

FIGURE 5. (a) RF switch connection (b) Bottom view of rotation platform (wheel position)

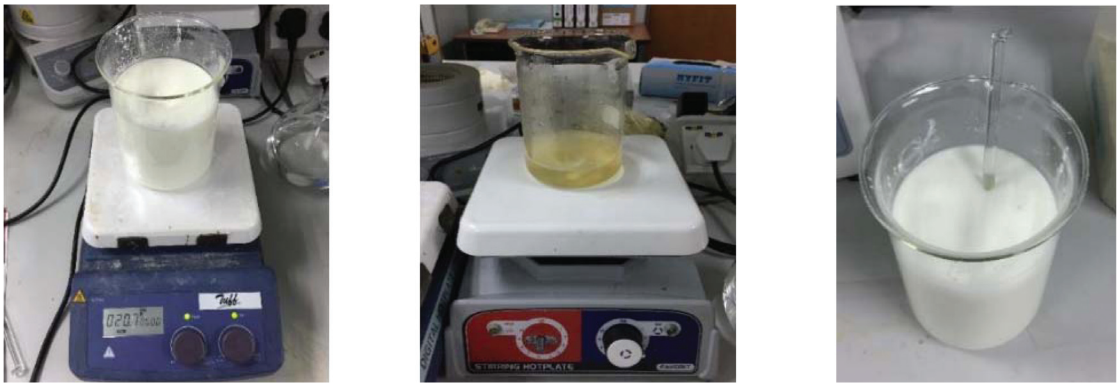
In the MIS, the characteristics of the antenna required include small in size, has a unidirectional radiation pattern, and wide bandwidth. CST software used for simulation and antenna design. Antipodal Vivaldi antenna recommended for MSI for stroke detection operating in the frequency range from 2.06 GHz - 2.61 GHz. It is sufficient to allow the signal to penetrate the human head and produce quality images. The tapered antenna of size 50 mm x 60 mm printed on both sides of the substrate Roger RO4350B. Figure 6 shows the antenna layout.

(a) (b)

FIGURE 6. Antipodal Vivaldi antenna layout (a) Front view (b) Rear view

The developed system used the multi-static radar mode of operation. In multi-static mode, one antenna applied as the transmitter, and the other eight antennas applied as the receiver. The Agilent N5227A VNA is used to generate and receive the microwave signal. The transmitting antenna connected to the port 1 of the VNA, and the other eight antennas connected to the RF switch, in which the output of the switch is connected directly to the port 2 of the VNA. The VNA will generate the signal in a step-frequency using 201 equidistant frequency points across the band from 2 GHz to 3 GHz. Agilent N5227A VNA uses the Virtual Instrument Software Architecture (VISA) via various types of buses, such as Local Area Network (LAN) ethernet, Universal Serial Bus (USB) and General Purpose Interface Bus (GPIB). The VNA connected to a laptop via the GPIB port. The MATLAB 2017b software is used to interface with the Raspberry Pi Python script and the VNA. The data acquired from the VNA are processed using MATLAB in the laptop. At the MATLAB code, instrument objects (VNA) configured by declaring all the variables that needed for data acquisition, such as the number of steps (rotation platform), antenna, and step frequency point. For the Raspberry Pi, Secure Shell (SSH) is used to access the command line, and the IP address (169.254.111.80) is used to open the terminal window for running the Python script.

The MIS validation done by collecting the reflected signal from the model of a human head that has a target structure and without target structure. The structure of the target is a white substance, which is one of the primary tissue found in the human brain. The material of white substances are gelatin (9.8 g), corn starch (185 g), water (364 ml), and sodium azide (0.36 g). Steps to prepare a white substance are as follows: Firstly, in a 2-liter beaker, at room temperature, mix corn starch (185 g), and ¾ part of water (273 ml). Figure 7(a) indicating the mixture stirred until a viscous syrup. Secondly, in another beaker, 9.8 g of gelatin was added while stirring with ¼ parts water (91 ml) as described in Table 3.5. Figure 7(b) shows a mixture of gelatin and water. The mixture is heated gradually to 90°C. The molten mixture cooled to 40°C. Thirdly, at this stage, the sodium oxides added to the mixture as an anti-bacterial. Lastly, corn starch is heated gradually, and on a low heat, add the mixture (from step 2) while stirring in gelatin. The mixture stirred until a thick gel obtained and allowed to cool at room temperature to a dough. Then, the material incorporated into the model. Figure 7(c) shows a mixture of cornstarch and gelatin.



(a) (b) (c)

FIGURE 7. (a) Corn starch and water mixture (b) Gelatin and water mixture (c) Corn starch and gelatin mixture

RESULTS AND DISCUSSION

Development of MIS for detecting brain stroke involves the construction of platform rotation, the wideband antenna, data collection, and validation system. Figure 8 shows the complete setup of MIS for stroke detection. It consists of imaging platform, antenna, head phantom, RPM, RF switch, VNA and laptop. In the imaging platform, Python code has been generated to control the rotation of the platform and RF switch.

Figure 9 shows the command window display of Python, Matlab, and SSH. Matlab code is successfully connected to the VNA with Python code and configure all the variables of the VNA and SSH. The display shown is the angle of rotation, and the order of the antenna receives the reflected signal. At every rotation angle, 7.2°, eight antenna will collect data in sequence until the angle of rotation has reached a full round, 360°. This display shows the synchronization between MATLAB code and Python code. Synchronization is vital to ensure that the RF switch can receive the reflected signal from the antenna, and the signal transmitted through the second port VNA. The "com established" in the MATLAB command window shows the connection between VNA with SSH the Raspberry Pi has been successful. Overall, the performance of the fabricated antenna is consistent with the simulation results, and meet the criteria for Microwave Imaging System (MIS) as summarized in Table 1. The ability of the antenna to achieve S11 < -10 dB is essential to ensure that the maximum power delivered and impedance matching can be in optimum condition. This value is the fulfillment of the requirements for most applications wherein at least 90% of the input power can be transmitted and only 10%

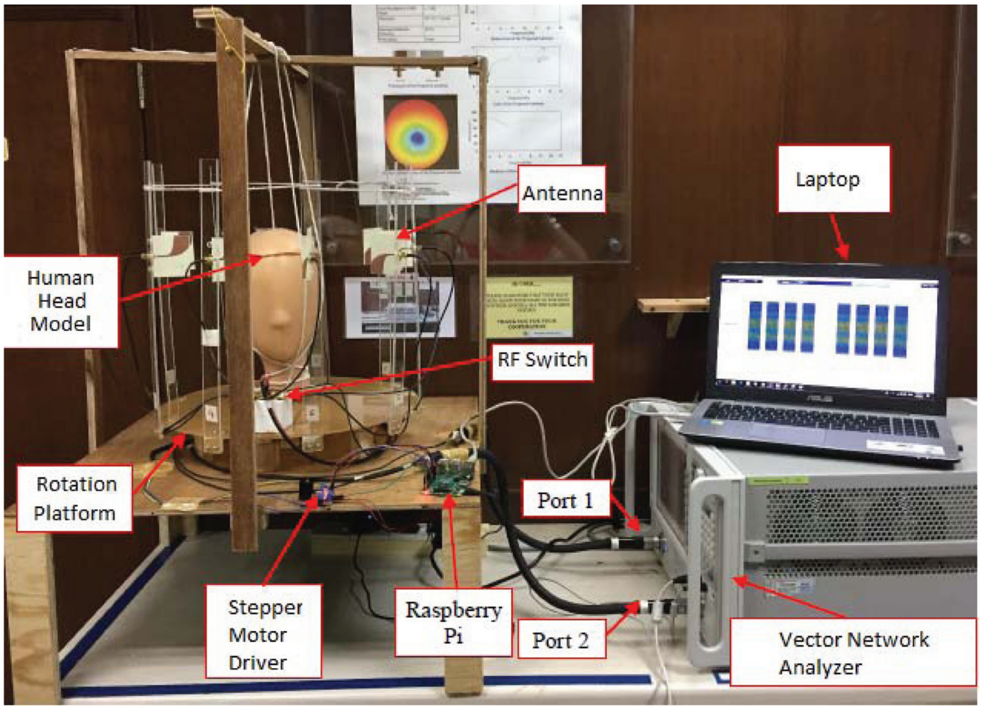
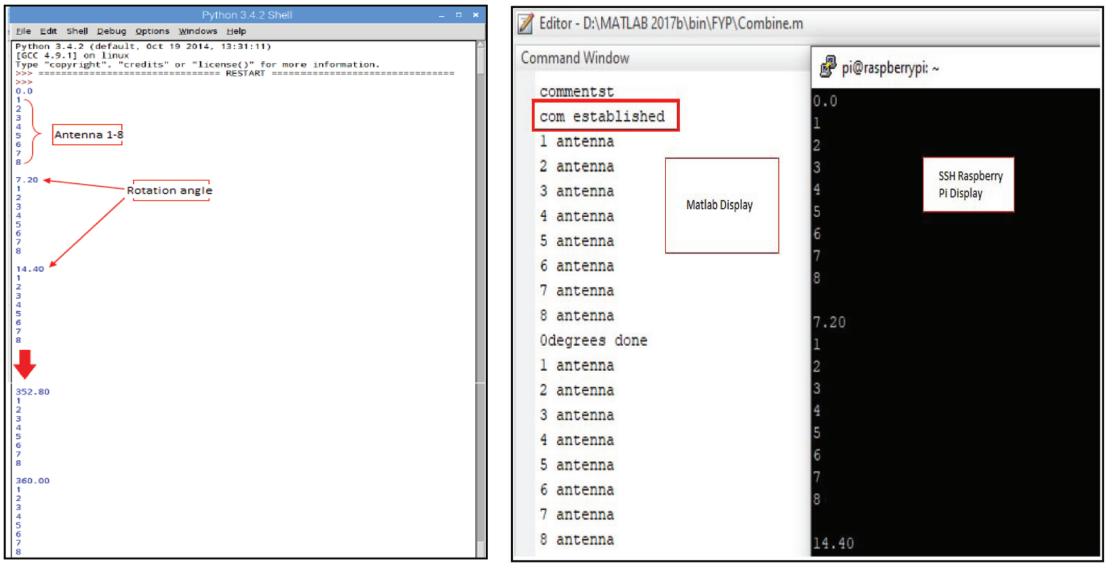


FIGURE 8. Setup of MIS for stroke detection



```
Python 3.4.2 (default, Oct 19 2014, 13:31:11)
[GCC 4.9.1] on linux
Type "copyright", "credits" or "license()" for more information.
>>> ================================ RESTART ================================
>>>
0.0
1
2
3
4
5
6
7
8

7.20
1
2
3
4
5
6
7
8

14.40
1
2
3
4
5
6
7
8

352.80
1
2
3
4
5
6
7
8

360.00
1
2
3
4
5
6
7
8
```

```
commentst
com established
1 antenna
2 antenna
3 antenna
4 antenna
5 antenna
6 antenna
7 antenna
8 antenna
0degrees done
1 antenna
2 antenna
3 antenna
4 antenna
5 antenna
6 antenna
7 antenna
8 antenna
```

```
0.0
1
2
3
4
5
6
7
8

7.20
1
2
3
4
5
6
7
8

14.40
```

(a) (b)

FIGURE 9. Command window display (a) Python (b) Matlab and SSH

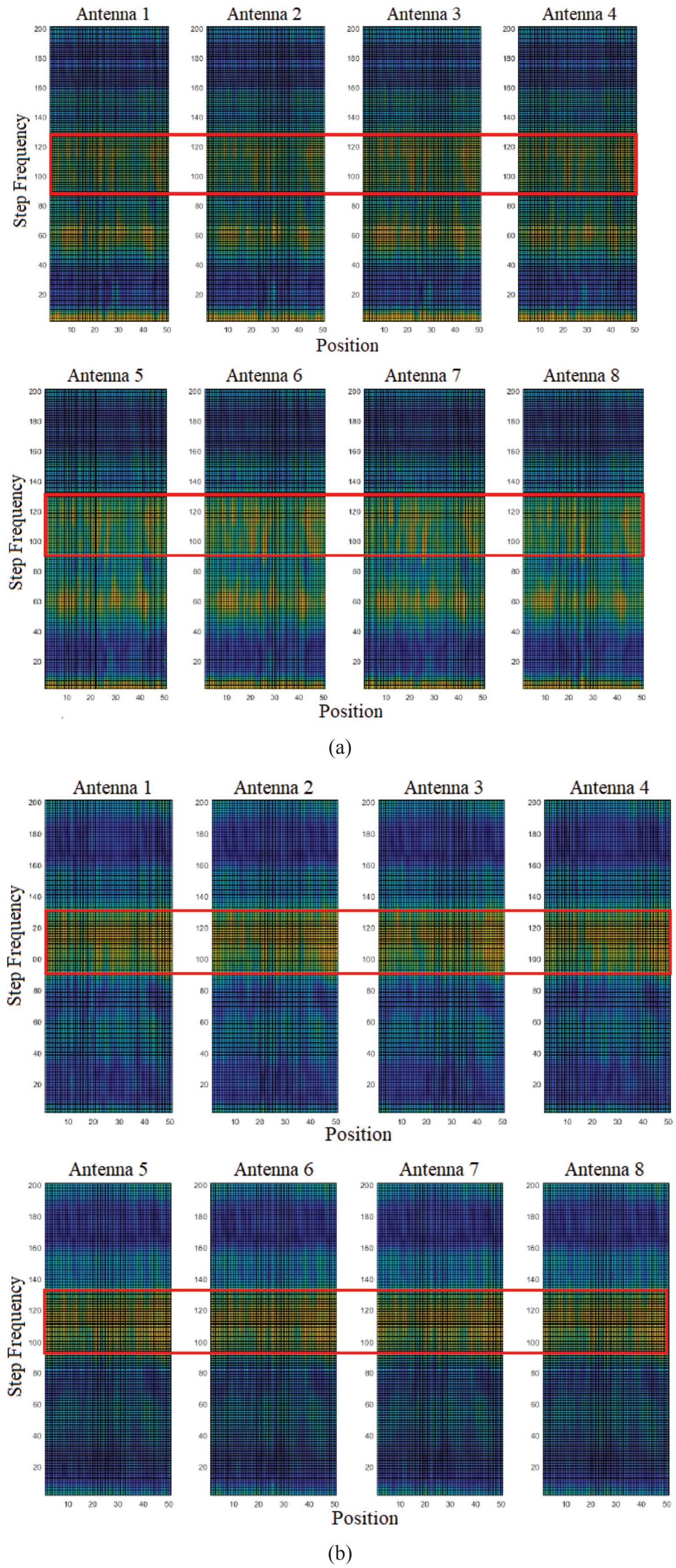
power of reflection. Roger substrate used at the rate of loss is low at high frequency, stable dielectric constant at 3.48, cost-effective and easy to fabricate. The directional antenna is more preferred to implement in MIS compared to the omnidirectional antenna because the less power bounced back from the head and lowering effect of the surrounding interference. The effectiveness of MWI system needs the high directivity of the antenna.

TABLE 1. Antipodal Vivaldi Antenna Specifications

Parameter	Value
Reflection Coefficient	< -10 dB
Operating Frequency	2.06 – 2.61 GHz
Bandwidth	500 MHz
Substrate	Roger RO4350B
Substrate Dielectric Constant	3.48
Substrate Loss Tangent	0.039
Average Efficiency	86.92 %
Average Gain	2.48 dBi
Radiation Pattern	Directional
Size	50 mm x 60 mm
Input Impedance	50 Ω
VSWR	≤ 2

The MIS validation done by collecting the reflected signal from the model of a human head that has a target structure and without target structure. The produced white material will be included in a model human head as shown in Figure 10. Figure 11 shows the color plot of the human head model with and without structural targets. The eight graphs are referring to the eight-antenna receiver which x-axis is 50 position antennas, and the y-axis is the 201 frequency steps. The color plot of with structure target shows higher pixel intensity compared to without structure at the mid-frequency step at 90-130. Change the color of the graph shows that the structure of the detected target.

FIGURE 10. White substance



(a)

(b)

FIGURE 11. Color plot (a) Without target (b) With target

CONCLUSION

Overall, the primary system for detecting brain stroke has been developed by using MWI. The system supported by a low-cost imaging platform and nine small-sized antipodal Vivaldi antennas with high directivity and a human head model based on white matter. Based on integration between RPM, RF switch, and Matlab software allows the data collection process is made more efficient and convenient. To improve these systems, where the occurrence of stroke can be translated more accurately through an image reconstruction algorithm, and realistic human head model to reflect the actual situation of the human brain. The compact and flexible Ultra-Wideband (UWB) antennas with high directivity able to improve the quality of the brain stroke image.

ACKNOWLEDGEMENT

The author would like to thank the Ministry of Education Malaysia and Universiti Teknikal Malaysia Melaka for the scholarship support. Universiti Kebangsaan Malaysia funded this research under grant number DIP-2017-014.

REFERENCES

Abbosh, A. & Mobashsher, A.T. 2014. Development of compact directional antenna utilising plane of symmetry for wideband brain stroke detection systems. *Electronics Letters* 50 (12): 850-851.

Ali, Hussein, A. Abdulsalam, S.I. & Nema, I.S. 2015. Detection and segmentation of ischemic stroke using textural analysis on brain CT images. *International Journal of Scientific and Engineering Research* 6 (2): 396-400.

Ayrum, Kim. & Yoo, H. 2015. Pre-study to detect cancer with RF coil: Brain and breast. *Electronics Letters* 51 (3): 209-211.

Azghani, Masoumeh, Kosmas, P. & Marvasti, F. 2015. Microwave medical imaging based on sparsity and an iterative method with adaptive thresholding. *IEEE Transactions on Medical Imaging* 34(2): 357-365.

Benjamin, Emelia, J. Muntner, C.P. Alonso, V.C.A. Bittencourt, F.S.M. Callaway, M.P.H.W.C. Carson, F.P.A. & Chamberlain, F.M.A. 2019. Heart Disease and Stroke Statistics – 2019 Update. American Heart Association Statistical Update.

Maasland, Lisette, Dorien Brouwer-Goossensen, Heleen M. Den Hertog, Peter J. Koudstaal, and Diederik W.J. Dippel. 2011. Health education in patients with a recent stroke or transient ischaemic attack: A comprehensive review. *International Journal of Stroke* 6(1): 67-74.

Bialkowski, K.S., Abbosh, A.M & Mohammed, B.J. 2015. Radar-Based Time-Domain Head Imaging using database of effective dielectric constant. *Electronics Letters* 51 (20): 1574-76.

Bisio, I., Fedeli, A. Lavagetto, F. Luzzati, G. Pastorino, M. Randazzo, A. & Tavanti, E. 2016. Brain Stroke Detection by Microwave Imaging Systems: Preliminary Two-Dimensional Numerical Simulations. In *2016 IEEE International Conference on Imaging Systems and Techniques (IST)* 330-34.

Brazzelli, Miriam, Francesca, M. Chappell, Miranda, H. Shuler, K. Dennis, M. Peter, A. G. Sandercock, Muir, K. & Wardlaw, J.M. 2014. Diffusion-weighted imaging and diagnosis of transient ischemic attack. *Annals of Neurology* 75 (1): 67-76.

Chouiti, Mohammed, S. Merad, L. Meriah, S.M. Raimundo, X. & Taleb-Ahmed, A. 2016. An efficient image reconstruction method for breast cancer detection using an ultra-wideband microwave imaging system. *Electromagnetics* 36 (4): 225-35.

Chowdhury, Ranjita. & Bandyopadhyay, S.K. 2017. Detection of stroke : A proposed method. *International Journal of Applied Research* 3 (4): 593-99.

Elahi, M. A. Lavoie, B.R. Glavin, M. Jones, E. Fear, E.C. & Halloran, M.O. 2018. Image reconstruction algorithms for confocal microwave imaging: Application to patient data. *Sensors* 18(6): 1678.

Glavin, M., Jones, E. O,. Loughlin, D.O., Halloran, M., Moloney, B.M. Glavin, M. Jones, E. & Adnan, M. 2018. Microwave Breast Imaging: Clinical Advances and Remaining Challenges. *IEEE Transaction on Biomedical Engineering* 65(11): 2580-2590.

Guo, & Lei. 2017. Processing and Imaging Techniques for Microwave-Based Head Imaging. Thesis PHD University of Queensland.

Gupta, Shivangi & Mishra, A. 2014. Ischemic Stroke Detection Using Image Processing And ANN. *IEEE International Conference on Advanced Communication Control and Computing Technologies* 1 (978): 1416-20.

Hubert, Gordian, J. Muller-Barna, P. & Audebert, H.J. 2014. Recent Advances in TeleStroke: A Systematic Review on Applications in Prehospital Management and Stroke Unit Treatment or TeleStroke Networking in Developing Countries. *International Journal of Stroke* 9 (8): 968-73.

Inum, Reefat, Rana, M.M & Quader, M.A. 2017. Modeling of an Efficient Microstrip Patch Antenna for Microwave Brain Imaging System. *3rd International Conference on Electrical Engineering and Information and Communication Technology* 1-6.

Islam, M. T. Mahmud, M.Z. Islam, M.T. Kibria, S. & Samsuzzaman, M. 2019. A Low Cost and Portable Microwave Imaging System for Breast Tumor Detection Using UWB Directional Antenna Array. *Scientific Reports* 9: 15491.

Islam, M. T. Mahmud, M.Z. Misran, N. Takada, J.I. & Cho, M. 2017. Microwave Breast Phantom Measurement System with Compact Side Slotted Directional Antenna. *IEEE Access* 5: 5321-30.

Jalilvand, M. Zwick, T. Wiesbeck, W. & Pancera, E. 2011. "UWB Synthetic Aperture-Based Radar System for Hemorrhagic Head-Stroke Detection." *IEEE National Radar Conference - Proceedings*.: 956-59.

Jamlos, Aminudin, M. & Mustafa, W.A. 2019. Improved Confocal Microwave Imaging Algorithm for Tumor Detection. *Journal of Futuristic Biosciences and Biomedical Engineering* 1 (1): 9-15.

Kanchana, R. & Menaka, R. 2015. Computer Reinforced Analysis for Ischemic Stroke Recognition: A Review. *Indian Journal of Science and Technology* 8 (35): 1-9.

Kibria, Salehin, Islam, T. Mahmud, Z. Misran, N. & Islam, M.T. 2019. Breast Phantom Imaging Using Iteratively Corrected Coherence Factor Delay and Sum. *IEEE Access* 7: 40822-40832.

Kooi, Wee, C. Peng, H.C. Aziz, Z.A & Looi, I. 2016. A Review of Stroke Research in Malaysia from 2000 – 2014. *The Medical Journal of Malaysia* 71: 58-69.

Kuzuoglu, M. & Ozgun, O. 2016. "A Microwave Imaging Method Based on Transformation Electromagnetics," *10th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (METAMATERIALS), Chania, Yunanistan*, 262-264.

Li, L. Niu, T. & Gao, Y. 2015. "Mathematical Methods and Applications in Medical Imaging. *Computational and Mathematical Method in Medicine* : 2-4.

Loughlin, Declan, O'. Oliveira, B.L. Elahi, M.A. Glavin, M. Jones, E. Popović, M. & O'Halloran, M. 2017. Parameter Search Algorithms for Microwave Radar-Based Breast Imaging: Focal Quality Metrics as Fitness Functions. *Sensors* 17 (12): 1-20.

Mahmood, Qaiser, Li, S. Fhager, A. & Candefjord, S. 2015. A Comparative Study of Automated Segmentation Methods for Use in a Microwave Tomography System for Imaging Intracerebral Hemorrhage in Stroke Patients. *Journal of Electromagnetic Analysis and Application* 7 (5): 152–167.

Meaney, P. M. Fanning, M.W. Li, D. Poplack, S.P. & Paulsen, K.D. 2000. "A Clinical Prototype for Active Microwave Imaging of the Breast." *IEEE Transactions on Microwave Theory and Techniques* 48 (11): 1841-53..

Mobashsher, A. T. Bialkowski, K.S. Abbosh, A.M. & Crozier, S. 2016. Design and Experimental Evaluation of a Non-Invasive Microwave Head Imaging System for Intracranial Haemorrhage Detection. *PLoS ONE* 11 (4): 1-29.

Mobashsher, A. T. Nguyen, P.T. &Abbosh, A. 2013. Detection and Localization of Brain Strokes in Realistic 3-D Human Head Phantom. *IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications, IMWS-BIO 2013 - Proceedings*, 11-14.

Mobashsher, A. T. & Abbosh, A.M. 2015. "Developments of Tomography and Radar-Based Head Imaging Systems, *International Symposium on Antenna and Propagation*, 16–19.

Mobashsher, Toaha, A. & Abbosh, A.M. 2016a. On-Site Rapid Diagnosis of Intracranial Hematoma Using Portable Multi-Slice Microwave Imaging System. *Scientific Reports* 6: 37620.

Mobashsher, Toaha, A. & Abbosh, A.M. 2016b. Performance of Directional and Omnidirectional Antennas in Wideband Head Imaging. *IEEE Antennas and Wireless Propagation Letters* 15: 1618-1621.

Mobashsher, Toaha, A. & Abbosh, A. 2014. Microwave Imaging System to Provide Portable-Low-Powered Medical Facility for the Detection of Intracranial Hemorrhage. In *AMS 2014 - 2014 1st Australian Microwave Symposium, Conference Proceedings,* 23-24.

Mobashsher, Toaha, A. Abbosh, A.M. & Wang, Y. 2014a. Microwave System to Detect Traumatic Brain Injuries Using Compact Unidirectional Antenna and Wideband Transceiver with Verification on Realistic Head Phantom. *IEEE Transactions on Microwave Theory and Techniques* 62 (9): 1826-1836.

Mobashsher, Toaha, A. Abbosh, A.M & Wang, Y. 2014b. Microwave System to Detect Traumatic Brain Injuries Using Compact Unidirectional Antenna and Wideband Transceiver with Verification on Realistic Head Phantom. *IEEE Transactions on Microwave Theory and Techniques* 62 (9): 1826-36.

Mobashsher, Toaha, A. Mahmoud, A. & Abbosh, A.M. 2016. Portable Wideband Microwave Imaging System for Intracranial Hemorrhage Detection Using Improved Back-Projection Algorithm with Model of Effective Head Permittivity. *Scientific Reports* 6: 20459.

Mohammed, B. J. Bertling, K. Abbosh, A.M. & Rakic, A.D. 2016. Microwave Head Imaging System Using Analogue Fibre-Optic Link for Improved Detection and Localisation. 52 (16): 1366-1368.

Mohammed, Beadaa, J. Abbosh, A.M. Mustafa, S. & Ireland, D. 2014. "Microwave System for Head Imaging." *IEEE Transactions on Instrumentation and Measurement* 63 (1): 117-123.

Munawar, Awais, Mustansar, Z. Nadeem, A.E. & Akhtar, M. 2016. An Investigation Into Electromagnetic Based Impedance Tomography Using Realistic Human Head Model *International Journal of Pharmacy and Pharmaceutical Sciences* 8 (2): 35-39.

Paulson, Christine, N. John, T. Chang, Romero, C.E. Watson, J. Pearce, F.J. & Levin, N. 2005. Ultra-Wideband Radar Methods and Techniques of Mmedical Sensing and Imaging. *Proceedings of SPIE* 6007:1-12.

Porter, Emily, Bahrami, H. Santorelli, A. Gosselin, B. Rusch, L.A & Popovic, M. 2016. A Wearable Microwave Antenna Array for Time-Domain Breast Tumor Screening. *IEEE Transactions on Medical Imaging* 35 (6).

Powers, William, J. Alejandro, A. Ackerson, R.T. Adeoye, O.M. Bambakidis, N.C. Becker, K. Biller, J. 2018. 2018 Guidelines for the Early Management of Patients With Acute Ischemic Stroke: A Guideline for Healthcare Professionals From the American Heart Association/ American Stroke Association." *Stroke* 49(3): e46-e99.

Qureshi, Munawar, A. & Mustansar, Z. 2018. Finite-element analysis of microwave scattering from a three-dimensional human head model for brain stroke detection. *Royal Society Open Science* 5(7): 180319

Rezaeieh, Ahdi, S. Zamani, A. & Abbosh, A.M. 2015. 3-D Wideband Antenna for Head-Imaging System with Performance Verification in Brain Tumor Detection. *IEEE Antennas and Wireless Propagation Letters* 14: 910-914..

Salleh, Azahari, Yang, C.C. Singh, M. Singh, J. & Islam, M.T. 2019. Development of antipodal vivaldi antenna for microwave brain stroke imaging system. *International Journal of Engineering & Technology* 8 (3): 162-68.

Samsuzzaman, M., Islam, M.T., Islam, M.T., Abdullah, A.S., Shovon, Faruque, R.I. & Misran, N. 2019. A 16-modified antipodal vivaldi antenna array for microwave-based breast tumor imaging applications. *Microwave and Optical Technology Letters* 61(9): 2110-18.

Shukla, D. 2015. Latest trends in microwave bioimaging & diagnostic technology. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* 4(5): 4464-4469.

Stroke Association. 2015. State of the Nation: Stroke Statistics 2015. State of the Natio*n*.

Tournier, P. Hecht, F. Nataf, F. Semenov, S. Bonazzoli, M. Rapetti, F. Dolean, V. 2017. Microwave Tomography for Brain Stroke Imaging. *2017 IEEE Antennas and Propagation Society International Symposium, Proceedings ,* 29-30.

Wu, Y. Zhang, Y. & Wang, Y. 2016. Brain stroke localization by using microwave-based signal classification 1 (412): 828-831.

Yu, H. Yang, G.H. Wu, Q. & Su, M.H. 2016. Design and Optimization of UWB Vivaldi Antenna for Brain Tumor Detection. *IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, 2-4.

Ramadhan, Rifqi, Rian Gilang Prabowo, Ria Aprilliyani, and Basari. 2018. Comparison Analysis between Filtered Back Projection and Algebraic Reconstruction Technique on Microwave Imaging. *AIP Conference Proceedings* 1933 (February): 1-10.

Zamani, A., Abbosh, A.M. & Mobashsher, A.T. 2016. Fast frequency-based multistatic microwave imaging algorithm with application to brain injury detection. *IEEE Transactions on Microwave Theory and Techniques* (99): 1-10.

Zhuge, X. Savelyev, T.G. Yarovoy, A.G. Ligthart, L.P. Matuzas, J. & Levitas, B. 2008. Human Body Imaging by Microwave UWB Radar.,*2008 IEEE European Radar Conference*, 148-151.