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Ultra-Wideband Confocal Microwave Imaging for Brain Tumor Detection

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Abstract. A high-performance UWB array antenna to identify a tumor in a human brain phantom using confocal microwave imaging technique is presented. The antenna operated within the ultra-wideband (UWB) from 1.2 GHz to 10.8 GHz. Its high gains of between 5.2 dB and 14.5 dB and compact 90 mm × 45 mm size enabled its functionality and eased its integration into the microwave imaging system. Besides developing UWB array antenna as the sensor, a low-cost human head phantom represented by tissue simulating liquid as layers of skin, fat, skull, and brain are also developed. The antenna transmits the signal through the head phantom from 9 different points and receives the scattered waves under two different conditions; in the presence and absence of the tumor. The recorded scattering parameters are further processed in an improved delay and sum imaging algorithm using Matrix Laboratory software to generate an accurate image. The produced image indicated the presence of the tumor with an error of less than 2 cm.

Keywords: Ultrawide Band, Microwave Imaging, Brain Tumor, Array Antenna, Head Phantom

1. Introduction

In 2030, it is estimated that around 13.2 million people worldwide will suffer and die due to cancer since cancer is one of the most complex diseases in the world [1]. Early cancer detection allows early cancer treatment and consequently improves the survival rate. Currently, conventional X-ray, magnetic resonance imaging (MRI), computed tomography (CT Scan) and ultrasound technique are the common imaging modalities utilized to detect cancer [2]. Microwave cancer imaging provides several substantial benefits including being fast, safe, low-cost, and non-invasive with good detection accuracy [3–5]. A brain tumor is defined as a mass of tissue formed by an accumulation of abnormal cells within the brain. It is arguably the most fatal of all cancers [6,7]. On the contrary, most researchers are still concentrating research efforts on breast cancer detection and imaging. Microwave imaging is one of the potential technologies in visualizing internal human structure by exposing it to electromagnetic fields at microwave frequencies between 300MHz and 30GHz [8]. Techniques for microwave imaging are generally divided into three major types: active, passive or hybrid technique. As for active microwave imaging, several antennas transmit microwave signals into tissues and the reflected (backscattered) signals are used to generate microwave images.

Active microwave imaging can be further separated into the ultra-wideband (UWB) radar imaging and tomography imaging for detection purpose. UWB radar imaging technique was initially introduced solely for breast tumor detection [9,10]. Similar operating principles were then implemented for stroke and tumor detection in the brain [11,12]. Radar-based techniques are less complex as it only needs to identify strong scattering point caused by inclusions with high frequent occasion [13]. Image processing algorithms such as the delay and sum confocal algorithm can then be used to detect the tumor. In microwave imaging, having high gain and good directional beam-width in a wide frequency band antennas are required for target detection, localization systems, and cancer screening applications. Tumor imaging using microwave energy for early treatment is currently gaining attention from the research community. Antenna arrays functioned to enhance the focus of the EM energy into the locality of the tumors. The antenna arrays are very efficient to capture the scattered signal that can be analyzed to solve the inverse problem and obtain the constructed images of the preferred tissues. Furthermore, increasing the number of element implemented could enhance the performance of antenna arrays in imaging and treatment [14]. Compared to advanced biomedical imaging systems such as the magnetic resonance imaging (MRI) and computed tomography scan (CT scan), current microwave imaging technology is far behind in term of capabilities. However, microwave imaging systems do have the great potential of being simple, portable and cost-effective [15].

High gain and wide bandwidth UWB antenna are very essential in successfully penetrating different material with high details of the image. Antenna with a significant size which has a length of several wavelengths required to achieve such high performance. Hence, it is a great challenge to reduce the physical dimensions of the antenna so that it can be incorporated in a compact microwave imaging detection system and at the same time maintain its broadband, high-gain, and distortionless performance [16–18]. While it is desirable to produce compact-size antennas for biomedical applications, it is very important to ensure that antennas demonstrate a good directivity and high power gain as well. However, it seems that the existing antennas exhibit poor directivity, moderate gain too large to be integrated into a portable technology, very expensive and difficult to manufacture [19,20]. In this paper, the ultra-wideband antenna applied with confocal microwave imaging for brain tumor detection is proposed. This paper organized as follow, introduction, ultra-wideband confocal microwave imaging technique, results, and discussion and conclusion.

2. Ultra-Wideband Confocal Microwave Imaging Technique

2.1 Sensor Design

Figure 1 demonstrated the simulated design of UWB reflector array antenna using Taconic (TLY-5) with a dielectric constant of $\varepsilon r = 2.2$, a thickness of $t = 1.5748+/-0.02$ and tangent loss of $\tan \delta = 0.0009$ as the substrate. The antenna is printed with 4×1 copper radiating patch array properly connected with quarter wave transformer transmission line associated with a copper parasitic element for the front side as shown in figure 1. The patches comprise of four identical circulars with a diameter of 15 mm. Parasitic element is placed on very close to feeding line with the gap only 0.2 mm. As shown in figure 1, each quarter-wave transmission line has its own specific wide dimension for 50Ω, 70.71Ω and 100Ω to ensure equal current distribution towards all four patches could be realized. Quarter-wave transformers of 70.71 Ω are used to have an ideal match between the 100 Ω lines and the 50 Ω lines [21].

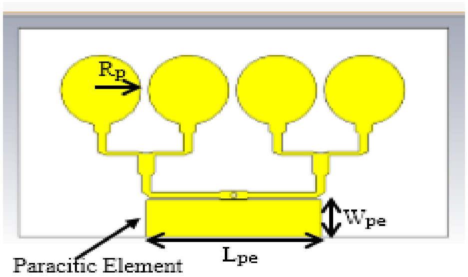

Figure 1. Quarter wave transformer

Some important parameters of the designed antenna are optimized to obtain the best result in term of compact size, high gain and wide bandwidth. The optimized dimensions for the antenna are tabulated in Table 1.

Table 1. Antenna Optimized Dimensions

PARAMETER	DIMENSION
R_p	7.50 mm
W_{pe}	8.00 mm
L_{pe}	32.4 mm

2.2 Sensor Performances

The simulation results of the reflection coefficient, S11 less than -10dB is shown in figure 2. From the figure, it clearly shows the proposed antenna recorded a wide range of operating frequency started from 2.6 GHz until 13.1 GHz which fulfilled the characteristic of the UWB antenna. Reflection coefficient less than -10 dB is selected due to the condition where 90% of the signals are successfully transmitted while only the left 10% is reflected back [22]. Partial ground technique and additional of parasitic element assure lower reflection coefficient achieved.

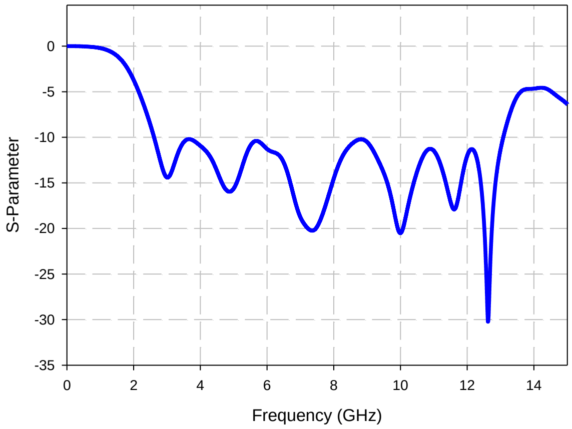

Figure 2. Graph of reflection coefficient (S11)

Figure 3 shows a graph for frequency domain and time domain for one same cycle of signals. Frequency domain represented by negative data values meanwhile time domain recorded positive data value. The data in the frequency domain need to be transformed to the time domain since confocal algorithm depends on round trip time for image generation.

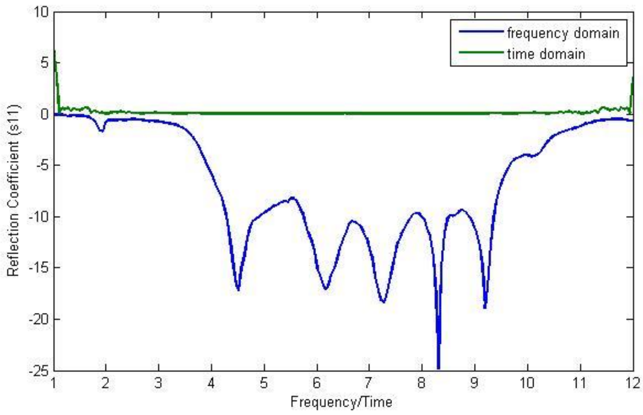

Figure 3. Frequency domain and time domain for one same cycle of signals

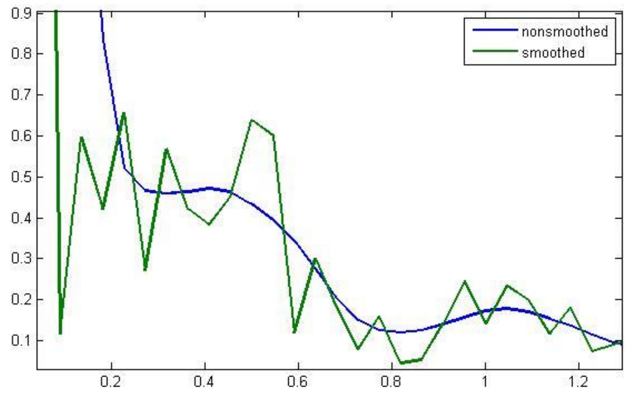

Figure 4. Smooth signal of time domain using IFFT

Meanwhile, figure 4 shows a smooth signal of time domain after undergoing the IFFT process towards the nonsmoothed original signal. The nonsmoothed signal associated with high and low spike form meanwhile smoothed signal represented by spline curve line. The smoothed signal is vital in generating high spatial resolution image for microwave brain tumor detection.

2.3 Microwave Imaging Measurement System

Figure 5 illustrated the measurement setup for brain tumor detection using microwave radar imaging technique. It consists of VNA, UWB sensor and human head phantom with the presence of a tumor. The measurements take place in the anechoic chamber to eliminate the unwanted signal that could interfere with the desired signal throughout the whole process of obtaining the data.

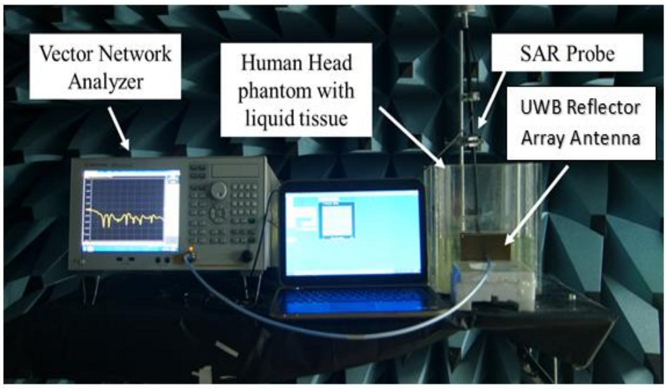

Figure 5. Measurement setup for microwave imaging

The UWB sensor is perfectly placed 10 mm away from the multilayer human head phantom to have maximum signal penetration. The sensor radiated the signal towards human head phantom with two different conditions which are one with tumor present meanwhile another one is without the tumor present to obtain the difference of the scattering parameter value. The sensor radiated the signal towards nine different areas to cover the whole one-sided area of the phantom as shown in figure 6 where the tumor located at position 5. Both data with and without tumor are subtracted from each other and the difference obtained is then processed in order to produce the desired image. Figure 7 shows the flow chart of the UWB confocal algorithm for data generation and image construction. The MATLAB software is used to process the data obtained using confocal microwave imaging algorithm.

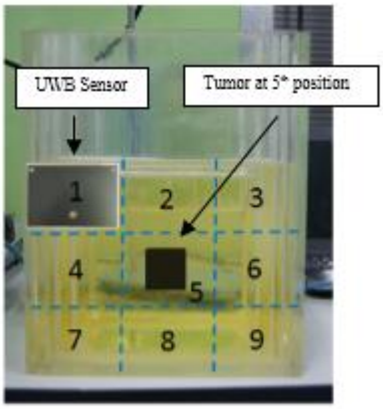

Figure 6. Scanning Area for Human Head Phantom

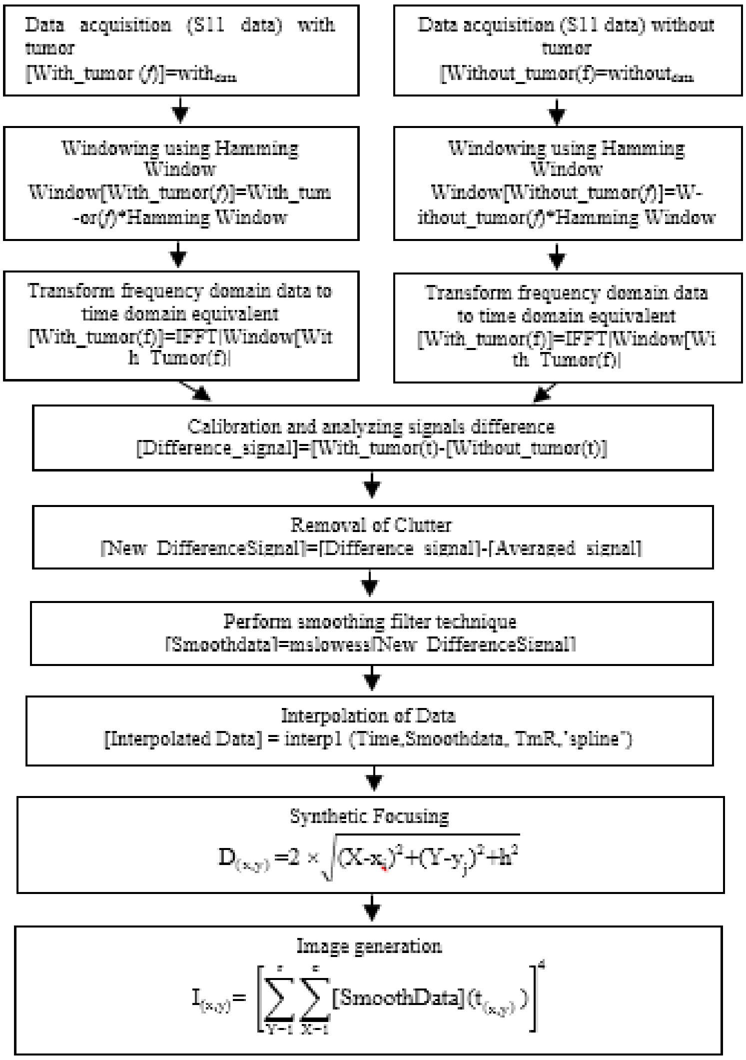

Figure 7. UWB Confocal Microwave Imaging Algorithm for image construction

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For the algorithm, averaging and interpolation step has been applied in order to have a better and clearer image. Averaging functioned to eliminate the effects of clutters originated from dominating reflections of the environment, equipment, and the antenna. On the other hand, theoretically, interpolation is a method of constructing new data points within the range of a discrete set of known data points. Meanwhile specifically for imaging, interpolation assists in filling the empty element between the adjacent pixels by assuming based on that particular adjacent pixels value [23–25].

3. Results and Discussions

Figure 8 shows the images processed using the original algorithm and the UWB confocal algorithm without tumor and with the tumor present, respectively. The images demonstrated the efficiency of the improved delay and sum algorithm with clearer and sharper images and areas with higher pixel intensity. Tumor in the image is represented by the highest color intensity (reddish orange spot), resulting from the strongest scattering region. This corresponds to tumor existence in the human head phantom.

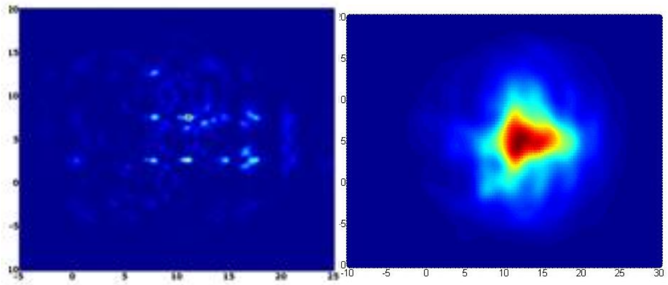

Figure 8. Resulted image without tumor; (a) with tumor (b)

Finally, an analysis of the localization error is performed to evaluate the effectiveness of the improved confocal microwave imaging algorithm. Since no minimum acceptable values are provided in literature for these errors, they are performed based on their relative distance from the real location of the tumor. Table 2 summarizes this for both UWB confocal and the original algorithm. The improved algorithm recorded a lesser error of 1.5 cm compared with the original algorithm, which recorded 1.8 cm.

Table 2. Tumor Localization Error

	Actual position		Position in image		
Axis	X' (cm)	Y' (cm)	X (cm)	Y (cm)	L.E (cm)
UWB confocal	10	5	10.5	5.5	1.5
Original	10	5	11.0	6.2	1.8

4. Conclusion

A high-performance antenna to identify a tumor in a human brain phantom using confocal microwave imaging technique is presented. It operates within the ultra-wideband (UWB) from 1.2 GHz to 10.8 GHz and produced gains of up to 14.5 dB in a compact 90 mm × 45 mm form. An in-house developed head phantom is used to experimentally validate the operation of this system. A UWB confocal microwave imaging algorithm which is used for image processing successfully improved the quality of the resulting image. Proposed future work includes investigating this system on the larger experimental region and with the presence of multiple tumors.

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