A Real-Time Three-Dimensional Diffuse Optical Tomography System for Breast Tumor Detection

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Abstract—Diffuse Optical Tomography (DOT) is a recent novel and non-invasive technology for medical imagery using near infrared light. The principle is based on the assessments of spatial variation in terms of light absorption and scattering coefficients that can be used to detect foreign bodies and tumors inside the human tissues. However, the current DOT technology is limited to a two-dimensional image reconstruction. In this paper, we propose an innovative three-dimensional nonlinear reconstruction algorithm to improve spatial and temporal resolutions. This algorithm has been implemented on an integrated mobile DOT system which comprises a light sensors array front-end circuit, an analog to digital converter, a Bluetooth wireless communication module to send the results to the GUI interface on a remote displaying device. The functionalities of the proposed system were verified using an experimental static human breast phantom. The experimental results show that the proposed system can detect a tumor of the size of 0.445cm^2 at a depth of 2cm from the surface of the skin.

I. INTRODUCTION

According to the World Health Organization, breast cancer is the most common cancer among women and still has a sustainable growth in the world. Therefore, early self-detection of breast cancer using a portable system at home is essential in order to proceed with early treatments. .

Based on Diffuse Optical Tomography theory [1], we use the Near-Infrared [2] light at two selected wavelengths between 600nm to 1000nm to explore several centimeters depths of unknown tissue. Hence, we exploit the intensity of diffusing photons to obtain the tissue's information. Finally, the target of a DOT system is to recover locally the spatial absorption coefficient and scattering coefficient of a specific area. Based on the photon migration principle in highly scattering media, the oxyhemoglobin (HbO2), de-oxyhemoglobin (Hb), water, and lipid have weak absorption optical properties in the near-infrared wavelength, whereas tumor exhibits a high absorption property. However, the majority of DOT systems literatures produce a two dimensional imaging reconstruction that limit the resolution of the reconstructed images due to the non-linear model applied. In this work, we proposed a novel DOT three-dimensional imaging reconstruction system implemented on FPGA.

II. METHODS

The proposed approach incorporates a multi-input and multi-output (MIMO) [3] based data extraction algorithm from a hexagonal sources and detectors (SD) array structure capable of scanning three layers of depth. This approach permits to increase the spatial resolution so we can apply a non-linear iterative algorithm and obtain a faster convergence. Another advantage is the ability to reconstruct three layers of tissue structure.

The concept of the algorithm is to divide the area into many segments and then according to the light propagation paths properties obtained to rebuild each grid point [5]. The modified Beer-Lambert Law [4] in (1) is used to describe the effect of light propagation path for the light intensity.

$$I_d = I_i \times \sum_m \left\{ R_m \times \prod\nolimits_n \left[exp(-\epsilon C_n U P_n) \right] \right\} \times \exp(-g) \qquad (1)$$

The incident light intensity and the received intensity, which is collected by the detector after propagation, correspond to I_i and I_d respectively. R_m is the probability of different diffusing path to occur. ϵ is the extinction coefficient of the molecules in $cm^{-1}mM^{-1}$, C_n is the concentration of the molecules in mM, U is the grid size defined as 0.667 cm, P_n is the ratio of the real length of propagation to U, and g is the geometry factor. For the modified Beer-Lambert Law (1), in order to simplify the equation we substitute some variables as show in (2) :

$$\begin{cases} O_{eq} = \dfrac{I_d}{I_i} \\ A_n = \exp(-\epsilon C_n U) \\ G_{eq} = \exp(-g) \end{cases} \qquad (2)$$

O_{eq} is the ratio of detected light intensity to incident light intensity. A_n is the absorption coefficient obtained for each grid point in the tissue. G_{eq} is the related geometry factor. After replacing the variables from (2), the modified Beer-Lambert Law can be rewritten as (3):

$$O_{eq} = \sum_m \left\{ R_m \times \prod\nolimits_n A_n^{P_n} \right\} \times G_{eq} \qquad (3)$$

The reconstruction order is from Top layer to Bottom layer. We use an initial data array to start the iterative reconstruction processing with the calculation of first the inverse equation and second the convergence equation that will determine whether the convergence condition is met or not. Once the convergence condition is met, the next layer reconstruction processing takes place. After the process accomplishes the reconstruction of a layer, it will use it as the initial value for the next layer's reconstruction. In [5] previous work and further detailed algorithms can be found.

III. OVERALL SYSTEM STRUCTURE

The proposed system is composed of a front-end circuit, a digital signal processing engine, a wireless transmission module and GUI interface as shown in Figure. 1.

In this work, the whole system has been implemented using an FPGA development platform connected with the front-end circuit and the wireless transmission module communicating with the GUI interface.

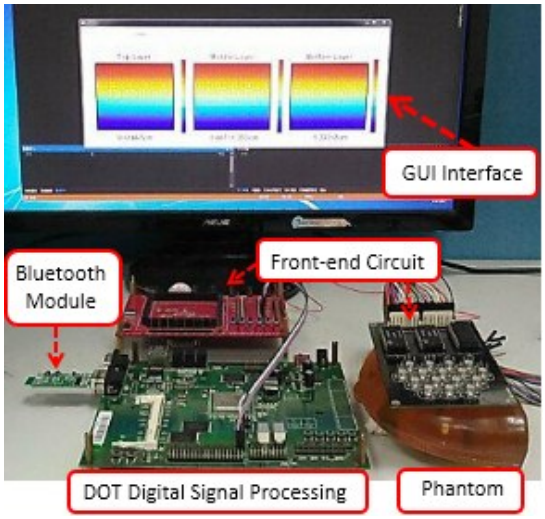

Fig.1 A real-time 3D-DOT system

The proposed front-end circuit is composed of near-infrared (NIR) LEDs array. It is used to acquire the light intensity after subject's tissues absorb the NIR. It contains 16 optical detectors, and 16 optical sources with dual-wavelength of 735nm and 890nm [6]. The digital signals are acquired by converting the analog signals measured from the front-end circuit using a 24bits per channel ADC. The DOT image reconstruction algorithm is implemented onto a Xilinx Virtex-5 FPGA. Finally, the reconstructed images are transmitted to the GUI on a monitor system using a Bluetooth module. In order to validate our algorithm functionalities, we use a set of 5 human tissue phantoms.

TABLE I PHANTOM TEST RESULTS

Breast Phantom	Resolution Images Layer by Layer			3D reconstruction image
	Top Layer	Middle Layer	Bottom Layer	
No.1	0-0.67cm	0.67-1.33cm	1.33-2cm	
No.2	0-0.67cm	0.67-1.33cm	1.33-2cm	
No.3	0-0.67cm	0.67-1.33cm	1.33-2cm	
No.4	0-0.67cm	0.67-1.33cm	1.33-2cm	
No.5	0-0.67cm	0.67-1.33cm	1.33-2cm	

IV. Results and Discussion

To compute our results, we use five different patterns with abnormal and normal tissues, with different depths and numbers of tumor areas to test. Table I shows the experiment results. The phantoms No.1 and No.2 respectively represent the normal and abnormal tissues, patterns that are successfully distinguished by our system. An identical tumor of a size of 0.445cm^2.is contained in phantoms No.3 and No.4 respectively at a depth of 0.5cm and 1.5cm, and obviously detected. The phantom No.5 has two tumors at depths of 0.4cm and 0.7cm, and respectively detected on the top and middle layers.

V. Conclusion

In this paper, we proposed and implemented a novel DOT reconstruct algorithm on a hardware system for breast tumor detection. The experiments used phantoms that have spectroscopy properties similar to humanoids in order to make the results coherent with real situations. For the system validation, we use phantoms with tumors at different locations and depths to evaluate our foreign body detection system's limits. The results show that the system can accurately identify the breast tumors with 3D images of the phantom patterns. The comparison with other works [7] shows that although we proposed a novel 3D reconstruction system, our work can be improved in terms of detection depth and image resolution, especially using recent neural networks approaches. The proposed system can successfully detect a tumor of the size of 0.445cm^2 at a depth of 2cm from the surface of the skin., this system is on the path to contribute to early detection of breast tumors in home healthcare programs.

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