A Non Invasive Tomography System for Characterization and Visualization of Tissue Optical Phantoms

Sivakumar R, Sujatha N

Abstract— Optical imaging techniques are treated with utmost importance due to their noninvasive and relatively inexpensive qualities. They have obvious advantages for continuous monitoring of physiological changes over diagnostic modalities like radiography and computed tomography which utilizes ionic radiation. Tomography is mathematical technique to get cross sectional details of an object from multiple trans-axial projections. A projection is a shadowgram obtained by illuminating a specimen by a penetrating radiation. In the proposed system the specimen is illuminated by using a near infrared laser and the transmitted optical radiation from the specimen are analyzed. Within the therapeutic window, from 600-1100 nm range tissues remain relatively transparent which helps to apply tomographic principles in obtaining the cross sectional details. The developed system was tested for its imaging capabilities as well as detection of abnormalities by using tissue mimicking structures called phantoms. Finally by using volume visualization techniques 3D visualization of the phantoms are also observed.

***Keywords*—**Optical imaging, Shadowgram, Tomography, Transillumination, Volume visualization**.**

I. INTRODUCTION

THIS non-invasive monitoring of physiological parameters and early diagnosis of pathological changes in tissues are of great importance for diagnosis and subsequent prevention of diseases. X-rays had been extensively used for the diagnosis of skeletal abnormalities, lesions in the chest and coronary blood vessels and breast-cancer screening. But due to its ionizing nature it cannot be used for continuous monitoring or frequent screening. On the other hand, magnetic resonance imaging, positron emission tomography, radionuclide imaging, etc. are too expensive and require contrast agents for which many people are allergic. Ultrasonography is often applied in tissue characterization and imaging, but precise localization of abnormalities in tissues at times is difficult due to similar acoustic characteristics and also the procedure requires perfect alignment of ultrasound transmitter and its receiver [1]-[3].Therefore, optical techniques, due to their nonionic, noninvasive and relatively inexpensive qualities, emerge as a natural choice of an alternative diagnostic modality.

Sivakumar R is with the Government Engineering College, Idukki, Kerala ,India (e-mail:nairsivan@gmail.com).

Sujatha N is with Department Of Applied Mechanics at Indian Institute Of Technology Madras,India. (e-mail: sujathan@iitm.ac.in).

The variation in optical properties plays a major role in differentiation of tissues between the normal and abnormal states. When the light propagate through the tissue optical processes like scattering, absorption or transmission occurs based on the medium and are also strongly wavelength dependent. High energy radiations like gamma rays or X rays are not scattered to a great extent but propagates through the tissues in straight path. The radiation attenuates due to absorption which varies with tissue types. High energy photon absorption might leads to bond breaking and ionization of molecules which ultimately causes malignancy conditions in the tissues. A low energy radiation like infra red and microwave induces excitation of rotational and vibrational energy levels in the molecules leading to temperature changes only [4]. Therefore near infra red radiations has become a potential tool for diagnosis in the medical field. Near infra red spectrum occupies approximately wavelength ranging from 650-1100 nm in the electromagnetic spectrum.

The light propagation in tissues is characterized by their optical parameters viz. absorption coefficient (μ_a), scattering coefficient (μ_s), scattering anisotropy parameter (g) and refractive index (n) [5]. The reduced scattering coefficient provides a scale for isotropic scattering is given by $\mu_s = \mu_s (1-g)$ [6] .The scattering anisotropy parameter (g) can vary between -1 and +1. Zero value for g indicates iso tropic scattering and g=1 means complete forward scattering and g= -1 means complete back scattering. Typical values of g in the tissue are in the range 0.7-0.95 ie. light gets forward scattered in tissues. The absorption coefficient is a measure of probability of photon being absorbed and its value in the tissue is in the order of $0.1mm^{-1}$ [7]. Because of variations in the refractive index in the tissues the near infra red light gets scattered and the scattering mean free path for NIR light is of the order of 10-100 microns. Absorption depends strongly on wavelength but scattering decreases very little with increasing wavelength. These parameters vary depending on the clinical conditions of the tissues [8]-[9].

Earlier applications of transillumination, technique of sample illumination by transmission of light through the sample resulted in poor-quality images due to multiple scattering of light in tissues [10]-[12]. But the availability of near infra red lasers especially within the therapeutic window region (600–1300 nm) has made significant contribution in the development of various diagnostic techniques [13]. Near infra red laser within this region can

penetrate deeper into the tissue and can be tolerated in large doses due to its non ionizing nature. When a laser beam is incident on tissue surface due to mismatch in refractive index at the air–tissue interface, a part of this is backscattered, where as the remaining part is absorbed or transmitted through the tissues. Due to high scattering and low absorption, the penetration of light within the therapeutic window is more. The spatial distribution of the backscattered and transmitted components contains information on the metabolic, physiologic or possibly structural status of tissues [14], [15].The proposed system makes use of these transmitted components to characterize the tissues as well as its visualization.

II. Materials and Methods

A. Experimental Technique

The system proposed uses transillumination technique, the concept of imaging of biological tissues based on illuminating light on to the tissue and detecting the light coming out of the tissues. The developments in this field include development of tomographic reconstruction of head phantom system using pulsed laser [16], multilayer imaging using continuous laser [17],continuous wave laser reflectance imaging[18] etc. The schematic of the laser transillumination tomographic system used is shown in the Fig.1. The imaging system consists of the following subsystems.

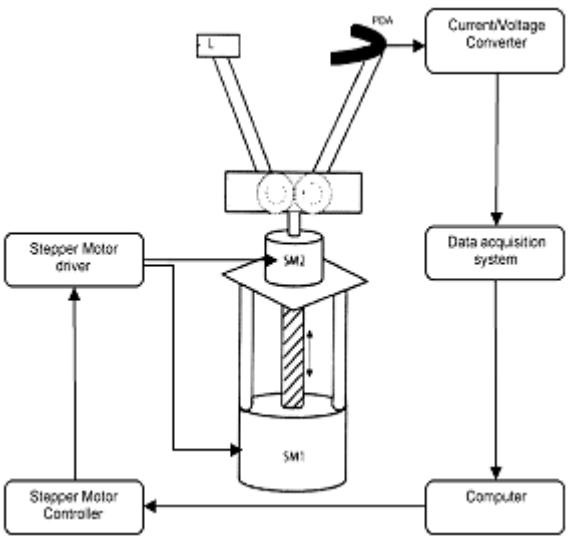

Fig.1. Schematic of laser transillumination tomography system. SM1, SM2 are stepper motors 1 and 2, L: laser source; PDA: photo diode array

1) Mechanical System: The mechanical system which serves the purpose of scanner helps to acquire the projections along the circumference and along the different heights of the phantom. The scanning is done by using two stepper motors. Stepper motor1 (SM1) helps in vertical scanning so that data along the various heights can be obtained and Stepper motor2 (SM2) helps in collecting data along the circumference of the phantom. A pantograph type arrangement carries laser source in one arm and an array of detectors in the other arm. The whole assembly can be moved up and down to cover the total height of the phantom by SM1.

2) Optical System: This system consists of laser pointer source (690nm) of 1mw with its driver and an array of photodetectors placed on the circumference of a circle forming a fan beam configuration [19]. The photodetectors used is a silicon photodiode BPW34 having fast response, low noise and low cost with peak spectral efficiency around 900nm. The diffused components of light through the phantom, which is placed at the centre of source detector assembly, are captured by an array of 16 photodiodes which are configured in fan beam geometry.

3) Data Acquisition System: The phantom is placed in the centre of the source detector assembly placed in the fan beam configuration and the stepper motors are brought to the initial position. SM1(Y motor) is first activated by loading the number of slices (say 6) to be taken along the object height. SM1 makes the source detector assembly to elevate so that it comes to the base position of the phantom. SM2(X motor) is then activated by loading the number of projections (say 100) to be taken along the circumference of the phantom. For each stepping in the circumferential direction, data is collected by the data acquisition unit from the array of 16 photodiodes and is stored in the computer. When it completes one scan it records the whole data in a 16x100 matrix. When one complete scanning is over SM1 is again activated so that the whole assembly moves to the next higher position. This process continues till the scanner scans the entire phantom and the data are finally placed in a 16x100x6 matrix.

4) Electronic System: This includes the electronic hardware system for the data acquisition system and the designed driver electronic circuitry for motor control and optical system. Further details of the scanning system are given elsewhere [20].

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B. Tomogram Visualisation

The diffusely transmitted light after light tissue interaction can serve as a good measure for finding the clinical condition of the concerned tissue. By applying tomographic principles to these transmitted component cross sectional details or tomograms of the tissue can be obtained. The cross section of the object was obtained by convolution back projection algorithm [19], [21]. This was carried out in the following steps.

Step 1: Each projection $R_{\beta i}(\gamma)$ was sampled with a sampling interval of angle α. If n denotes integer value and βi represents angles at which projections were taken, then $R_{\beta i}(n\alpha)$ denotes the fan beam projection. For each projection the modified projection $R'_{\beta i}(n\alpha)$ is

obtained as

$$R'_{\beta i}(n\alpha) = R_{\beta i}(n\alpha) D \cos n\alpha \quad (1)$$

where

D is the distance of the source from the origin

n =0 corresponds to the ray passing through the center of the object

Step2: Filtered projection was obtained by convoluting each modified projection $R'_{\beta i}(n\alpha)$ with the impulse response of a filter function $g(n\alpha)$

$$Q'_{\beta i}(n\alpha) = R'_{\beta i}(n\alpha * g(n\alpha) \quad (2)$$

Step 3: Finally, the reconstructed image was obtained by

$$f(x,y) = \Delta\beta \sum_{i=1}^{M} \left(\frac{1}{L^2}(x, y, \beta i) \times Q_{\beta i}(\gamma') \right) \quad (3)$$

where

γ'' angle of the fan beam array passing through the point (x ,y) and $\Delta\beta = 2\pi/M$;

M total number of angles;

L distance from the source S to the point (x ,y)

The reconstructed images were displayed as 128 x 128 pixel image matrices. Further processing of image was performed by image enhancement techniques. Standard image processing techniques such as low pass filtering, median filtering, contrast stretching were done to reduce noise and to improve dynamic range of illumination.

C. Three Dimensional Reconstruction From Two-Dimensional Slices

The cross sectional details will not give a better understanding of the diagnosing problem. By applying visualization technique a better insight to the volume of the object could be obtained. Volume visualization [22] is a method of extracting meaningful information from volumetric datasets through the use of interactive graphics and imaging. It is concerned with the representation, manipulation, and rendering of volumetric datasets [23]. It involves projecting a multidimensional data into a two dimensional image plane by using an array of techniques for projecting and shading a volumetric dataset or properties. This is accomplished by series of processes like transformations, cuts, segmentation, translucency control, measurements etc. The volumetric dataset is represented as a 3D discrete regular grid of volume elements know as voxels. The numeric values associated with each voxel represents some measurable properties of the real phenomenon of object residing in the unit volume.

The scanning system scans the prepared phantom both along the circumference and also along its height. During its scanning it takes 100 projections along the circumference and each projection is registered in the array of 16 photodetectors in fan beam configuration. So after one complete scan in the circumferential direction a matrix of 16x100x1 is registered in the computer. Then the stepper motor SM1 of the scanning system Fig.1. is incremented one step to take projections in the next height. Likewise the system scans the whole phantom in 6 increments and a projection matrix of size 16x100x6 is obtained. This matrix is stored and processed for reconstruction by using filtered back projection technique and during this process it is resized to 128x128x6 matrix. The noise removal is performed by Hamming filter. All the processes are done by using Matlab. The scalar volume data which is a collection of slices taken progressively through whole volume is further processed using image processing techniques. In the present work isosurface method of volume visualization is applied to the 3D grid containing the discrete values of the density function which represents the optical properties of the tissue phantom. For effective visualization of the volume data, it is converted to surface form and texture map is applied to visualize the surface. The isosurface of a particular isovalue is the set of all points whose interpolated density equals that isovalue. Matlab's custom isosurface algorithm for visualization which returns a triangulated surface like marching cube algorithm is used for this purpose. When combined with isocaps this technique revealed information about interior of the isosurface. Apart from this Matlab provided several commands to control shading, lighting and camera viewpoints while rendering 3D plots and volumetric data. These controls resemble Open Graphics Library structures, style and behaviors. Appropriate Matlab functions to control the camera rotation, position, viewing direction and orientation were used for the target volume visualization to obtain better insight of the viewed surface.

D. Phantom Preparation

To evaluate the potential of developed system for imaging tissues, synthetic tissue model phantoms were prepared by using agar as a host medium, Intralipid and India ink as simulators[24]-[26]. All these constitute turbid media similar to biological tissue.

Cylindrical solid phantoms of height 6cm and diameter 4cm which matches with the dimensions of the fan beam geometry were prepared for validation. Agar powder is the host material used in tissue mimicking phantom which basically provides structural support so that solid phantom layers could be made. In order to simulate different tissue properties three phantoms Fig.2. with different concentration of absorber and scatterer are made for the testing purpose. Intralipid is used for the reason that it can simulate the scattering properties of biological tissues [24]. India ink are also used along with intralipid in different concentration which mimics the purpose of absorber in the real tissue [25].

Agar was used in the concentrations 1:6 (6g in 100ml distilled water) in order to give more mechanical strength to the phantom sets. For these phantoms India Ink was used as absorbing medium and Intralipid simulated

scattering phenomena. For phantom 1, an initial concentration of 20 µl of India Ink was diluted to 100 ml distilled water was used as a stock solution. 1% Intralipid and 20 µl of the stock solution diluted to 5ml are then added to the host medium. For phantom 2, 2% Intralipid and 30 µl of the stock solution was diluted to 5ml and added to the host medium For phantom 3, India Ink (30 µl) was added to the host medium directly to simulate more absorption with 0.5% Intralipid. Increased absorption or scattering is an indication of malignancy in a tissue.

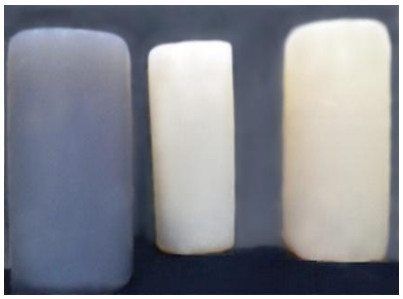

Fig.2 Phantoms prepared: from left phantom3, phantom1 and phantom2

The mixture of agar and distilled water is heated to a temperature of about 90 degrees and is then allowed to cool for about 60 degrees [26]. When it attains this temperature intralipid and India ink of required concentration are added and is again allowed to cool till 40 degrees. During the whole process the mixture is stirred well for getting uniform concentration. Then the mixture is allowed to settle and after solidification it is taken out of the glass mould and is used for experimental purposes

III. Results and Discussion

The non-invasive determination of optical parameters plays a vital role in medical diagnostic imaging. The technique presented here provides a method for studying the variations of optical parameters on tissue model phantoms using optical tomography. To analyze the variations 2D images of different layers of tissue phantoms are recorded. The obtained image is color coded which will enhance the chances of extracting information regarding abnormalities in a much simpler way. Tissue phantoms with varying concentrations of absorber and scattering medium were used for testing this tomographic method.

The phantoms with a height of 6cm are scanned using the developed system at an interval of 0.5cm.In each circumferential scanning 100 projections are made so that at the end of the whole scan a matrix of 16x100x6 is stored on the computer. This data is then used for reconstructing the tomograms and visualization of the volume. The tomograms obtained for the three phantoms are shown in Fig.3.

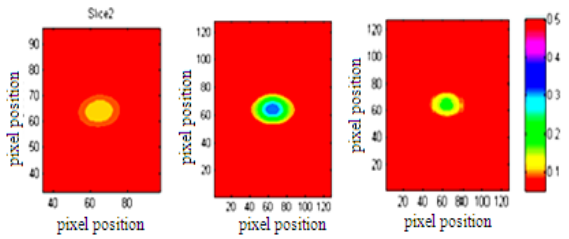

Fig.3. Tomograms obtained for three phantoms : from left phantom3, phantom1 and phantom2

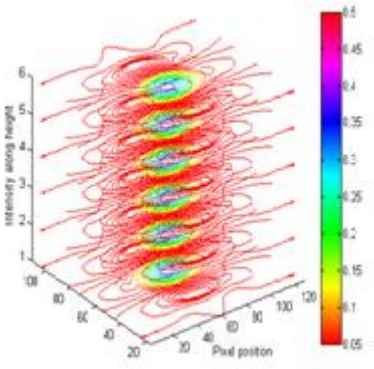

Fig.4. Placement of tomograms as a stack of six slices for Phantom1

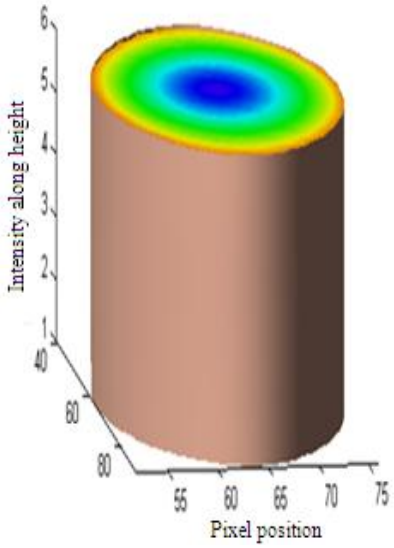

Fig.5. Volume visualized with cut away sections for Phantom1

The reconstructed tomogram of the phantoms shows significant differences with each other. During preparation of phantom1 the absorber and scatterer concentration included was very less and so maximum light output is obtained from that phantom. Tomograms analysis of phantom1 shows blue color in the centre followed by concentric rings of its low gradation colors. From the

color bar, blue color corresponds to a maximum intensity value compared to tomograms of phantom2 and phantom3 which had green and yellow at its centre with intensity equivalent values less than that of blue. So the light output from phantom1 is maximum which means that absorption and scattering is very less when compared to other two phantoms. Phantom 1 and Phantom 2 cannot be distinguished by direct eye sight but their tomograms Fig.3.shows distinct variations because of their variations in optical properties. There is no inhomogenities included in the phantoms and hence all the tomograms obtained for a particular phantom showed the same color map. Since variation in optical properties may be due to inhomogenities this methods finds application for distinguishing normal/abnormal tissues. Once tomograms are reconstructed an attempt to visualize the volume had been done to get a better insight to the structural variations of the phantom under consideration. For this tomograms of the six slices of the respective phantom are stacked one over the other Fig.4. Then volume rendering is done to visualize the whole volume using isosurface method of volume visualization. Fig.5 shows the reconstructed volume visualized for phantom1.Simlar structures are visualized for the remaining phantoms also. The method used for volume rendering requires lot of human intervention to set the threshold values in the algorithm and hence advanced techniques could be used to enhance the visualization**.**

In conclusion, a tomographic system consisting of red laser source and photodetectors has been developed. The number of detectors could be increased for better resolution and accuracy of the optical properties determination. Algorithms based on compressed sensing can be used which reduces the number of projections and thereby reduces the scanning time. Highly directional laser source with adequate power which does not cause tissue damage can be used so that false information due to scattered output can be minimized. Advanced image processing algorithms for tomographic reconstruction and volume visualization can be implemented to provide better results. The clinical potential of this system can be further extended to real time tissue samples for further evaluation

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