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Diffuse Optic Tomography (DOT) Techniques for Biomedical Imaging

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Abstract:

Diffuse optic tomography (DOT) techniques are part of the classification of molecular biomedical optic imaging modality. DOT has the device instrumentation and mathematical image reconstruction parties. In device instrumentation part, electronic, optic and mechanic combinations are prepared for laser data acquisition processes. Basically, DOT devices have light source and photo detector units. Depend on the source and detector placement on imaging tissue surface, device geometry may be transmission through, back-reflected, cylindirical ring or spherical. Laser sources are illumination devices. Laser photons with specific wavelength are sent through tissue from tissue surface. Molecules have different absorption coefficients depend on the laser wavelength. Detector units can be semiconductor PIN photodiodes, CCD or CMOS imagers. Different approaches can be used for geometrical DOT source-detector placements such that transmission through, back-reflected, cylindirical ring or spherical models. For instance, multi-sources and detectors might be placed like chessboard shape for back-reflected tissue imaging geometry. DOT imaging modality is also divided into three major branches depend on the run mode principle. Continuous Wave (CW), Frequency Domain (FD), and Time Resolved (TR) techniques are using different laser sources. CW technique is using steady state laser source. FD technique is using wide frequency range. TR technique is using picosecond (ps) or femtosecond (fs) pulsed laser source. All of these techniques are trying to investigate tissue molecule concentrations and spatial distributions by using acquired data in image reconstruction algorithm.

Keywords: Biomedical Optic Imaging; Diffuse Optic Tomography (DOT) Technique; Run Geometry; Run Modes.

DOI:

1. INTRODUCTION

Diffuse Optic Tomography (DOT) techniques involve several sub-groups depend on the geometrical shape and run mode philosophy. Geometrical structure can be divided into three basic physical appearances. These are transmission through, back reflected, and cylindrical geometries. Researchers from entire academic societies are using three fundamental physical geometries. Depend on the medical application clinic, geometry can be varied, for example breast tumor imaging instrumentation is usually setup in cylindrical ring geometry. On the ring geometry, laser sources and photo-detectors are placed such that they are looking center of the circle. From the source positions, collimated isotropic gaussian laser photons usually beam on specific wavelength laser (exception for hyperspectral imaging) on tissue interface. Typical representation of hanging breast inside the intralipid liquid is shown in Fig.1.

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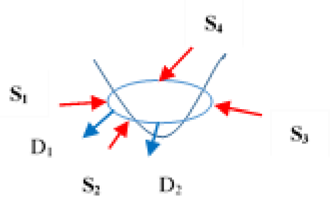

Figure 1. Breast ring imager instrument

The usual form of device instrumentation for ring shape breast diffuse optical tomography (DOT) was shown in Fig.1. based on the literature [1-3]. Isotropic collimated gaussian laser source and photodiode detector fiber optic probes were placed around the ring-shaped circle. Since breast has conical shape, it is appropriate to place source and detector fiber optic probes around ring-shaped circle and hang the breast inside the cone. Hence, ring-shaped geometry was developed and used by researchers in entire biomedical imaging society, successfully.

X-ray mammography screening diagnostic tool has not good accuracy rates for women whose ages are younger than 40 years. Hence, alternative biomedical imaging methodologies and devices have always been attractive for researchers. DOT devices are using near infrared (NIR) laser source to detect tumor blood voxels, especially 800-808 nm wavelength lasers are mostly used, since this narrowband has isotropic point, which has the same photonic absorption coefficients at this wavelength for oxy-hemoglobin (HbO2) and deoxy-hemoglobin (Hb). No technological development necessary to set ring-shaped breast laser diffuse optical imaging (DOI) systems. Semiconductor lasers, photodiodes, fiber optic cables, SMA jack connectors, fiber optic probe manufacturing kits, optic switches, electronic controller board with embedded software, PC interface programs, mechanical equipment such as metallic rings and other mechanical parts are necessary to build device. For experiments, intralipid, indocyanine green (ICG) liquids, dark room, optic table are necessary. Novel technological developments are not necessary to make DOT devices, however the contrast accuracy of diffuse optical imaging (DOI) is very low and it is only good for if one type of homogeneous tissue layer exists, for example it is good for breast tissue imaging. Multi-layer model such as adult head is not good example, since adult head has at least seven different tissue layers such as hair, epidermis, dermis, skull, scalp, cerebrospinal fluid (CSF), gray, and white matter, hence it is complicated, and varies from patient to patient. Thicknesses of layers are also changing for different patients. Another issue is the optical problems. Weak energy photons are scattering much more than x-ray imaging Bremsstrahlung photons, since they have lower energy than x-ray photons. Low power laser photons are scattering in entire tissue imaging medium depend on the tissue optical scattering coefficients. Scattering mechanism is making DOI modality not reliable and giving to researcher hard time.

Beside the ring-shaped DOI device instrumentations, there is also parallel plate mechanical shape [4]. Parallel plate has the advantages of press and measure capability, but it is only convenient for breast imaging, unless otherwise the other imaging objects cannot take the shape of imager multi-probe device structure. They have usually easily portable ultrasonic hand-held mechanical geometric shape such as in literature [4-6]. Hand-held parallel plate systems have some advantages over bed systems, since they are small and easily transportable, consume low energy, and fill small spaces. However, the philosophical problems are keep staying over DOI modality.

Other classification is based on the running mode, which can be divided into three different groups such as Continuous Wave (CW), Time Resolved (TR), and Frequency Domain (FD). At the beginning of DOI researches, researchers were focus on their studies with CW run mode. It is easiest and cheapest methodology. It constitutes general-purpose semiconductor laser diodes, and semiconductor photodiodes as photodetectors. Since photon' s scattering nature in imaging biological tissues, they started to change their focus onto the TR mode devices. Nevertheless, building TR mode devices are much more expensive than the building CW devices. It constitutes very expensive solid-state semiconductor Titanium-Sapphire (TiSa) lasers and single photon counting photo-multiplier tubes (PMTs). It has advantageous over CW imaging systems from the view of deep tissue inclusion investigation. Pulsed laser is sent through tissue from tissue surface at source position, migrated photons escape from detector points. The first incoming photons in detector location are superficial photons, which sweep superficial voxels. Later on, the deeper swept photons come to detector points. The analysis of escaped photons from different source-detector separation (SDS) is giving depth information about where the blood voxel inclusions are buried. The third run mode is the frequency domain (FD) DOI modality which involves frequency modulation (FM) techniques applied to incident source light. Frequency and phase shift is

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observed in this technique, and it is predicted to find blood voxel inclusions inside the imaging medium. FM technique is also rarely used by DOI researchers.

2. REVIEW to GEOMETRICAL CLASSIFICATION

Depend on the biomedical imaging tissue geometries back-reflected, transmission-through and circular ring geometries, source and detector placement onto the mechanical imager device can be different. Imager devices might have multi-source and detector numbers. In the spectroscopic definition, single source or detector is known as fiber optic probe. Imager physically has multi source and detector probes on its surface. It may have different placement schema like chessboard shape. This device geometry is used for back-reflected laser imaging modality. Source and detector probes are on the same imager surface, only difference is in two dimensional (2d) xy coordinate plane. Collimated isotropic point gaussian laser beam photons are sent through tissue from imager surface. If photodiodes are used for photo-detecting purpose at the detector locations, imager should touch the tissue surface, otherwise escaping photons from tissue surface release everywhere in the dark experiment room. It becomes impossible to collect back-reflected escaping photons from device-tissue touch surface. If other than photodiodes, intensified CMOS imagers or CCD cameras were used as detector unit, it would not be necessary to touch the imaging tissue surface. However, in that situation experiment room should be dark, there should be no light artefact or noise, since any other light source can generate photocurrent on the CCD, CMOS imager, or photo-multiplier tube (PMT). In chessboard-shaped back-reflected touch mode run diffuse optic tomography (DOT) device, source and detector points have some definite distances between them. The main philosophical gain when making conventional DOT imager instrument is to benefit from perturbation data, which is connected experimental measurements between with inclusion and non-inclusion. Perturbation data is natural logarithm of the division of the two consecutive experimental measurements which one is with inclusion and the other one is with non-inclusion. That is why any heterogeneity in the imaging tissue media is affecting all image reconstruction algorithm. Breast imaging is more appropriate than any other tissue type, since breast tissue is more likely to homogeneous tissue type. For the homogeneous tissue type, perturbation data can be clearly made by simply dividing two different experimental measurement data and by taking natural logarithm of it. In this situation, grouping of similar neighborhoods is the key element for better analyze methods, since imaging geometry has the same tissue optic properties, all measurement results should be the same for all neighborhoods. For back-reflected chessboard-shaped geometry, neighborhood relations can be set by mathematical analyze software. Before putting it into mathematical inverse problem solution algorithms, same neighborhood classifications can give relative ideas about where the inclusion is buried in tissue, which might tell us (x, y, z) coordinate location information of buried inclusion, successfully. The only thing that there should be no electrical noise, optical artefact and, imaging tissue medium should be homogeneous, that is why researchers are mostly making their experiments with homogeneous solid or liquid phantoms such as solid graphite + titanium dioxide (TiO_2) + Silicon + Silicon Curing mix powder made or liquid intralipid phantoms. Researchers are using handmade homogeneous phantoms by this way, which mimic real tissues. Intralipid is more likely to the breast tissue.

Some researchers are grouping diffuse optical imaging (DOI) geometries to sub-groups not like transmission-through, back reflected or circular ring model. They group geometries based on the source and detector placements around the geometric shape. They show symbolically these geometries' source and detector shapes and placements based on the incoming and outgoing arrow lines [7]. The circular is ring model like breast imaging geometry structure. Single or multi source and detector fiber optic probes are placed around the circular ring shape. Hence, it cannot be completely interpreted as transmission-through or back-reflected geometry. The other geometrical model approach is fan-beam structure, which sources, and detectors are rotated around ring. Back-reflected geometry is the sub-surface model. The finally, slab flat model is made in flat plane geometry.

3. RESULTS and DISCUSSION

For entire DOT imaging models, the main motivation is to use theoretical physics or MC simulation methods, experimental device instrumentation, calibration, and measurements for both breast tumor imaging and brain blood hemoglobin rates for DOT methods. The philosophical thoughts are needed for DOT imaging methodology, since it is stuck because of scattering nature

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of unpolarized weak energy photons. Scattering is making reconstructed images always blurred and it is also vanishing depth information of scanned tissue. Philosophical thoughts are needed to develop new technological devices. It is not completely necessary to develop such as novel spintronic or semiconductor devices, but it is necessary to invent new ideas to practically combine affordable semiconductor devices together and work. There is a gap needed to be filled by novel ideas. Scattering nature of weak energy photons is the big block in front of the development of DOT imaging modality. Hopefully, new methods are invented to be solved by researchers.

4. CONCLUSION

DOT imaging is mostly used to image voxels which contain more blood chromophores. Existing biomedical imaging modalities are mostly based on the nuclear imaging techniques such as PET and MRI. DOT imaging technique is using near infrared (NIR) laser which has 808 nm wavelength, since it has isosbestic point for both dirty and clean blood which contains non-hemoglobin and hemoglobin chromophores. DOT devices are trying to investigate absorption (□a) and scattering (□s) tissue optic property differences over homogeneous tissue type. Breast, brain, and joints are the three major clinical application field for diagnostic investigations. Device instrumentation based on the run principle can be separated into three sub-groups such as Continuous Wave (CW), Time Resolved (TR), and Frequency Domain (FD) modes. As previously mentioned DOT devices are not reliable, since scattering nature of weak energy un-polarized photons. Bremsstrahlung x-ray beam is the ionizing, straight going light. It has almost no scattering effect. In the image reconstruction algorithms, it is easy to solve inverse problem by applying pseudoinverse or any other back projection algorithmic methods. Novel ideas are needed to pass through the next level of laser imaging but not DOT, theoretical weak energy photon diffusion approach is not helping to researchers to pick the blocking rocks from their way.

5. ACKNOWLEDGMENT

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