Image reconstruction algorithm of near infrared optical tomography

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The principle of the algorithm for stability near infrared (NIR) optical Tomography (CT) is introduced. The forward problem of optical CT is how to solve the Boltzmann transmitting equation based on finite rlement method (FEM). The influence of high reduced scattering coefficient and high absorption coefficient distribution of simulation background was discussed. The inverse problem is to reconstruct the map of the background tissue from the boundary data, and the image reconstruction algorithm is the key problem for optical CT. Generic algorithm (GA) and FEM simulation was used to solve the inverse problem.

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Stability near infrared (NIR) optical tomography (CT) is a new technology in noninvasive medical examination[1]. The NIR light is delivered to the surface of a patient (brain or breast) by a fiber-optic (referred to as an optode), which is put around the surface of the patient. The NIR light is absorbed and scattered by the tissue, which is collected by another fiber-optic (7 or more) called detector at several centimeters distant near the patient. The tissue must be a highly light scattering medium, such as brain and breast. The light collected by detectors is dependent on absorption coefficient and the reduced scattering coefficient. We can reconstruct the map of the optical properties in medium from the data of detectors. The cancer tissue and the normal tissue's scattering and absorption coefficients are different, so we can derive the spatial distribution within the tissue based on the scattering or absorption coefficient distribution map.

Because the NIR light can provide the structural and functional image, so it can determine the level of canner especially in the early stages. There are many research and applications about optical CT[2,3]. For functional brain imaging, the regions of the brain due to some special neurological activations can be defined, which can be used to guide the treatment of some abnormities in brain. Optical CT can also be used to detect and prediagnose the breast cancer.

The forward problem model can be defined as follows.

Given the source light $\{s\}$ on the boundary $\partial\Omega$ of a tissue Ω, and an optical properties distribution $\{q\}$ within the tissue Ω, find the light intensities set $\{M\}$ on $\partial\Omega$. Define as the following operator $\{M\} = F[\{q\}]$.

The light distribution in the tissue depends on the optical properties, including scattering coefficients $\mu_{\rm s}$ ($\rm mm^{-1}$), absorption coefficient $\mu_{\rm a}$ ($\rm mm^{-1}$) and the anisotropic parameter g. The reduced scattering coefficient $\mu'_{\rm s}$ is given by $\mu'_{\rm s} = (1-g)\mu_{\rm s}$. If the tissue is the highly scattering medium, $\mu'_{\rm s} \gg \mu_{\rm a}$, the Boltzmann transmitting equation is used as the most general model photon transport in tissue. The Boltzmann transmitting equation

$$\frac{1}{c}\cdot\frac{\partial}{\partial t}\Phi(r,t) - \nabla\cdot\kappa\nabla\Phi(r,t) + \mu_{\rm a}\Phi(r,t) = s(r,t), \quad (1)$$

where diffusion coefficient is given by

$$\kappa = \frac{1}{3[\mu_{\rm a} + (1-g)\mu_{\rm s}]}, \quad (2)$$

c is the light velocity in vacuum, $\Phi(r,t)$ is photon density, $s(r,t)$ is light source.

There are many methods to solve Eq. (1), but finite element method (FEM)[4−7] is one of the most precise methods. In order to get the numerical solver to the transport equation, researchers have done many work before the Femlab simulation software was used. Femlab software can solve differential equation based on FEM. With the proper settings of the differential coefficient, the Eq. (1) can be solved by Femlab easily and precisely.

The key of inverse problem is how to get reconstruct optimization algorithm, generic algorithm (GA) and Femlab software were presented in this paper.

First, the inverse problem model is defined as follows.

Given a distribution of light sources $\{q\}$ and a distribution of light intensities in detector points $\{M\}$ on the boundary $\partial\Omega$ derive the optical properties distribution $\{p\}$ in Ω. Define as the following operator $\{p\} = F^{-1}[\{M\}]$.

The steps of the inverse problem model based on Femlab and GAs are :

1) Define the initial optical parameters $\{\mu_{\rm a}, \mu'_{\rm s}\} = \{\mu_{\rm a0}, \mu'_{\rm s0}\}$ of the tissue.

2) Get data $\{M\}$ around tissue boundary by detectors of instrument.

3) Solve the forward problem model by the software Femlab with the optical parameters $\{\mu_{\rm a}, \mu'_{\rm s}\}$.

4) Transfer data simulated from Femlab into the Matlab and get data at the optode points into $\{\hat{M}\}$.

5) Calculate the fitness function $\|\{M\} - \{\hat{M}\}\|$.

6) If the $\|\{M\} - \{\hat{M}\}\|$ does not get the minimized value, change the optical parameters $\{\mu_{\rm a0}, \mu'_{\rm s0}\}$ into $\{\mu_{\rm a}, \mu'_{\rm s}\} = \{\mu_{\rm a0} + \Delta\mu_{\rm a}, \mu'_{\rm s0} + \Delta\mu'_s\}$, repeat from step 2) to 6).

7) If $\|\{M\} - \{\hat{M}\}\|$ get the minimized value, the optical parameters $\{\mu_{\rm a}, \mu'_{\rm s}\}$ are what we want.

8) At last, $\{\mu_{\rm a}, \mu'_{\rm s}\}$ can be used to reconstruct the image of tissue.

Figure 1 is the optical distribution map simulated by Femlab. Figure 2 is the light intensity from left to right through the white line in Fig. 1, when two circles (which means two targets in tissue) in Fig. 1 have different absorption and reduced scattering coefficients. Two target's

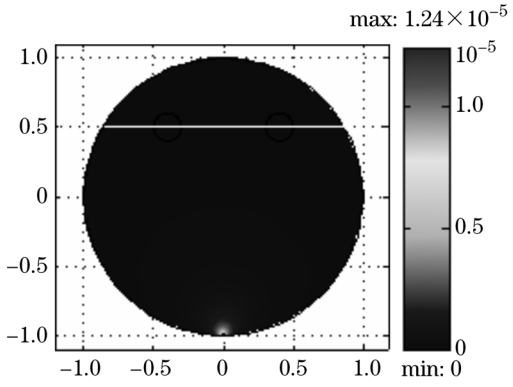

Fig. 1. Three-region forward problem model.

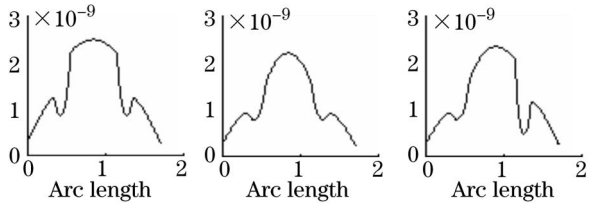

Fig. 2. The light intensities through the white line from left to right in Fig. 1 with the different optical properties of the two circles.

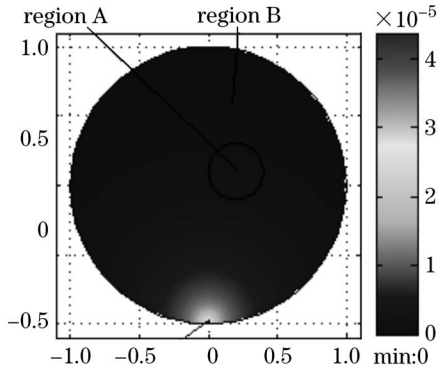

Fig. 3. Two regions inverse problem model. Region A is the cancer with $\mu_a = 0.3$ mm^{-1} and $\mu_s' = 2.081$ mm^{-1}. Region B is the background tissue with $\mu_a = 0.1$ mm^{-1} and $\mu_s' = 40$ mm^{-1}.

optical parameters of Fig. 2 have three cases: ($\mu_a = 0.1$ mm^{-1}, $\mu_s' = 1111$ mm^{-1}), ($\mu_a = 0.8$ mm^{-1}, $\mu_s' = 76.72$ mm^{-1}) and (left: $\mu_a = 0.8$ mm^{-1}, $\mu_s' = 76.72$ mm^{-1}; right $\mu_a = 0.1$ mm^{-1}, $\mu_s' = 1111$ mm^{-1}). Optical parameters of the tissue background are $\mu_a = 0.1$ mm^{-1} and $u_s' = 40$ mm^{-1}.

Table 1. The Measured and Optimized Parameter in Region A of Fig. 3

Parameter	Measure	Optimized	Error (%)
μ_a (mm^{-1})	0.300	0.300	0
μ_s' (mm^{-1})	2.081	2.026	2.64

The simulation result has been verified by Gao *et al.*[8], so the Femlab software is a very efficient tool to solve the forward problem.

The inverse image reconstruction result is as follows.

The model is the homogeneous tissue and the air is outside. The light energy is 1 J and the cross size of light source is 0.01 ×0.01 mm. The region A is the circle at (0,0) with 10 mm radius. The region B is the circle at (2,1) with 2 mm radius. Region A and B are shown in Fig. 3.

From the results listed in Table 1 we can conclude that the method to solve the inverse problem model is efficient. We can get the optical distribution of tissue by this optimization algorithm. Because the optical properties are different in the different tissues, so we can segment the tissue based on optical properties.

The inverse problem model is solved as optimization problem by Femlab and GAs. The optical coefficients can be derived and the tissue image can reconstruct by GAs.

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