Research on Image Reconstruction for Optical Tomography Based on Gradient Tree Algorithm

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Abstract: Optical coherence tomography is a new imaging method, which is widely used in many fields such as biomedicine and materials. Image reconstruction is the process of reconstructing the optical properties of tissue by using the data measured on the surface of the medium and the transport model of photons in the medium. An image reconstruction method based on gradient tree for optical tomography is presented in this paper. Experiments show that this method can effectively reconstruct optical tomography images, reducing computation and improving reconstruction speed.

1. Introduction

Optical imaging has important application value in medical field, which greatly promotes the development of medical diagnosis and treatment technology [1]. In order to achieve optical tomography, photodetectors are placed at different positions on the surface of human body such as arms, breasts and brain to collect the energy transmitted by near infrared light through tissues, and some reconstruction algorithm is used to process the collected energy data, which can realize the imaging of tissues. Compared with other imaging technologies, optical tomography technology has the following advantages. Near infrared radiation is non-ionizing and non-destructive to human body at low doses. It can be used for routine photography and continuous monitoring. The technique provides a means to distinguish different soft tissues, which differ in optical property absorption coefficient and scattering coefficient. It has higher time resolution and can theoretically achieve milliseconds or even higher. Functional information can be obtained from the specific absorption characteristics of natural photons in the tissue. The amount of oxygen transported to tissues depends mainly on blood flow and blood volume. Regional changes in cerebral blood flow and volume are caused by the expansion of cerebrovascular, which is a response to increased intracerebral pressure. Local cerebral blood volume and cortical oxygenation are closely related to local brain activity. Therefore, the measurement of the above functional information is one of the main applications of optical tomography. Because of the strong multiple scattering of light when it propagates in chaotic media, its coherence will be lost quickly and the polarization effect and interference effect will be lost. Therefore, in the practical application of optical tomography, it is not necessary to deal with the fluctuation of light, as long as the light is treated as particles, satisfactory results can be obtained.

2. Image Reconstruction Method for Optical Tomography Based on Gradient Tree Algorithm

2.1 Definition of Objective Function.

The objective function is the objective form expressed by design variables, so the objective function is the function of design variables [2]. In engineering sense, the objective function is the performance standard of the system, such as the lightest weight, the lowest cost and the most reasonable form of a structure, the shortest production time and the least energy consumption of a product, the best formula of an experiment, etc. The process of establishing the objective function is to find the relationship between design variables and objectives. The relationship between objective functions and design variables can be represented by curves, surfaces or hypersurfaces. In optical tomography, the propagation of photons in scattering media obeys Boltzmann transport model, which

is called transport equation for short. At present, most reconstruction algorithms are based on Boltzmann equation, which is an approximate form of diffusion equation. However, this approximation only applies to cases where scattering is much larger than absorption. Optical tomography problems often have many feasible design schemes. The task of optimal design is to find out the best one. The criterion for evaluating the optimal scheme should be that it can best reflect some specific objectives of the design. Usually, these objectives can be expressed as mathematical functions of design variables, which are called objective functions. Therefore, an optical tomographic image reconstruction algorithm based on radiation transfer equation is proposed and applied to image reconstruction with hollow regions. The final goal of image reconstruction is to solve the distribution vector of optical parameters and minimize the objective function value. The most commonly used objective function optimization method is gradient optimization algorithm. The key of the algorithm is gradient calculation. The imaging problem can be regarded as an optimization problem of a nonlinear objective function. If the predicted data vector calculated by the forward model is the actual measured data vector, the objective function can be defined as the square error function between the predicted data and the measured data.

2.2 Joint Difference Algorithm.

At present, most reconstruction methods are based on gradient iterative image reconstruction method. In recent years, several research groups have applied this method to optical tomography image reconstruction. They have applied this method to diffusion equation-based reconstruction and radiation transfer equation-based reconstruction. In image reconstruction, the steepest descent method, conjugate gradient method and other local optimization algorithms only need to calculate the first-order gradient to achieve iterative updating of optical parameters. The joint differential algorithm does not need to explicitly compute the matrix, nor does it need to repeatedly compute the inverse. Many variables in the objective world are discrete in themselves, and the functions they represent are also discrete. In real life, there are a large number of continuous functional relationships which are difficult to be expressed by analytic formulas. People can only measure a series of values and get a sequence of numbers. Although some functional relationships can be expressed by functions, their analytic formulas are more complex. Without prejudice to the validity of the results, people are also willing to convert the study of continuous functions into the study of logarithmic series. The development of computer technology provides convenience for the study of sequence, and the application of sequence is becoming more and more extensive. In social and economic activities and natural science research, we often encounter variables related to time t, and people can only observe or record the values of these variables at discrete time t. For such variables, how to study their interrelationship is inseparable from the tools of difference and difference equation. Differential and differential equations in calculus are in fact derived from difference and difference equations. Therefore, difference and difference equations are primitive, objective and vivid materials. In the process of solving joint difference algorithm, with the increase of evolutionary algebra, the diversity of population will be reduced, convergence to local minimum prematurely, or the algorithm will stagnate. This is undoubtedly fatal to the algorithm that relies on population differences to evolve, and makes the performance of the algorithm worse in the process of evolution [3].

2.3 Gradient Tree Calculation.

The combined difference method is used to calculate the direct gradient of the objective function to the optical parameters in optical tomography [4]. In order to apply this method, we first decompose the objective function into a series of basic differentiable functions. The gradient value can be obtained by systematically applying chain derivation rules to each basic function level along the reverse direction of forward model iteration calculation. It reflects only the relationship between the objective function and the boundary points. What really relates to the internal optical parameters is the calculation. Therefore, it is the most critical part in the gradient calculation. It is a measure of the extent to which the numerical value of the boundary points is affected by the internal optical parameters. Its calculation accuracy directly affects the quality of the reconstructed image. At the same time, it is the most complicated and time-consuming in gradient computing. We discuss the

calculation method of gradient and other cases can carry out similar analysis. In vector calculus, the gradient of scalar field is a vector field. The gradient at a point in the scalar field points to the direction where the scalar field grows fastest, and the length of the gradient is the biggest change rate. Strictly speaking, the gradient of a function from Euclidean space to real space is the best linear approximation at a certain point. In this sense, gradient is a special case of Jacobi matrix. In the case of a real function of a single variable, the gradient is only a derivative, or, for a linear function, the slope of the line. Gradient enhancement is one of the Boost algorithms. The original Boost algorithm assigns an equal weight to each sample at the beginning of the algorithm, that is to say, at the beginning, everyone is equally important. At the end of each step, we need to deal with the weight value, and the way to deal with it is to increase the weight of the wrong classification points and reduce the weight of the correct classification points at the same time. In this way, if some points are always misclassified, they will be assigned a very high weight.

3. Image Reconstruction Experiment for Optical Tomography Based on Gradient Tree Algorithm

3.1 Experiment Process.

This experiment is aimed at the reconstruction of scattering coefficient and the absorption coefficient of the whole model. The light source is placed in the middle of each edge, and the detector is placed on the grid points except the other three edges. The spacing between the detectors is equal, so the detector is composed. The position of the light source and detector when the light source is at the bottom, where the arrow represents the position of the light source, and the small black rectangle represents the position of the detector. The highest level in the structure is the broadest and most complete description of objectives, but the description of these objectives is vague and not operable. Along the layered structure, the objective function becomes more and more specific and more operable. If there is a way to evaluate the level to achieve this goal, this goal is operable. To facilitate the realization of the practical algorithm, a series of attributes are assigned to the lowest level objective function of the hierarchical structure. Attribute is a measurable quantity, and its value reflects the degree of achieving a specific goal. In some cases, some targets cannot find one or more obvious attributes to directly measure the degree they reach, but there are still one or several attributes that can indirectly reflect the degree of achievement of the target even if they are measured. This attribute is called substitutional attributes. In the case of multi-objective decision-making, after having clear decision-making objectives and attributes, there must be some decision-making rules in order to compare the advantages and disadvantages of different schemes. Moreover, decision rules are not entirely objective, they often reflect the preferences of decision makers for different decision objectives, so there is no perfect method to deal with such problems. The solution is to use several methods to solve the problem and compare the results of various methods in order to get a more reliable sequencing scheme.

3.2 Experiment Result.

The experimental program runs on a computer, and it takes about 20 minutes to iterate once. The number of branches taken in the experiment is about eighty percent of the total number. Among them, the reconstruction result after the second iteration is the result of the second iteration. From the experimental results, it can be seen that although the approximate gradient method is used, only a few iterations are needed to obtain a better reconstructed image, which shows that the approximate gradient method is effective. In addition, the reconstruction problem is an ill-posed problem. There is a certain gap between the reconstructed data and the real data. In the following chapters, image priori information will be added to reconstruct the image under constraints, so as to improve the quality of image reconstruction, reduce the gap between reconstructed data and real data, and make the reconstructed image approach the original image more truthfully. Secondly, as a specific application, this chapter also uses the gradient tree-based reconstruction algorithm to achieve the image reconstruction of the region with holes under the radiation transfer equation, which further proves the

effectiveness of the method for image reconstruction. Compared with the regularized reconstruction method, the multi-criteria reconstruction method has more advantages in the selection of weight coefficients. In the regularization reconstruction method, the determination of regularization parameters is a difficult problem. So far, there is no mature theory and method. Usually, it is determined by trial method, and the weight coefficients should be re-determined for different images. The multi-criteria reconstruction method presented in this paper proposes an algorithm to dynamically determine the weight coefficients, which is suitable for various images and has greater universality. By introducing multiple objective functions, this method improves the ill-pawedness of the reconstruction problem and improves the quality of image reconstruction. The method of determining the dynamic weight coefficient overcomes the drawback of determining the weight coefficient in regularization reconstruction.
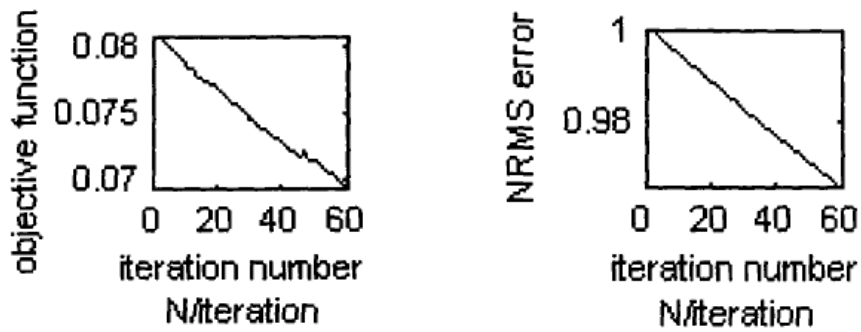

Figure 1. Curves of objective function and NRMS error in the Image Reconstruction process

From the curve in the graph, we can see that with the increase of iteration times, the value of objective function and the value of NRMS become smaller and smaller. The decline of objective function value fluctuates, while the decline trend of the NRMS is basically linear, which confirms that the reconstruction is gradually improved.

3.3 Result Analysis.

Optical tomography is a non-invasive imaging technology, which reconstructs the absorption and scattering coefficients of optical properties in biological tissues. It is suitable for imaging human muscles, breasts, brain and other tissues. Among them, one of the main applications of optical tomography is infant brain imaging, which can understand and prevent brain disorders by detecting changes in oxidative status in specific areas of the brain. Within the brain, there are some areas that do not have scattering properties, but they still have absorption properties. They are called hollow areas, such as cerebrospinal fluid surrounding the brain. At this time, the diffusion equation cannot accurately describe the photon transport in tissue, which will lead to the failure of image reconstruction. As a specific application, this chapter also uses the gradient tree-based reconstruction algorithm to reconstruct the image of the region with holes under the radiation transfer equation, which further proves the effectiveness of this method for image reconstruction. However, the validation of the algorithm in this chapter is only based on a simulation model imitating CSF, and the reconstruction model is regular. In the future work, we will improve the reconstruction algorithm, introduce real structure information, and explore the reconstruction method under the irregular boundary and complex background of real brain model. In this section, we discuss the image reconstruction method under the transport model and cavity area. It is proved that image reconstruction based on transport model can overcome the disadvantage of diffusion equation reconstruction in non-scattering region and accurately reconstruct optical tomography image. But the validation of the algorithm in this chapter is only a simulation model imitating cerebrospinal fluid, and the reconstructed model is regular. This method can reduce the computational complexity of gradient and speed up the process of image reconstruction. The key is the choice of the number of branches. Improper selection will directly affect the quality of image reconstruction. However, the validation of the algorithm in this chapter is only based on a simulation model imitating CSF, and the

reconstruction model is regular. In the future work, we will improve the reconstruction algorithm, introduce real structure information, and explore the reconstruction method under the irregular boundary and complex background of real brain model.

4. Conclusion

In this paper, we discuss the image reconstruction method based on gradient tree with void regions in the transport model. It is proved that image reconstruction based on transport model can overcome the disadvantage of diffusion equation reconstruction in non-scattering region, reduce the computational complexity of gradient, accelerate the process of image reconstruction, and accurately reconstruct optical tomography images. We introduce the maximum entropy, local smoothing function and Markov random field into the objective function of image reconstruction.

Acknowledgements

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