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研究论文

基于点加权最小二乘无网格法的光学成像光传输模型求解

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摘要:

漫射方程是目前光学成像中应用最广泛的光传输模型，通常采用有限元方法进行求解。但是，有限元方法依赖于对整个求解域的网格剖分，而对于类似生物组织的非规则形状求解域的网格剖分是非常困难的，甚至昂贵的商业软件也难以很好地处理。本文将点加权最小二乘无网格法应用于漫射方程的求解。这种方法只需要在求解域内布置一系列规则分布的配点即可进行数值求解，从而可以完全避免有限元方法中困难的剖分工作。此外，这种方法通过最小化控制方程和边界条件在每个配点上产生的残量加权平方和，建立光源功率和光流率密度之间的关系，不需要进行任何数值积分运算，非常适合应用于非规则求解域的求解。基于数字鼠模型的数值仿真实验验证了该方法的准确性和有效性。

关键词: 无网格法 漫射方程 光传输模型 光学成像

Point Weighted Least-Squares Meshless Method for Photon Transport in Complex Biological Tissues

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Abstract:

Diffusion equation is a widely used model for photon transport in biological tissues. Commonly, it can be solved by the finite element method, which depends on the mesh discretization of interesting area. However, this kind of discretization is quite difficult for complex geometries such as biological tissues, even using commercial software. In this paper, a point weighted least-squares (PWLS) meshless method for the photon transport in diffusive biological tissues with complex and irregular geometries is presented. The proposed method does the calculation with some collocation points distributed regularly in the interesting area, so that complicated mesh generation required by finite element method can be avoided. Moreover, our method establishes the relationship between the source distribution and the photon flux density by minimizing the weighted residuals quadratic sum of all collocation points. Thus, it doesn't need the complicated integration calculation, which provides more convenience for the application in irregular shaped region like biological tissues. Numerical simulations with the phantoms constructed based on mouse tissues demonstrate the accuracy and effectiveness of the proposed method.

Keywords: Meshless method Diffusion equation Light transport model Optical imaging

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参考文献：

1. Cherry S. In vivo molecular and genomic imaging: New challenges for imaging physics. Phys Med Biol, 2004, 49:13~48
2. Weissleder R, Ntziachristos V. Shedding light onto live molecular targets. Nat Med, 2003, 9: 124~128
3. Bhaumik S, Gambhir SS. Optical imaging of Renilla luciferase reporter gene expression in living mice. Proc Natl Acad Sci USA, 2002, 99: 377~382
4. Massoud TF, Gambhir SS. Molecular imaging in living subjects: Seeing fundamental biological processes in a new light. Genes Dev, 2003, 17: 545~580
5. Rice W, Cable MD, Nelson MB. In vivo imaging of light-emitting probes. J Biomed Opt, 2001, 6: 432~440
6. Gibson AP, Hebden JC, Arridge SR. Recent advances in diffuse optical imaging. Phys Med Biol, 2005, 50: 1~43
7. Wang G, Cong W, Li Y, Han W, Kumar D, Qian X, Shen H, Jiang M, Zhou T, Cheng J, Tian J, Lv Y, Li H, Luo J. Recent development in bioluminescence tomography. Curr Imaging Rev, 2006, 2: 453~457
8. Arridge SR, Dehghani H, Schweiger M, Okada E. The finite element model for the propagation of light in scattering media: A direct method for domains with nonscattering regions. Med Phys, 2000, 27: 252~264
9. Wang Q, Li H, Lam K. Development of a new meshless-point weighted least-squares (PWLS) method for computational mechanics. Comput Mech, 2005, 35: 170~181
10. Ntziachristos V, Tung C, Bremer C, Weissleder R. Fluorescence molecular tomography resolves protease activity in vivo. Nat Med, 2002, 8: 757~760
11. Schweiger M, Arridge SR, Hiraoka M, Delpy DT. The finite element method for the propagation of light in scattering media: Boundary and source conditions. Med Phys, 1995, 22: 1779~1792
12. Belytschko T, Krongauz Y, Organ D. Meshless methods: An overview and recent developments. Comput Method Appl Mech Eng, 1996, 139: 3~47
13. Wang L, Jacques SL, Zheng L. MCML-Monte Carlo modeling of photon transport in multi-layered tissues. Comput Meth Prog Biomed, 1995, 47: 131~146
14. Boas D, Culver J, Stott J, Dunn A. Three dimensional Monte Carlo code for photon migration through complex heterogeneous media including the adult human head. Opt Express, 2002, 10: 159~169
15. Ren NN, Liang JM, Qu XC, Li JF, Lu BJ, Tian J. GPU-based Monte Carlo simulation for light propagation in complex heterogeneous tissues. Opt Express, 2010, 18: 6811~6823
16. Dogdas B, Stout D, Chatziioannou A, Leahy RM. Digimouse: A 3D whole body mouse atlas from CT and cryosection data. Phys Med Biol, 2007, 52: 577~587
17. Alexandrakis G, Rannou FR, Chatziioannou AF. Tomographic bioluminescence imaging by use of a combined optical-PET (OPET) system: A computer simulation feasibility study. Phys Med Biol, 2005, 50: 4225~4241
18. Klose AD, Larsen EW. Light transport in biological tissue based on the simplified spherical harmonics equations. J Comput Phys, 2006, 220: 441~470

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