

光子学报 2011, 40(11) 1607-1618 DOI: 10.3788/gzxb20114011.1607 ISSN: 1004-4213 CN: 61-1235/O4

本期目录 | 下期目录 | 过刊浏览 | 高级检索

[打印本页] [关闭]

## 论文

### 高分辨和超分辨光学成像技术在空间和生物中的应用

姚保利<sup>a</sup>, 雷铭<sup>a</sup>, 薛彬<sup>a,b</sup>, 邵鹏<sup>a</sup>, 严绍辉<sup>a</sup>, 赵惠<sup>a,b</sup>, 赵卫<sup>a</sup>, 杨建峰<sup>a,b</sup>, 樊学武<sup>a,b</sup>, 邱跃洪<sup>a,b</sup>, 高伟<sup>a,b</sup>, 赵葆常<sup>a,b</sup>, 李英才<sup>a,b</sup>

a. 中国科学院西安光学精密机械研究所 瞬态光学与光子技术国家重点实验室 高分辨光学成像技术联合研究室, 西安 710119;

b. 中国科学院西安光学精密机械研究所 空间光学技术研究室, 西安 710119

#### 摘要:

大到天文光学望远镜观察浩瀚的宇宙, 小到光学显微镜探察细微的纳米世界, 光学成像技术在人类探索和发现未知世界奥秘的活动中扮演着至关重要的角色. 看得更远、看得更细、看得更清楚是人们不断追求的目标. 传统光学理论已证明所有经典光学系统都是一个衍射受限系统, 即光学系统空间分辨率的物理极限是由光的波长和系统的相对孔径(或数值孔径)决定的. 能否突破这个极限? 能否不断提高光学系统的成像分辨率? 围绕着这个问题, 本文综述了近年来开展的各种光学高分辨和超分辨成像技术, 及其在空间探测和生物领域中的应用.

**关键词:** 高分辨 超分辨 光学成像 空间光学遥感 显微成像

### Progress and Applications of High-resolution and Super-resolution Optical Imaging in Space and Biology

YAO Bao-li<sup>a</sup>, LEI Ming<sup>a</sup>, XUE Bin<sup>a,b</sup>, GAO Peng<sup>a</sup>, YAN Shao-hui<sup>a,b</sup>, ZHAO Hui<sup>a</sup>, ZHAO Wei<sup>a</sup>, YANG Jian-feng<sup>a,b</sup>, FAN Xue-wu<sup>a,b</sup>, QIU Yue-hong<sup>a,b</sup>, GAO Wei<sup>a,b</sup>, ZHAO Bao-chang<sup>a,b</sup>, LI Ying-cai<sup>a,b</sup>

a. Joint Research Laboratory of High-resolution Optical Imaging, State Key Laboratory of Transient Optics and Photonics, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China;

b. Laboratory of Space Optical Technology, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China

#### Abstract:

Large to observe the boundless expanse of universe with astronomical optical telescopes, small to detect the infinitesimal nano-world with optical microscopes, optical imaging technology plays a very important role for human beings in the exploration and discovery of the mysteries of the unknown world. To see farther, to see more details and to see more clearly are people's constantly pursuing goal. The traditional optics theory has proved that all classical optical systems are diffraction-limited, i.e., the physical limit of the spatial resolution of optical systems is determined by the light wavelength and the relative aperture (or numerical aperture) of the system. Can this diffraction-limited barrier be broken through? Is it possible to continue to improve the imaging resolution of optical systems? Around this issue, this paper reviews the recent progress of a variety of high-resolution and super-resolution optical imaging techniques, and their developments in the fields of space exploration and biological applications.

**Keywords:** High-resolution Super-resolution Optical imaging Space optical remote sensing Microscopy

收稿日期 2011-10-22 修回日期 2011-11-18 网络版发布日期 2011-11-25

DOI: 10.3788/gzxb20114011.1607

#### 基金项目:

国家自然科学基金项目(No.10874240, No. 61077005)和国家重大科学研究计划项目(No. 2012CB921900)资助

#### 通讯作者:

#### 作者简介:

#### 参考文献:

- [1] BORN M, WOLF E. 杨葭菀, 译. Optics principle[M]. 7版. 北京: 电子工业出版社, 2006.
- [2] RICHARDS B, WOLF E. Electromagnetic diffraction in optical systems II. Structure of the image field in an aplanatic system. Proceedings of the Royal Society A, 1959, 253: 358-379. 
- [3] DORN R, QUABIS S, LEUCHS G. Sharper focus for a radially polarized light beam[J]. *Physical Review Letters*, 2003, 91(23): 3901.
- [4] ZHAO Bao-chang, YANG Jian-feng, WEN De-sheng, et al. Overall scheme and on-orbit images of Chang'e-2 lunar satellite CCD stereo camera[J]. *Science China: Technological Sciences*, 2011, 54(9): 2237-2242. 
- [5] XUE Bin, ZHAO Bao-chang, YANG Jian-Feng, et al. Auto-compensation of velocity-height ratio for Chang'e-2 satellite CCD stereo camera[J]. *Science China: Technological Sciences*, 2011, 54(9): 2243-2246. 
- [6] 刘新平, 高瞻, 邓年茂, 等. 面阵CCD作探测器的亚像元成像方法及实验[J]. 科学通报, 1999, 44(15): 1603-1605.
- [7] LATRY C, ROUGE B. Optimized sampling for CCD instruments: the supermode scheme. IEEE Proceedings IGARSS, 2000, 4: 2322-2324.
- [8] DOWSKI E R Jr, CATHEY W T. Extended depth of field through wave-front coding[J]. *Applied Optics*, 1995, 34(11): 1859-1866.
- [9] LEE S H, PARK N C, PARK K S, et al. Upscaling image resolution of compact imaging systems using wavefront coding and a property of the point-spread function[J]. *JOSA A*, 2010, 27(10): 2304-2312. 
- [10] QIAO Yan-feng, LIU Kun, DUAN Xiang-yong. Optical synthetic aperture imaging techniques and development[J]. *Chinese Journal of Optics and Applied Optics*, 2009, 2(3): 175-182. 乔彦峰, 刘坤, 段相永. 光学合成孔径成像技术及发展现状[J]. 中国光学与应用光学, 2009, 2(3): 175-182.
- [11] LIANG Shi-tong, YANG Jian-feng, LI Xiang-juan, et al. Study of a new sparse-aperture system[J]. *Acta Photonica Sinica*, 2010, 39(1): 148-152. 梁士通, 杨建峰, 李湘眷, 等. 一种新型稀疏孔径结构的研究[J]. 光子学报, 2010, 39(1): 148-152. 
- [12] YU Qian-yang, QU Hong-song. Realization of high-resolution visible earth observation on geostationary earth orbit[J]. *Chinese Optics and Applied Optics*, 2009, 2(1): 129. 于前洋, 曲宏松. 实现同步轨道(GEO)高分辨力对地观测的技术途径(下) [J]. 中国光学与应用光学, 2009, 2(1): 129.
- [13] LU Chang-ming, WANG Jian-jun, GAO Xin, et al. A study on the theory of Fourier telescope and its improvement[J]. *Journal of Spacecraft TT & C Technology*, 2010, 29(2): 17-20. 陆长明, 王建军, 高昕, 等. 傅里叶望远镜原理及改进研究[J]. 飞行器测控学报, 2010, 29(2): 17-20.

## 扩展功能

### 本文信息

- Supporting info
- PDF(4706KB)
- HTML
- 参考文献

### 服务与反馈

- 把本文推荐给朋友
- 加入我的书架
- 加入引用管理器
- 引用本文
- Email Alert
- 文章反馈
- 浏览反馈信息

### 本文关键词相关文章

- 高分辨
- 超分辨
- 光学成像
- 空间光学遥感
- 显微成像

### 本文作者相关文章

- 姚保利


- [14] GIEPMANS B N, ADAMS S R, ELLISMAN M H, *et al.* The fluorescent toolbox for assessing protein location and function[J]. *Science*, 2006, 312(5771): 217-224. [crossref](#)
- [15] LORD S J, LEE H L, MOERNER W E. Single-molecule spectroscopy and imaging of biomolecules in living cells[J]. *Analytical Chemistry*, 82(6): 2192-2203.
- [16] XIE X S, CHOI P J, LI G W, *et al.* Single-molecule approach to molecular biology in living bacterial cells[J]. *Annual Review of Biophysics*, 2008, 37: 417-444. [crossref](#)
- [17] PAWLEY J B. Handbook of biological confocal microscopy[M]. 3rd ed. USA: Springer, 2006.
- [18] FORKEY J N, QUINLAN M E, GOLDMAN Y E. Measurement of single macromolecule orientation by total internal reflection fluorescence polarization microscopy[J]. *Biophysical Journal*, 2005, 89(2): 1261-1271.
- [19] SYNGE E H. A suggested method for extending microscopic resolution into the ultra-microscopic region[J]. *Philosophical Magazine*, 1928, 6: 356-362.
- [20] BETZIG E, LEWIS A, HAROOTUNIAN A, *et al.* Near-field scanning optical microscopy(NSOM)-development and biophysical applications [J]. *Biophysical Journal*, 1986, 49(1): 269-279. [crossref](#)
- [21] MOERNER W E. New directions in single-molecule imaging and analysis. *Proc Natl Acad Sci, USA*, 104, 2007: 12596-12602.
- [22] THOMPSON R E, LARSON D R, WEBB W W. Precise nanometer localization analysis for individual fluorescent probes[J]. *Biophysical Journal*, 2002, 82(5): 2775-2783. [crossref](#)
- [23] YILDIZ A, FORKEY J N, MCKINNEY S A, *et al.* Myosin V walks hand-over-hand: single fluorophore imaging with 1.5 nm localization[J]. *Science*, 2003, 300(5628): 2061-2065.
- [24] PERTSINIDIS A, ZHANG Y, CHU S. Subnanometre single-molecule localization, registration and distance measurements[J]. *Nature*, 2010, 466(7306): 647-651. [crossref](#)
- [25] BETZIG E, PATTERSON G H, SOUGRAT R, *et al.* Imaging intracellular fluorescent proteins at nanometer resolution[J]. *Science*, 2006, 313(5793): 1642-1645. [crossref](#)
- [26] RUST M J, BATES M, ZHUANG X. Sub-diffraction-limit imaging by stochastic optical reconstruction microscopy (STORM)[J]. *Nature Methods*, 2006, 3(10): 793-795.
- [27] LV Zhi-jian, LU Jing-ze, WU Ya-qiong, *et al.* Introduction to theories of several super-resolution fluorescence microscopy methods and recent advance in the field[J]. *Progress in Biochemistry and Biophysics*, 2009, 36(12): 1626-1634. 吕志坚, 陆敬泽, 吴雅琼, 等. 几种超分辨率荧光显微技术的原理和近期进展[J]. *生物化学与生物物理进展*, 2009, 36(12): 1626-1634.
- [28] HUANG B, BATES M, ZHUANG X. Super-resolution fluorescence microscopy[J]. *Annual Review of Biochemistry*, 2009, 78: 993-1016. [crossref](#)
- [29] SHROFF H, GALBRAITH C G, GALBRAITH J A, *et al.* Live-cell photoactivated localization microscopy of nanoscale adhesion dynamics [J]. *Nature Methods*, 2008, 5(5): 417-423. [crossref](#)
- [30] PATTERSON G, DAVIDSON M, MANLEY S, *et al.* Superresolution imaging using single-molecule localization[J]. *Annual Review of Physical Chemistry*, 2010, 61: 345-367. [crossref](#)
- [31] HELL S W, WICHMANN J. Breaking the diffraction resolution limit by stimulated emission: stimulated-emission-depletion fluorescence microscopy[J]. *Optics Letters*, 1994, 19(11): 780-782. [crossref](#)
- [32] KLAR T A, JAKOBS S, DYBA M, *et al.* Fluorescence microscopy with diffraction resolution barrier broken by stimulated emission[J]. *Proceedings of the National Academy of Sciences of the United States of America*, 2000, 97(15): 8206-8210.
- [33] RITTWEGER E, HAN K Y, IRVINE S E, *et al.* STED microscopy reveals crystal colour centres with nanometric resolution[J]. *Nature Photonics*, 2009, 3: 144-147. [crossref](#)
- [34] WESTPHAL V, RIZZOLI S O, LAUTERBACH M A, *et al.* Video-rate far-field optical nanoscopy dissects synaptic vesicle movement[J]. *Science*, 2008, 320(5873): 246-249. [crossref](#)
- [35] WILLIG K I, RIZZOLI S O, WESTPHAL V, *et al.* STED microscopy reveals that synaptotagmin remains clustered after synaptic vesicle exocytosis[J]. *Nature*, 2006, 440(7086): 935-939. [crossref](#)
- [36] GUSTAFSSON M G L. Surpassing the lateral resolution limit by a factor of two using structured illumination microscopy[J]. *Journal of Microscopy*, 2000, 198(2): 82-87.
- [37] GUSTAFSSON M G L. Nonlinear structured-illumination microscopy: wide-field fluorescence imaging with theoretically unlimited resolution[J]. *Proceedings of the National Academy of Sciences of the United States of America*, 2005, 102(37): 13081-13086. [crossref](#)
- [38] GUSTAFSSON M G L, SHAO L, CARITON P M, *et al.* Three-dimensional resolution doubling in wide-field fluorescence microscopy by structured illumination[J]. *Biophysical Journal*, 2008, 94(12): 4957-4970.
- [39] SCHERMELLEH L, CARLTON P M, HAASE S, *et al.* Subdiffraction multicolor imaging of the nuclear periphery with 3D structured illumination microscopy[J]. *Science*, 2008, 320(5881): 1332-1336.
- [40] SHAO L, ISAAC B, UZAWA S, *et al.* Gustafsson. ISM: wide-field light microscopy with 100-nm-scale resolution in three dimensions[J]. *Biophysical Journal*, 2008, 94(12): 4971-4983.
- [41] <http://www.lynceetec.com/content/view/481/192/>.
- [42] MICO V, ZALEVSKY Z, FERREIRA C, *et al.* Superresolution digital holographic microscopy for three-dimensional samples[J]. *Optics Express*, 2008, 16(23): 19260-19270. [crossref](#)
- [43] SCHWARZ C J, KUZNETSOVA Y, BRUECK S R J. Imaging interferometric microscopy[J]. *Optics Letters*, 2003, 28(16): 1424-1426. [crossref](#)
- [44] ALLEN R D, DAVID G B, NOMARSKI G. The Zeiss-Nomarski differential equipment for transmitted light microscopy[J]. *Z Wiss*

*Mickrosk*, 1969, 69(4): 193-221.


[45] FU D, OH S, CHOI W, *et al.* Quantitative DIC microscopy using an off-axis self-interference approach[J]. *Optics Letters*, 2010, 35(14): 2370-2372.

[46] McINTYRE T J, MAURER C, BERNET S, *et al.* Differential interference contrast imaging using a spatial light modulator[J]. *Optics Letters*, 1999, 34(19): 2988-2990.

[47] McINTYRE T J, MAURER C, FASSL S, *et al.* Quantitative SLM-based differential interference contrast imaging[J]. *Optics Express*, 2010, 18(13): 14063-14078.


[48] HEISE B, STIFTER D. Quantitative phase reconstruction for orthogonal-scanning differential phase-contrast optical coherence tomography[J]. *Optics Letters*, 2009, 34(9): 1306-1308. 


[49] ZERNIKE F. Phase contrast, a new method for the microscopic observation of transparent objects[J]. *Physica*, 1942, 9: Part I, 686-698, Part II, 974-986.

[50] POPESCU G, DEFLORES L P, VAUGHAN J C, *et al.* Fourier phase microscopy for investigation of biological structures and dynamics[J]. *Optics Letters*, 2004, 29(21): 2503-2505. 

[51] <http://www.microscopyu.com/articles/phasecontrast/phasemicroscopy.html>.

[52] GAO P, YAO B, HARDER I, *et al.* Phase-shifting Zernike phase contrast microscopy for quantitative phase measurement[J]. *Optics Letters*, 2011, 36(21): 4305-4307.

[53] LI X, YAMAUCHI T, IWAI H, *et al.* Full-field quantitative phase imaging by white-light interferometry with active phase stabilization and its application to biological samples[J]. *Optics Letters*, 2006, 31(12): 1830-1832. 

[54] MASSATSCH P, CHARRI RE F, CUCHE E, *et al.* Time-domain optical coherence tomography with digital holographic microscopy[J]. *Applied Optics*, 2005, 44(10): 1806-1812. 

#### 本刊中的类似文章

1. 张约品;夏海平;李佐宜;沈德芳;干福熹.GdFeCo/TbFeCo磁超分辨磁光记录薄膜研究[J]. 光子学报, 2005,34(9): 1376-1379
2. 王吉明;刘立人;云茂金;赵栋;刘锡民;郎海涛.电控径向滤波器的横向超分辨与轴向焦移[J]. 光子学报, 2006,35(10): 1488-1492
3. 陈荣利;耿利寅;马臻;李英才.空间相机的热分析和热设计[J]. 光子学报, 2006,35(1): 154-157
4. 周春大;张岩.基于微位移技术提高CCD分辨率的方法[J]. 光子学报, 2006,35(12): 1969-1974
5. 吕涛;肖青;李正佳.钕激光脉冲消融泌尿结石和胆结石比较研究[J]. 光子学报, 2011,40(8): 1215-1219
6. 葛华勇;王保华;任秋实.共聚焦成像系统中探测器对分辨率的影响[J]. 光子学报, 2006,35(4): 587-590
7. 王大勇;伏西洋;郭红锋;赵博;郑怡嘉;陶世荃.光学稀疏孔径系统的成像及其图像复原[J]. 光子学报, 2005,34(10): 1557-1560
8. 陈荣利; 赵信民; 解永杰; 马臻; 樊学武; 李英才.高分辨率空间相机的工程分析[J]. 光子学报, 2005,34(2): 267-271
9. 高万荣;胡茂海;杨晓春;张仙玲;谢仁龙;沈为民.界面折射率不一致对显微成像穿透深度的限制[J]. 光子学报, 2005,34(6): 814-816
10. 陈荣利;张禹康;樊学武;马臻;李英才.空间高分辨率CCD相机次镜支架最佳结构设计[J]. 光子学报, 2004,33(10): 1251-1254
11. 郭舒文 郭汉明 庄松林.非对称三区光瞳滤波器实现一维横向超分辨[J]. 光子学报, 2008,37(11): 2222-2226
12. 赵琳 金伟其 陈翼男 张桂清 沈亚中 杨春松.一种新的运动模糊图像超分辨力盲复原算法[J]. 光子学报, 2008,37(11): 2355-2359
13. 王大勇 韩骥 刘汉承 伏西洋 郭红锋 陶世荃.光学稀疏孔径系统的成像及其评价方法[J]. 光子学报, 2008,37(6): 1208-1212
14. 钱义先 高晓东 梁伟 程晓薇.多光谱大面阵彩色CCD数字航测相机设计[J]. 光子学报, 2008,37(12): 2473-2477
15. 朱化凤 王秀民 王宁 李代林 高鸿奕 干慧菁 .改进型基于径向双折射晶体的超分辨滤波器[J]. 光子学报, 2007,36(10): 1876-1880

文章评论 (请注意:本站实行文责自负, 请不要发表与学术无关的内容!评论内容不代表本站观点.)

反馈人

邮箱地址

反馈标题

验证码

反馈内容

提交