光学 精密工程
OPTICS AND PRECISION ENGINEERING
核心期刊
主管：中国科学院
主办：中国科学院长春光学精密机械与物理研究所
中国仪器仪表学会
主编：曹健林



光学精密工程 2013, 21(10) 2488-2494 ISSN: 1004-924X CN: 22-1198/TH DOI:10.3788/OPE.20132110.2488



现代应用光学

# 光子计数三维成像激光雷达反转误差的校正

何伟基1,2*,司马博羽1,苗壮2,陈云飞1,陈钱1,顾国华1

1. 南京理工大学 江苏省微光成像与智能感知重点实验室，江苏 南京 210094;
2.微光夜视技术重点实验室，陕西 西安 710005

摘要： 实施光子飞行时间测量法时，光子飞行时间测量值受激光回波信号能量的影响会出现测量反转误差，从而影响系统三维成像的精度。本文描述了一种光子计数三维成像激光雷达系统反转误差的校正方法及其实验。提出的反转误差校正方法包含先验模型标定和反转误差校正两个步骤。首先，通过标定法得到系统反转误差相对于激光脉冲响应率的函数关系，建立系统的反转误差预测函数。然后，由系统反转误差函数预测出原始三维图像的反转误差图像并实现原始三维图像的反转误差校正。实验搭建了光子计数三维成像激光雷达系统，采用盖格-雪崩光电二极管（Gm-APD)作为光子探测器，由高速扫描振镜二维扫描获取三维图像。通过时间相关记录仪获取光子到达时间分布，分别得到原始三维图像和激光脉冲响应率。在反转误差校正的测试实验中，系统的测量均方差由校正前的33.2 mm提高至8.1 mm。实验结果表明，该反转误差校正方法可以有效降低光子计数三维成像激光雷达的反转误差。

关键词： 单光子计数 激光雷达 三维成像 反转误差 误差校正

# Correction of reversal errors in photon counting 3D imaging lidar

HE Wei-ji1,2*, SIMA Bo-yu1, MIAO Zhuang2, CHEN Yun-fei1, CHEN Qian1, GU Guo-hua1

1. Jiangsu Key Laboratory of Spectral Imaging & Intelligence Sense (SIIS),
Nanjing University of Science and Technology, Nanjing 210094, China;
2.Science & Technology on Low-light-level Night Vision Laboratory, Xi′ an 710005, China

Abstract: When photon time-of-flight measurement is used, the measurement accuracy will decrease due to the reversal error of time-of-flight measurement. In this paper, a method to correct the reversal error is described in detail. The correction method proposed here included two steps: prior modeling calibration and reversal error correction. Firstly, the function relationship between laser pulse response rate and reversal error was obtained by the calibration method and the reversal error prediction function was established. Then, the reversal error of an original 3D image was calculated by the reversal error prediction function and the 3D image was corrected. Finally, a photon counting 3D imaging lidar system was constructed, in which the Geiger mode Avalanche Photodiode(Gm-APD) was used as a photon detector and the high-speed galvanometer as a scanner. A Time Correlation Single Photon Counting (TCSPC) module was used to mark the arrival time of each photon event. The original 3D image and laser pulse response rate were acquired by the arrival time distribution of photon events. In performance evaluation test, the mean square error of ranging results is improved from 33.2 mm to 8.1 mm after correction. The reversal error correction method proposed in this paper effectively reduces the reversal error caused by the energy fluctuation of laser echo pulse in the photon counting 3D imaging lidar.

Keywords: counting Radar 3d image reversal error Error correction

收稿日期 2013-04-01 修回日期 2013-05-31 网络版发布日期 2012-10-19

基金项目:

波长轮换与相移扫描相结合的表面形貌干涉测量方法;波长轮换与相移扫描相结合的表面形貌干涉测量方法;波长轮换与相移扫描相结合的表面形貌干涉测量方法;国家博士后基金面上项目

通讯作者: 何伟基

作者简介: 何伟基(1981-)，男，广东韶关人，博士，讲师，2004年、2010年于南京理工大学分别获得学士、博士学位，主要从事微光成像器件机理及应用方面的研究工作。
作者Email: njustheweiji@163.com

参考文献：

[1]CHEN F,BROWN G M, SONG M M. Overview of three-dimensional shape measurement using optical methods [J]. Opt. Eng., 2000, 39:10-22. [2]MASSA J S,WALLACE A M, BULLER G S, et al.. Laser depth measurement based on time-correlated single-photon counting [J]. Opt. Lett., 1997, 22:543-545. [3]MARINO R M,DAVIS W R. Jigsaw: a foliage-penetrating 3D imaging laser radar system [J]. Lincoln Lab. J, 2005, 15: 23-36. [4]WARBURTON R E,MCCARTHY A,WALLACE A M, et al.. Sub-centimeter depth resolution using a single-photon counting time-of-flight laser ranging system at 1550 nm wavelength [J]. Opt. Lett., 2007, 32: 2266-2268. [5]OH M S,KONG H J,KIM T H, et al.. Time-of-flight analysis of three-dimensional imaging laser radar using a geiger-mode avalanche photodiode [J]. Japanese Journal of Applied Physics, 2010, 49: 026601-1-026601-6. [6]GATT P, JOHNSON S, NICHOLS T. Geiger-mode avalanche photodiode ladar receiver performance characteristics and detection statistics [J]. Appl. Optics, 2009, 48(17): 3261-3276. [7]WANG F,ZHAO Y,ZHANG Y, et al.. Range accuracy limitation of pulse ranging systems based on Geiger mode single-photon detectors [J]. Appl. Opt., 2010, 49: 5561-5566. [8]KIRCHNER G,KOIDL F. Time walk compensated SPAD: multiple photon versus single photon operation [J]. SPIE, 1997, 3218: 106-112. [9]OH M S,KONG H J,KIM T H, et al.. Reduction of range walk error in direct detection laser radar using a Geiger mode avalanche photodiode [J]. Optics

Communications, 2010, 283: 304-308. [10]MCCARTHY A,COLLINS R J,KRICHEL N J, et al.. Long-range time-of-flight scanning sensor based on high-speed time-correlated single-photon counting [J]. Appl. Optics, 2009, 48 (32): 6241-6251. [11]OH M S,KONG H J,KIM T H, et al.. Development and analysis of a photon-counting three-dimensional imaging laser detection and ranging (LADAR) system [J]. Opt. Soc. Am, 2011, 28: 759-765.

本刊中的类似文章

1．张雷 杨勇 赵星 方志良 袁小聪.多级投影式集成成像三维显示视场角拓展[J]. 光学精密工程, 2013,21(1): 1-6

2．焦小雪, 赵星, 杨勇, 方志良, 袁小聪.基于相机阵列的三维集成成像记录系统[J]. 光学精密工程, 2012,(8): 1653-1660

3．周娜, 安志勇, 李丽娟, 朱运.飞机数字化测量网络布站设计[J]. 光学精密工程, 2012,20(7): 1485-1491

4．张雷, 杨勇, 赵星, 方志良, 袁小聪.基于小发散角的投影式集成成像三维显示再现深度的拓展[J]. 光学精密工程, 2012,20(6): 1159-1165

5．郭裕兰, 万建伟, 鲁敏, 谭志国.激光雷达目标三维姿态估计[J]. 光学精密工程, 2012,20(4): 843-850

6．来志, 曾晓东, 冯喆君, 曹长庆.精密控制谐振腔获得合成孔径激光雷达信号的方法[J]. 光学精密工程, 2011,19(7): 1531-1537