

Image Processing & Computer Vision (<http://www.ipcv.org/>)

图像处理与计算机视觉



On visual slam

在 2017 年 11 月 11 日 (<http://www.ipcv.org/on-visual-slam/>) 上张贴 由 admin
(<http://www.ipcv.org/author/admin/>)

技术博客



- 泡泡机器人微信公众号（视觉SLAM漫谈）
- SLAM 学习与开发经验分享
 - <https://github.com/GeekLib/Lee-SLAM-source>
(<https://github.com/GeekLib/Lee-SLAM-source>)
- Visual SLAM 算法笔记
 - <http://blog.csdn.net/mulinb/article/details/53421864>
(<http://blog.csdn.net/mulinb/article/details/53421864>)
- Tombone's Computer Vision Blog
 - <http://www.computervisionblog.com/2016/01/why-slam-matters-future-of-real-time.html> (<http://www.computervisionblog.com/2016/01/why-slam-matters-future-of-real-time.html>)
- OpenSlam
 - <http://www.openslam.org/> (<http://www.openslam.org/>)
- ROS
 - <http://wiki.ros.org/> (<http://wiki.ros.org/>)
- Others:
 - HITCM: <http://www.cnblogs.com/hitcm> (<http://www.cnblogs.com/hitcm>)
 - 半闲居士: <http://www.cnblogs.com/gaoxiang12/>
(<http://www.cnblogs.com/gaoxiang12/>)
 - Being_young: <http://www.cnblogs.com/li-yao7758258/>
(<http://www.cnblogs.com/li-yao7758258/>)
- 经典算法:
 - 基于Kalman滤波方法: MonoSLAM(2003ICCV);
 - 基于稀疏特征匹配的方法: Nister VO(2004CVPR)à PTAM(2007ISMAR)à ORB-SLAM (2015TOR)
 - 基于稠密点直接匹配方法: DTAM(2011 ICCV)à SVO(2013ICCV, 2014ICRA)à LSD-SLAM(2014ECCV) à DSO(direct sparse VO2016Arxiv);

- 融合IMU方法：
 - Kalman策略：MSCKF 1.0(2007ICRA)à MSCKF 2.0(2013IJRR)
 - Keyframe策略：OKVIS(2015IJRR), ROVIO(2017IJRR)

相关人物

- Anastasios Mourikis
 - <http://www.ee.ucr.edu/~mourikis/> (<http://www.ee.ucr.edu/~mourikis/>)
 - MSCKF 1.0(2007ICRA) 和 MSCKF 2.0(2013IJRR)的作者
- Andrew Davison
 - <https://www.doc.ic.ac.uk/~ajd/index.html>
(<https://www.doc.ic.ac.uk/~ajd/index.html>)
- Active Vision Lab
 - <http://www.robots.ox.ac.uk/ActiveVision/index.html>
(<http://www.robots.ox.ac.uk/ActiveVision/index.html>)
- Frank Dellaert
 - https://www.cc.gatech.edu/~dellaert/FrankDellaert/Frank_Dellaert/Frank_Dellaert.html
(https://www.cc.gatech.edu/~dellaert/FrankDellaert/Frank_Dellaert/Frank_Dellaert.html)
 - GTSAM的作者
- Daniel Cremers
 - <https://vision.in.tum.de/research/vslam>
(<https://vision.in.tum.de/research/vslam>)
 - LSD-SLAM的作者
- Jianxiong Xiao
- ASL
 - <http://rpg.ifi.uzh.ch/publications.html>
(<http://rpg.ifi.uzh.ch/publications.html>)
- MATS
 - <http://mars.cs.umn.edu/> (<http://mars.cs.umn.edu/>)
 -
- Stefan Leutenegger
 - <http://wp.doc.ic.ac.uk/sleutene/> (<http://wp.doc.ic.ac.uk/sleutene/>)
 - Leader of smart robotic lab.
 - OKVIS(2015IJRR)的作者
- Jakob Engel
 - <https://vision.in.tum.de/members/engelj>
(<https://vision.in.tum.de/members/engelj>)
 - LSD-SLAM(2014ECCV)和DSO(2016Arxiv) 的作者



公共数据集

- ICL-NUIM dataset
 - <https://www.doc.ic.ac.uk/~ahanda/VaFRIC/iclnuim.html>
(<https://www.doc.ic.ac.uk/~ahanda/VaFRIC/iclnuim.html>)
- TUM RGB-D benchmark

- <https://vision.in.tum.de/data/datasets/rgbd-dataset/tools>
(<https://vision.in.tum.de/data/datasets/rgbd-dataset/tools>)

CVPR

- 2017 CVPR 3D Point Cloud Registration for Localization using a Deep Neural Network Auto-Encoder
 - http://openaccess.thecvf.com/content_cvpr_2017/papers/Elbaz_3D_Point_Cloud_CVPR_2017_paper.pdf
(http://openaccess.thecvf.com/content_cvpr_2017/papers/Elbaz_3D_Point_Cloud_CVPR_2017_paper.pdf)
 - <https://github.com/gilbaz/LORAX> (<https://github.com/gilbaz/LORAX>)
 - <http://cadlab.net.technion.ac.il/prof-anath-fischer/>
(<http://cadlab.net.technion.ac.il/prof-anath-fischer/>)
 - <https://github.com/neilgu00365/A.I> (<https://github.com/neilgu00365/A.I>).
 - 基本思想：用CNN网络进行点云的对齐和冗余剔除；
- 2017 CVPR CNN-SLAM: Real-Time Dense Monocular SLAM With Learned Depth Prediction
 - <http://vision.deis.unibo.it/fede/research>
(<http://vision.deis.unibo.it/fede/research>)
 - <http://campar.in.tum.de/Chair/ProjectCNNSLAM>
(<http://campar.in.tum.de/Chair/ProjectCNNSLAM>)
 - 基本思想：融合了单视图深度估计，场景解析和相机定位的SLAM方法；
- 2004 CVPR Visual Odometry for Ground Vehicle Applications
 - David Nister, Oleg Naroditsky, and James Bergen
 - <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.91.5767&rep=rep1&type=pdf>
(<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.91.5767&rep=rep1&type=pdf>)
 - 从3D Vision的视角出发设计的一个SLAM方案，整个方案设计的比较简单，只是着重连续较少帧的相对camera pose的估计，并没有完整的地图维护机制，因此容易造成drift。不过其3D Vision的算法和思想是后续很多的SLAM算法中都使用到的。
 - 基本思想：1) 特征点匹配(harris+patch correlation)；2)相对姿态估计(五点法)；3)三维空间点估计(三角形法)；4)其它帧的pose估计(P3P法)；4)三维点优化(BA)；2D correspondence -> essential matrix -> pose -> triangulation -> 3D to 2D correspondence -> P3P -> optimization.



ECCV

- 2014 ECCV LSD-SLAM: LargeScale Direct Monocular SLAM (LSD-SLAM)
 - Jakob Engel, Thomas Schops, and Daniel Cremers
 - http://github.com/tum-vision/lsd_slam (http://github.com/tum-vision/lsd_slam)
 - <https://vision.in.tum.de/research/vslam/lsdslam>
(<https://vision.in.tum.de/research/vslam/lsdslam>)

- 基本思想：不是基于特征点提取完成的相机定位，而是直接根据图像，深度和相机姿态进行的迭代优化策略；Ros上的代码，貌似不错；dense指的是尽量多的利用image信息，direct是相对应于feature matching/projection的直接image alignment方法（通常feature-based methods是最小化reprojection error，而direct image alignment methods中是最小化photometric error）。
- 更dense的tracking和mapping会大幅度提高SLAM的精度和鲁棒性。直觉上想想，如果整幅图像的信息都可以拿来用，的确信息量会比提一些feature多很多。

ICCV

- 2013 ICCV Semi-Dense Visual Odometry for a Monocular Camera(SVO)
 - Jakob Engel, Jurgen Sturm, and Daniel Cremers
 - http://vision.in.tum.de/_media/spezial/bib/engel2013iccv.pdf (http://vision.in.tum.de/_media/spezial/bib/engel2013iccv.pdf)
 - 2014 ECCV
 - http://vision.in.tum.de/_media/spezial/bib/engel14eccv.pdf (http://vision.in.tum.de/_media/spezial/bib/engel14eccv.pdf)
 - 基本思想：
- 2011 ICCV DoubleWindow Optimisation for Constant Time Visual SLAM
 - http://wp.doc.ic.ac.uk/robotvision/software_dataset/ (http://wp.doc.ic.ac.uk/robotvision/software_dataset/)
- 2011 ICCV DTAM: Dense tracking and mapping in real-time
 - https://www.robots.ox.ac.uk/~vgg/rg/papers/newcombe_davison__2011__dtam.pdf (https://www.robots.ox.ac.uk/~vgg/rg/papers/newcombe_davison__2011__dtam.pdf)
 - RGBD下的SLAM定位；
 - 更dense的tracking和mapping会大幅度提高SLAM的精度和鲁棒性。直觉上想想，如果整幅图像的信息都可以拿来用，的确信息量会比提一些feature多很多
- 2007 ICCV Monocular SLAM as a Graph of Coalesced Observations
 - Ethan Eade and Tom Drummond
 - <http://ethaneade.com/> (<http://ethaneade.com/>)
 - <http://ethaneade.com/eadeICCV2007.pdf> (<http://ethaneade.com/eadeICCV2007.pdf>)
 -
- 2003 ICCV Real-Time Simultaneous Localisation and Mapping with a Single Camera
 - Andrew Davison, Ian Reid, Nicholas Molton, and Olivier Stasse
 - https://www.doc.ic.ac.uk/~ajd/Publications/davison_iccv2003.pdf (https://www.doc.ic.ac.uk/~ajd/Publications/davison_iccv2003.pdf)
 - https://www.doc.ic.ac.uk/~ajd/Publications/davison_etal_pami2007.pdf (https://www.doc.ic.ac.uk/~ajd/Publications/davison_etal_pami2007.pdf)
 - <https://www.doc.ic.ac.uk/~ajd/Scene/Release/monoslamtutorial.pdf> (<https://www.doc.ic.ac.uk/~ajd/Scene/Release/monoslamtutorial.pdf>)



- <https://github.com/hanmekim/SceneLib2>
(<https://github.com/hanmekim/SceneLib2>)
- <http://www.doc.ic.ac.uk/~ajd/software.html>
(<http://www.doc.ic.ac.uk/~ajd/software.html>)
- 其中的Kalman filter和Particle filter:
 - <https://www.udacity.com/course/artificial-intelligence-for-robotics--cs373> (<https://www.udacity.com/course/artificial-intelligence-for-robotics--cs373>)
 - <http://www.bzarg.com/p/how-a-kalman-filter-works-in-pictures/>
(<http://www.bzarg.com/p/how-a-kalman-filter-works-in-pictures/>)
 - https://www.doc.ic.ac.uk/~ajd/Publications/strasdat_etal_ivc2012.pdf
(https://www.doc.ic.ac.uk/~ajd/Publications/strasdat_etal_ivc2012.pdf)
- SLAM的开篇大作，Andrew Davison从Robotics领域的视角出发，将经典的non-camera的SLAM算法应用到使用single camera做SLAM的方案中，使用了经典的EKF框架，经过后续改进就是TPAMI 2007的MonoSLAM[2]算法。
- 将传统机器人领域中基于laser range-finder的EKF-SLAM应用到了single camera的SLAM中，算法相对于Nister VO更加完整，其中关键的提高在于通过guided feature matching取代invariant feature matching提高了计算速度。
- 基本思想：基于Filter的Visual SLAM，更新状态包括相机位置，速度，角速度，场景中的三维点坐标；



ICRA

- 2016 ICRA Real-Time Loop Closure in 2D LIDAR SLAM
 - <https://github.com/googlecartographer/cartographer>
(<https://github.com/googlecartographer/cartographer>)
 - <https://www.zhihu.com/question/51348391>
(<https://www.zhihu.com/question/51348391>)
- 2014 RSS LOAM: Lidar Odometry and Mapping in Real-time
 - <http://www.roboticsproceedings.org/rss10/p07.pdf>
(<http://www.roboticsproceedings.org/rss10/p07.pdf>)
 - https://github.com/laboshinl/loam_velodyne
(https://github.com/laboshinl/loam_velodyne)
- 2016 ICRA Multilevel mapping: Real-time dense monocular slam
- 2014 ICRA REMODE: Probabilistic, monocular dense reconstruction in real time
- 2014 ICRA SVO: Fast Semi-Direct Monocular Visual Odometry (SVO)
 - http://rpg.ifi.uzh.ch/docs/ICRA14_Forster.pdf
(http://rpg.ifi.uzh.ch/docs/ICRA14_Forster.pdf)
 - https://github.com/uzh-rpg/rpg_svo (https://github.com/uzh-rpg/rpg_svo)
 - Christian Forster, Matia Pizzoli, Davide Scaramuzza
 - SVO是一种hybrid的方法，结合了direct method和feature-based method的成分，算法虽然依赖于feature correpondence，但是避免了显式计算feature matching和outlier handling，因此也节约了不少无谓的计算量
- 2014 ICRA Using superpixels in monocular SLAM
- 2014 ICRA A Benchmark for {RGB-D} Visual Odometry, {3D} Reconstruction and {SLAM}

- <https://www.doc.ic.ac.uk/~ahanda/VaFRIC/iclnuim.html>
(<https://www.doc.ic.ac.uk/~ahanda/VaFRIC/iclnuim.html>)
- 2012 ICRA Closed-form Online Pose-chain SLAM
 - <http://www.openslam.org/copslam.html>
(<http://www.openslam.org/copslam.html>)
 - COP-SLAM is a highly efficient closed-form 3-D SLAM approach, It optimizes pose-chains on-line and it is compatible with g2o.
- 2011 ICRA g2o: A General Framework for Graph Optimization
 - <http://www.openslam.org/g2o.html> (<http://www.openslam.org/g2o.html>)
 - g2o is an open-source C++ framework for optimizing graph-based nonlinear error functions
- 2007 ICRA A Multi-State Constraint Kalman Filter for Vision-aided Inertial Navigation(MSCKF 1.0)
 - Anastasios Mourikis, Stergios Roumeliotis
 - <http://www.ee.ucr.edu/~mourikis/papers/MourikisRoumeliotis-ICRA07.pdf>
(<http://www.ee.ucr.edu/~mourikis/papers/MourikisRoumeliotis-ICRA07.pdf>)
 -

Other



- 2017 ICRL CARLA: An Open Urban Driving Simulator
 - <http://vladlen.info/publications/carla-open-urban-driving-simulator/>
(<http://vladlen.info/publications/carla-open-urban-driving-simulator/>)
- 2017 IJRR Iterated extended Kalman filter based visual-inertial odometry using direct photometric feedback(ROVIO)
 - 2015 IROS Robust Visual Inertial Odometry Using a Direct EKF-Based Approach
 - <https://github.com/ethz-asl/rovio> (<https://github.com/ethz-asl/rovio>)
- 2017 IJRR ElasticFusion: Real-Time Dense SLAM and Light Source Estimation
 - <https://github.com/mp3guy/ElasticFusion>
(<https://github.com/mp3guy/ElasticFusion>)
 - RGBD下的SLAM;
- 2016 Arxiv Direct Sparse Odometry (DSO)
 - Jakob Engel, Vladlen Koltun, and Daniel Cremers
 - <https://vision.in.tum.de/members/engelj>
(<https://vision.in.tum.de/members/engelj>)
 - <https://github.com/JakobEngel/dso> (<https://github.com/JakobEngel/dso>)
 - <http://vladlen.info/publications/> (<http://vladlen.info/publications/>)
 - LSD-SLAM的扩展版本，目前性能较优；
- 2016 TOR On-Manifold Preintegration for Real-Time Visual-Inertial Odometry(GTSAM)
 - <https://bitbucket.org/gtborg/gtsam> (<https://bitbucket.org/gtborg/gtsam>)
 - 将imu积分得到一个不依赖于前一个视频帧estimated pose的constraint。当然与之而来的还有如何将uncertainty也做类似的propagation（考虑imu的bias建模），以及如何计算在optimization过程中需要的Jacobian.
- 2015 RSS Orbiting a Moving Target with Multi-Robot Collaborative Visual SLAM

- https://github.com/huangrui815/CoSLAM_for_Target_Following
(https://github.com/huangrui815/CoSLAM_for_Target_Following)
-
- 2015 IJRR Keyframe-based visual-inertial odometry using nonlinear optimization(OKVIS)
 - <https://github.com/ethz-asl/okvis> (<https://github.com/ethz-asl/okvis>)
- 2015 Real-time and scalable incremental segmentation on dense slam
 - <http://campar.in.tum.de/view/Chair/ProjectInSeg>
(<http://campar.in.tum.de/view/Chair/ProjectInSeg>)
- 2015 TOR ORB-slam: A versatile and accurate monocular slam system
 - <http://webdiis.unizar.es/~raulmur/MurMontielTardosTRO15.pdf>
(<http://webdiis.unizar.es/~raulmur/MurMontielTardosTRO15.pdf>)
 - http://github.com/raulmur/ORB_SLAM2
(http://github.com/raulmur/ORB_SLAM2)
 - keyframe-based SLAM派系的一个集大成者；
 - ORB-SLAM算法基本沿用了PTAM的框架，将近几年来被验证有效的module都加了进来，做出一个稳定性和精度很高、可以用于室内/室外和小规模/大规模等各种场景的全能系统，刷爆各种benchmark，并开源了质量很高的代码。
- 2014 TOR 3D Mapping with an RGB-D Camera
 - http://felixendres.github.io/rgbdslam_v2/
(http://felixendres.github.io/rgbdslam_v2/)
 - RGBD下的SLAM
- 2014 CVPR Tutorial Visual SLAM Tutorial
 - http://frc.ri.cmu.edu/~kaess/vslam_cvpr14/
(http://frc.ri.cmu.edu/~kaess/vslam_cvpr14/)
- 2014 IJPP Real-time large scale dense RGB-D SLAM with volumetric fusion
- 2014 IJRR Keyframe-based visual-inertial odometry using nonlinear optimization(OKVIS)
 - Stefan Leutenegger, Simon Lynen, Michael Bosse, Roland Siegwart, Paul Timothy Furgale
 -
- 2013 IJRR High-Precision, Consistent EKF-based Visual-Inertial Odometry(MSCKF 2.0)
 - Mingyang Li, Anastasios Mourikis
 - <http://www.ee.ucr.edu/~mourikis/> (<http://www.ee.ucr.edu/~mourikis/>)
 - Google Project Tango中的SLAM算法就是用的MSCKF算法
 - predict step跟EKF一样，但是将update step推迟到某一个3D map point在多个frame中观测之后进行计算，在update之前每接收到一个frame，只是将state vector扩充并加入当前frame的pose estimate。这个思想基本类似于local bundle adjustment（或者sliding window smoothing），在update step时，相当于基于多次观测同时优化pose和3D map point
- 2013 TOR Appearance-Based Loop Closure Detection for Online Large-Scale and Long-Term Operation(RTAB-MAP)
 - <http://wiki.ros.org/rtabmap> (<http://wiki.ros.org/rtabmap>)
 - <https://github.com/introlab/rtabmap/wiki/Installation>
(<https://github.com/introlab/rtabmap/wiki/Installation>)
 - 双目或者基于RGB-D；



- 2013 IROS Dense Visual SLAM for RGB-D Cameras(DVO)
 - https://github.com/tum-vision/dvo_slam (https://github.com/tum-vision/dvo_slam)
 - 基于RGBD的SLAM;
- 2012 ICIRS A benchmark for the evaluation of RGB-D SLAM systems
- 2011 SSRR A Flexible and Scalable SLAM System with Full 3D Motion Estimation
 - http://wiki.ros.org/hector_slam (http://wiki.ros.org/hector_slam)
 - 基本思想: 基于纯激光点云的SLAM;
- 2011 ISMAR KinectFusion: Real-time dense surface mapping and tracking
- 2007 TOR Improved Techniques for Grid Mapping with Rao-Blackwellized Particle Filters
 - <http://openslam.org/gmapping.html> (<http://openslam.org/gmapping.html>)
 - <http://wiki.ros.org/gmapping> (<http://wiki.ros.org/gmapping>)
 - 基本思想: 基于纯激光点云的SLAM;
- 2007 ISMAR Parallel Tracking and Mapping for Small AR Workspaces (PTAM)
 - Georg Klein and David Murray
 - <http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2007ISMAR.pdf> (<http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2007ISMAR.pdf>)
 - <http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2008ECCV.pdf> (<http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2008ECCV.pdf>)
 - <http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2009ISMAR.pdf> (<http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2009ISMAR.pdf>)
 - Georg Klein: <http://www.robots.ox.ac.uk/~gk/> (<http://www.robots.ox.ac.uk/~gk/>)
 - <https://github.com/Oxford-PTAM/PTAM-GPL> (<https://github.com/Oxford-PTAM/PTAM-GPL>)
 - 基本思想: 开创了多线程SLAM的时代, 后来的多数keyframe-based SLAM都是基于这个框架; 受到了广泛采用bundle adjustment (BA)的Nister算法的启发, 将tracking和mapping分成两个单独的线程, 这样既不影响tracking的实时体验, 又可以在mapping线程中放心使用BA来提高精度 (另外BA也没有必要对所有frame做, 只对一些keyframe进行BA即可)。这样以来, 由于BA的引入, PTAM的精度得到了大幅提高. 系统运行时通常有大约100个keyframes和几千个3D map points.


总结

- Visual Slam大概分为: 1)基于Keyframe 特征匹配; 2)基于Kalman滤波估计的;
- 基于Keyframe特征匹配方法分为: 1)基于稀疏特征提取和匹配; 2)基于稠密直接投影;
- 基于稀疏特征的方法, 经典之作是Nister Vo(2004CVPR); PTAM(2007ISMAR)贡献在于实现了tracking和mapping两个线程; ORB-SLAM (2015TOR)从各个模块进行优化和鲁棒性, 并增加了loop closure线程;
- 混合特征匹配和稠密直接的方法: semi-dense VO(2013ICCV), semi-direct VO(2014ICRA)
- 数据源: 单目视觉, 双目视觉, 多目视觉, RGBD, 激光点云和IMU。

张贴在Others (<http://www.ipcv.org/category/uncategorized/>)

← On motion estimation
(<http://www.ipcv.org/on-motion-estimation/>)

2018 CVPR → (<http://www.ipcv.org/2018-cvpr/>)

WordPress (<http://cn.wordpress.org/>) | Fara (<http://justfreethemes.com/fara>)  回到页眉

