视觉 SLAM 开源方案大合集

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前言：

- **1.** 本文简单将各种方案**分为以下 7 类**（固然有不少文章无法恰当分类，比如动态语义稠密建图的 VISLAM +_+）：
  - **一、Geometric SLAM**
  - **二、Semantic / Deep SLAM**
  - **三、Multi-Landmarks / Object SLAM**
  - **四、VIO / VISLAM**
  - **五、Dynamic SLAM**
  - **六、Mapping**
  - **七、Optimization**
- **2.** 本文来源我的 Gihub 仓库：https://github.com/wuxiaolang/Visual_SLAM_Related_Research 。由于此仓库自 2019 年 3 月开始整理，所以以下的代码除了经典的框架之外**基本都集中在 19-20 年**；此外个人比较关注 VO、物体级 SLAM 和多路标 SLAM，所以以下内容收集的也**不完整**，无法涵盖视觉 SLAM 的所有研究，也欢迎大家有好的方案可以在 **issue** 中分享补充。

一、Geometric SLAM（20 项）

> 这一类是传统的基于特征点、直接法或半直接法的 SLAM，虽说传统，但 2019 年也新诞生了 9 个开源方案。

1. PTAM

- **论文**：Klein G, Murray D. **Parallel tracking and mapping for small AR workspaces**[C]//Mixed and Augmented Reality, 2007. ISMAR 2007. 6th IEEE and ACM International Symposium on. IEEE, **2007**: 225-234.
- **代码**：https://github.com/Oxford-PTAM/PTAM-GPL
- 工程地址：http://www.robots.ox.ac.uk/~gk/PTAM/
- 作者其他研究：http://www.robots.ox.ac.uk/~gk/publications.html

2. S-PTAM（双目 PTAM）

- **论文**：Taihú Pire,Thomas Fischer, Gastón Castro, Pablo De Cristóforis, Javier Civera and Julio Jacobo Berlles. **S-PTAM: Stereo Parallel Tracking and Mapping**. Robotics and Autonomous Systems, **2017**.
- **代码**：https://github.com/lrse/sptam
- 作者其他论文：Castro G, Nitsche M A, Pire T, et al. **Efficient on-board Stereo SLAM through constrained-covisibility strategies**[J]. Robotics and Autonomous Systems, **2019**.

3. MonoSLAM

- **论文**：Davison A J, Reid I D, Molton N D, et al. **MonoSLAM: Real-time single camera SLAM**[J]. IEEE transactions on pattern analysis and machine intelligence, **2007**, 29(6): 1052-1067.
- **代码**：https://github.com/hanmekim/SceneLib2

4. ORB-SLAM2

- **论文**：Mur-Artal R, Tardós J D. **Orb-slam2: An open-source slam system for monocular, stereo, and rgb-d cameras**[J]. IEEE Transactions on Robotics, **2017**, 33(5): 1255-1262.
- **代码**：https://github.com/raulmur/ORB_SLAM2
- 作者其他论文：

- **单目半稠密建图**：Mur-Artal R, Tardós J D. Probabilistic Semi-Dense Mapping from Highly Accurate Feature-Based Monocular SLAM[C]//Robotics: Science and Systems. **2015**, 2015.
- **VIORB**：Mur-Artal R, Tardós J D. Visual-inertial monocular SLAM with map reuse[J]. IEEE Robotics and Automation Letters, **2017**, 2(2): 796-803.
- **多地图**：Elvira R, Tardós J D, Montiel J M M. ORBSLAM-Atlas: a robust and accurate multi-map system[J]. arXiv preprint arXiv:1908.11585, **2019**.

> 以下5, 6, 7, 8几项是 TUM 计算机视觉组全家桶，官方主页：https://vision.in.tum.de/research/vslam/dso

5. DSO

- **论文**：Engel J, Koltun V, Cremers D. **Direct sparse odometry**[J]. IEEE transactions on pattern analysis and machine intelligence, **2017**, 40(3): 611-625.
- **代码**：https://github.com/JakobEngel/dso
- **双目 DSO**：Wang R, Schworer M, Cremers D. **Stereo DSO: Large-scale direct sparse visual odometry with stereo cameras**[C]//Proceedings of the IEEE International Conference on Computer Vision. **2017**: 3903-3911.
- **VI-DSO**：Von Stumberg L, Usenko V, Cremers D. **Direct sparse visual-inertial odometry using dynamic marginalization**[C]//2018 IEEE International Conference on Robotics and Automation (ICRA). IEEE, **2018**: 2510-2517.

6. LDSO

- 高翔在 DSO 上添加闭环的工作
- **论文**：Gao X, Wang R, Demmel N, et al. **LDSO: Direct sparse odometry with loop closure**[C]//2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2018**: 2198-2204.
- **代码**：https://github.com/tum-vision/LDSO

7. LSD-SLAM

- **论文**：Engel J, Schöps T, Cremers D. **LSD-SLAM: Large-scale direct monocular SLAM**[C]//European conference on computer vision. Springer, Cham, **2014**: 834-849.
- **代码**：https://github.com/tum-vision/lsd_slam

8. DVO-SLAM

- **论文**：Kerl C, Sturm J, Cremers D. **Dense visual SLAM for RGB-D cameras**[C]//2013 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, **2013**: 2100-2106.
- **代码 1**：https://github.com/tum-vision/dvo_slam
- **代码 2**：https://github.com/tum-vision/dvo
- 其他论文：
  - Kerl C, Sturm J, Cremers D. **Robust odometry estimation for RGB-D cameras**[C]//2013 IEEE international conference on robotics and automation. IEEE, **2013**: 3748-3754.
  - Steinbrücker F, Sturm J, Cremers D. **Real-time visual odometry from dense RGB-D images**[C]//2011 IEEE international conference on computer vision workshops (ICCV Workshops). IEEE, **2011**: 719-722.

9. SVO

- 苏黎世大学机器人与感知课题组
- **论文**：Forster C, Pizzoli M, Scaramuzza D. **SVO: Fast semi-direct monocular visual odometry**[C]//2014 IEEE international conference on robotics and automation (ICRA). IEEE, **2014**: 15-22.
- **代码**：https://github.com/uzh-rpg/rpg_svo
- Forster C, Zhang Z, Gassner M, et al. **SVO: Semidirect visual odometry for monocular and multicamera systems**[J]. IEEE Transactions on Robotics, **2016**, 33(2): 249-265.

10. DSM

- **论文**：Zubizarreta J, Aguinaga I, Montiel J M M. **Direct sparse mapping**[J]. arXiv preprint arXiv:1904.06577, **2019**.
- **代码**：https://github.com/jzubizarreta/dsm ； Video

11. openvslam

- 论文：Sumikura S, Shibuya M, Sakurada K. **OpenVSLAM: A Versatile Visual SLAM Framework**[C]//Proceedings of the 27th ACM International Conference on Multimedia. **2019**: 2292-2295.
- 代码：https://github.com/xdspacelab/openvslam； 文档

12. se2lam（地面车辆位姿估计的视觉里程计）

- **论文**：Zheng F, Liu Y H. **Visual-Odometric Localization and Mapping for Ground Vehicles Using SE (2)-XYZ Constraints**[C]//2019 International Conference on Robotics and Automation (**ICRA**). IEEE, **2019**: 3556-3562.
- **代码**：https://github.com/izhengfan/se2lam
- 作者的另外一项工作
  - 论文：Zheng F, Tang H, Liu Y H. **Odometry-vision-based ground vehicle motion estimation with se (2)-constrained se (3) poses**[J]. IEEE transactions on cybernetics, **2018**, 49(7): 2652-2663.
  - 代码：https://github.com/izhengfan/se2clam

13. GraphSfM（基于图的并行大尺度 SFM）

- 论文：Chen Y, Shen S, Chen Y, et al. **Graph-Based Parallel Large Scale Structure from Motion**[J]. arXiv preprint arXiv:1912.10659, **2019**.
- 代码：https://github.com/AIBluefisher/GraphSfM

14. LCSD_SLAM（松耦合的半直接法单目 SLAM）

- **论文**：Lee S H, Civera J. **Loosely-Coupled semi-direct monocular SLAM**[J]. IEEE Robotics and Automation Letters, **2018**, 4(2): 399-406.
- **代码**：https://github.com/sunghoon031/LCSD_SLAM； 谷歌学术； 演示视频
- 作者另外一篇关于**单目尺度**的文章 代码开源： Lee S H, de Croon G. **Stability-based scale estimation for monocular SLAM**[J]. IEEE Robotics and Automation Letters, **2018**, 3(2): 780-787.

15. RESLAM（基于边的 SLAM）

- **论文**：Schenk F, Fraundorfer F. **RESLAM: A real-time robust edge-based SLAM system**[C]//2019 International Conference on Robotics and Automation (ICRA). IEEE, **2019**: 154-160.
- **代码**：https://github.com/fabianschenk/RESLAM； 项目主页

16. scale_optimization（将单目 DSO 拓展到双目）

- **论文**：Mo J, Sattar J. **Extending Monocular Visual Odometry to Stereo Camera System by Scale Optimization**[C]. International Conference on Intelligent Robots and Systems (**IROS**), **2019**.
- **代码**：https://github.com/jiawei-mo/scale_optimization

17. BAD-SLAM（直接法 RGB-D SLAM）

- **论文**：Schops T, Sattler T, Pollefeys M. **BAD SLAM: Bundle Adjusted Direct RGB-D SLAM**[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. **2019**: 134-144.
- **代码**：https://github.com/ETH3D/badslam

18. GSLAM（集成 ORB-SLAM2，DSO，SVO 的通用框架）

- **论文**：Zhao Y, Xu S, Bu S, et al. **GSLAM: A general SLAM framework and benchmark**[C]//Proceedings of the IEEE International Conference on Computer Vision. **2019**: 1110-1120.
- **代码**：https://github.com/zdzhaoyong/GSLAM

19. ARM-VO（运行于 ARM 处理器上的单目 VO）

- **论文**：Nejad Z Z, Ahmadabadian A H. **ARM-VO: an efficient monocular visual odometry for ground vehicles on ARM CPUs**[J]. Machine Vision and Applications, **2019**: 1-10.
- **代码**：https://github.com/zanazakaryaie/ARM-VO

20. cvo-rgbd（直接法 RGB-D VO）

- **论文**：Ghaffari M, Clark W, Bloch A, et al. **Continuous Direct Sparse Visual Odometry from RGB-D Images**[J]. arXiv preprint arXiv:1904.02266, **2019**.
- **代码**：https://github.com/MaaniGhaffari/cvo-rgbd

二、Semantic / Deep SLAM（12 项）

> SLAM 与深度学习相结合的工作当前主要体现在两个方面，一方面是将语义信息参与到建图、位姿估计等环节中，另一方面是端到端地完成 SLAM 的某一个步骤（比如 VO，闭环等）。个人对后者没太关注，也同样欢迎大家在 **issue** 中补充。

21. MsakFusion

- **论文**：Runz M, Buffier M, Agapito L. **Maskfusion: Real-time recognition, tracking and reconstruction of multiple moving objects**[C]//2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR). IEEE, **2018**: 10-20.
- **代码**：https://github.com/martinruenz/maskfusion

22. SemanticFusion

- **论文**：McCormac J, Handa A, Davison A, et al. **Semanticfusion: Dense 3d semantic mapping with convolutional neural networks**[C]//2017 IEEE International Conference on Robotics and automation (ICRA). IEEE, **2017**: 4628-4635.
- **代码**：https://github.com/seaun163/semanticfusion

23. semantic_3d_mapping

- **论文**：Yang S, Huang Y, Scherer S. **Semantic 3D occupancy mapping through efficient high order CRFs**[C]//2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2017**: 590-597.
- **代码**：https://github.com/shichaoy/semantic_3d_mapping

24. Kimera（实时度量与语义定位建图开源库）

- 论文：Rosinol A, Abate M, Chang Y, et al. **Kimera: an Open-Source Library for Real-Time Metric-Semantic Localization and Mapping**[J]. arXiv preprint arXiv:1910.02490, **2019**.
- 代码：https://github.com/MIT-SPARK/Kimera；演示视频

25. NeuroSLAM（脑启发式 SLAM）

- **论文**：Yu F, Shang J, Hu Y, et al. **NeuroSLAM: a brain-inspired SLAM system for 3D environments**[J]. Biological Cybernetics, **2019**: 1-31.
- **代码**：https://github.com/cognav/NeuroSLAM
- 第四作者就是 Rat SLAM 的作者，文章也比较了十余种脑启发式的 SLAM

26. gradSLAM（自动分区的稠密 SLAM）

- **论文**：Jatavallabhula K M, Iyer G, Paull L. **gradSLAM: Dense SLAM meets Automatic Differentiation**[J]. arXiv preprint arXiv:1910.10672, **2019**.
- **代码**（预计 20 年 4 月放出）：https://github.com/montrealrobotics/gradSLAM；项目主页，演示视频

27. ORB-SLAM2 + 目标检测/分割的方案语义建图

- https://github.com/floatlazer/semantic_slam
- https://github.com/qixuxiang/orb-slam2_with_semantic_labelling
- https://github.com/Ewenwan/ORB_SLAM2_SSD_Semantic

28. SIVO（语义辅助特征选择）

- **论文**：Ganti P, Waslander S. **Network Uncertainty Informed Semantic Feature Selection for Visual SLAM**[C]//2019 16th Conference on Computer and Robot Vision (CRV). IEEE, **2019**: 121-128.
- **代码**：https://github.com/navganti/SIVO

29. FILD（临近图增量式闭环检测）

- **论文**：Shan An, Guangfu Che, Fangru Zhou, Xianglong Liu, Xin Ma, Yu Chen. **Fast and Incremental Loop Closure Detection using Proximity Graphs**. pp. 378-385, The 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS **2019**)
- **代码**：https://github.com/AnshanTJU/FILD

30. object-detection-sptam（目标检测与双目 SLAM）

- **论文**：Pire T, Corti J, Grinblat G. **Online Object Detection and Localization on Stereo Visual SLAM System**[J]. Journal of Intelligent & Robotic Systems, **2019**: 1-10.
- **代码**：https://github.com/CIFASIS/object-detection-sptam

31. Map Slammer（单目深度估计 + SLAM）

- **论文**：Torres-Camara J M, Escalona F, Gomez-Donoso F, et al. **Map Slammer: Densifying Scattered KSLAM 3D Maps with Estimated Depth**[C]//Iberian Robotics conference. Springer, Cham, **2019**: 563-574.
- **代码**：https://github.com/jmtc7/mapSlammer

32. NOLBO（变分模型的概率 SLAM）

- **论文**：Yu H, Lee B. **Not Only Look But Observe: Variational Observation Model of Scene-Level 3D Multi-Object Understanding for Probabilistic SLAM**[J]. arXiv preprint arXiv:1907.09760, **2019**.
- **代码**：https://github.com/bogus2000/NOLBO

三、Multi-Landmarks / Object SLAM（12 项）

> 其实多路标的点、线、平面 SLAM 和物体级 SLAM 完全可以分类在 Geometric SLAM 和 Semantic SLAM 中，但个人对这一方向比较感兴趣（也是我的研究生课题），所以将其独立出来，开源方案相对较少，但很有意思。

33. PL-SVO（点线 SVO）

- **论文**：Gomez-Ojeda R, Briales J, Gonzalez-Jimenez J. **PL-SVO: Semi-direct Monocular Visual Odometry by combining points and line segments**[C]//Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on. IEEE, **2016**: 4211-4216.
- **代码**：https://github.com/rubengooj/pl-svo

34. stvo-pl（双目点线 VO）

- **论文**：Gomez-Ojeda R, Gonzalez-Jimenez J. **Robust stereo visual odometry through a probabilistic combination of points and line segments**[C]//2016 IEEE International Conference on Robotics and Automation (**ICRA**). IEEE, **2016**: 2521-2526.
- **代码**：https://github.com/rubengooj/stvo-pl

35. PL-SLAM（点线 SLAM）

- **论文**：Gomez-Ojeda R, Zuñiga-Noël D, Moreno F A, et al. **PL-SLAM: a Stereo SLAM System through the Combination of Points and Line Segments**[J]. arXiv preprint arXiv:1705.09479, **2017**.
- **代码**：https://github.com/rubengooj/pl-slam
- Gomez-Ojeda R, Moreno F A, Zuñiga-Noël D, et al. **PL-SLAM: a stereo SLAM system through the combination of points and line segments**[J]. IEEE Transactions on Robotics, **2019**, 35(3): 734-746.

36. PL-VIO

- **论文**：He Y, Zhao J, Guo Y, et al. **PL-VIO: Tightly-coupled monocular visual–inertial odometry using point and line features**[J]. Sensors, **2018**, 18(4): 1159.
- **代码**：https://github.com/HeYijia/PL-VIO
- **VINS + 线段**：https://github.com/Jichao-Peng/VINS-Mono-Optimization

37. lld-slam（用于 SLAM 的可学习型线段描述符）

- **论文**：Vakhitov A, Lempitsky V. **Learnable line segment descriptor for visual SLAM**[J]. IEEE Access, **2019**, 7: 39923-39934.

- **代码**：https://github.com/alexandervakhitov/lld-slam； **Video**

> 点线结合的工作还有很多，国内的比如
>
> - 上交邹丹平老师的 Zou D, Wu Y, Pei L, et al. **StructVIO: visual-inertial odometry with structural regularity of man-made environments**[J]. IEEE Transactions on Robotics, **2019**, 35(4): 999-1013.
> - 浙大的 Zuo X, Xie X, Liu Y, et al. **Robust visual SLAM with point and line features**[C]//2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2017: 1775-1782.

38. PlaneSLAM

- **论文**：Wietrzykowski J. **On the representation of planes for efficient graph-based slam with high-level features**[J]. Journal of Automation Mobile Robotics and Intelligent Systems, **2016**, 10.
- **代码**：https://github.com/LRMPUT/PlaneSLAM
- 作者另外一项开源代码，没有找到对应的论文：https://github.com/LRMPUT/PUTSLAM

39. Eigen-Factors（特征因子平面对齐）

- **论文**：Ferrer G. **Eigen-Factors: Plane Estimation for Multi-Frame and Time-Continuous Point Cloud Alignment**[C]//2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2019**: 1278-1284.
- **代码**：https://gitlab.com/gferrer/eigen-factors-iros2019； 演示视频

40. PlaneLoc

- **论文**：Wietrzykowski J, Skrzypczyński P. **PlaneLoc: Probabilistic global localization in 3-D using local planar features**[J]. Robotics and Autonomous Systems, **2019**, 113: 160-173.
- **代码**：https://github.com/LRMPUT/PlaneLoc

41. Pop-up SLAM

- **论文**：Yang S, Song Y, Kaess M, et al. **Pop-up slam: Semantic monocular plane slam for low-texture environments**[C]//2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2016**: 1222-1229.
- **代码**：https://github.com/shichaoy/pop_up_slam

42. Object SLAM

- **论文**：Mu B, Liu S Y, Paull L, et al. **Slam with objects using a nonparametric pose graph**[C]//2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2016**: 4602-4609.
- **代码**：https://github.com/BeipengMu/objectSLAM； Video

43. voxblox-plusplus（物体级体素建图）

- **论文**：Grinvald M, Furrer F, Novkovic T, et al. **Volumetric instance-aware semantic mapping and 3D object discovery**[J]. IEEE Robotics and Automation Letters, **2019**, 4(3): 3037-3044.
- **代码**：https://github.com/ethz-asl/voxblox-plusplus

44. Cube SLAM

- **论文**：Yang S, Scherer S. **Cubeslam: Monocular 3-d object slam**[J]. IEEE Transactions on Robotics, **2019**, 35(4): 925-938.
- **代码**：https://github.com/shichaoy/cube_slam
- 对，这就是带我入坑的一项工作，2018 年 11 月份看到这篇论文（当时是预印版）之后开始学习物体级 SLAM，个人对 Cube SLAM 的一些注释和总结：链接。
- 也有很多有意思的但没开源的物体级 SLAM
  - Ok K, Liu K, Frey K, et al. **Robust Object-based SLAM for High-speed Autonomous Navigation**[C]//2019 International Conference on Robotics and Automation (ICRA). IEEE, **2019**: 669-675.
  - Li J, Meger D, Dudek G. **Semantic Mapping for View-Invariant Relocalization**[C]//2019 International Conference on Robotics and Automation (ICRA). IEEE, **2019**: 7108-7115.
  - Nicholson L, Milford M, Sünderhauf N. **Quadricslam: Dual quadrics from object detections as landmarks in object-oriented slam**[J]. IEEE Robotics and Automation Letters, **2018**, 4(1): 1-8.

四、VIO / VISLAM（10 项）

> 在传感器融合方面只关注了视觉 + 惯导，其他传感器像 LiDAR，GPS 关注较少（SLAM 太复杂啦 -_-! ）。这一类的新工作也相对较少，基本一些经典的方案就够用了。

45. msckf_vio

- **论文**：Sun K, Mohta K, Pfrommer B, et al. **Robust stereo visual inertial odometry for fast autonomous flight**[J]. IEEE Robotics and Automation Letters, **2018**, 3(2): 965-972.
- **代码**：https://github.com/KumarRobotics/msckf_vio ； Video

46. rovio

- **论文**：Bloesch M, Omari S, Hutter M, et al. **Robust visual inertial odometry using a direct EKF-based approach**[C]//2015 IEEE/RSJ international conference on intelligent robots and systems (IROS). IEEE, **2015**: 298-304.
- **代码**：https://github.com/ethz-asl/rovio ； Video

47. R-VIO

- **论文**：Huai Z, Huang G. **Robocentric visual-inertial odometry**[C]//2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2018**: 6319-6326.
- **代码**：https://github.com/rpng/R-VIO ； Video

48. okvis

- **论文**：Leutenegger S, Lynen S, Bosse M, et al. **Keyframe-based visual–inertial odometry using nonlinear optimization**[J]. The International Journal of Robotics Research, **2015**, 34(3): 314-334.
- **代码**：https://github.com/ethz-asl/okvis

49. VIORB

- **论文**：Mur-Artal R, Tardós J D. Visual-inertial monocular SLAM with map reuse[J]. IEEE Robotics and Automation Letters, **2017**, 2(2): 796-803.
- **代码**：https://github.com/jingpang/LearnVIORB （VIORB 本身是没有开源的，这是王京大佬复现的一个版本）

50. VINS-mono

- **论文**：Qin T, Li P, Shen S. **Vins-mono: A robust and versatile monocular visual-inertial state estimator**[J]. IEEE Transactions on Robotics, **2018**, 34(4): 1004-1020.
- **代码**：https://github.com/HKUST-Aerial-Robotics/VINS-Mono
- 双目版 **VINS-Fusion**：https://github.com/HKUST-Aerial-Robotics/VINS-Fusion
- 移动段 **VINS-mobile**：https://github.com/HKUST-Aerial-Robotics/VINS-Mobile

51. VINS-RGBD

- **论文**：Shan Z, Li R, Schwertfeger S. **RGBD-Inertial Trajectory Estimation and Mapping for Ground Robots**[J]. Sensors, **2019**, 19(10): 2251.
- **代码**：https://github.com/STAR-Center/VINS-RGBD ； **Video**

52. Open-VINS

- **论文**：Geneva P, Eckenhoff K, Lee W, et al. **Openvins: A research platform for visual-inertial estimation**[C]//IROS 2019 Workshop on Visual-Inertial Navigation: Challenges and Applications, Macau, China. **IROS 2019**.
- **代码**：https://github.com/rpng/open_vins

53. versavis（多功能的视惯传感器系统）

- 论文：Tschopp F, Riner M, Fehr M, et al. **VersaVIS—An Open Versatile Multi-Camera Visual-Inertial Sensor Suite**[J]. Sensors, **2020**, 20(5): 1439.

- 代码：https://github.com/ethz-asl/versavis

54. CPI（视惯融合的封闭式预积分）

- **论文**：Eckenhoff K, Geneva P, Huang G. **Closed-form preintegration methods for graph-based visual–inertial navigation**[J]. The International Journal of Robotics Research, 2018.
- **代码**：https://github.com/rpng/cpi ； **Video**

五、Dynamic SLAM（5 项）

> 动态 SLAM 也是一个很值得研究的话题，这里不太好分类，很多工作用到了语义信息或者用来三维重建，收集的方案相对较少，欢迎补充 **issue**。

55. DynamicSemanticMapping（动态语义建图）

- **论文**：Kochanov D, Ošep A, Stückler J, et al. **Scene flow propagation for semantic mapping and object discovery in dynamic street scenes**[C]//Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on. IEEE, **2016**: 1785-1792.
- **代码**：https://github.com/ganlumomo/DynamicSemanticMapping ； wiki

56. DS-SLAM（动态语义 SLAM）

- **论文**：Yu C, Liu Z, Liu X J, et al. **DS-SLAM: A semantic visual SLAM towards dynamic environments**[C]//2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2018**: 1168-1174.
- **代码**：https://github.com/ivipsourcecode/DS-SLAM

57. Co-Fusion（实时分割与跟踪多物体）

- **论文**：Rünz M, Agapito L. **Co-fusion: Real-time segmentation, tracking and fusion of multiple objects**[C]//2017 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2017: 4471-4478.
- **代码**：https://github.com/martinruenz/co-fusion ； Video

58. DynamicFusion

- **论文**：Newcombe R A, Fox D, Seitz S M. **Dynamicfusion: Reconstruction and tracking of non-rigid scenes in real-time**[C]//Proceedings of the IEEE conference on computer vision and pattern recognition. **2015**: 343-352.
- **代码**：https://github.com/mihaibujanca/dynamicfusion

59. ReFusion（动态场景利用残差三维重建）

- **论文**：Palazzolo E, Behley J, Lottes P, et al. **ReFusion: 3D Reconstruction in Dynamic Environments for RGB-D Cameras Exploiting Residuals**[J]. arXiv preprint arXiv:1905.02082, **2019**.
- **代码**：https://github.com/PRBonn/refusion ； **Video**

六、Mapping（18 项）

> 针对建图的工作一方面是利用几何信息进行稠密重建，另一方面很多工作利用语义信息达到了很好的语义重建效果，三维重建本身就是个很大的话题，开源代码也很多，以下方案收集地可能也不太全。

60. InfiniTAM（跨平台 CPU 实时重建）

- 论文：Prisacariu V A, Kähler O, Golodetz S, et al. **Infinitam v3: A framework for large-scale 3d reconstruction with loop closure**[J]. arXiv preprint arXiv:1708.00783, **2017**.
- 代码：https://github.com/victorprad/InfiniTAM ； project page

61. BundleFusion

- **论文**：Dai A, Nießner M, Zollhöfer M, et al. **Bundlefusion: Real-time globally consistent 3d reconstruction using on-the-fly surface reintegration**[J]. ACM Transactions on Graphics (TOG), **2017**, 36(4): 76a.

- **代码**：https://github.com/niessner/BundleFusion ； 工程地址

62. KinectFusion

- **论文**：Newcombe R A, Izadi S, Hilliges O, et al. **KinectFusion: Real-time dense surface mapping and tracking**[C]//2011 10th IEEE International Symposium on Mixed and Augmented Reality. IEEE, **2011**: 127-136.
- **代码**：https://github.com/chrdiller/KinectFusionApp

63. ElasticFusion

- **论文**：Whelan T, Salas-Moreno R F, Glocker B, et al. **ElasticFusion: Real-time dense SLAM and light source estimation**[J]. The International Journal of Robotics Research, **2016**, 35(14): 1697-1716.
- **代码**：https://github.com/mp3guy/ElasticFusion

64. Kintinuous

- ElasticFusion 同一个团队的工作，帝国理工 Stefan Leutenegger 谷歌学术
- **论文**：Whelan T, Kaess M, Johannsson H, et al. **Real-time large-scale dense RGB-D SLAM with volumetric fusion**[J]. The International Journal of Robotics Research, **2015**, 34(4-5): 598-626.
- **代码**：https://github.com/mp3guy/Kintinuous

65. ElasticReconstruction

- **论文**：Choi S, Zhou Q Y, Koltun V. **Robust reconstruction of indoor scenes**[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. **2015**: 5556-5565.
- **代码**：https://github.com/qianyizh/ElasticReconstruction ； 作者主页

66. FlashFusion

- **论文**：Han L, Fang L. **FlashFusion: Real-time Globally Consistent Dense 3D Reconstruction using CPU Computing**[C]. RSS, 2018.
- **代码（一直没放出来）**：https://github.com/lhanaf/FlashFusion ； Project Page

67. RTAB-Map（激光视觉稠密重建）

- **论文**：Labbé M, Michaud F. **RTAB-Map as an open-source lidar and visual simultaneous localization and mapping library for large-scale and long-term online operation**[J]. Journal of Field Robotics, **2019**, 36(2): 416-446.
- **代码**：https://github.com/introlab/rtabmap ； Video ； project page

68. RobustPCLReconstruction（户外稠密重建）

- **论文**：Lan Z, Yew Z J, Lee G H. **Robust Point Cloud Based Reconstruction of Large-Scale Outdoor Scenes**[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. **2019**: 9690-9698.
- **代码**：https://github.com/ziquan111/RobustPCLReconstruction ； Video

69. plane-opt-rgbd（室内平面重建）

- **论文**：Wang C, Guo X. **Efficient Plane-Based Optimization of Geometry and Texture for Indoor RGB-D Reconstruction**[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops. **2019**: 49-53.
- **代码**：https://github.com/chaowang15/plane-opt-rgbd

70. DenseSurfelMapping（稠密表面重建）

- **论文**：Wang K, Gao F, Shen S. **Real-time scalable dense surfel mapping**[C]//2019 International Conference on Robotics and Automation (ICRA). IEEE, **2019**: 6919-6925.
- **代码**：https://github.com/HKUST-Aerial-Robotics/DenseSurfelMapping

71. surfelmeshing（网格重建）

- **论文**：Schöps T, Sattler T, Pollefeys M. **Surfelmeshing: Online surfel-based mesh reconstruction**[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, **2019**.
- **代码**：https://github.com/puzzlepaint/surfelmeshing

72. DPPTAM（单目稠密重建）

- **论文**：Concha Belenguer A, Civera Sancho J. **DPPTAM: Dense piecewise planar tracking and mapping from a monocular sequence**[C]//Proc. IEEE/RSJ Int. Conf. Intell. Rob. Syst. **2015** (ART-2015-92153).
- **代码**：https://github.com/alejocb/dpptam
- **相关研究**：基于超像素的单目 SLAM：**Using Superpixels in Monocular SLAM** ICRA 2014； 谷歌学术

73. VI-MEAN（单目视惯稠密重建）

- **论文**：Yang Z, Gao F, Shen S. **Real-time monocular dense mapping on aerial robots using visual-inertial fusion**[C]//2017 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2017: 4552-4559.
- **代码**：https://github.com/dvorak0/VI-MEAN； Video

74. REMODE（单目概率稠密重建）

- **论文**：Pizzoli M, Forster C, Scaramuzza D. **REMODE: Probabilistic, monocular dense reconstruction in real time**[C]//2014 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2014: 2609-2616.
- **原始开源代码**：https://github.com/uzh-rpg/rpg_open_remode
- **与 ORB-SLAM2 结合版本**：https://github.com/ayushgaud/ORB_SLAM2 https://github.com/ayushgaud/ORB_SLAM2

75. DeepFactors（实时的概率单目稠密 SLAM）

- 帝国理工学院戴森机器人实验室
- **论文**：Czarnowski J, Laidlow T, Clark R, et al. **DeepFactors: Real-Time Probabilistic Dense Monocular SLAM**[J]. arXiv preprint arXiv:2001.05049, **2020**.
- **代码**：https://github.com/jczarnowski/DeepFactors （还未放出）
- 其他论文：Bloesch M, Czarnowski J, Clark R, et al. **CodeSLAM—learning a compact, optimisable representation for dense visual SLAM**[C]//Proceedings of the IEEE conference on computer vision and pattern recognition. **2018**: 2560-2568.

76. probabilistic_mapping（单目概率稠密重建）

- 港科沈邵劼老师团队
- **论文**：Ling Y, Wang K, Shen S. **Probabilistic dense reconstruction from a moving camera**[C]//2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, **2018**: 6364-6371.
- **代码**：https://github.com/ygling2008/probabilistic_mapping
- 另外一篇稠密重建文章的代码一直没放出来 Github： Ling Y, Shen S. **Real-time dense mapping for online processing and navigation**[J]. Journal of Field Robotics, **2019**, 36(5): 1004-1036.

77. ORB-SLAM2 单目半稠密建图

- **论文**：Mur-Artal R, Tardós J D. Probabilistic Semi-Dense Mapping from Highly Accurate Feature-Based Monocular SLAM[C]//Robotics: Science and Systems. **2015**, 2015.
- **代码**（本身没有开源，贺博复现的一个版本）：https://github.com/HeYijia/ORB_SLAM2
- 加上线段之后的半稠密建图
  - **论文**：He S, Qin X, Zhang Z, et al. **Incremental 3d line segment extraction from semi-dense slam**[C]//2018 24th International Conference on Pattern Recognition (ICPR). IEEE, **2018**: 1658-1663.
  - **代码**：https://github.com/shidahe/semidense-lines
  - 作者在此基础上用于指导远程抓取操作的一项工作：https://github.com/atlas-jj/ORB-SLAM-free-space-carving

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七、Optimization（6 项）

> 个人感觉优化可能是 SLAM 中最难的一部分了吧 +_+ ，我们一般都是直接用现成的因子图、图优化方案，要创新可不容易，分享山川小哥的**入坑指难**。

78. 后端优化库

- **GTSAM**：https://github.com/borglab/gtsam ； 官网
- **g2o**：https://github.com/RainerKuemmerle/g2o
- **ceres**：http://ceres-solver.org/

79. ICE-BA

- **论文**：Liu H, Chen M, Zhang G, et al. **Ice-ba: Incremental, consistent and efficient bundle adjustment for visual-inertial slam**[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. **2018**: 1974-1982.
- **代码**：https://github.com/baidu/ICE-BA

80. minisam（因子图最小二乘优化框架）

- **论文**：Dong J, Lv Z. **miniSAM: A Flexible Factor Graph Non-linear Least Squares Optimization Framework**[J]. arXiv preprint arXiv:1909.00903, **2019**.
- **代码**：https://github.com/dongjing3309/minisam ； 文档

81. SA-SHAGO（几何基元图优化）

- **论文**：Aloise I, Della Corte B, Nardi F, et al. **Systematic Handling of Heterogeneous Geometric Primitives in Graph-SLAM Optimization**[J]. IEEE Robotics and Automation Letters, **2019**, 4(3): 2738-2745.
- **代码**：https://srrg.gitlab.io/sashago-website/index.html#

82. MH-iSAM2（SLAM 优化器）

- **论文**：Hsiao M, Kaess M. **MH-iSAM2: Multi-hypothesis iSAM using Bayes Tree and Hypo-tree**[C]//2019 International Conference on Robotics and Automation (ICRA). IEEE, **2019**: 1274-1280.
- **代码**：https://bitbucket.org/rpl_cmu/mh-isam2_lib/src/master/

83. MOLA（用于定位和建图的模块化优化框架）

- **论文**：Blanco-Claraco J L. **A Modular Optimization Framework for Localization and Mapping**[J]. Proc. of Robotics: Science and Systems (RSS), FreiburgimBreisgau, Germany, **2019**, 2.
- **代码**：https://github.com/MOLAorg/mola ； **Video** ； 使用文档

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