Intelligent Image and Graphics Processing

智能图像图形处理

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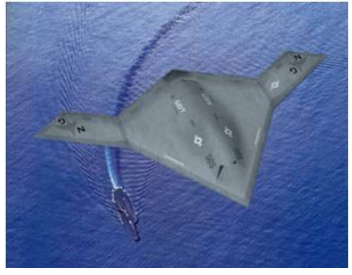
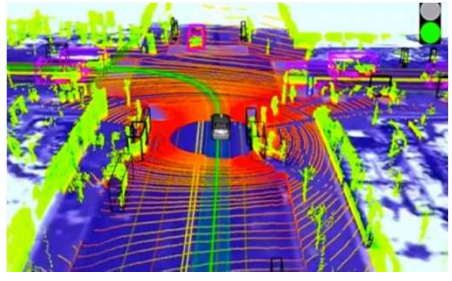
http://www.adv-ci.com



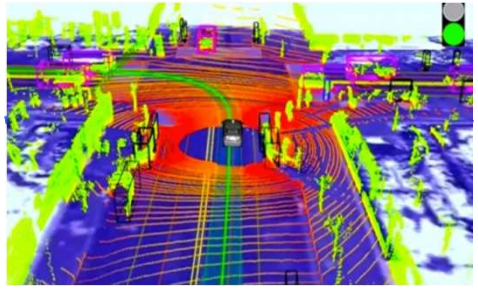


General SLAM (G-SLAM)

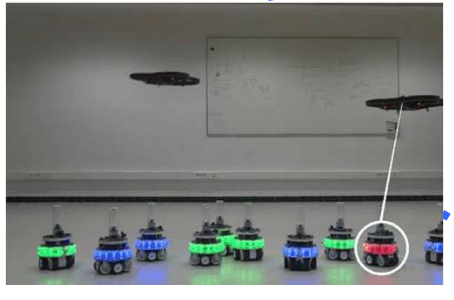
Contents

- Background
- G-SLAM
  - Real-time Map for UAV（RT-Map）
  - Semi-direct Tracking and Mapping (SDTAM)
- Related research
- Future

未来？ 即将到来！



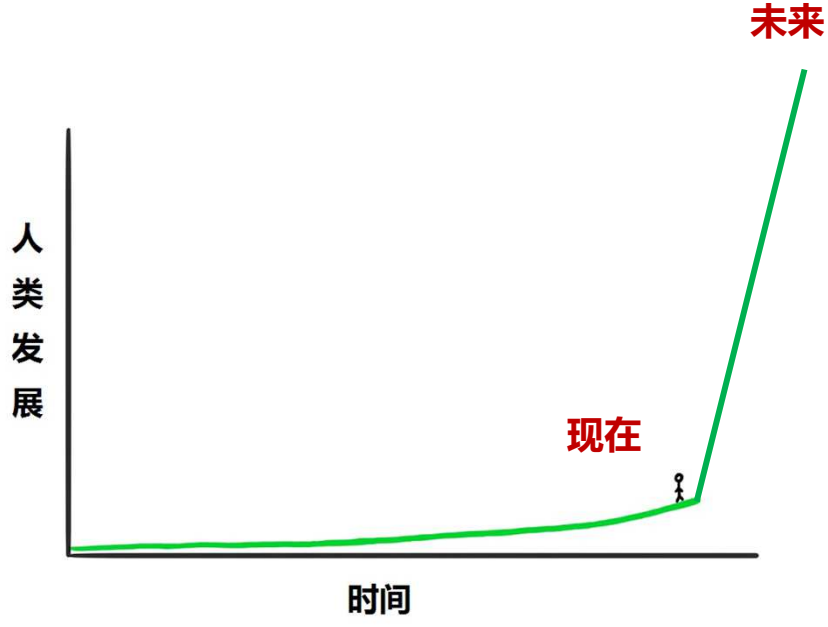
人工智能



人工智能时代的机遇


Can your phone improve your health?
Vitamin C and cancer cell metabolism
In search of stem cells
Science
AAAS
Machine intelligence
AI learns to read and write letters


nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
At last — a computer program that can beat a champion Go player PAGE 484
ALL SYSTEMS GO
SONGBIRDS À LA CARTE
SAFEGUARD TRANSPARENCY
WHEN GENES GOT 'SELFISH'


未来
人类发展
现在
时间

面临的挑战

人工智能

环境感知

SLAM

场景理解

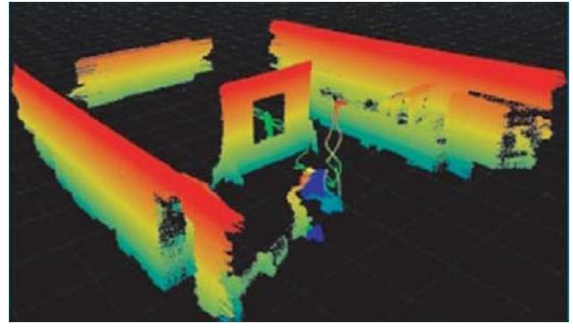
推理

决策

多数据源
图像
LiDAR
红外
多光谱，高光谱
IMU
MAP

实时，低延时

复杂环境
电磁环境，气象环境



LiDAR data

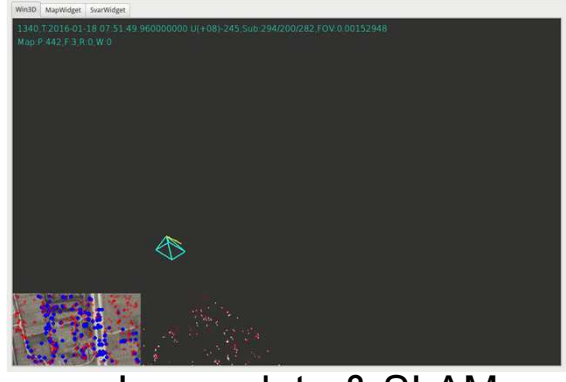
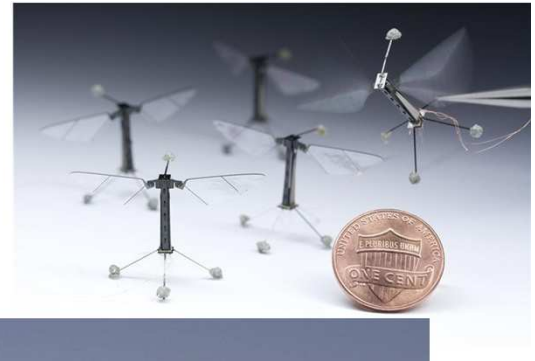


Image data & SLAM

无人机 – 人工智能的载体

无人机因具有体积小、造价低、使用方便、对作战环境要求低、战场生存能力较强等优点，备受世界各国军队的青睐，广泛应用于反恐，侦查等领域。在民用领域也逐步受到极大的关注。



无人机的操控

无人机目前主要以人工操控的方式来控制其飞行或执行任务。存在较多的问题，例如工作负荷大，需要专业训练，无法控制多架飞机或编队飞机。

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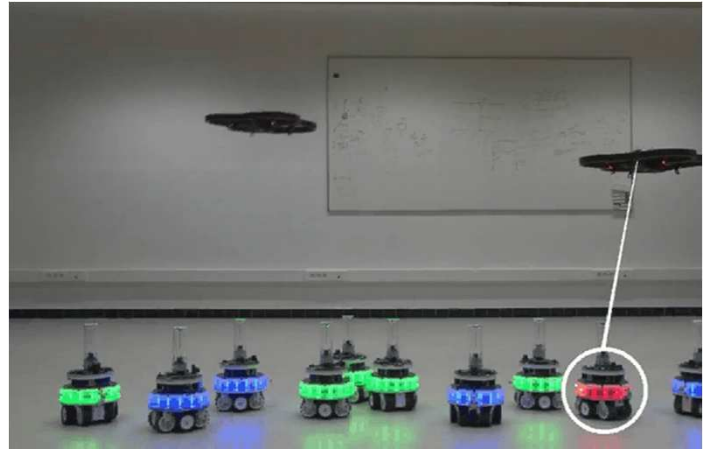
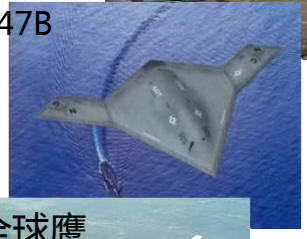


无人机与自主飞行

无人战斗武装旋翼机UCAR

X47B



全球鹰

捕食者

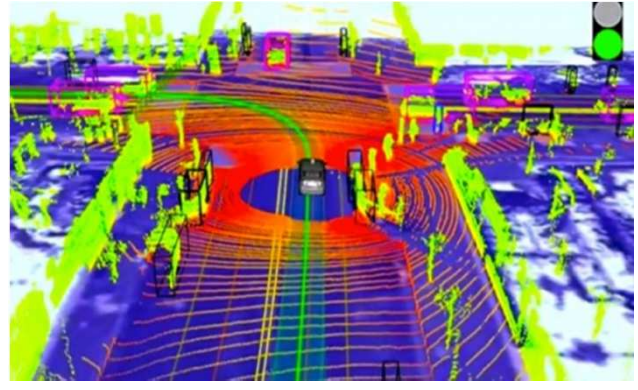
一般旋翼机

ACL级别	级别描述	制导	导航	控制
10	完全自主式	人类级别的策略制定，不用外部系统的干预能够完成大多数飞行任务	对于大多数飞行任务具有与人类似的导航能力，但在极其复杂的环境下快速环境感知能力要优于人	在相同条件下比有人驾驶飞机有相同或更优的飞行性能
9	团队认知和决策	在无监督情况下，完成分布式的策略组规划，策略目标选择和任务执行	长期对非常复杂环境的跟踪意识，对其他机体意图和策略的推断和预期，属于高层次团队环境感知	基于对当前和将来环境的理解，有选择合适的控制结构的能力
8	环境感知和认定	主要在旋翼无人机的监督下，完成推理和高层次决策、任务规划、选择策略目标和环境认知	对复杂环境有学习意识，推断自身和其他机体意图，对即将发生事件及结果预期，属于高逼真环境感知	依据对当前和将来环境的理解，具有在不同控制策略间切换的能力
7	实时协作式任务规划	协作式任务规划和执，多机体任务性能的评价和优化	在复杂和不确定环境下，是层次5和层次6能力的组合，属协作式中层次环境感知	控制策略同上一层次(无额外控制性能要求)
6	动态任务规划	推理和高层次决策，任务驱动型决策，对任务分配、改变有高度适应性	较高层次的物体、事件检测，以及推断他们属性的能力，属中层次环境感知	控制策略同上一层次(无额外控制性能要求)
5	实时协作式导航和路径规划	碰撞检测、协作式路径规划，同一目标的任务执行	旋翼无人机之间相对导航、协作感知、数据共享和碰撞检测(共享式低层次环境感知)	分布式或集中式飞行控制结构，协调机动

无人机系统自主能力和鲁棒性的提高,能够改进对战场的感知,提高目标定位的速度和精度,增强生命力,扩大任务的灵活性,计划到**2015 年无人机系统将实现感知-规避能力,到2034 年实现在线态势感知,具有完全自主能力。**

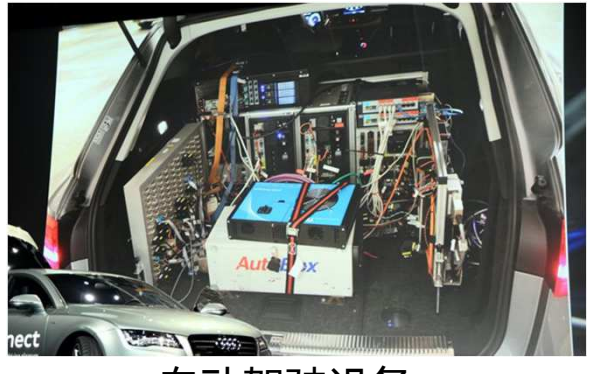
自主运行系统在其他领域

- 对于自动驾驶汽车和机器人，其未来的主要发展方向同样也是自主运行。
- 多家知名公司已基本实现汽车的自动驾驶，但其缺陷是使用较为复杂的传感器和计算设备，导致系统价格高、全天候运行能力差等。
- 目前主要的研究方向是**如何减少传感器的使用量，并提高其对环境的感知能力**，例如高精度、高实时性的行人和车辆的监测、识别等。
- 预期到**2020年左右，自动驾驶系统将成熟并实现商业化运作**。

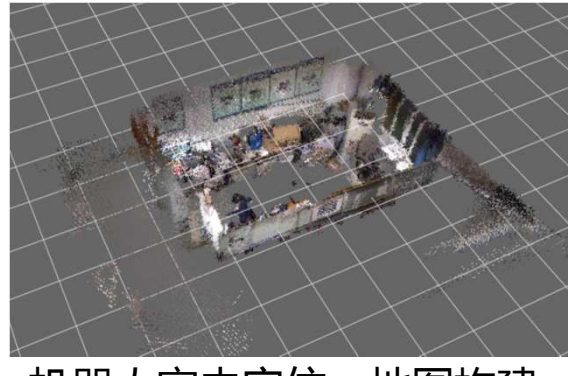


环境感知、规避障碍

汽车自动驾驶

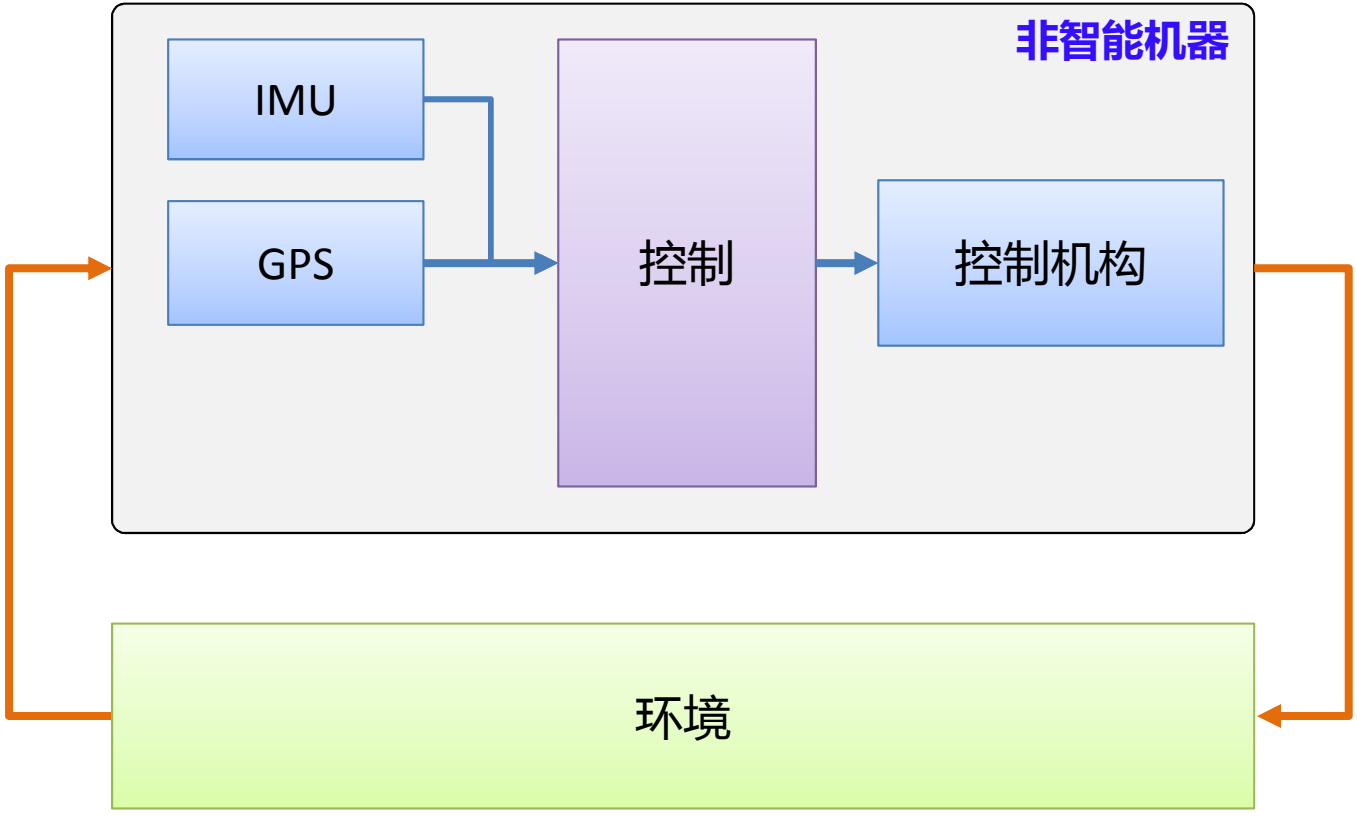


自动驾驶设备

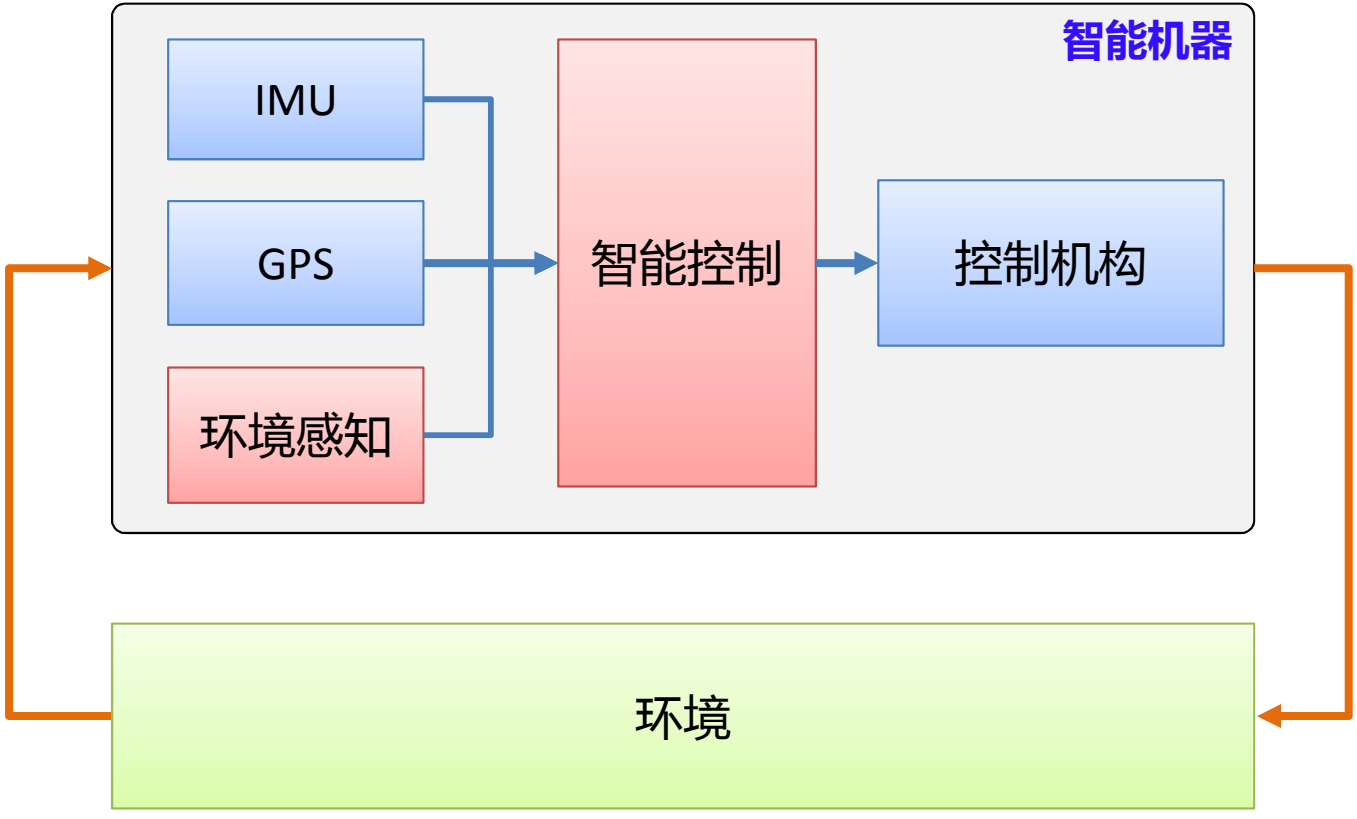


机器人室内定位、地图构建

目前成熟的

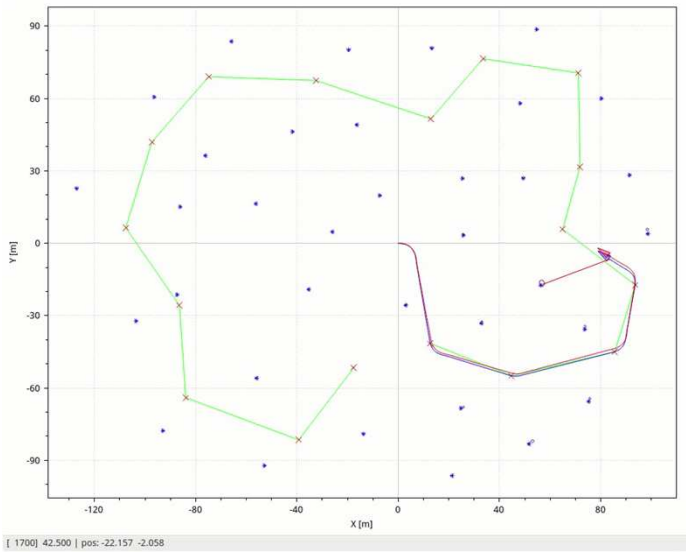


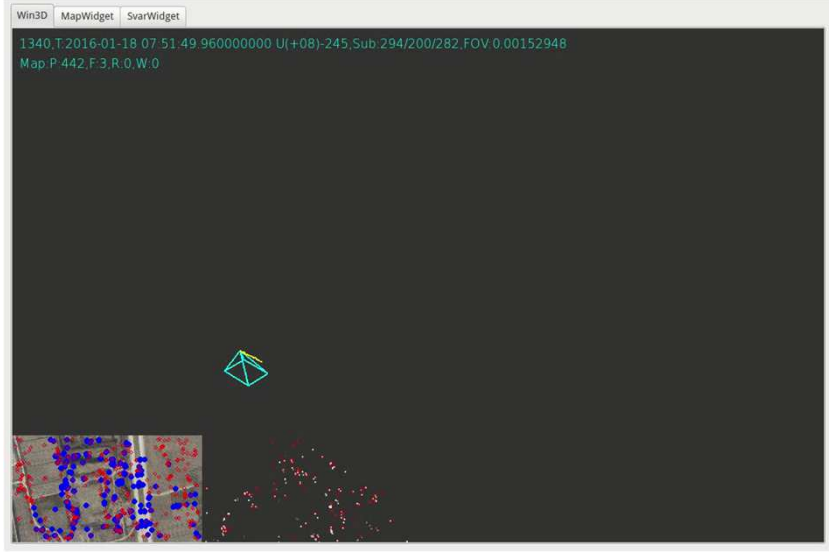
正在路上的



SLAM ?

SLAM (Simultaneous Localization and Mapping), 即时定位与地图构建，最早由美国著名学者Smith于1988年提出，它是解决机器人视觉的关键核心技术，被很多学者认为是实现真正全自主移动机器人的关键。由于早期SLAM算法设计的局限性，以及传感器技术、计算机处理能力的限制，未能广泛推广应用。





Demo can be downloaded at: http://www.adv-ci.com/blog/source/fastslam-gui/

SLAM: 视觉? 激光?

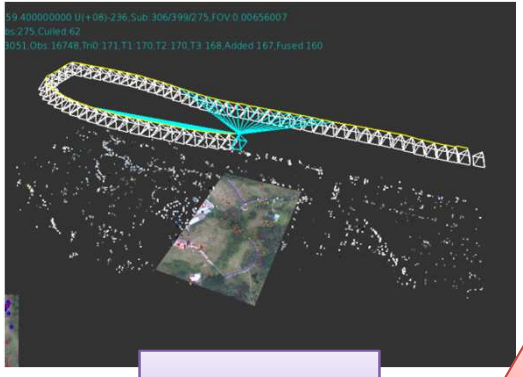
- 低成本
- cm ~ km 范围
- 丰富的信息
- 精度相对低
- 与人类似的感知
- 视觉SLAM难度高（门槛高）
- 应用前景广泛

- 高成本
- cm ~ m 范围
- 只有距离信息
- 精度高
- 超人类的感知
- 激光SLAM难度低（门槛低）
- 应用范围受限

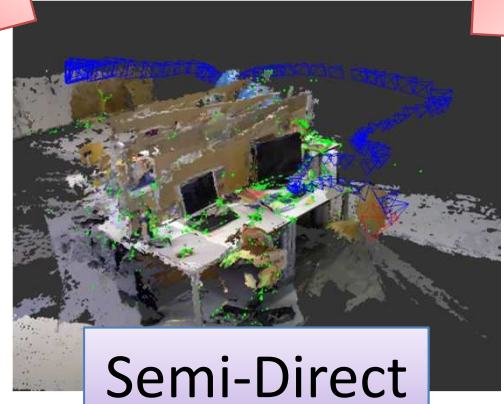
视觉

激光

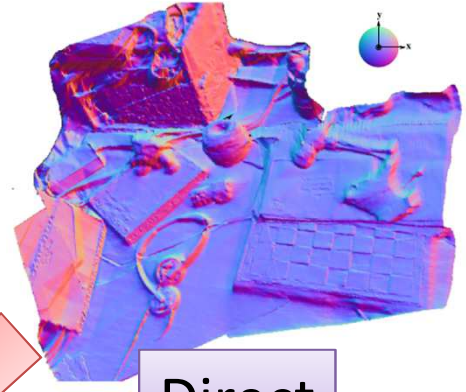
视觉SLAM – 基本分类



Feature

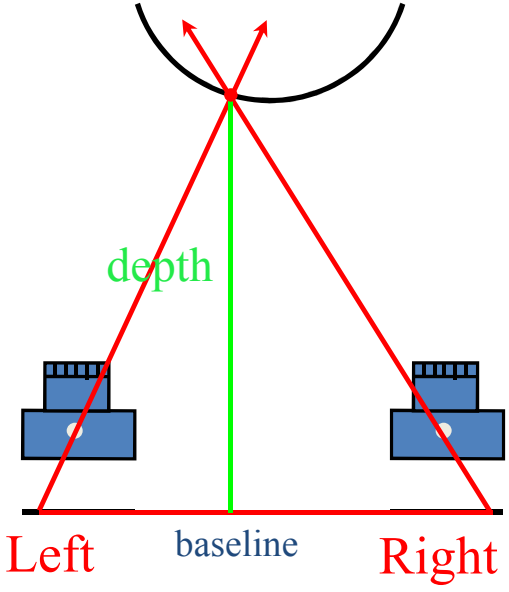


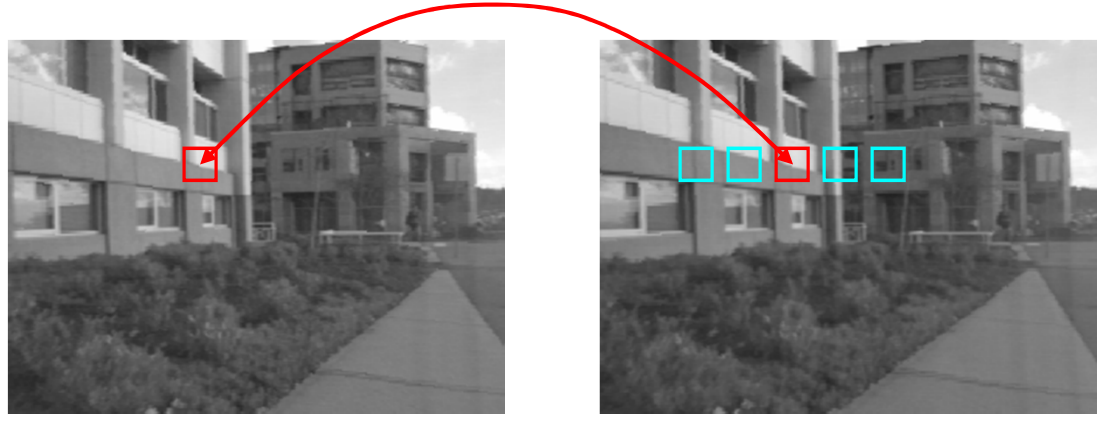
Semi-Direct



Direct

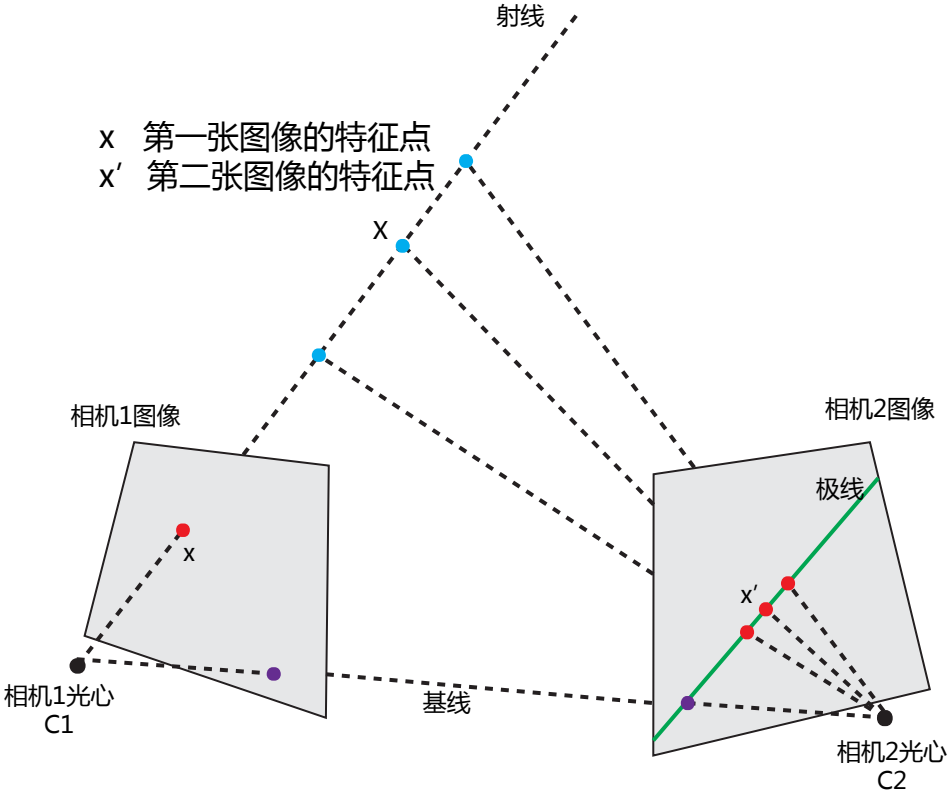
视觉SLAM原理 – 基本原理





通过三角化两张图像上对应的点，能够恢复物体点到相机的相对深度值

视觉SLAM原理 – 如何计算相机的位置和姿态



$x'^{T}Fx = 0$

几组特征对应关系
得到 F

F，基本矩阵

$E = K^{T}FK$

F矩阵和相机内参矩阵
得到本征矩阵 E

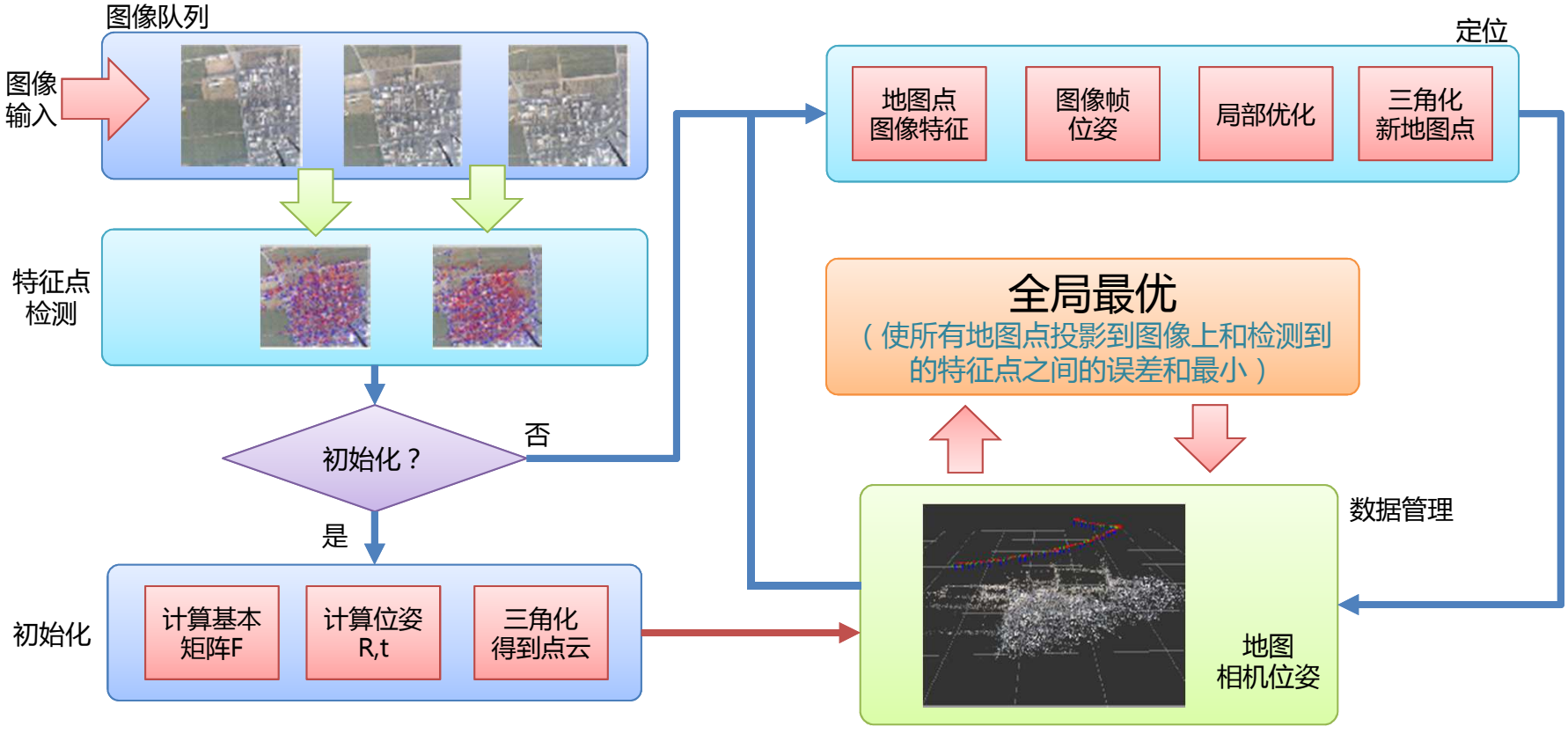
E

R, t

得到第二张图像的
位置，姿态

假设第一张图像位于远点，可以得到
第二张图像的位置和姿态

视觉SLAM原理 – Feature Based Methods

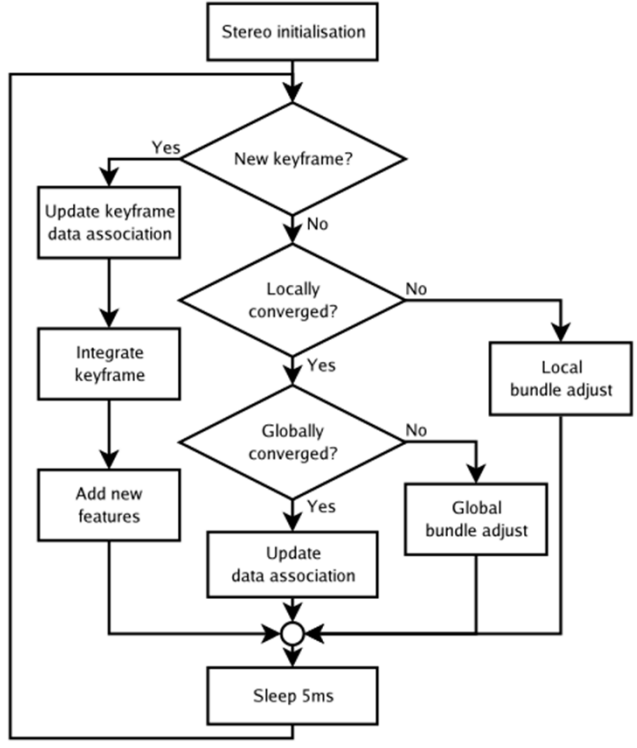


Feature Based Methods - Parallel Tracking and Mapping

- Tracking and Mapping are separated, and run in two parallel threads
- Mapping is based on keyframes, which are processed using bundle adjustment
- The map is densely intialised from a stereo pair
- New Points are initialised with an epipolar search
- Large numbers of points are mapped

G. Klein, D. Murray, Parallel Tracking and Mapping for Small AR Workspaces, 2007

Feature Based Methods - Parallel Tracking and Mapping



G. Klein, D. Murray, Parallel Tracking and Mapping for Small AR Workspaces, 2007

Feature Based Methods – ORB-SLAM

- Covisibility information to operate at large scale
- BoW based place recognition system for relocalisation and loop closing

Raúl Mur-Artal, J. M. M. Montiel and Juan D. Tardós. ORB-SLAM: A Versatile and Accurate Monocular SLAM System, 2015

Feature Based Methods – ORB-SLAM

ORB-SLAM

Raúl Mur-Artal, J. M. M. Montiel and Juan D. Tardós

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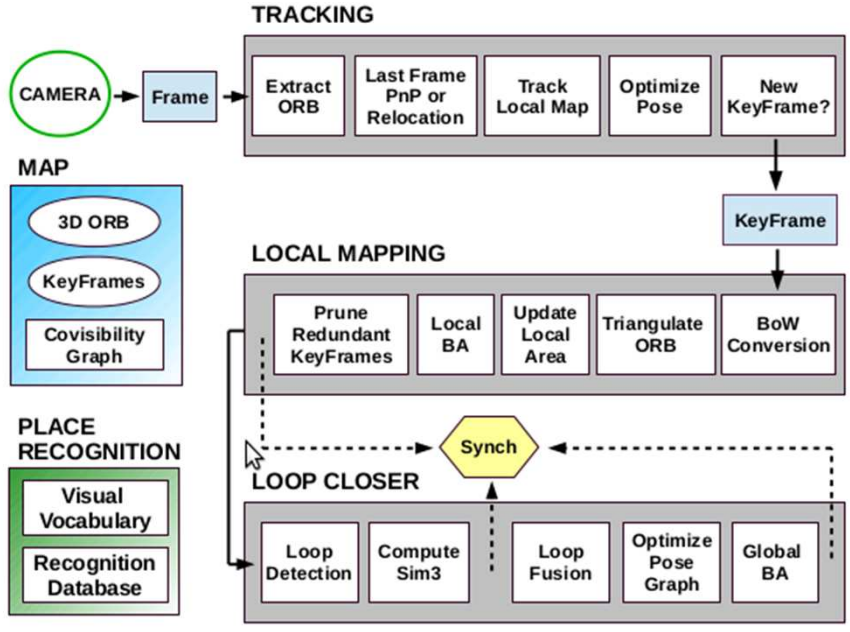
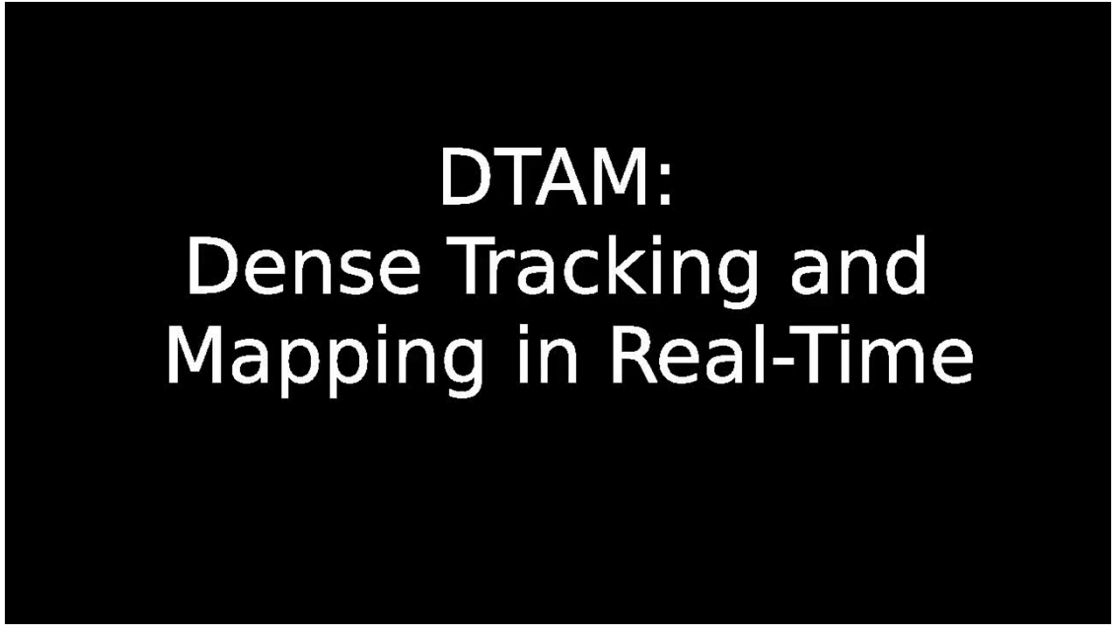


Raúl Mur-Artal, J. M. M. Montiel and Juan D. Tardós. ORB-SLAM: A Versatile and Accurate Monocular SLAM System, 2015

Direct Based Methods – Dense Tracking and Mapping (DTAM)

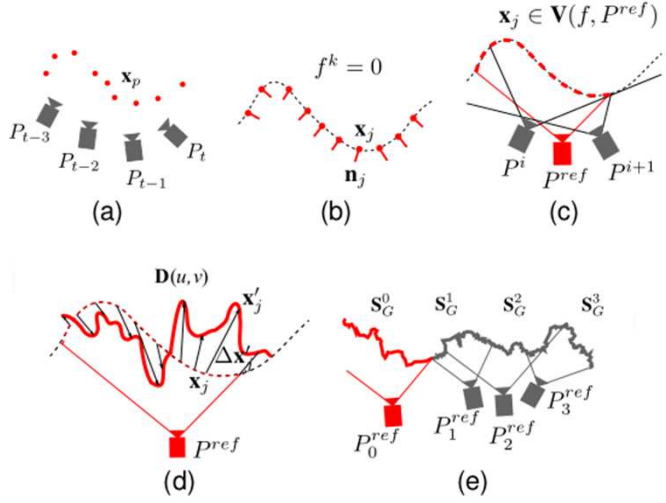


- Utilizing a coarse base surface model as the initial starting point for dense reconstruction
- Depth map creation is pipelined, and multiple depth maps are straightforwardly fused to create complete scene reconstructions
- Using GPU to accelerate the speed

R.A. Newcombe, S.J. Lovegrove and A.J. Davison, DTAM: Dense Tracking and Mapping in Real-Time, 2011

Direct Based Methods – Dense Tracking and Mapping (DTAM)

DTAM:
Dense Tracking and
Mapping in Real-Time



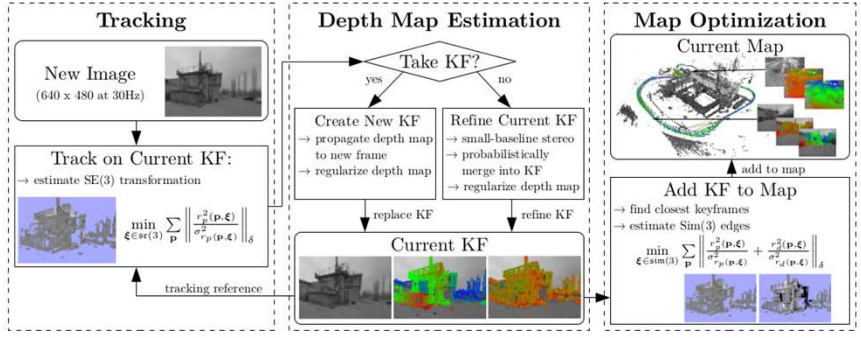
R.A. Newcombe, S.J. Lovegrove and A.J. Davison, DTAM: Dense Tracking and Mapping in Real-Time, 2011

Direct Based Methods – Large-Scale Direct Monocular SLAM (LSD-SLAM)

- Using direct image alignment coupled with filtering-based estimation of semi-dense depth maps
- Probabilistically consistent incorporation of uncertainty of the estimated depth into tracking

J. Engel, T. Schops, and D. Cremers, LSD-SLAM: Large-Scale Direct Monocular SLAM, 2014

Direct Based Methods – Large-Scale Direct Monocular SLAM (LSD-SLAM)



J. Engel, T. Schops, and D. Cremers, LSD-SLAM: Large-Scale Direct Monocular SLAM, 2014

Make precise infinity

G-SLAM

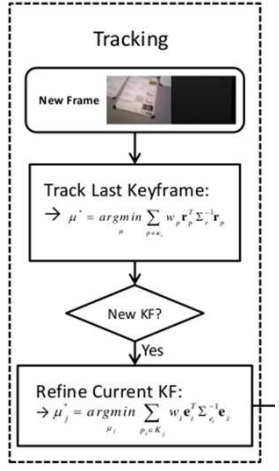
General SLAM

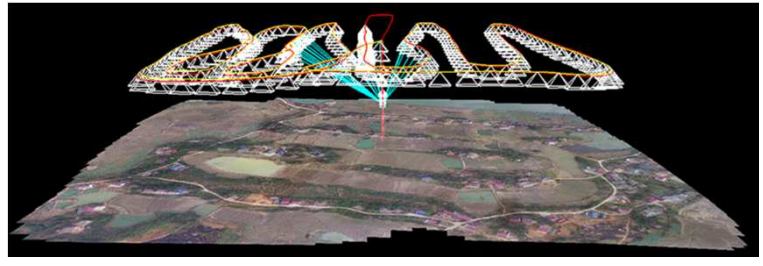
G-SLAM目标

- **High robustness:** Anti-rotation, fast moving
- **High efficiency:** > 30Hz (1080p)
- **High accuracy:** < 0.1% error
- **Multi-modal data support:** Image, Video, GPS, LiDAR
- **Joint optimization:** GPS-denied environment
- **General usage:** Autonomous robot, AR, …

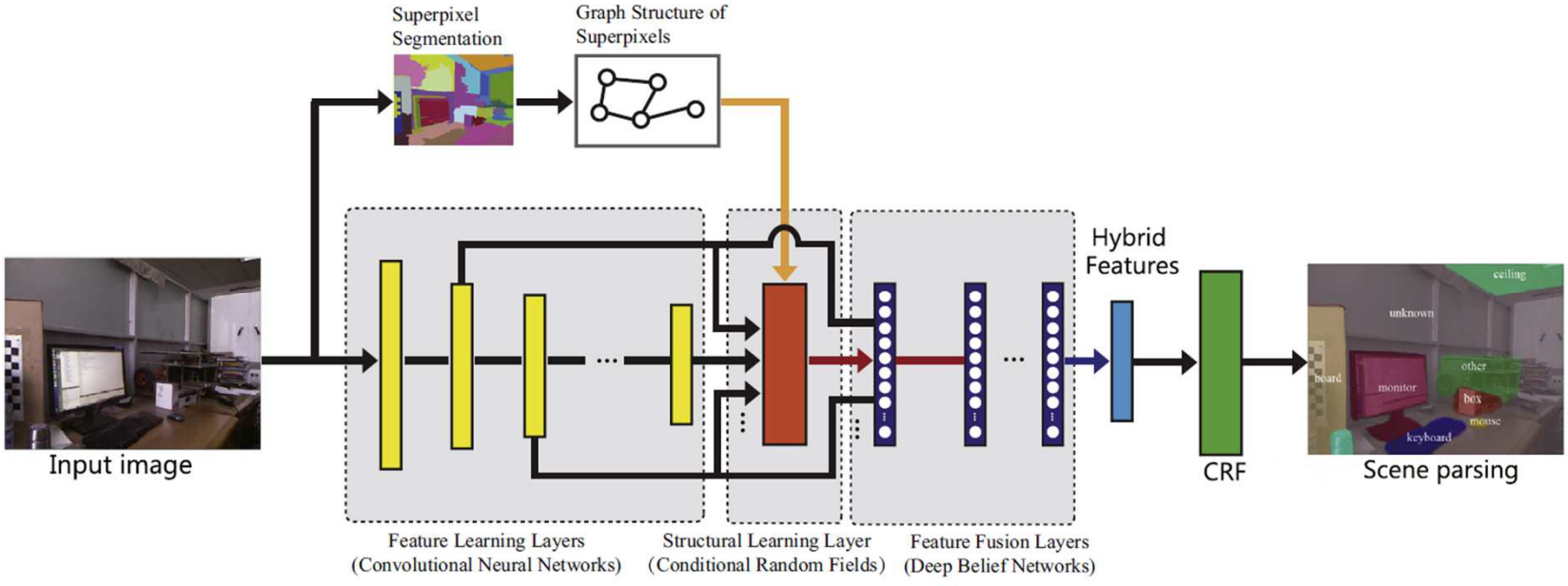
G-SLAM特点

- **Semi-direct Tracking and Mapping:** Input frame are first tracked by direct align, then refined by graph optimization
  - Anti-rotation, fast moving
  - Fast processing and high speed
- **Graph optimization:** using graph optimization for local and global optimization
  - Multi-modal data support
  - Large scale scene can be handled
- **Real-time orthoimage blender:** using adaptive weighting method to blend mapping
- **Deep learning based place recognition:** using CNN to extract representative feature, semantic level SLAM



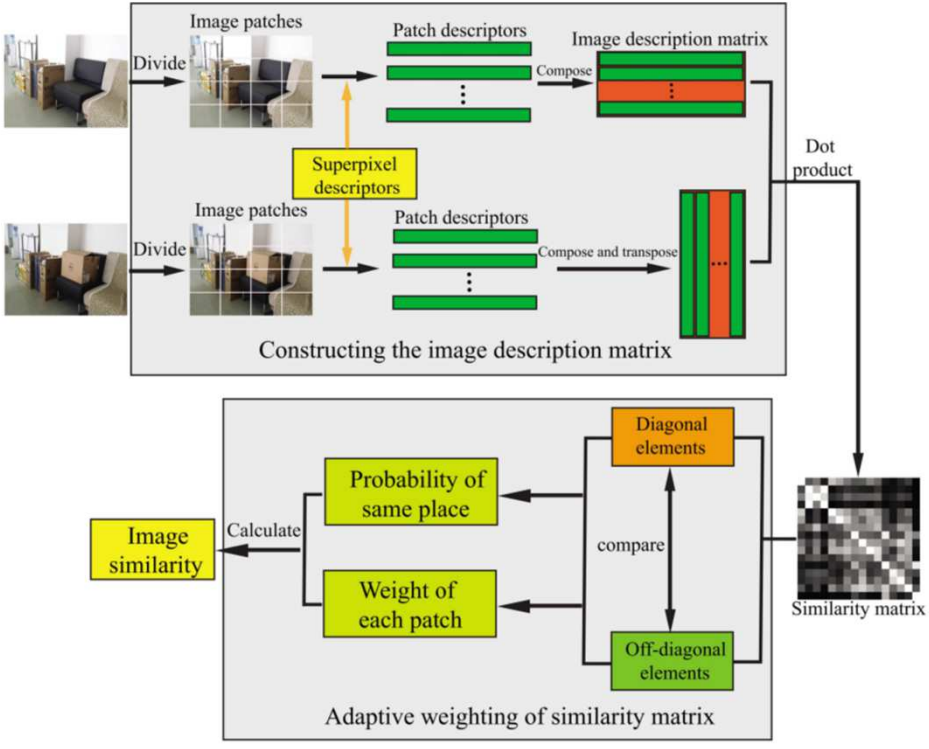


G-SLAM特点 – Deep Learning



Shuhui Bu, et al. Pattern Recognition, 2016.

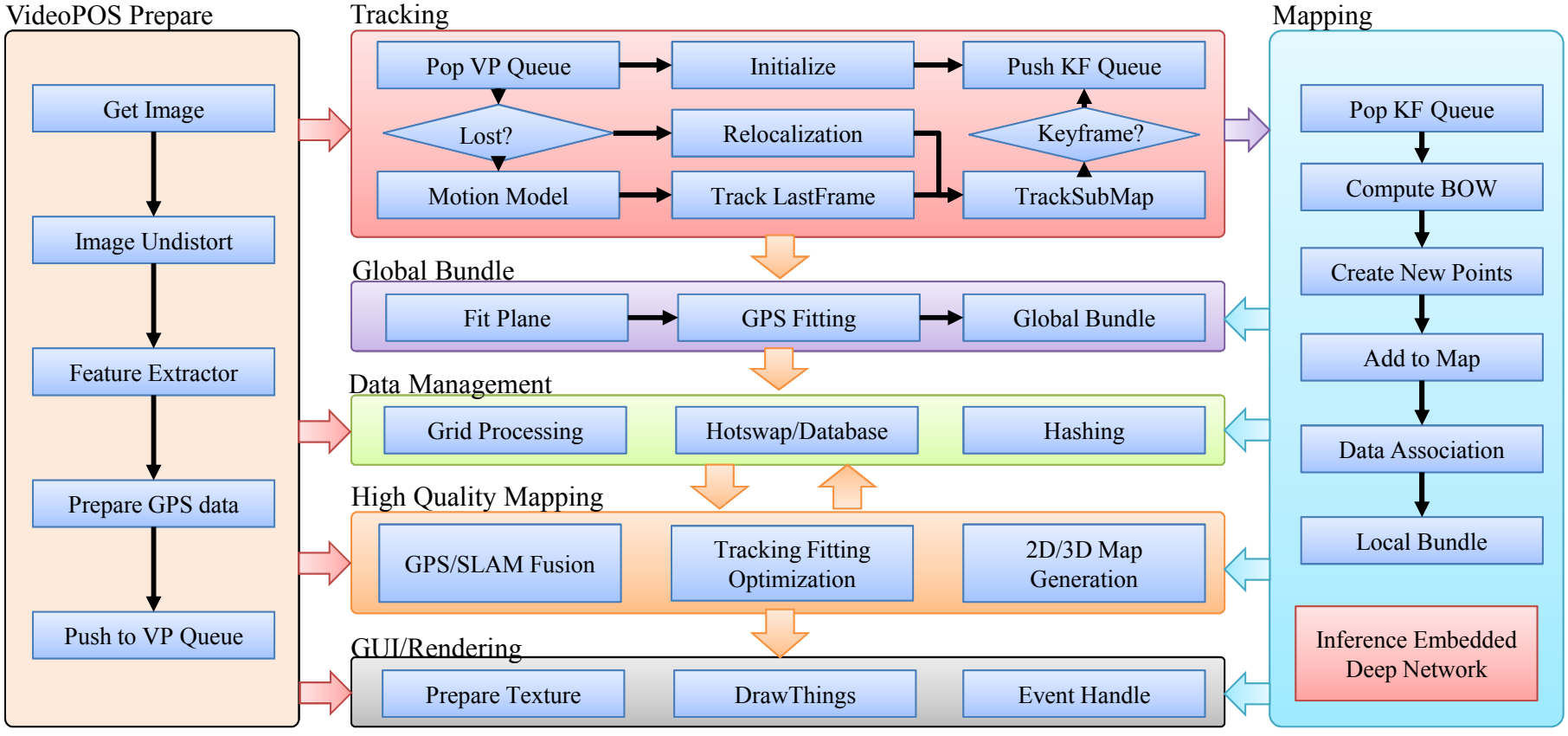
G-SLAM特点 – Deep Learning



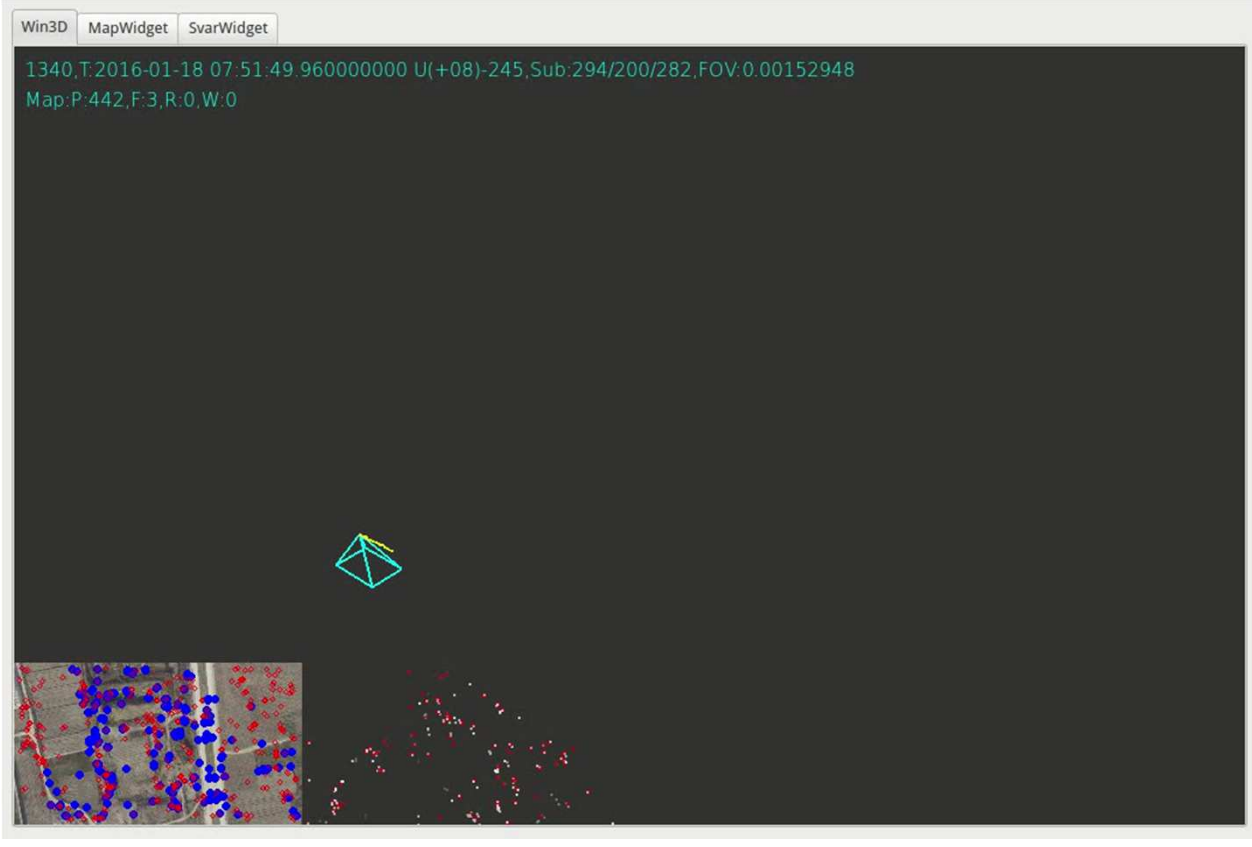
- Using CNN to extract representative feature
- Considering spatial relationship between objects in scene

Qing Li, et al., Place Recognition Based on Deep Feature and Adaptive Weighting of Similarity Matrix, Neurocomputing, 2016.
Part of source codes: http://www.adv-ci.com/blog/source/pi-cnn and http://www.adv-ci.com/blog/source/pi-slic

G-SLAM系统架构


VideoPOS Prepare
Get Image
Image Undistort
Feature Extractor
Prepare GPS data
Push to VP Queue
Tracking
Pop VP Queue
Initialize
Push KF Queue
Lost?
Relocalization
Keyframe?
Motion Model
Track LastFrame
TrackSubMap
Global Bundle
Fit Plane
GPS Fitting
Global Bundle
Data Management
Grid Processing
Hotswap/Database
Hashing
High Quality Mapping
GPS/SLAM Fusion
Tracking Fitting Optimization
2D/3D Map Generation
GUI/Rendering
Prepare Texture
DrawThings
Event Handle
Mapping
Pop KF Queue
Compute BOW
Create New Points
Add to Map
Data Association
Local Bundle
Inference Embedded Deep Network

G-SLAM


Win3D
MapWidget
SvarWidget
1340,T:2016-01-18 07:51:49.960000000 U(+08)-245,Sub:294/200/282,FOV:0.00152948
Map:P:442,F:3,R:0,W:0

MAKE PRECISE INFINITY

无人机实时影像地图
RT-Map

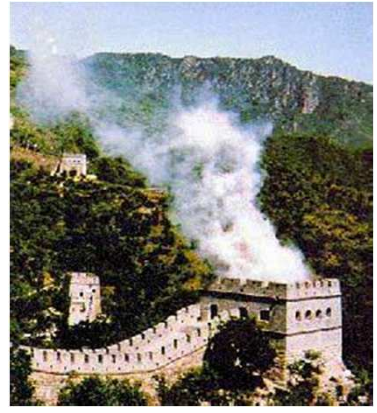
战争与地图

兵法有云：

“知己知彼，百战不殆”

- 凡是战争都离不开信息，现代战争是信息主导的战争，信息在战争中具有十分显著的地位和作用。
- 作战地图是作战指挥人员策划战术的重要依据，现阶段往往通过遥感、航拍甚至实地勘测等手段制作高精度的军事地图。

在实际作战中战场环境却不是一成不变的。

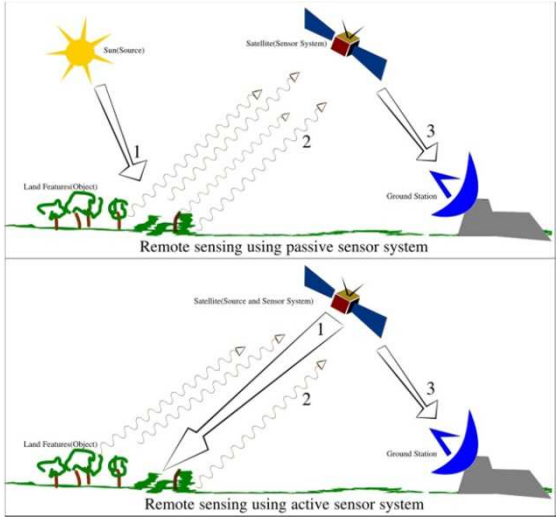


烽火

三维电子作战地图

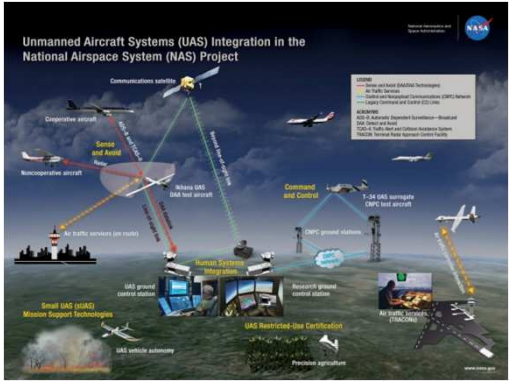
地图与遥感

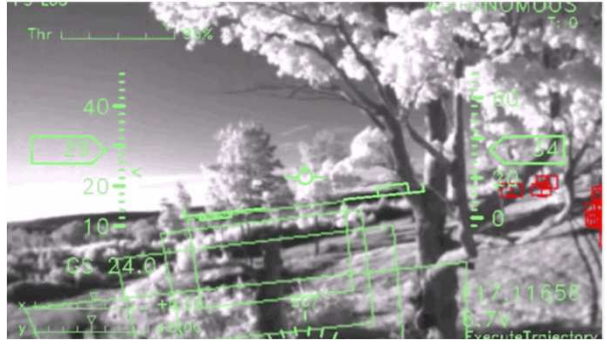
非接触的，远距离的探测技术。一般指运用传感器/遥感器对物体的电磁波的辐射、反射特性的探测。



无人机自主飞行

由于环境的复杂，无人机数据链路中断，GPS受到干扰等情况下，必须自主飞行。自主飞行需要对环境进行感知，从而指导无人机的飞行。在无GPS的情况下，需要多种导航手段来提供导航信息。





遥感与环境感知

随着对无人机自主飞行的要求逐步提高，遥感必定成为无人机环境感知的一部分，因此对遥感提出了新的要求。

现在的遥感

实时
全自动
全天候
多信息源融合
。 。 。

？

“未来”的无人机环境感知

弥补传统方法的实时性不足

速度

实时在线

小时

天

非专业知识/全自动

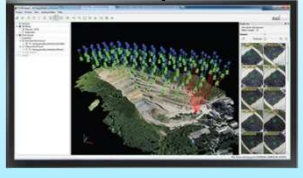
一定专业知识/操作复杂

专业知识/操作复杂

专业知识/操作复杂

RT-Map/SLAM

Pix4D/SfM



航摄仪/测绘

卫星/测绘

万

十万

百万

亿

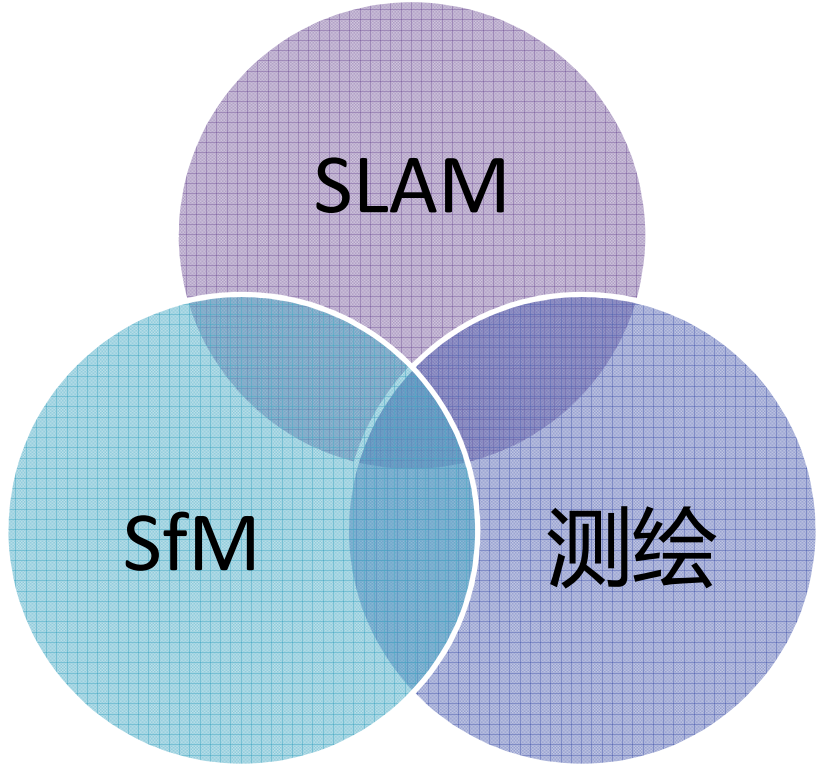
价格

性能

解决之道

SLAM与SfM对比

- SLAM更多考虑图像之间的关系
- SLAM对算法做了更多的优化，能够达到实时
- **设计巧妙的算法能够实时融合采集的图像得到DOM**



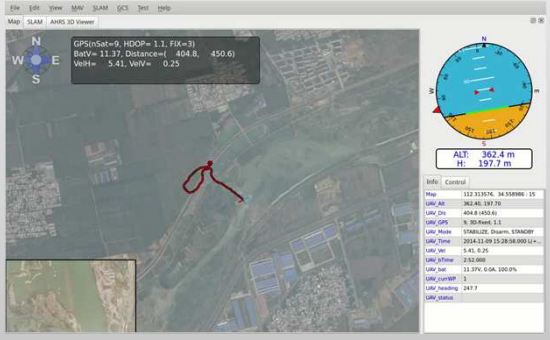
SLAM与测绘方法对比

- 能够达到90%以上的精度
- 使用POS数据的方式不同，SLAM能够进行联合优化
- SLAM对算法做了更多的优化，能够达到实时
- **定位与地图生成同步进行，能够用到机器人自主导航**

SfM即Structure from Motion，计算机视觉的三维重建方法，Pix4D等使用的方法

解决方案

自动飞行控制
实时数据处理



地面站

综合数据链路

手动控制

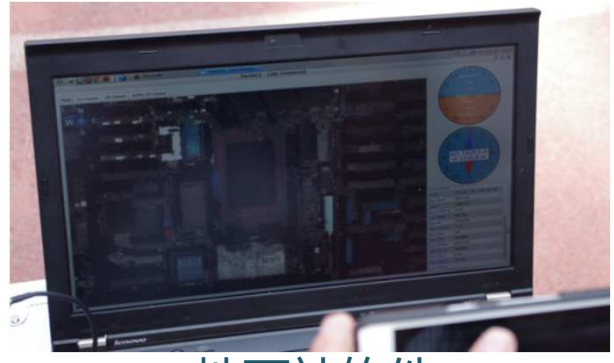
摇杆控制

- 高可靠性
- 操作简单
- 自动飞行
- 实时数据处理
- G-SLAM
- 鲁棒性高

硬件系统

无人机系统

综合数据链路

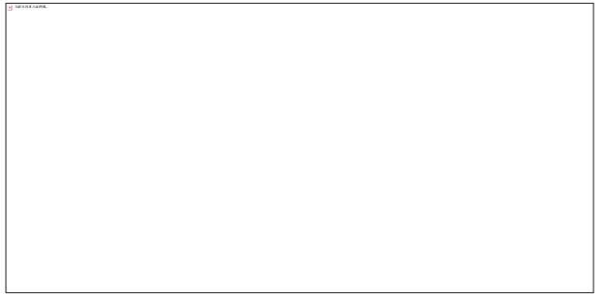


地面站软件

运行实况

飞行实况

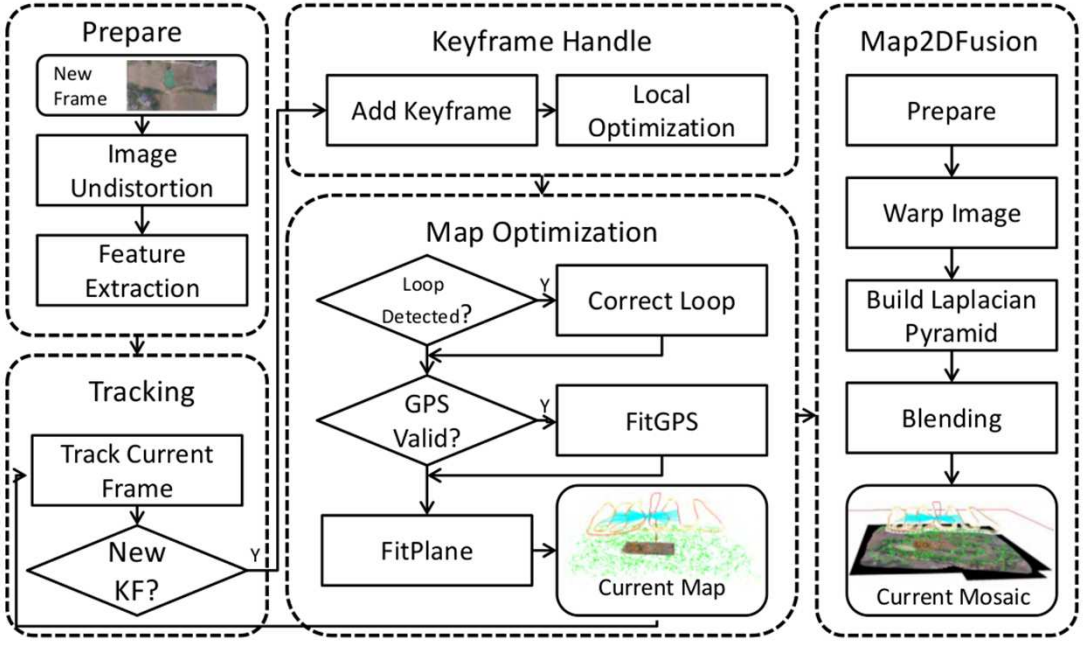
综合数据链路



拍摄画面

地面站

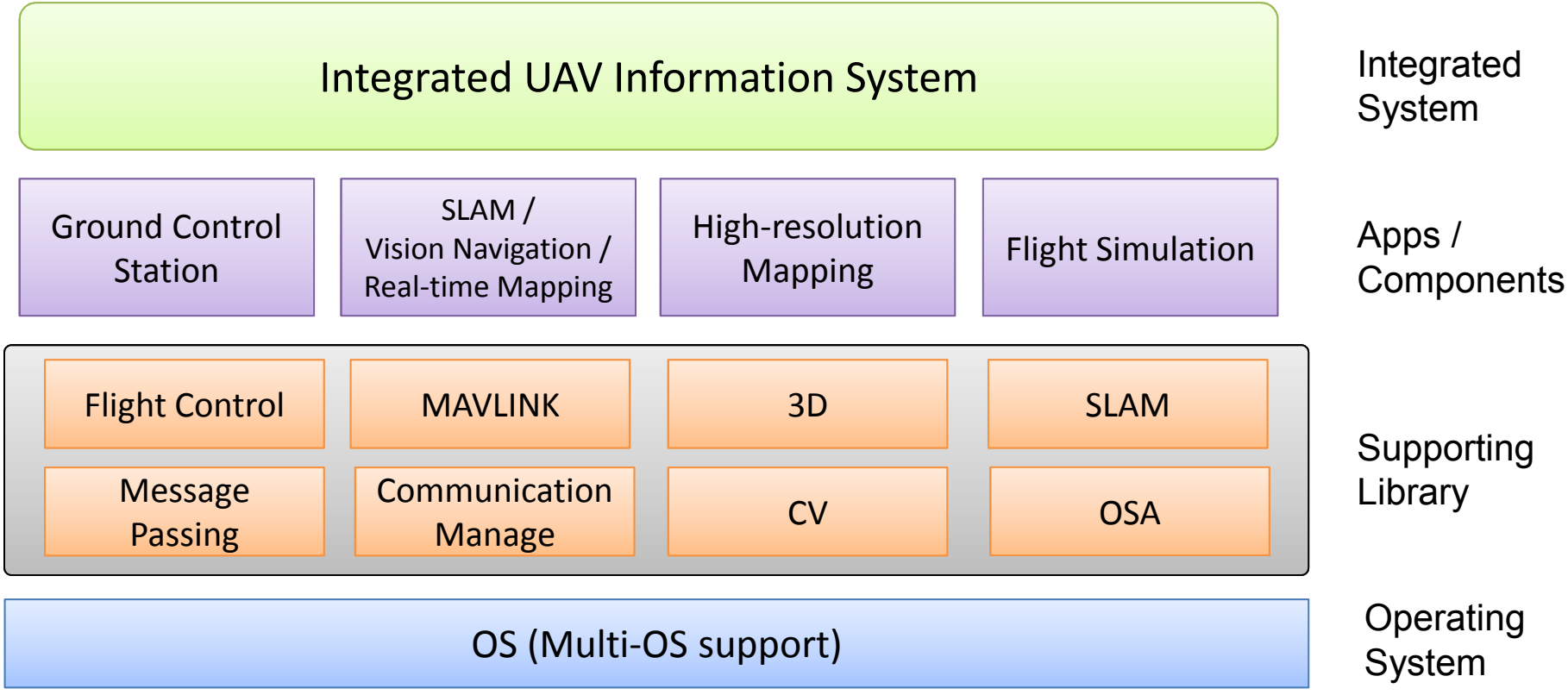
软件系统 – 核心算法



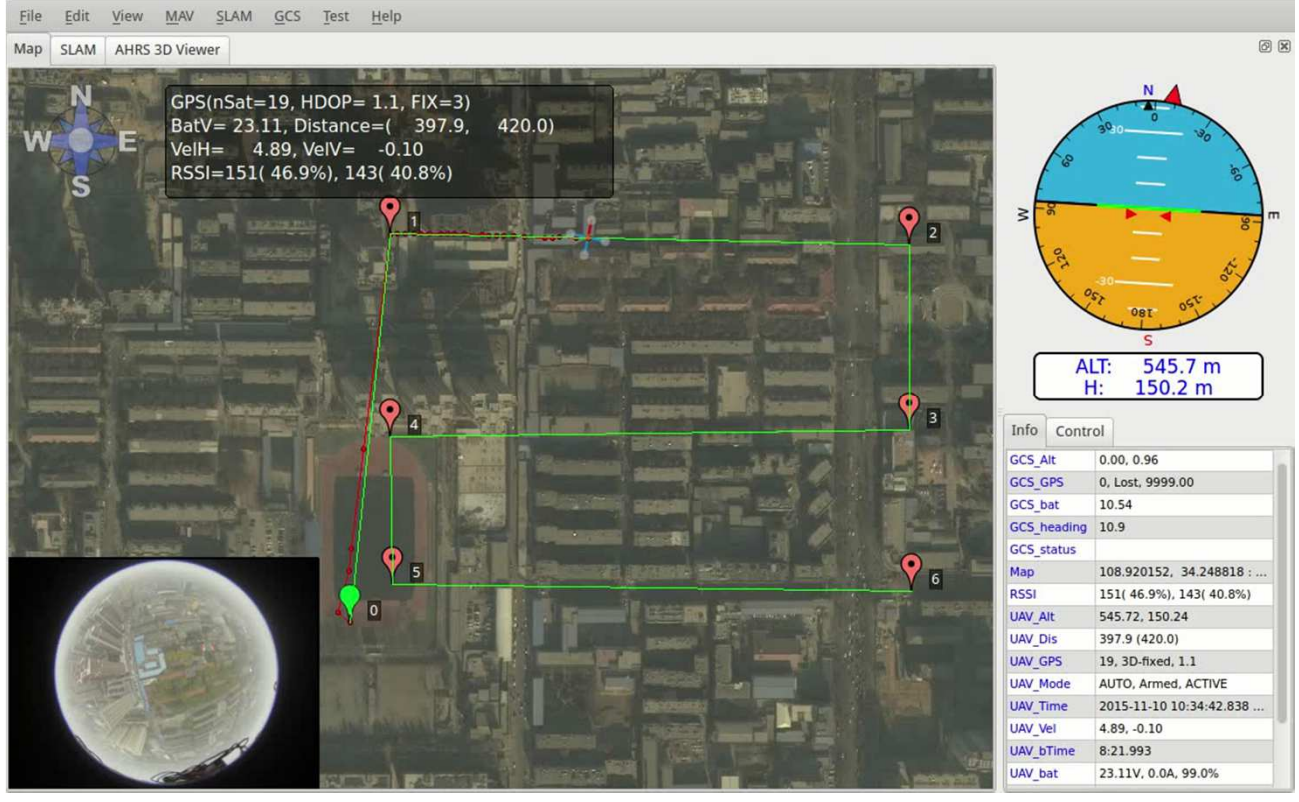
- **Automatic GPS and video synchronization**: a graph based optimization is proposed to synchronize video time with GPS time from coarse to fine.
- **Real-time orthoimage blender**: an adaptive weighted multi-band method to blend and visualize images incrementally in real-time.

Shuhui Bu, Yong Zhao, et al., Map2DFusion: Real-time Incremental UAV Image Mosaicing based on Monocular SLAM, IROS, 2016

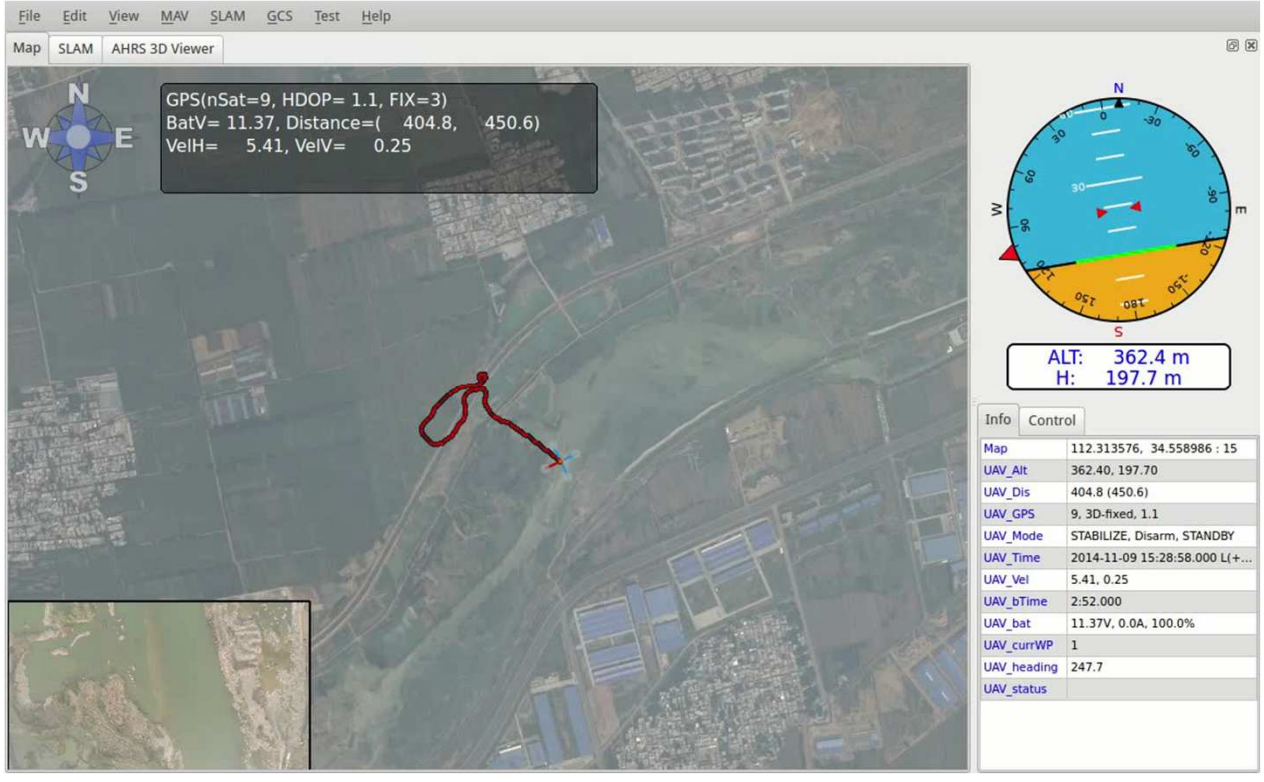
软件系统 – 体系架构


Integrated UAV Information System
Integrated System
Ground Control Station
SLAM / Vision Navigation / Real-time Mapping
High-resolution Mapping
Flight Simulation
Apps / Components
Flight Control
MAVLINK
3D
SLAM
Message Passing
Communication Manage
CV
OSA
Supporting Library
OS (Multi-OS support)
Operating System

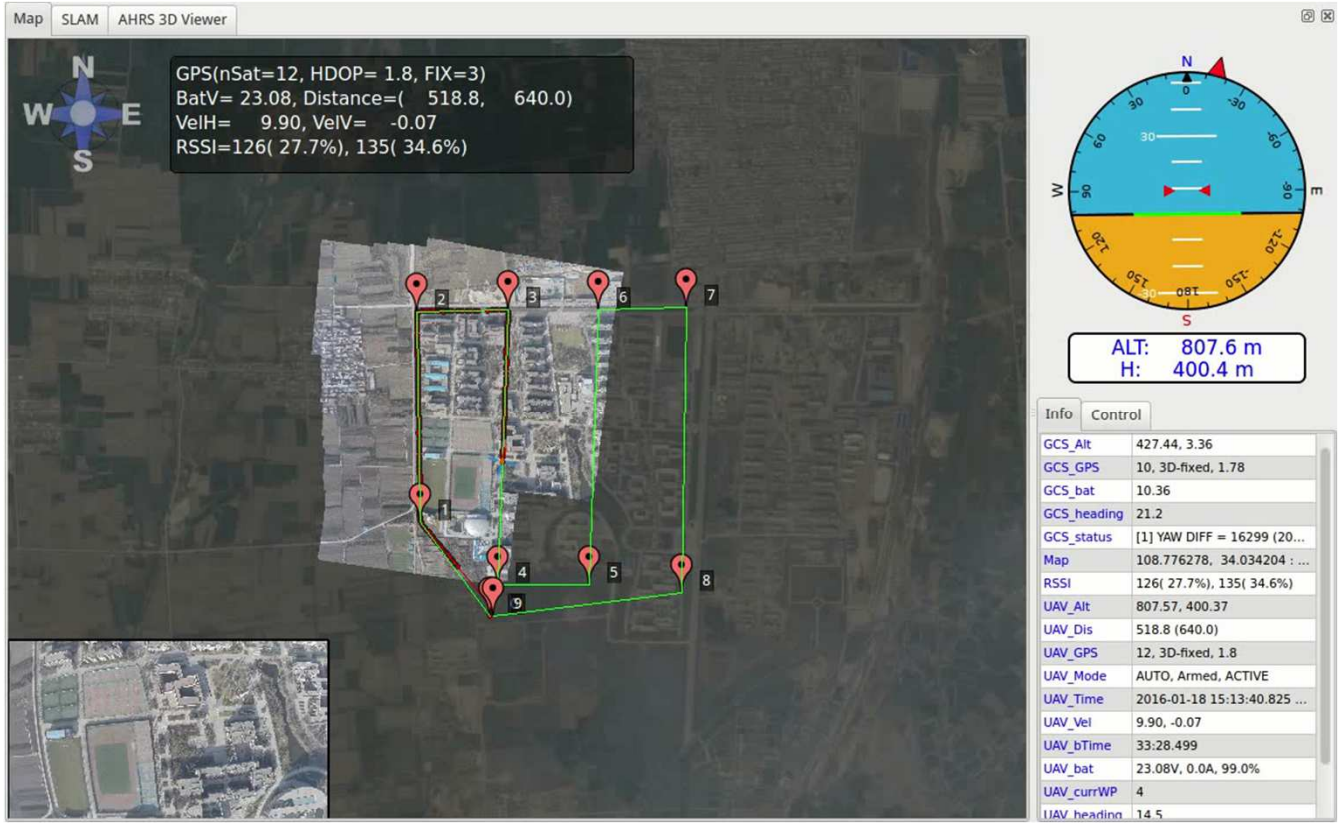
软件系统 – 地面站系统


File Edit View MAV SLAM GCS Test Help
Map SLAM AHRS 3D Viewer
GPS(nSat=19, HDOP= 1.1, FIX=3)
BatV= 23.11, Distance=(397.9, 420.0)
VelH= 4.89, VelV= -0.10
RSSI=151(46.9%), 143(40.8%)
N W E S
ALT: 545.7 m
H: 150.2 m
Info Control
GCS_Alt 0.00, 0.96
GCS_GPS 0, Lost, 9999.00
GCS_bat 10.54
GCS_heading 10.9
GCS_status
Map 108.920152, 34.248818 : ...
RSSI 151(46.9%), 143(40.8%)
UAV_Alt 545.72, 150.24
UAV_Dis 397.9 (420.0)
UAV_GPS 19, 3D-fixed, 1.1
UAV_Mode AUTO, Armed, ACTIVE
UAV_Time 2015-11-10 10:34:42.838 ...
UAV_Vel 4.89, -0.10
UAV_bTime 8:21.993
UAV_bat 23.11V, 0.0A, 99.0%

软件系统 – SLAM


File Edit View MAV SLAM GCS Test Help
Map SLAM AHRS 3D Viewer
N
W E
S
GPS(nSat=9, HDOP= 1.1, FIX=3)
BatV= 11.37, Distance=(404.8, 450.6)
VelH= 5.41, VelV= 0.25
ALT: 362.4 m
H: 197.7 m
Info Control
Map 112.313576, 34.558986 : 15
UAV_Alt 362.40, 197.70
UAV_Dis 404.8 (450.6)
UAV_GPS 9, 3D-fixed, 1.1
UAV_Mode STABILIZE, Disarm, STANDBY
UAV_Time 2014-11-09 15:28:58.000 L(+...
UAV_Vel 5.41, 0.25
UAV_bTime 2:52.000
UAV_bat 11.37V, 0.0A, 100.0%
UAV_currWP 1
UAV_heading 247.7
UAV_status

软件系统 – 实时地图


Map
SLAM
AHRS 3D Viewer
N
W
E
S
GPS(nSat=12, HDOP= 1.8, FIX=3)
BatV= 23.08, Distance=(518.8, 640.0)
VelH= 9.90, VelV= -0.07
RSSI=126(27.7%), 135(34.6%)
1
2
3
4
5
6
7
8
9
ALT: 807.6 m
H: 400.4 m
Info
Control
GCS_Alt 427.44, 3.36
GCS_GPS 10, 3D-fixed, 1.78
GCS_bat 10.36
GCS_heading 21.2
GCS_status [1] YAW DIFF = 16299 (20...
Map 108.776278, 34.034204 : ...
RSSI 126(27.7%), 135(34.6%)
UAV_Alt 807.57, 400.37
UAV_Dis 518.8 (640.0)
UAV_GPS 12, 3D-fixed, 1.8
UAV_Mode AUTO, Armed, ACTIVE
UAV_Time 2016-01-18 15:13:40.825 ...
UAV_Vel 9.90, -0.07
UAV_bTime 33:28.499
UAV_bat 23.08V, 0.0A, 99.0%
UAV_currWP 4
UAV_heading 14.5

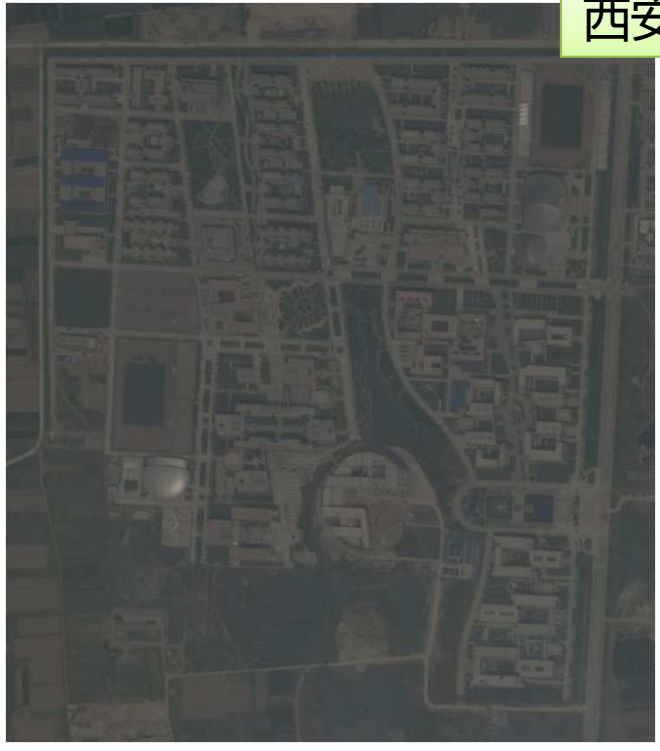
实时正射影像地图 RT-DOM

卫星地图

RT-Map

实时正射影像地图 RT-Map

西安 – 西北工业大学



卫星地图

RT-Map

离线三维地图

西安 - 西北工业大学

效果对比 一样？其实大不同！

PhotoScan

Pix4D

RT-Map

效果对比 1

PhotoScan

Pix4D

RT-Map

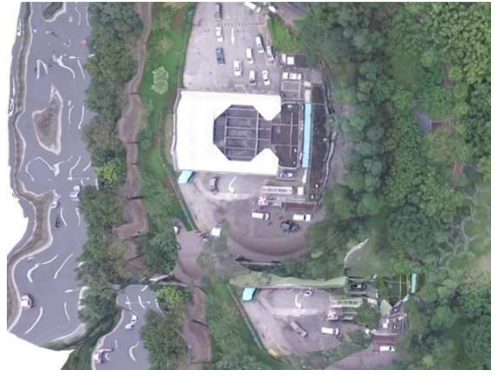
效果对比 2

PhotoScan

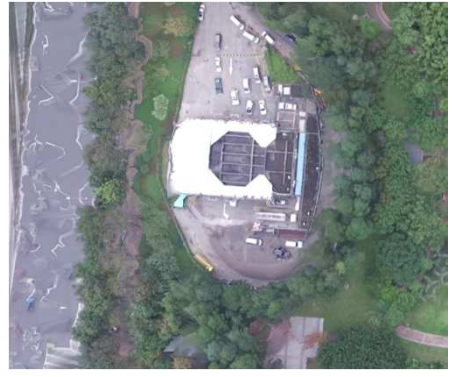
Pix4D

RT-Map

效果对比 3



PhotoScan



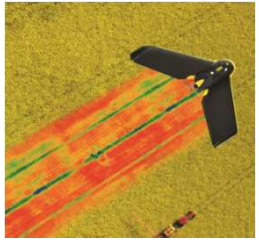
Pix4D

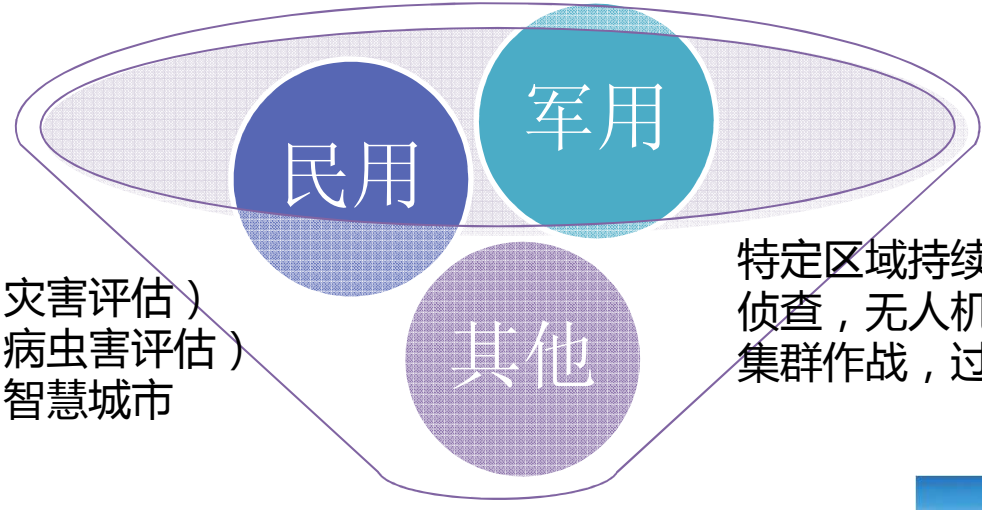
RT-Map

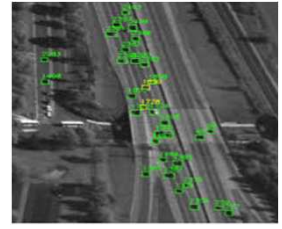
相关解决方法的对比

	Pix4D PhotoScan	DroneDeploy	航空摄影 测绘 倾斜摄影测量	本系统 RT-Map
实时性	离线计算（数小时）	网络云计算（需要联网）	离线计算（数天）	在线实时
安全性	一般	较低	一般	高
测量精度	中	中	高	中
多信息源融合	无	无	具备	具备
地面站整合能力	无	无	无	具备
系统硬件要求	低	较低	高	较低
二次开发能力	无	无	无	具备
使用成本	高	高	很高	低
功能	DEM，DOM，三维重建	DEM，DOM，三维重建	DEM，DOM，三维重建	DEM，DOM，三维重建 地图构建、无GPS导航定位

应用领域

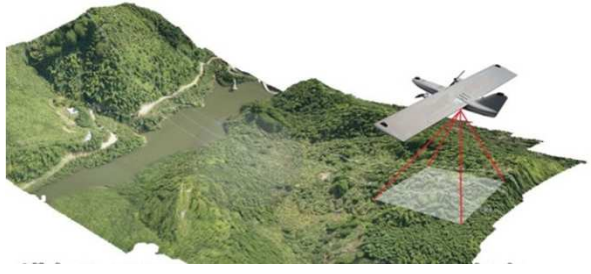


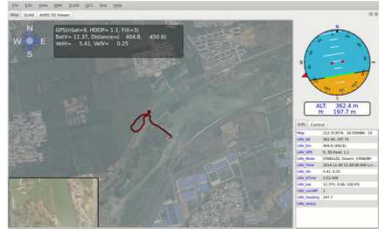




抗震救灾（灾害评估）
农业植保（病虫害评估）
自动驾驶，智慧城市

特定区域持续监视
侦查，无人机作战
集群作战，过饱和攻击





Make precise infinity

SDTAM: Semi-Direct Tracking and Mapping

RGB-D SLAM

Kinect3D体感摄影机

传感器,用于实时获取深度图与彩色图像

ArDrone 2

室内飞行平台

Kinect与四旋翼搭载的成果图

RGB-D SLAM

获取原始彩色图、深度图

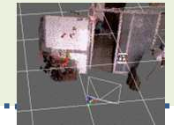
飞行控制
障碍躲避
路径规划

计算机中程序并行完成：

获取单帧点云
对齐深度图

分层次的实时位姿估计
（最小化重投影误差）

处理关键帧
更新特征地图及点云

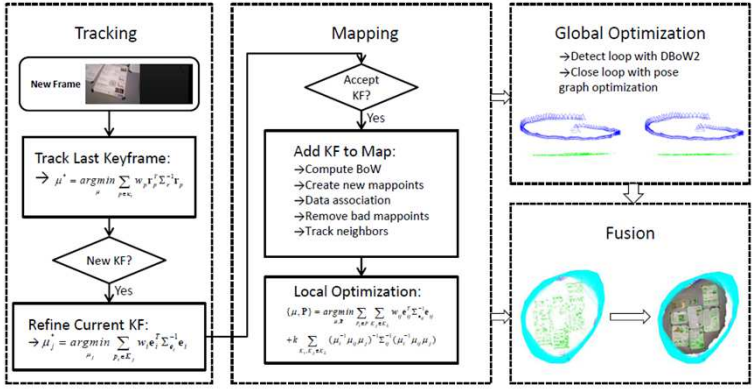


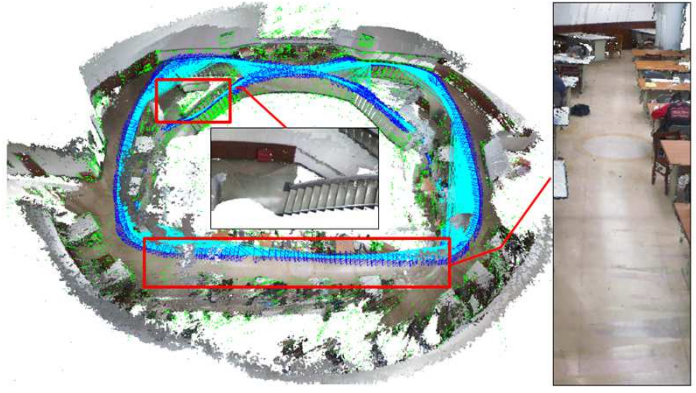
全局点云

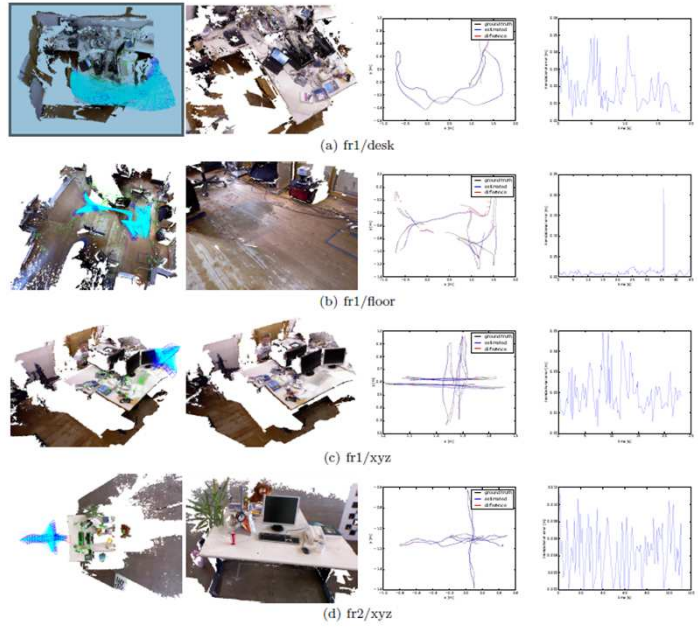
实时姿态

飞行路径

SDTAM







Shuhui Bu, Yong Zhao, et al., Semi-direct Tracking and Mapping with RGB-D Camera for MAV, MTAP, 2016.

SDTAM: Comparison

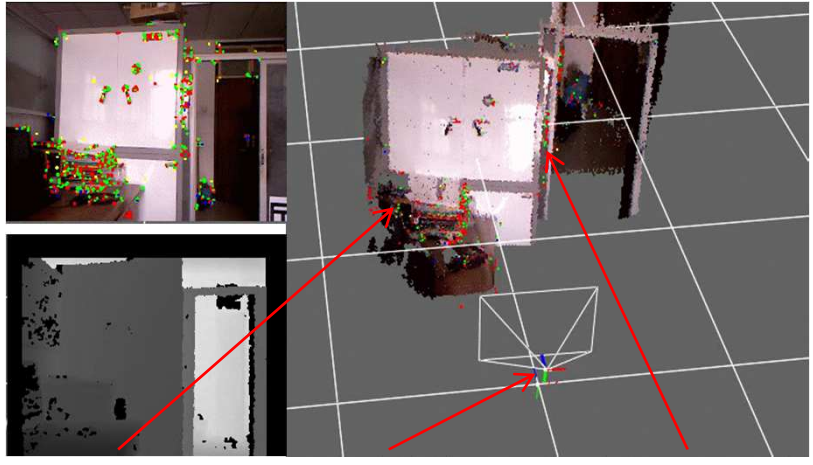
Experiments on TUM dataset

Sequence Name	SDTAM (Ours)			DVO [34]	Kinect Fusion [29]	RGB-D SLAM [25]	Volume Fusion [36]
	Direct	Direct+KF	Direct+KF+Loop				
fr1/xyz	0.054	**0.011**	**0.011**	**0.011**	0.026	0.014	0.017
fr1/rpy	0.086	0.031	0.031	**0.020**	0.133	0.026	0.028
fr1/desk	0.055	**0.018**	**0.018**	0.021	0.057	0.023	0.037
fr1/desk2	0.117	**0.043**	**0.043**	0.046	0.420	0.043	0.071
fr1/room	0.305	0.205	0.084	**0.053**	0.313	0.084	0.075
fr1/plant	0.039	0.072	0.034	**0.028**	0.598	0.091	0.047
fr2/xyz	0.017	0.015	0.015	0.018	-	**0.008**	0.029
fr2/person	0.180	**0.079**	**0.079**	-	-	-	-
fr3/long	0.104	0.018	**0.010**	0.035	0.064	0.032	0.030
fr3/nst	0.045	0.020	**0.013**	0.018	-	0.017	0.031
fr3/far	0.010	**0.009**	**0.009**	0.017	-	-	-
fr3/sit_xyz	0.028	**0.008**	**0.008**	-	-	-	-
fr3/sit_halfsph	0.116	**0.012**	**0.012**	-	-	-	-
fr3/walk_xyz	1.436	**0.011**	**0.011**	-	-	-	-
fr3/walk_halfsph	0.649	**0.060**	**0.060**	-	-	-	-

Shuhui Bu, Yong Zhao, et al., Semi-direct Tracking and Mapping with RGB-D Camera for MAV, MTAP, 2016.

SDTAM

- 实时，精确
- 室内无GPS导航定位
- 室内机器人
- 狭小空间的搜救、侦查



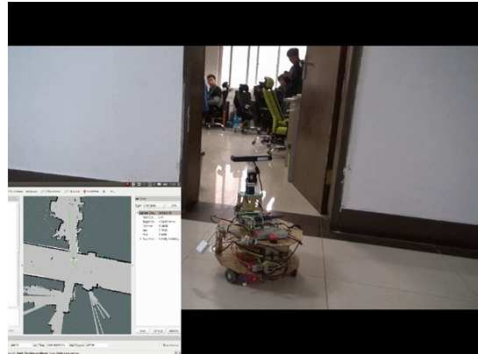
特征点　　关键帧　　全局点云

Shuhui Bu, Yong Zhao, et al., Semi-direct Tracking and Mapping with RGB-D Camera for MAV, MTAP, 2016.

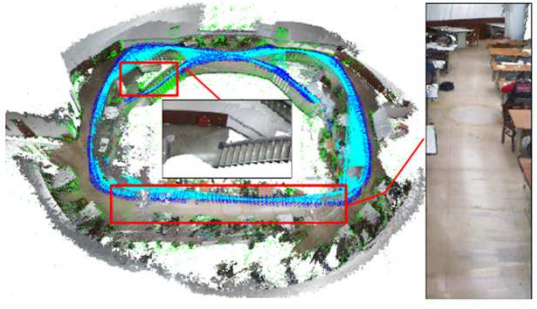
相关研究

核心技术

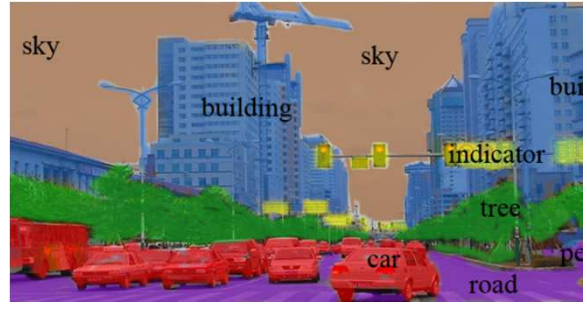
Smart Machines



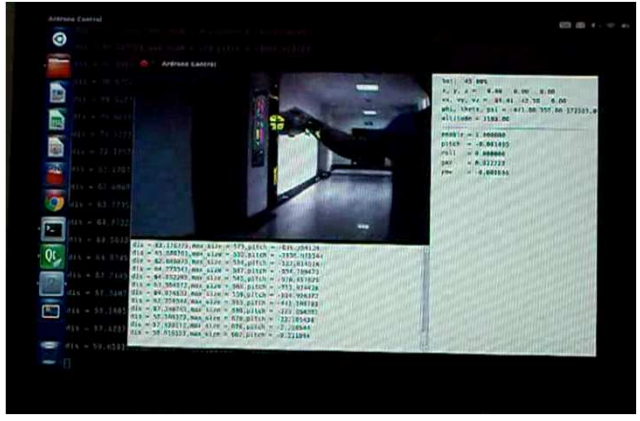
Computer Vision

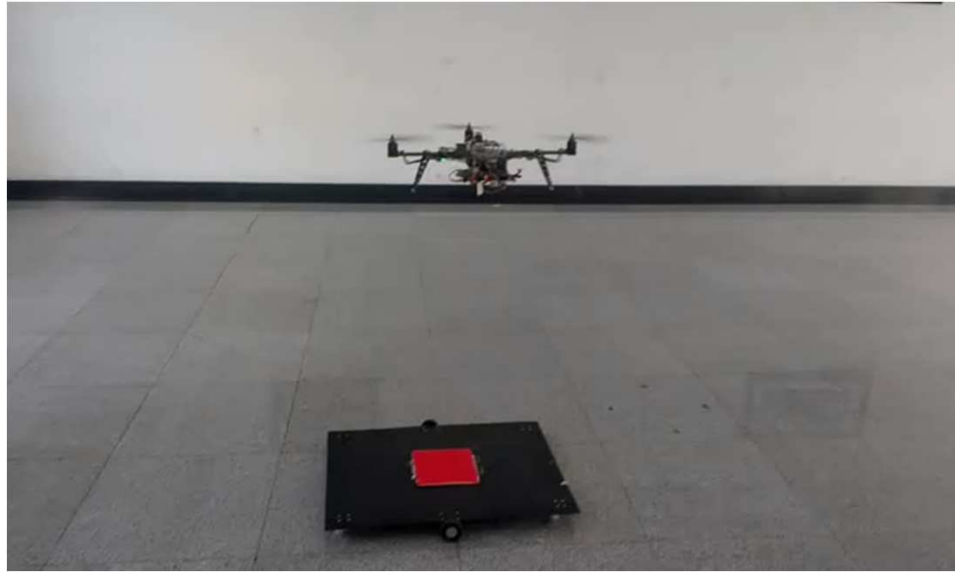


Machine Learning

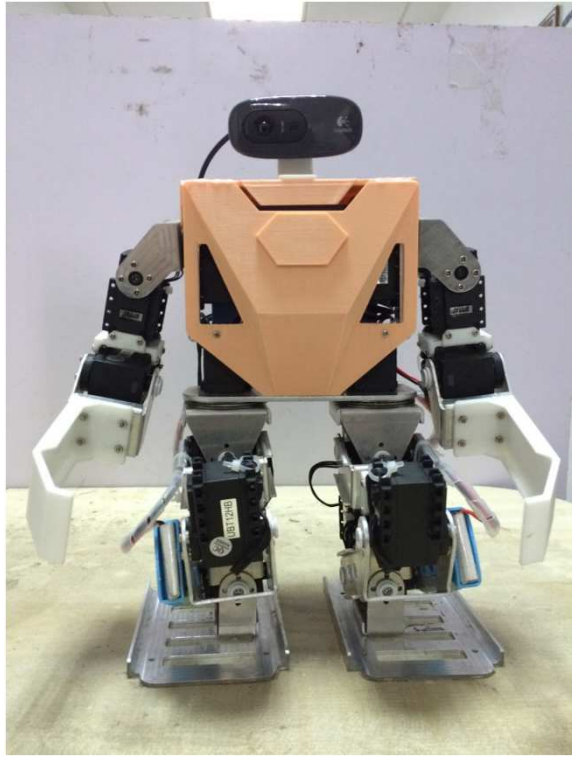


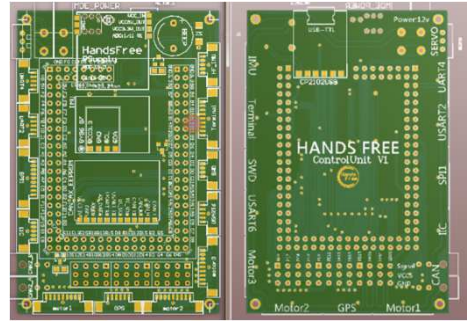
（1）基于视觉的无人机自动飞行



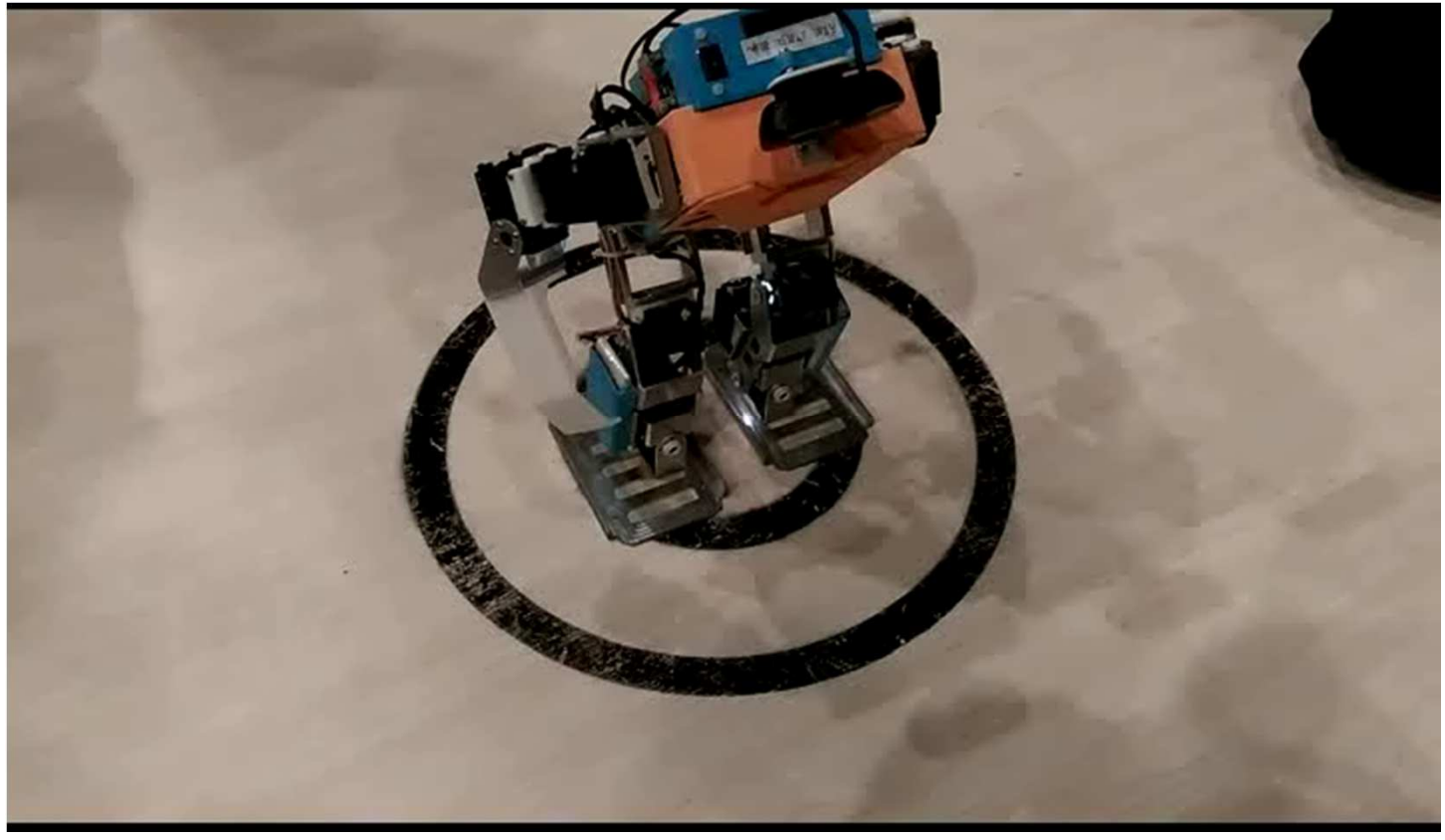


（2）ROS机器人平台 – HandsFree





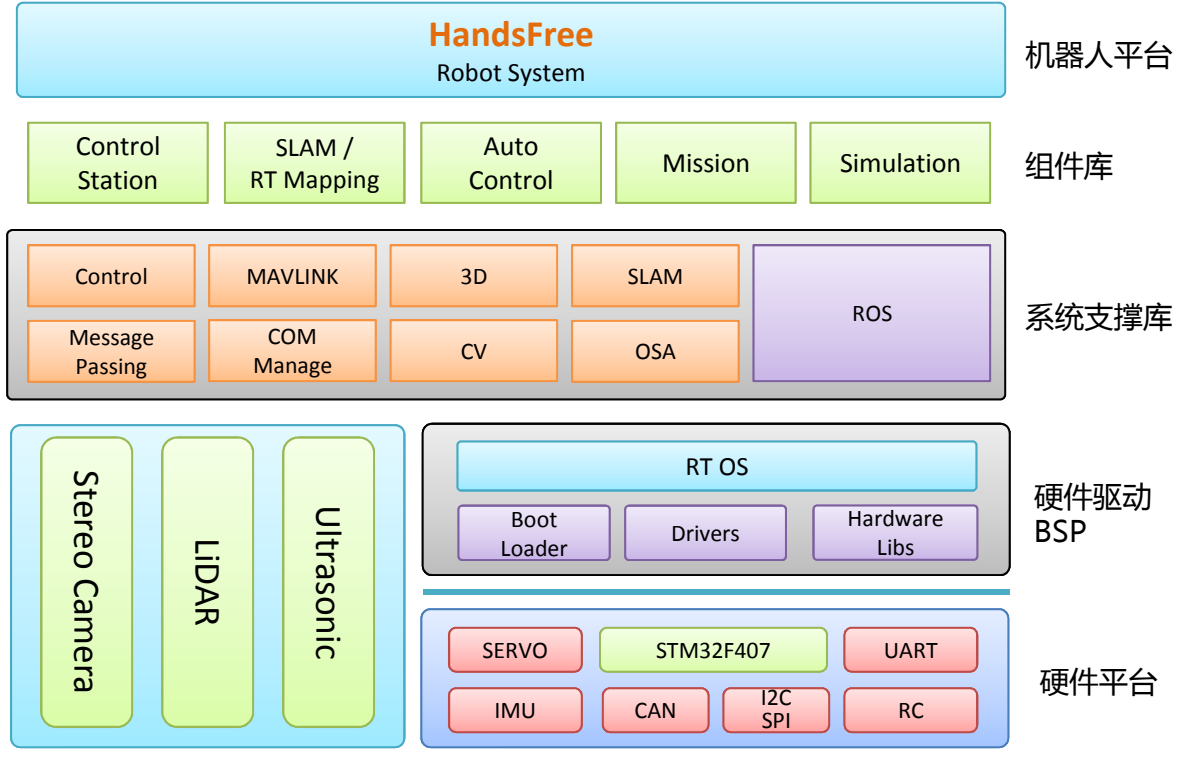
（2）ROS机器人平台 – HandsFree



（2）ROS机器人平台 – HandsFree

ROS

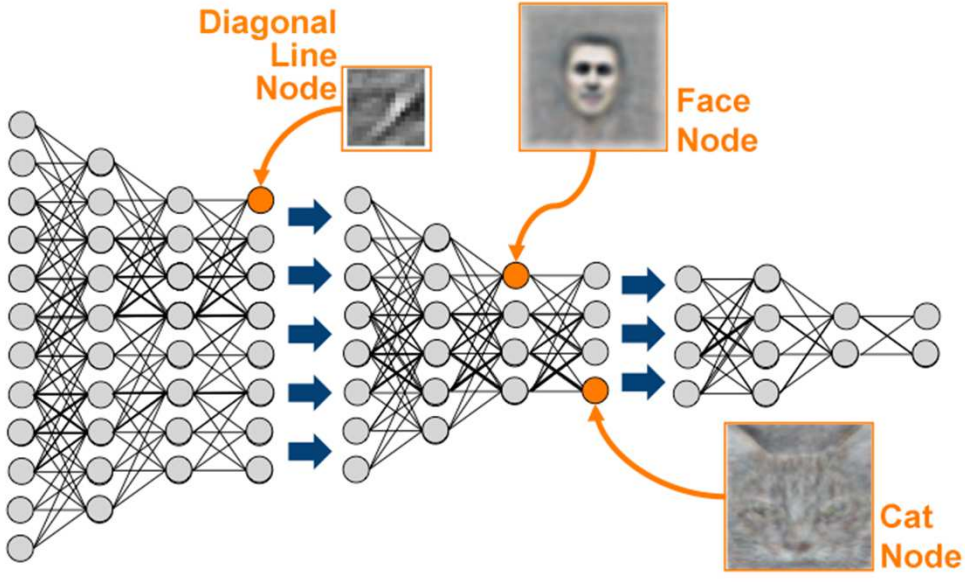
- 基于ROS（Robot Operation System）
- 多传感器：立体视觉，LiDAR，RGB-D，超声
- 优秀的架构设计
- 全自主设计
- 国内最为完整的开源机器人平台
- 国内领先的机器人研究、开发、实验平台
- 软硬件开源
- 全套开发、使用手册
- 国内知名的ExBot社区合作推广



（3）深度学习

Shortcomings of existing deep learning methods

- Lack explicit structural learning & strong “spatial reasoning”.
- Ability of collecting information is limited.



（3）深度学习 – 场景解析

Image data

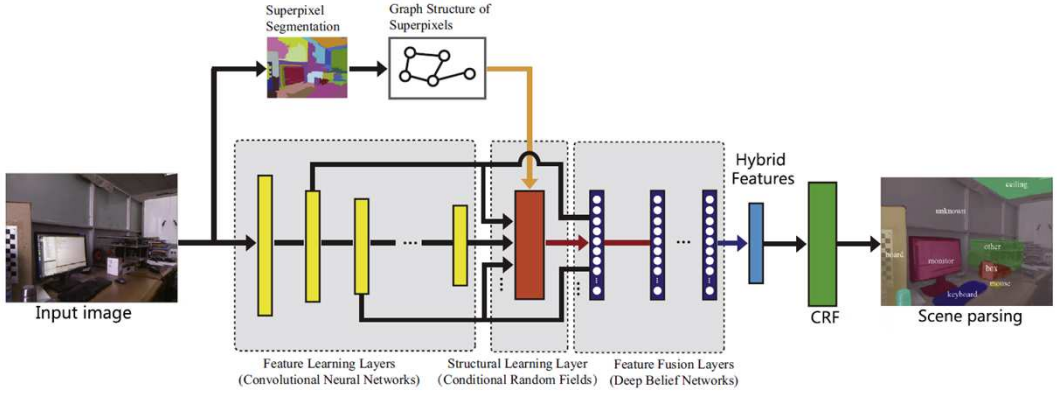
3D data

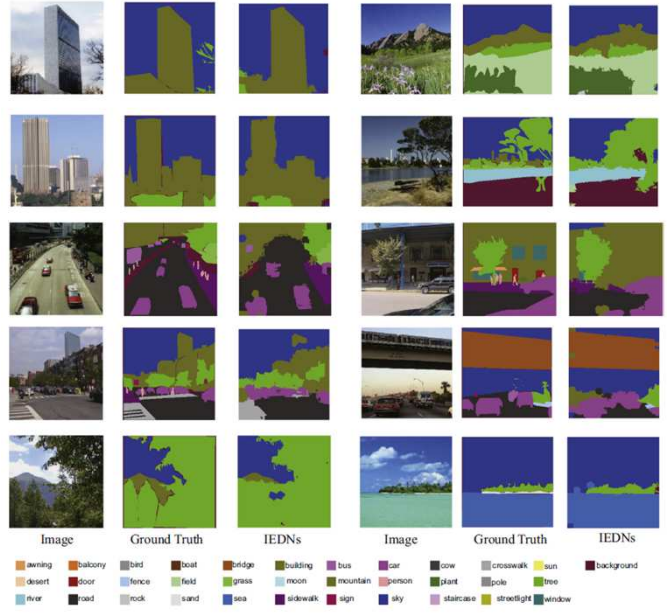
Scene Understanding

- Middle or large range structural reasoning is required
- Multi-source data fusion

Shuhui Bu, et al. Pattern Recognition, 2016.

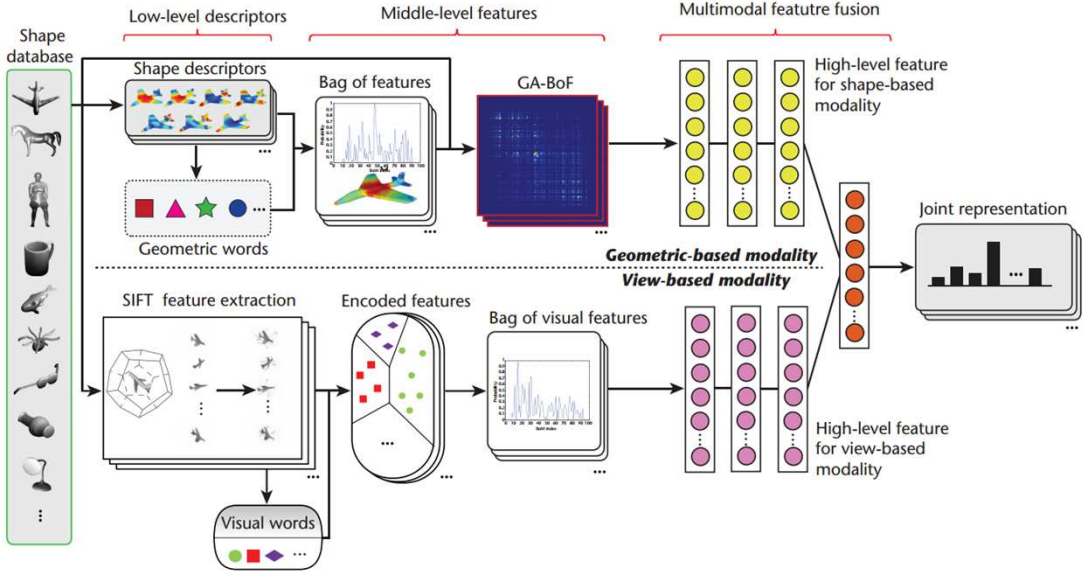
（3）深度学习 – 场景解析

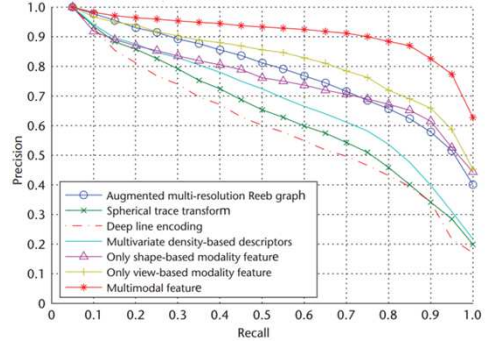


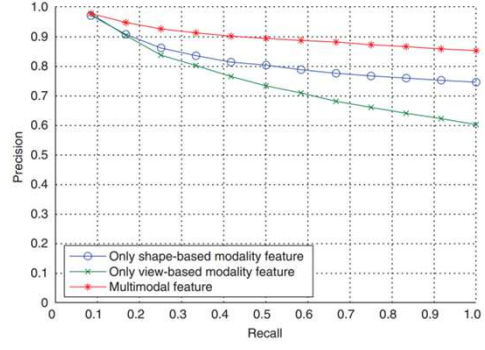


Shuhui Bu, et al. Pattern Recognition, 2016.

（3）深度学习 – 三维形状分析







Bu et al. IEEE Trans. Multimedia, 2014.

Bu et al. IEEE Multimedia, 2014.

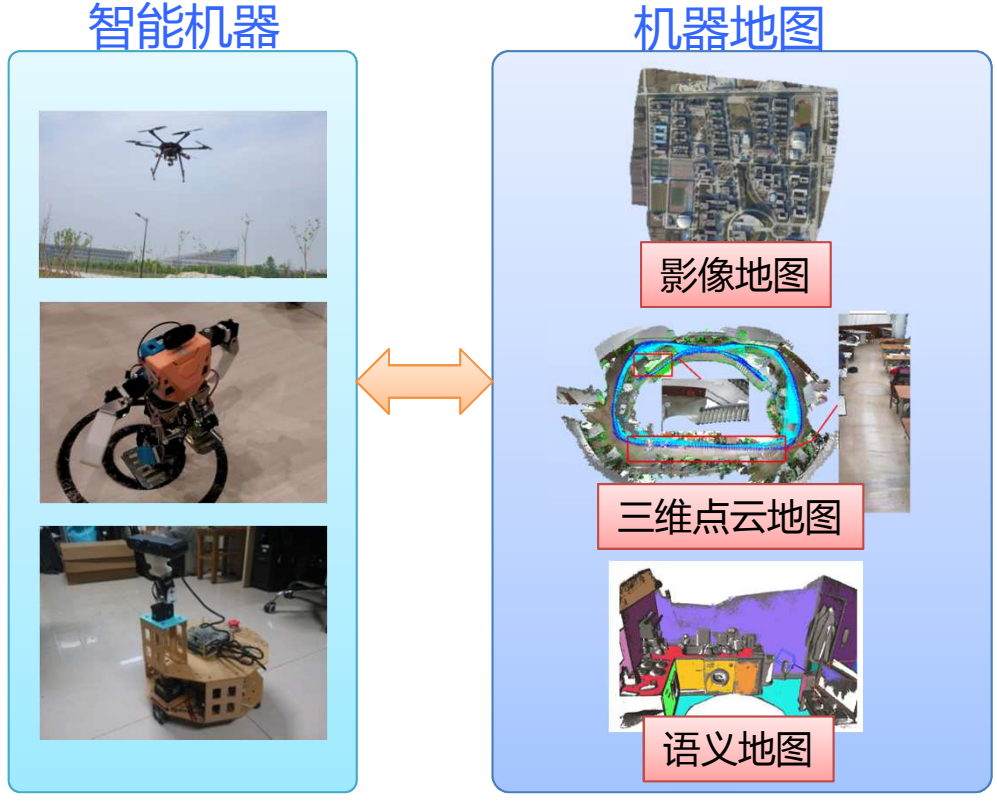
展望未来

未来之路

- 鲁棒性高、精度高的SLAM
- 基于深度学习的场景理解方法
- 智能多机协同系统
- 推理、决策系统

地图与机器 -> 机器地图

- 地图不仅仅是为人提供空间信息的工具
- 更多是为机器提供空间信息，导航定位、环境感知
- 智能机器不仅仅是地图的使用者，也是地图的生成者，两者相互依赖
- 要求更高的实时性，更多样的表达形式



THANK YOU

Detail information can be found at: http://www.adv-ci.com