西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

Visual SLAM and Realtime Mapper

Shuhui Bu

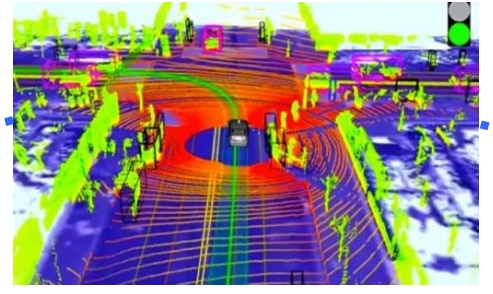
Dec. 2019

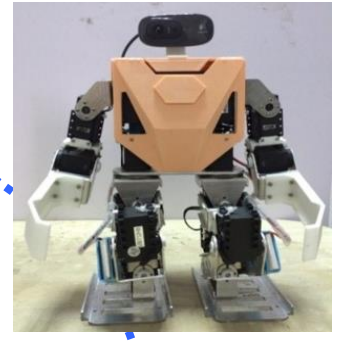
Northwestern Polytechnical University

Focuses on science and technology of
aviation, aerospace, marine, and related fields.

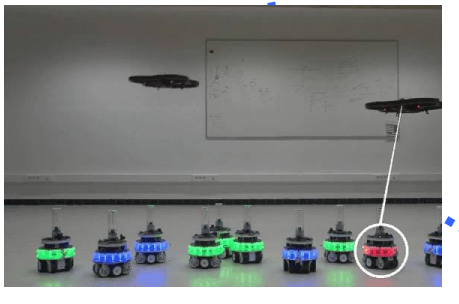
Contents

Future?

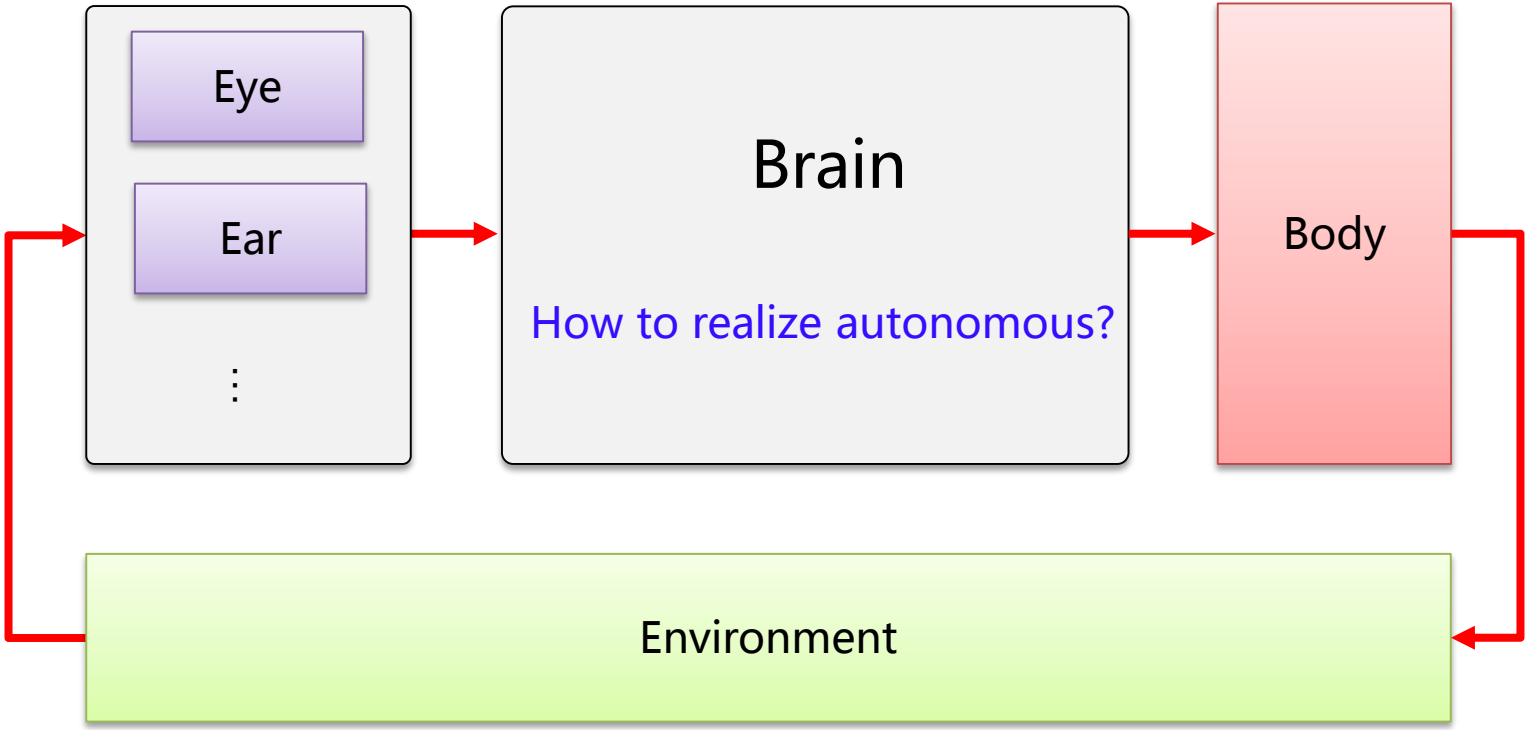




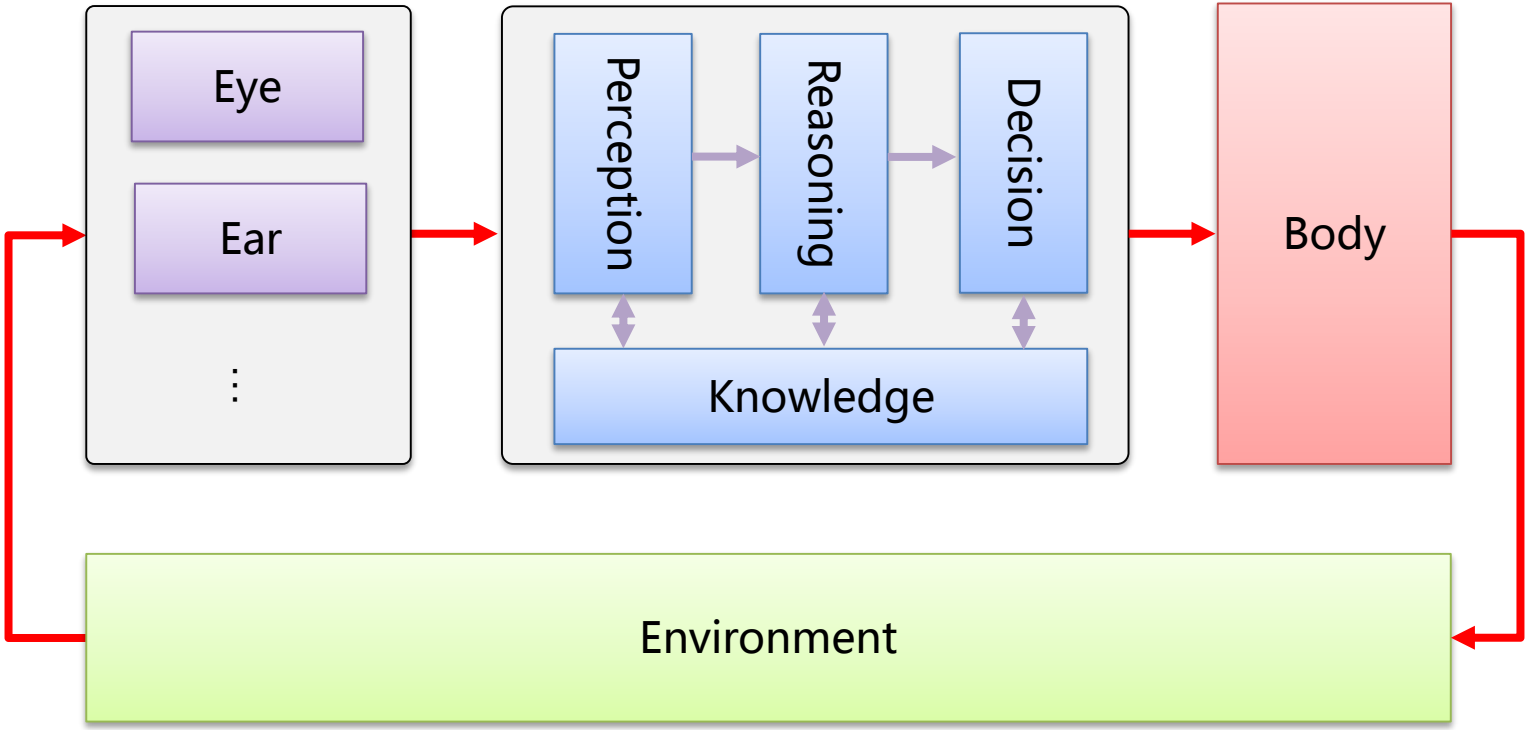
AI



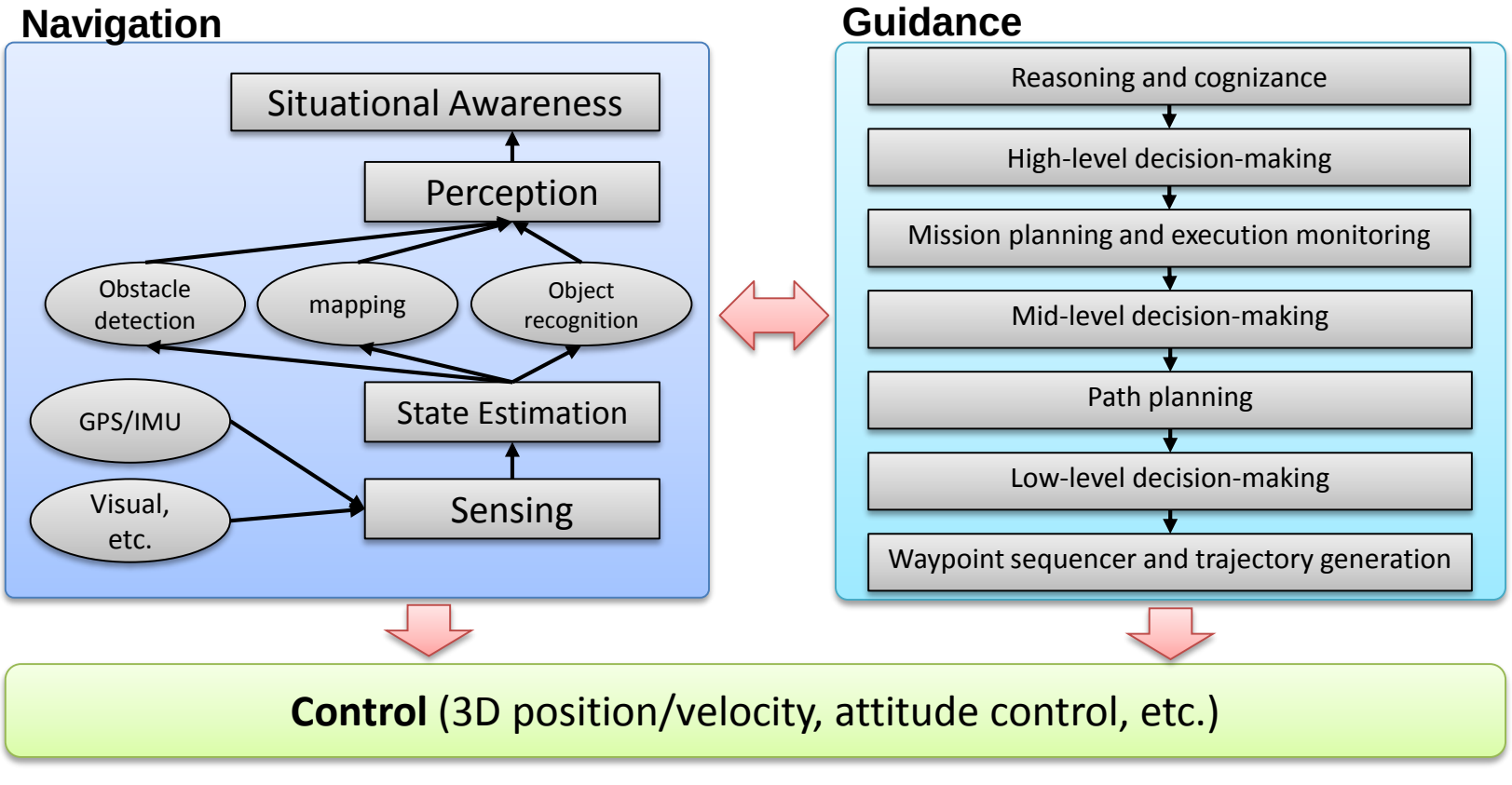
How to Realize Autonomous?



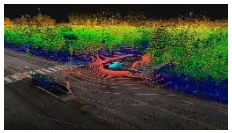
How to Realize Autonomous?

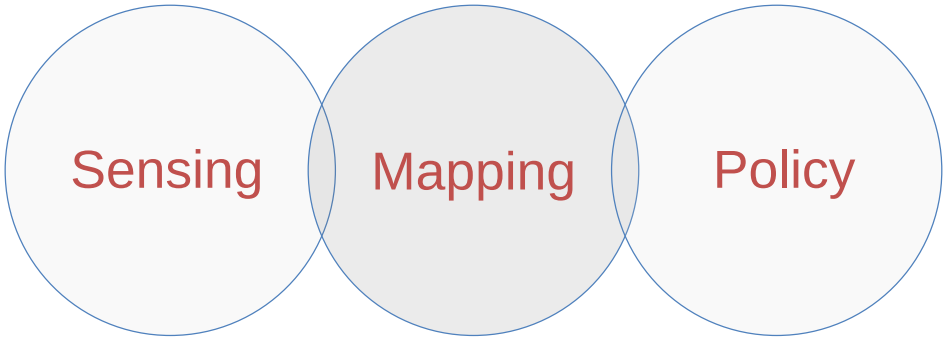


Architecture of GNC



New Challenges

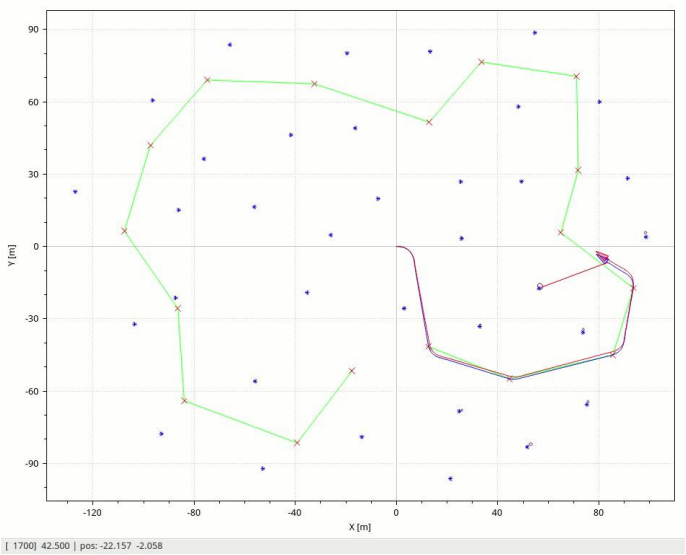



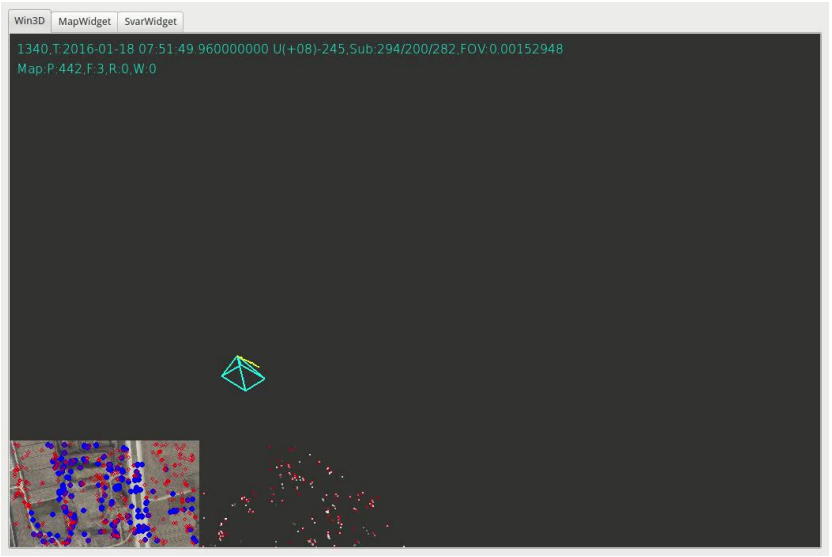
- Multi-type sensors: IMU, GPS, Image, LiDAR, RADAR …
- High quality and real-time speed required

SLAM ?

Simultaneous Localization and Mapping (SLAM) is the key technique to realize autonomous robot

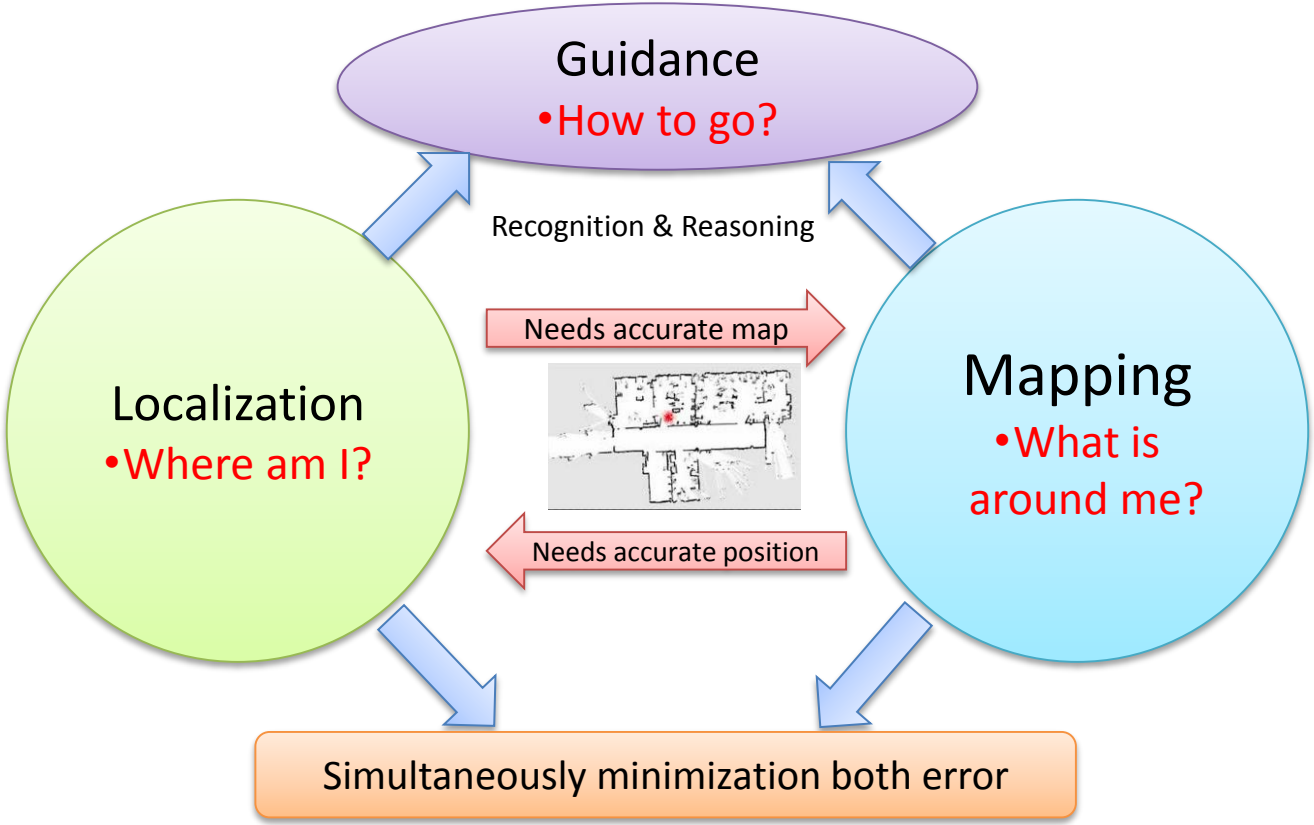
- Fusing & joint optimizing multiple-source data
- Providing position, attitude and environment map simultaneously





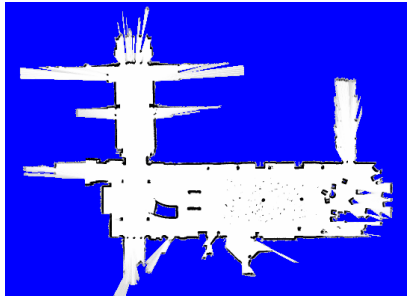
Demo can be downloaded at: http://www.adv-ci.com/blog/source/fastslam-gui/

SLAM – Key Functions

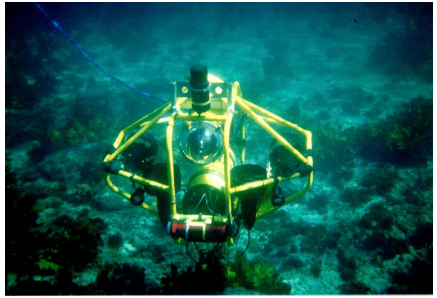


SLAM – Applications

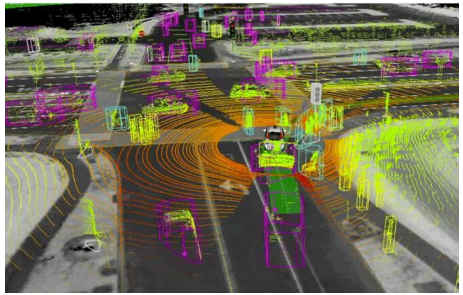
Robot

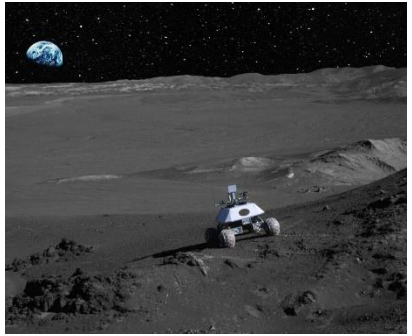


Underwater vehicle



Autonomous car





Space exploration

Underground exploration

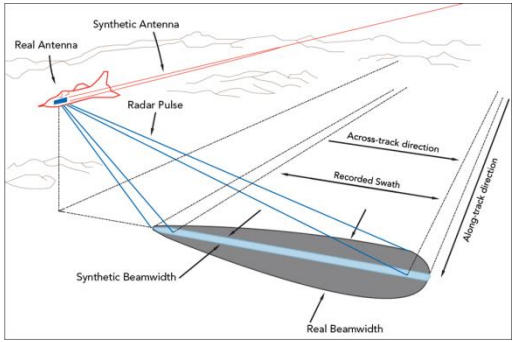
UAV

AR

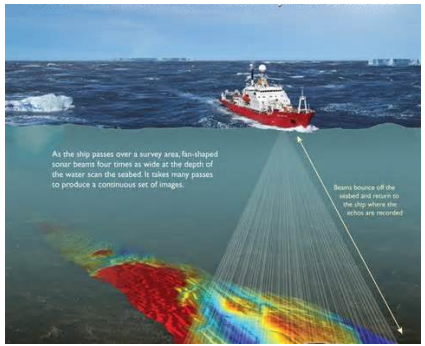
SLAM – Sensors

LiDAR

Camera

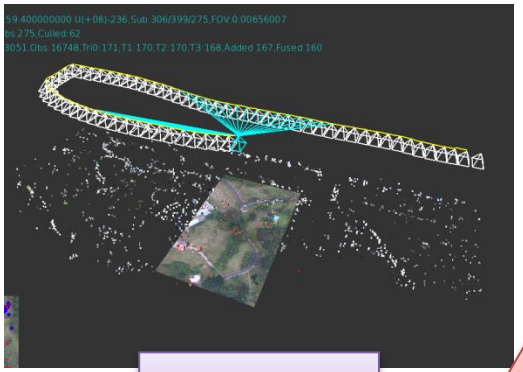


SAR

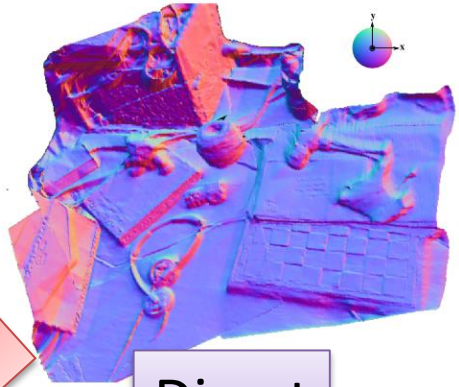


SONAR

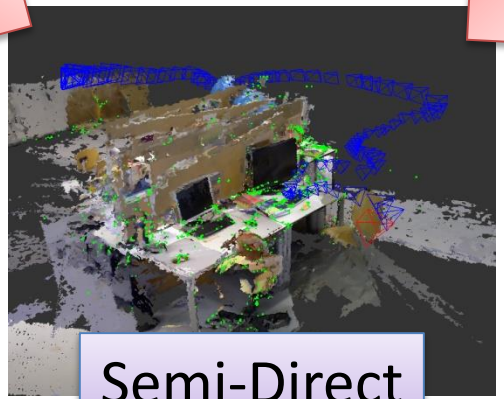
Visual SLAM – Different Types



Feature

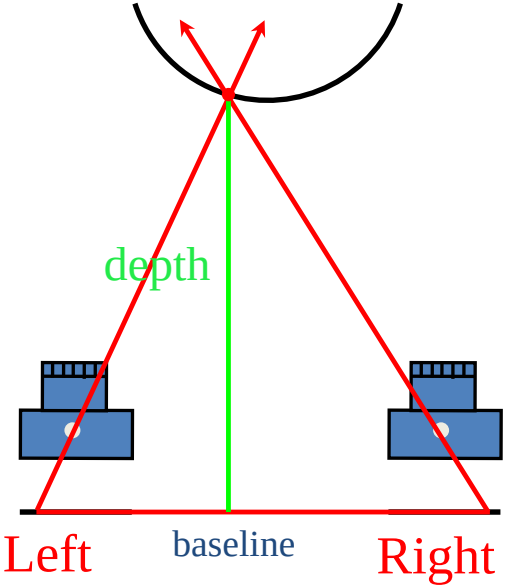


Direct



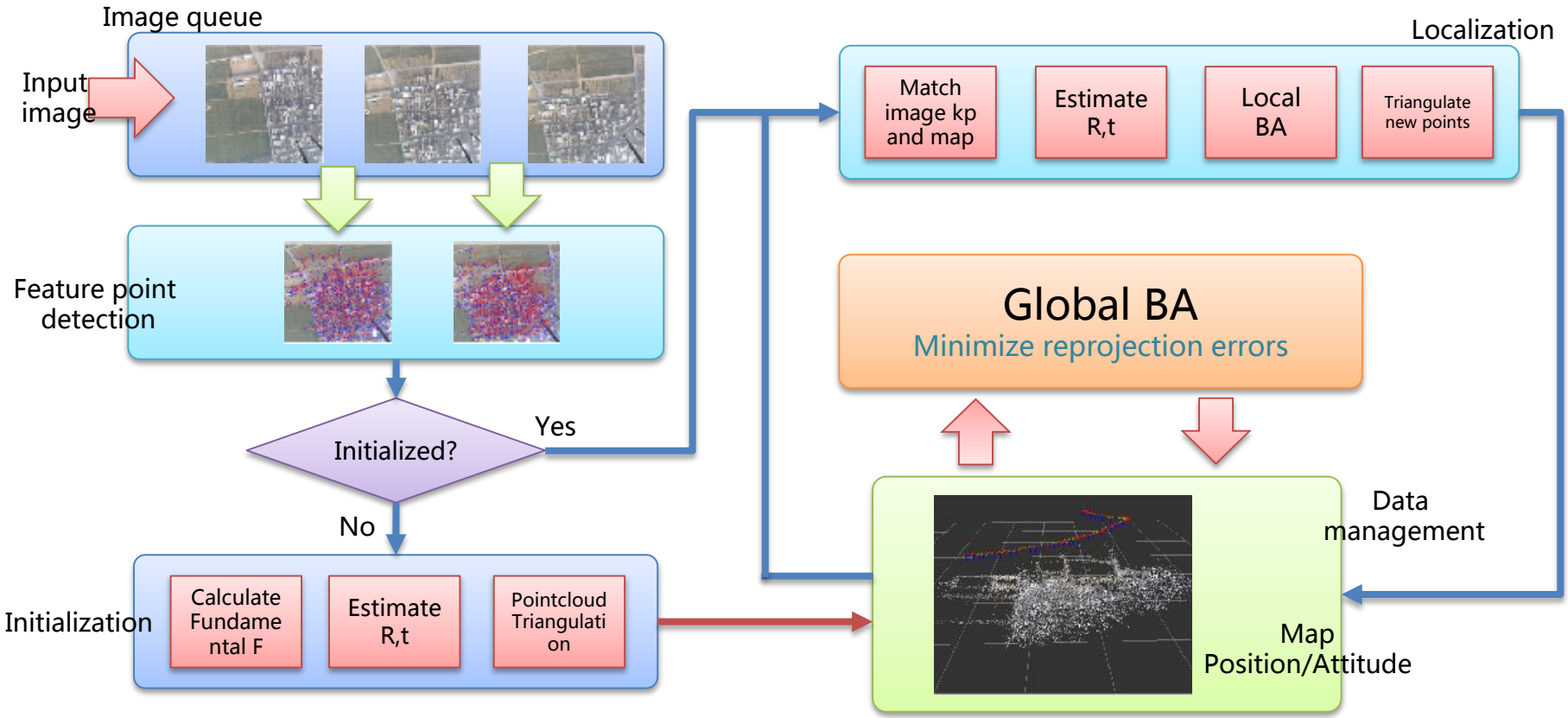
Semi-Direct

Visual SLAM - Principle



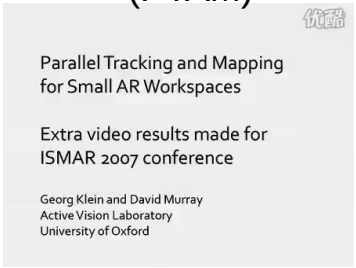
The object point's depth can be recovered through triangulation

Visual SLAM – Keypoint Methods



Visual SLAM – Progress

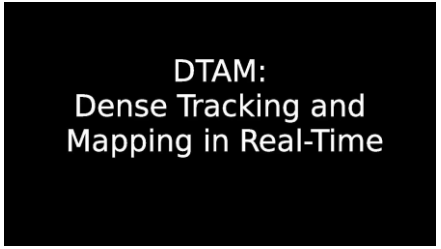
Parallel Tracking and Mapping (PTAM)



Large-scale Direct Monocular SLAM (LSD-SLAM)

sfmLearner

2007 2011 2014 2016 2018



Dense Tracking and Mapping (DTAM)

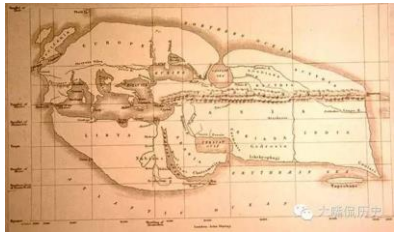
ORB-SLAM

Semi-direct Tracking and Mapping (SDTAM)

Contents

- Background
- RTMapper
  - G-SLAM
  - MapFusion
  - SemanticAnalysis
- Market & Applications
- Conclusion

Map ?



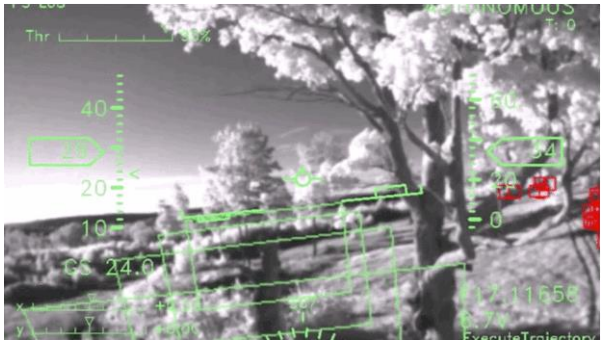
BC 276

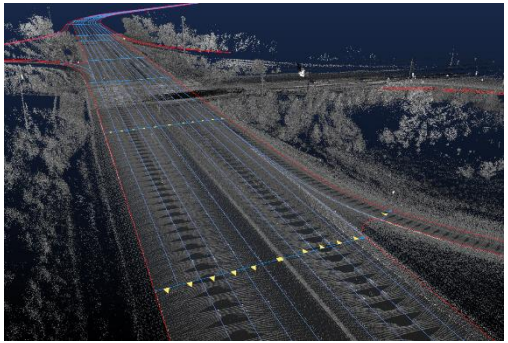
Middle Ages

Present

Maps for Machine

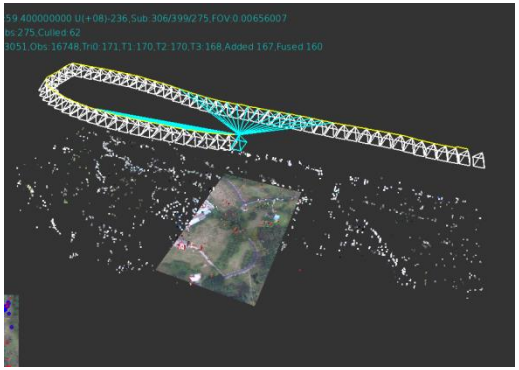
- Navigation map is a key technique to improve capability of robot/autonomous car/UAV
- Realtime perception not only uses map but also generates maps
- Realtime mapping and cooperation will bring various applications

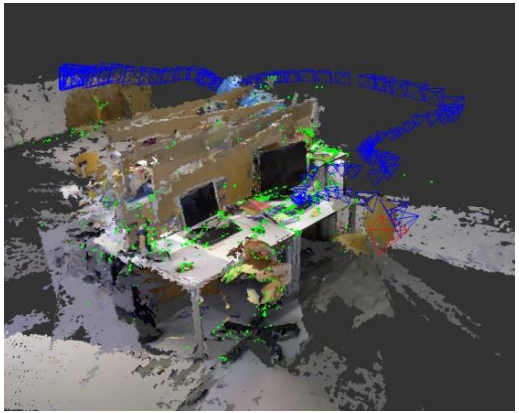




Problems in SLAM

- Mapping just for fast localization
- Mainly output 3D sparse pointcloud
- Low environment representation
- Low storage efficiency
- Low re-localization accuracy for long time interval
- DOM, DEM, 3D Map, HD Maps are required



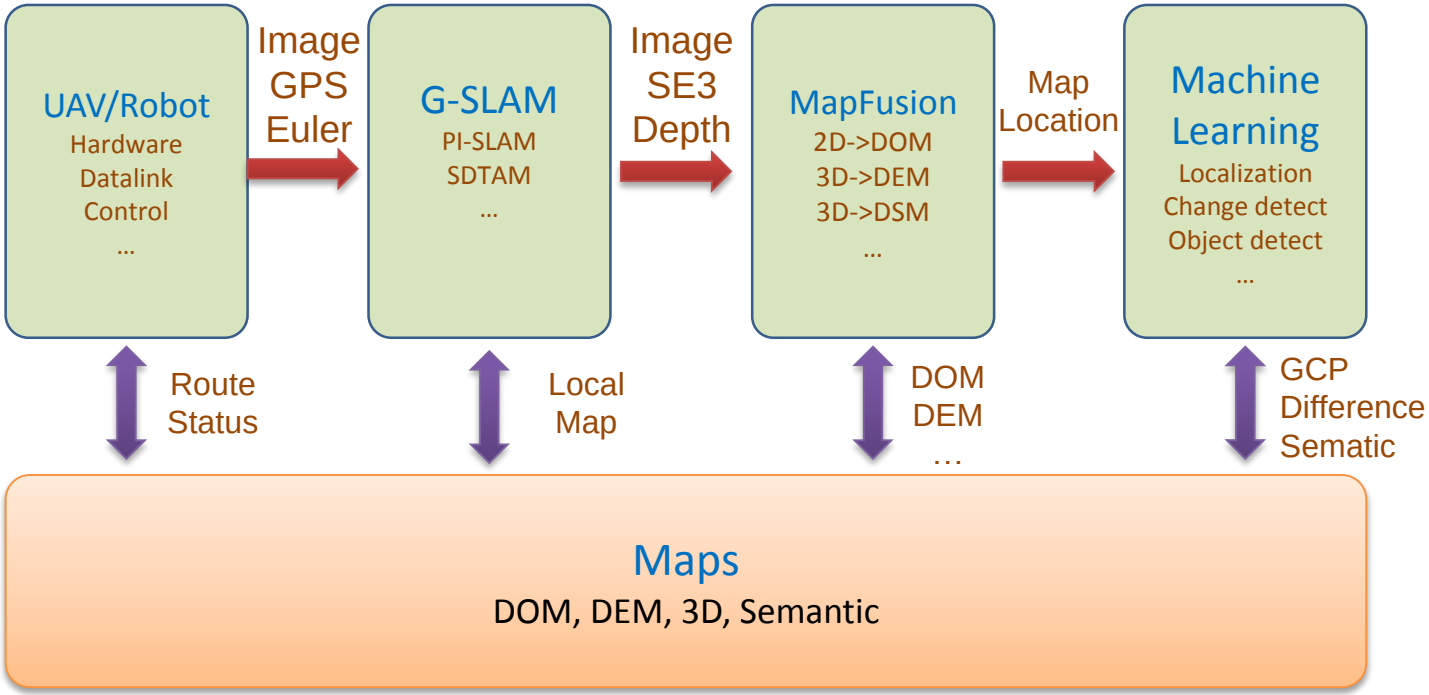


Enhance Mapping

RT MAPPER

Realtime Mapper

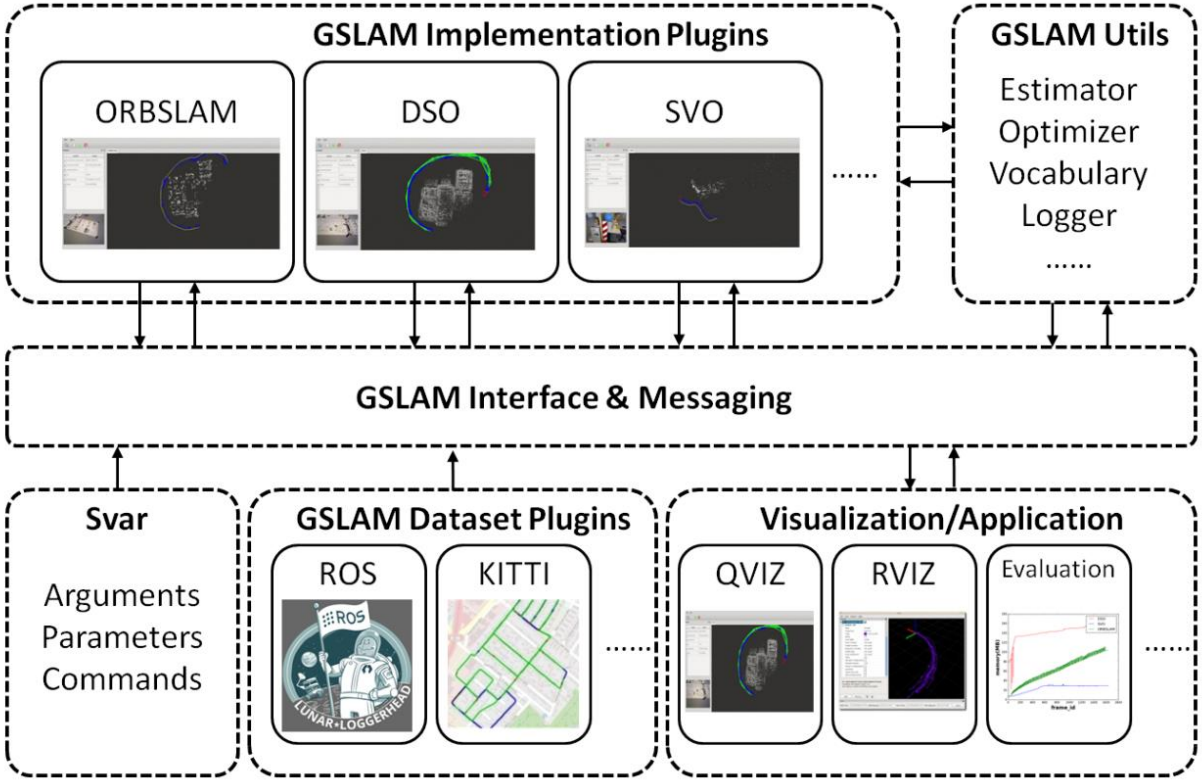
Architecture of RTMapper



(1) UAV / Platform

- Robustness
- Simple Operation
- Realtime map creation
- G-SLAM/RTMapper

(2) GSLAM



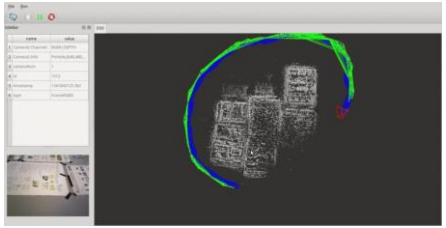
- General platform for SLAM development
- Plugin architecture
- High performance components/utils
- C++ 11
- Python/Javascript bindings

Yong Zhao, et al., General SLAM Framework and Benchmark, ICCV 2019

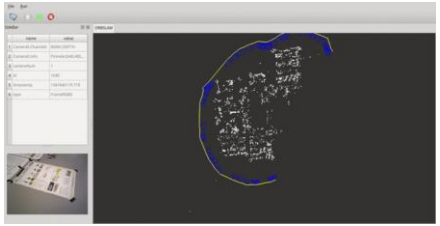
https://github.com/zdzhaoyong/GSLAM

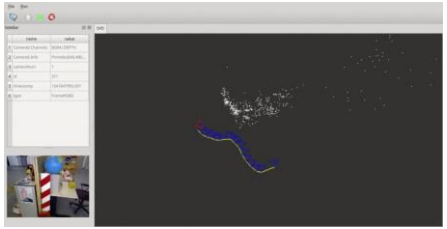
(2) GSLAM – Implemented SLAMs

DSO

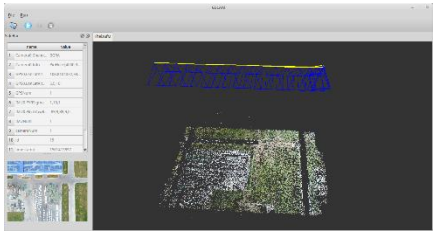


ORB-SLAM

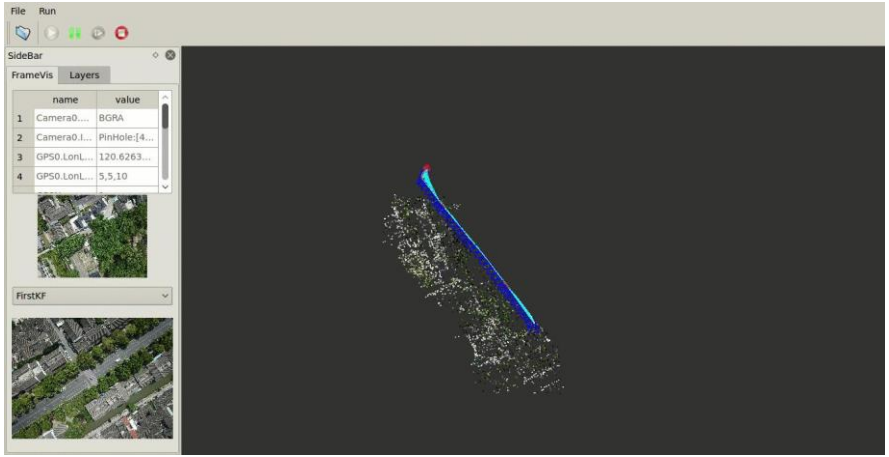




SVO



TheiaSfM



PI-SLAM

(2) GSLAM – Components/Utils

3D Transformation

Method		GSLAM	Sophus	TooN	Ceres
$SO(3)$	*mult*	**14.9**	34.3	17.8	159.1
	trans	15.4	17.2	**14.5**	90.4
	exp	**80.7**	98.4	106.8	-
	log	**55.7**	72.5	63.8	-
$SE(3)$	*mult*	**28.6**	55.2	29.3	-
	trans	19.3	19.8	**12.1**	-
	exp	152.4	249.2	**99.2**	-
	log	**152.7**	194.0	205.8	-
$SIM(3)$	*mult*	**33.2**	58.5	34.5	-
	trans	16.9	17.2	**13.7**	-
	exp	**180.2**	286.8	229.0	-
	log	**202.5**	341.6	303.6	-

Estimator

Algorithm		Ref.	Model
2D-2D	*F8-Point*	[19]	Fundamental
	F7-Point	[33]	Fundamental
	E5-Stewenius	[62]	Essential
	E5-Nister	[54]	Essential
	E5-Kneip	[42]	Essential
	H4-Point	[33]	Homography
	A3-Point	[4]	Affine2D
2D-3D	*P4-EPnP*	[43]	SE3
	P3-Gao	[26]	SE3
	P3-Kneip	[41]	SE3
	P3-GPnP	[40]	SE3
	P2-Kneip	[38]	SE3
	T2-Triangulate	[39]	Translation
3D-3D	*A4-Point*	[4]	Affine3D
	S3-Horn	[34]	SIM3
	P3-Plane	[41]	SE3

Yong Zhao, et al., General SLAM Framework and Benchmark, ICCV 2019

https://github.com/zdzhaoyong/GSLAM

(2) GSLAM – Components/Utils

Visual Vocabulary

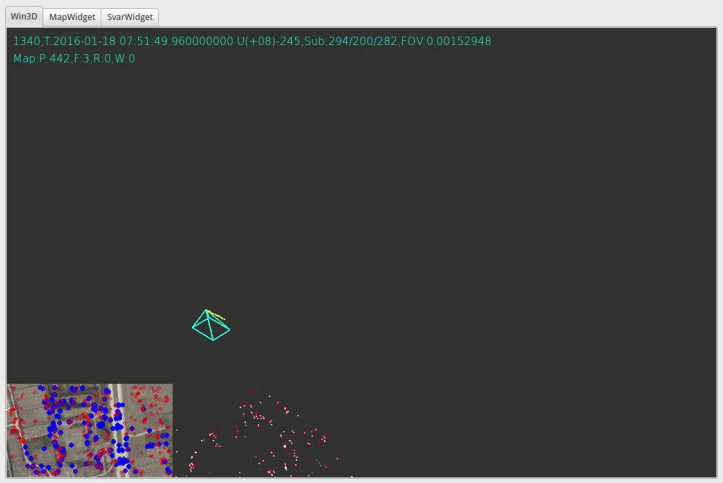
Implementation		Ours	DBoW2	DBoW3	FBoW
Load	*ORB-4*	**67.3us**	47.2ms	7.1ms	72.3us
	ORB-6	**7.2ms**	6.8 s	1.1 s	9.5ms
	SIFT-4	**1.0ms**	436.1ms	5.1ms	1.1ms
Save	*ORB-4*	**437.9us**	40.4ms	1.7ms	553.1us
	ORB-6	34.4ms	4.8 s	632.4ms	**20.6ms**
	SIFT-4	4.4ms	437.6ms	6.7ms	**2.7ms**
Train	*ORB-4*	**7.6 s**	24.8 s	23.6 s	8.5 s
	ORB-6	**230.5 s**	1.1Ks	911.4 s	270.4 s
	SIFT-4	23.5 s	327.7 s	299.0 s	**18.7 s**
Trans	*ORB-4*	**615.5us**	2.1ms	1.9ms	862.4us
	ORB-6	**723.7us**	6.0ms	4.9ms	1.2ms
	SIFT-4	**1.1ms**	10.3ms	9.2ms	11.5ms
Mem	*ORB-4*	**0.44MB**	2.5MB	2.5MB	0.45MB
	ORB-6	**44.4MB**	247.1MB	246.5MB	45.3MB
	SIFT-4	**5.8MB**	7.8MB	7.8MB	5.8MB

Dataset Loader

Dataset	Year	Environment	Type
KITTI [28]	2012	outdoors	multi-cam, imu
TUMRGBD [64]	2012	indoors	RGBD
ICL [32]	2014	simulation	RGBD
TUMMono [17]	2016	indoors	mono
Euroc [8]	2016	indoors	stereo, imu
NPUDroneMap [7]	2016	aerial	mono
TUMVI [60]	2018	in/outdoors	stereo, imu
CVMono [4]	-	-	mono
ROS [57]	-	-	-

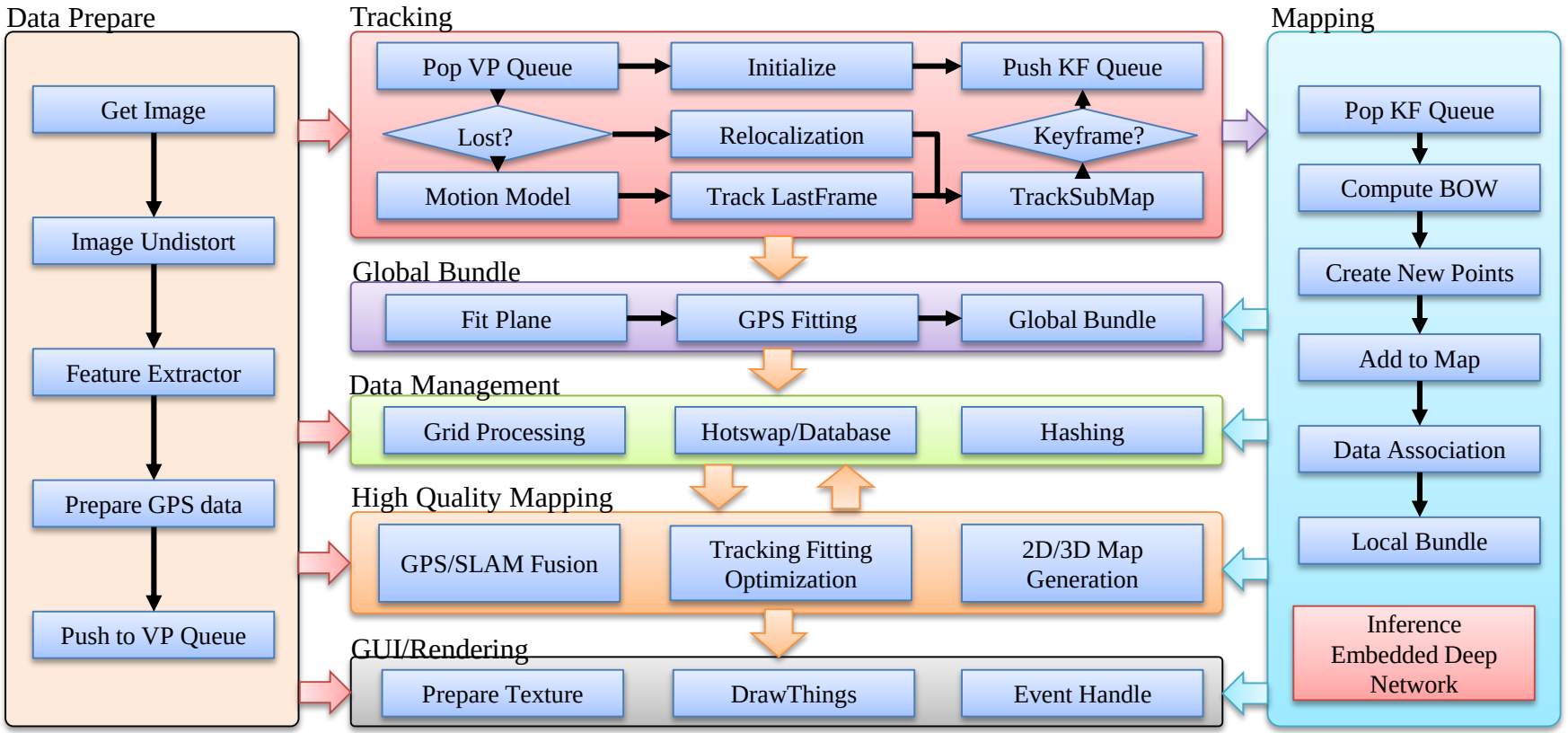
（2）G-SLAM： PI-SLAM

Pilot Intelligent SLAM
（PI-SLAM）



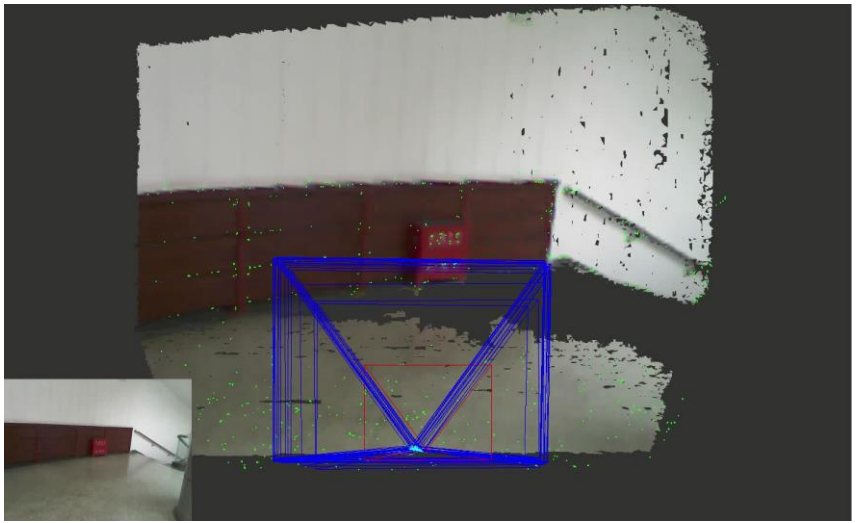
- **High processing speed：** 30 FPS for 1080p images
- **Balance between SLAM and SfM:** Support 40M pixel photo with high processing speed
- **Multisource fusion：** Vision and GPS data can be joint optimized
- **Realtime DOM/DSM:** Adaptive multi-band method for realtime DOM generation
- **large area support：** Data grid, hot swap

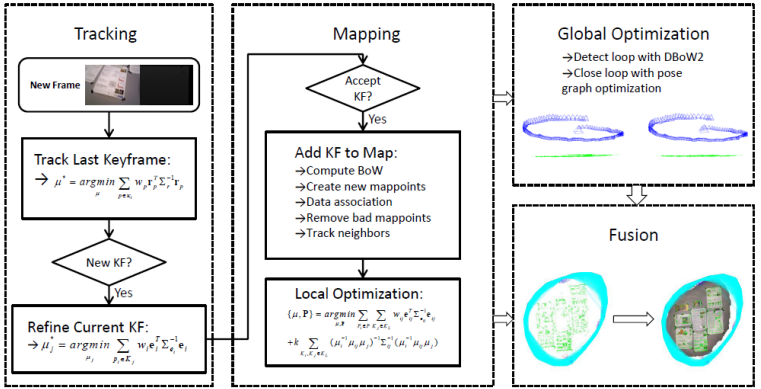
（2）G-SLAM：PI-SLAM



(2) G-SLAM : SDTAM

Semi-direct Tracking and Mapping

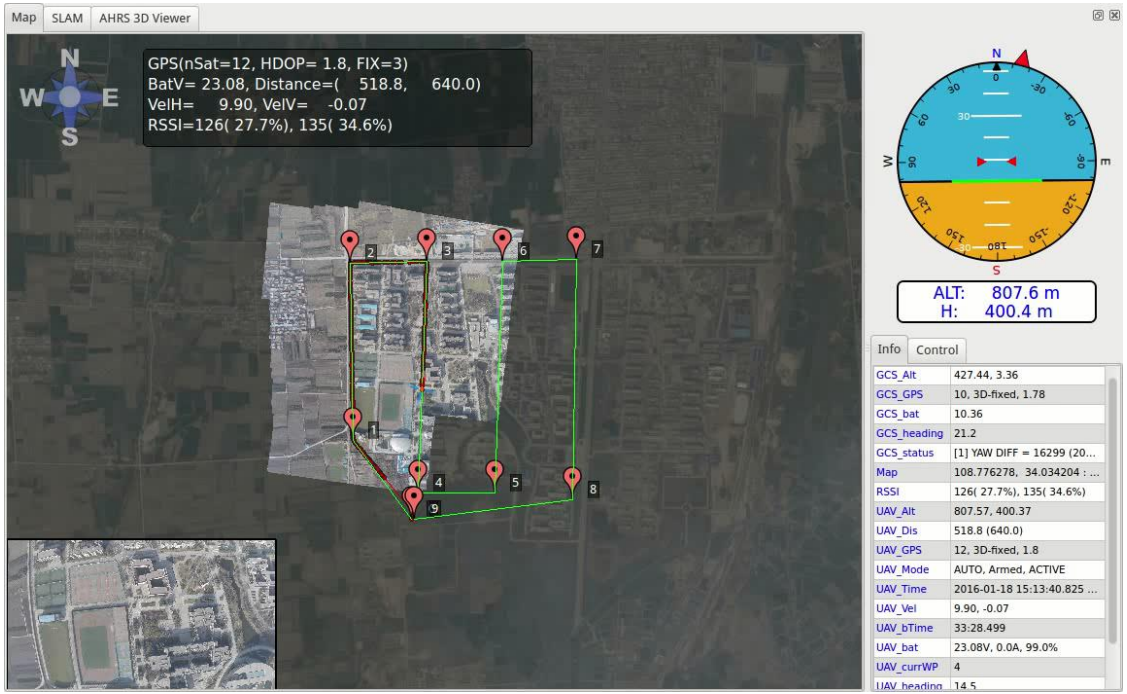




- Use direct method to fast tracking new frame's position, and then use keypoint method to realize precisely optimization
- Define a novel error function which incorporate depth and geometric measures
- Speed and accuracy balance can be achieved

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

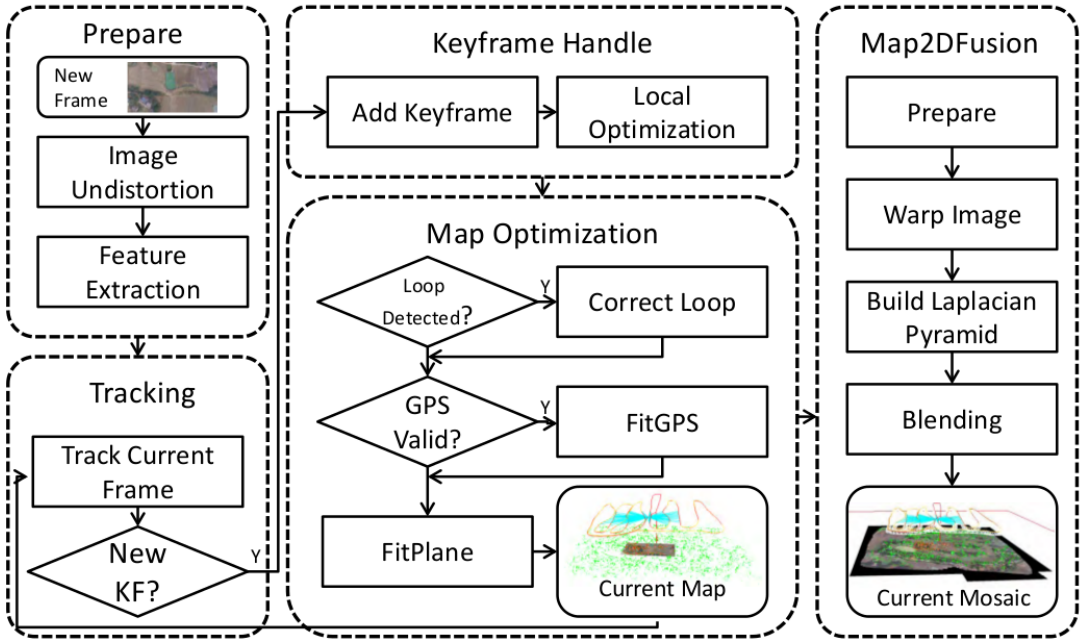
(3) MapFusion



- Realtime fuse 2D maps (DOM), 2.5D maps (Terrain), 3D (Mesh)
- Capability of extension
- Integrating data process / analysis

Shuhui Bu, Yong Zhao, et al., Map2DFusion: Real-time Incremental UAV Image Mosaicing based on Monocular SLAM, IROS, 2016
http://www.adv-ci.com/blog/projects/map2dfusion/

(3) MapFusion – Map2DFusion



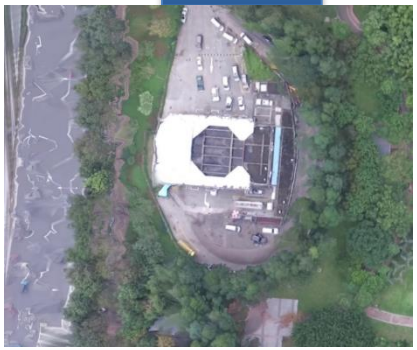
- **Feature based Visual SLAM System: PI-SLAM**
- **Automatic GPS and video synchronization**: a graph based optimization is proposed to synchronize video time with GPS time from coarse to fine.
- **Real-time orthoimage blender**: an adaptive weighted multi-band method to blend and visualize images incrementally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

Shuhui Bu, Yong Zhao, et al., Map2DFusion: Real-time Incremental UAV Image Mosaicing based on Monocular SLAM, IROS, 2016
http://www.adv-ci.com/blog/projects/map2dfusion/

(3) MapFusion – Map2DFusion

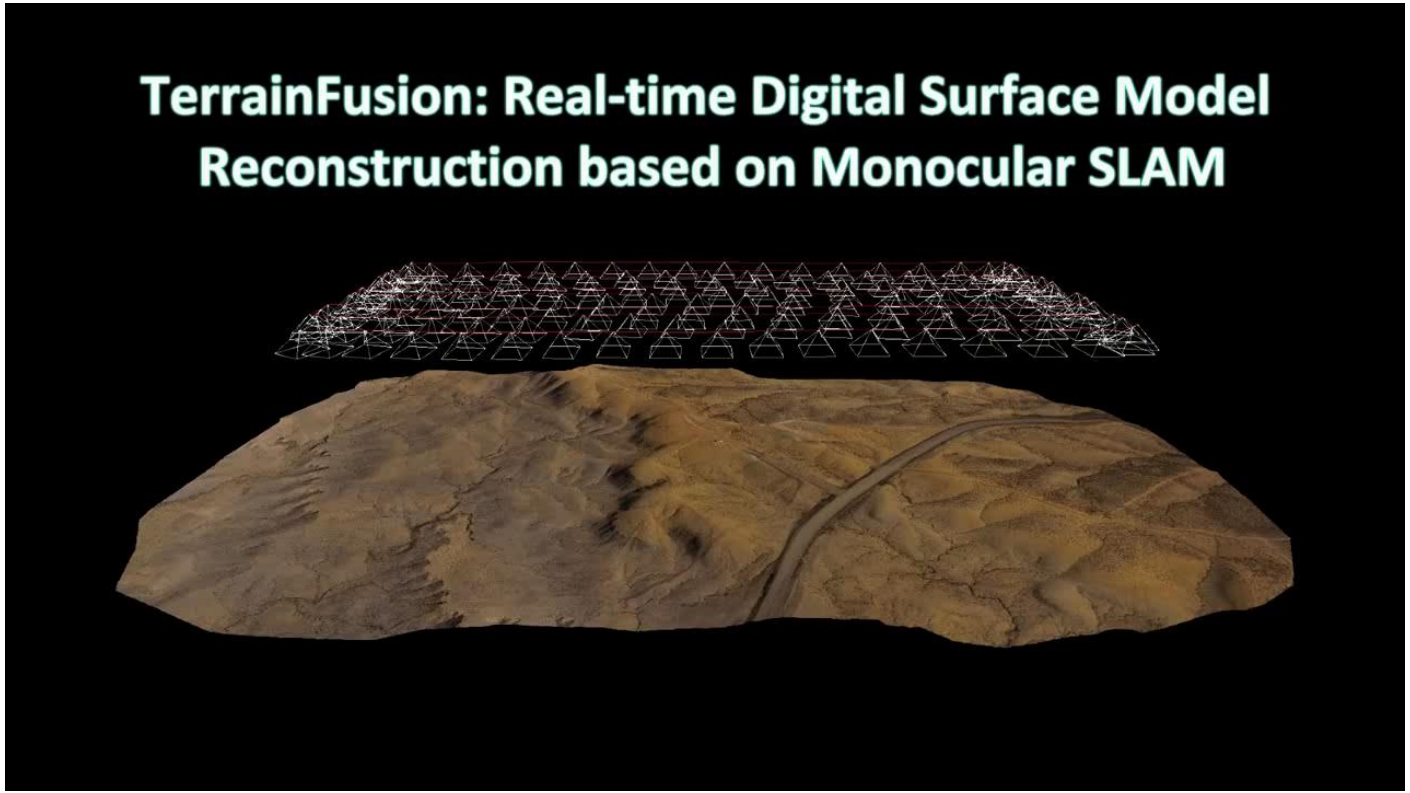
PhotoScan

Pix4D



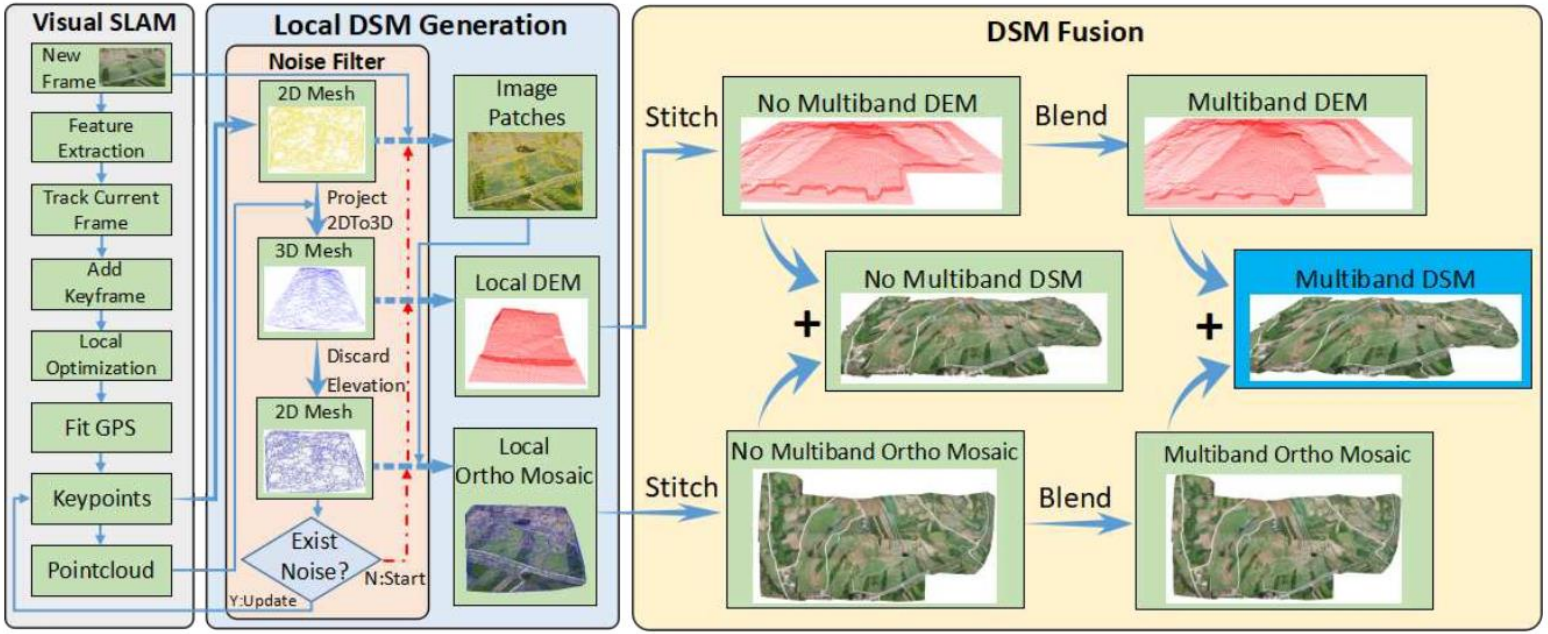
RTMapper

(3) MapFusion – TerrainFusion



Wei Wang, et al., TerrainFusion:Real-time Digital Surface Model Reconstruction based on Monocular SLAM, iROS 2019

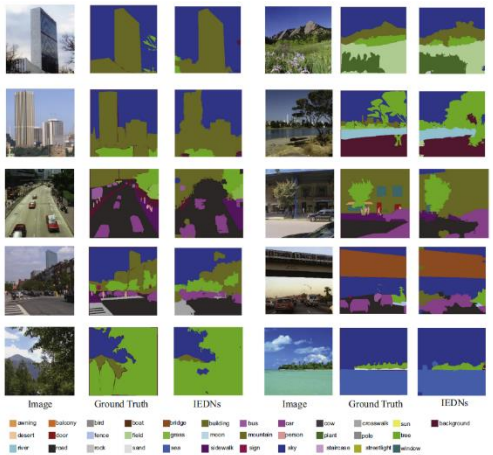
(3) MapFusion – TerrainFusion



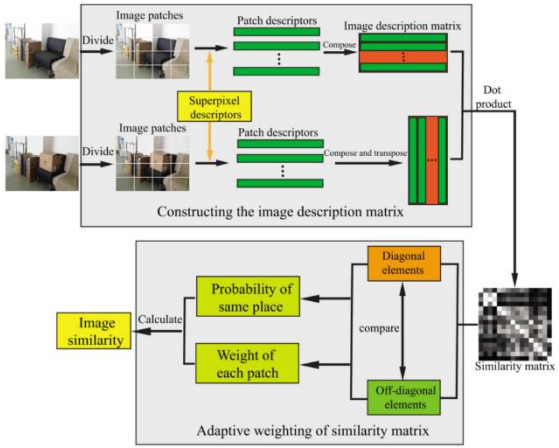
- Realtime 2.5 DSM generation
- Improved DOM quality
- Large area support
- Adaptive quality support

Wei Wang, et al., TerrainFusion:Real-time Digital Surface Model Reconstruction based on Monocular SLAM, iROS 2019

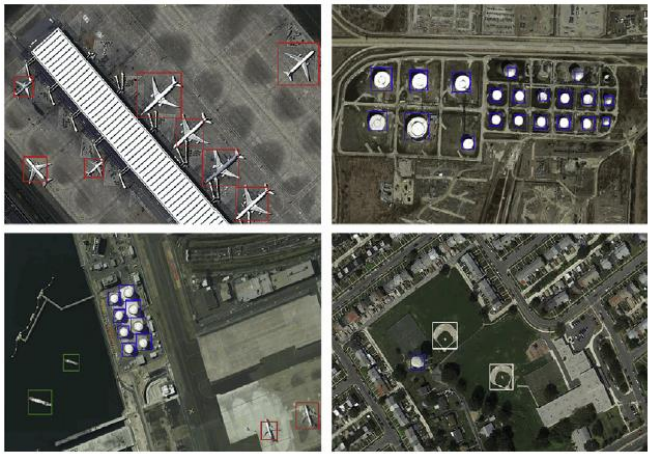
(4) SemanticAnalysis



Scene Segmentation



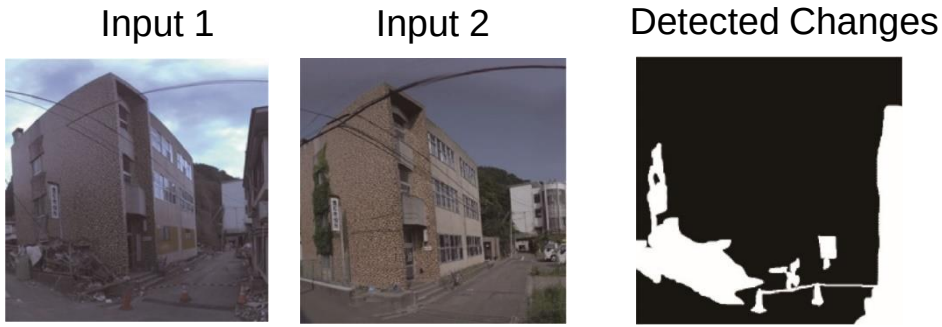
Scene Recognition

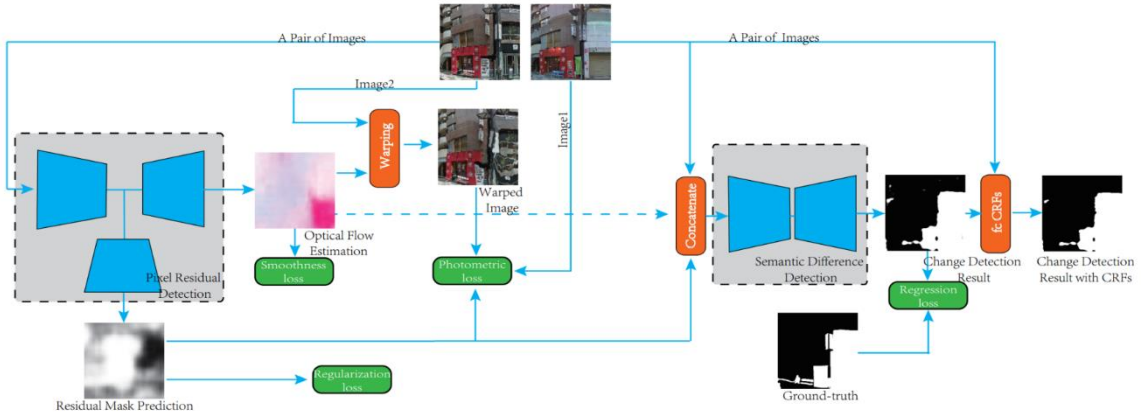


Object Recognition

Shuhui Bu, et al. Pattern Recognition, 2016.
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

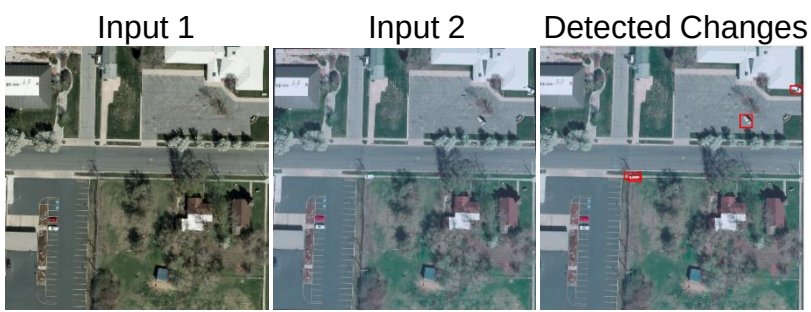
(4) SemanticAnalysis – Change Detection

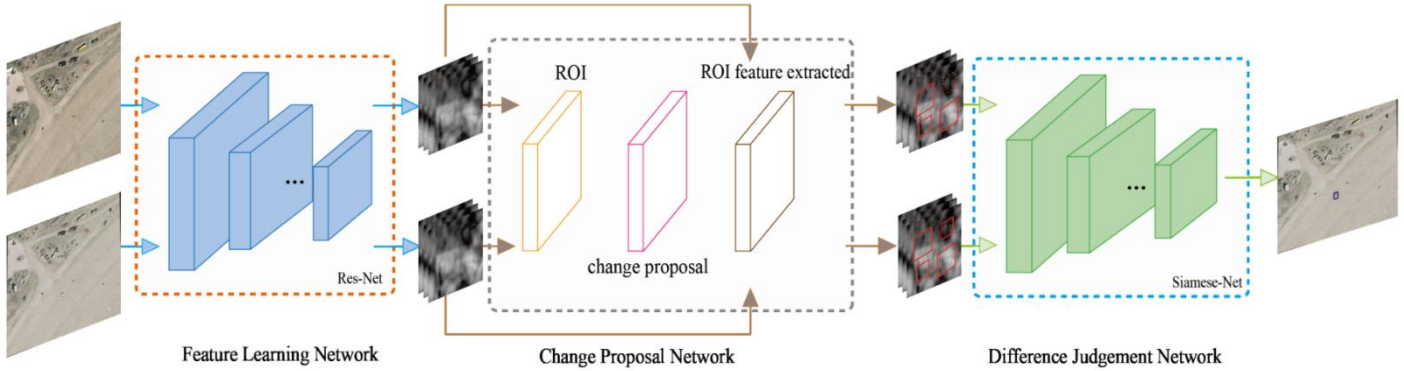




Shuhui Bu, et al., Pixel-level Semantic Change Detection using Mask-CDNet

(4) SemanticAnalysis – Change Detection

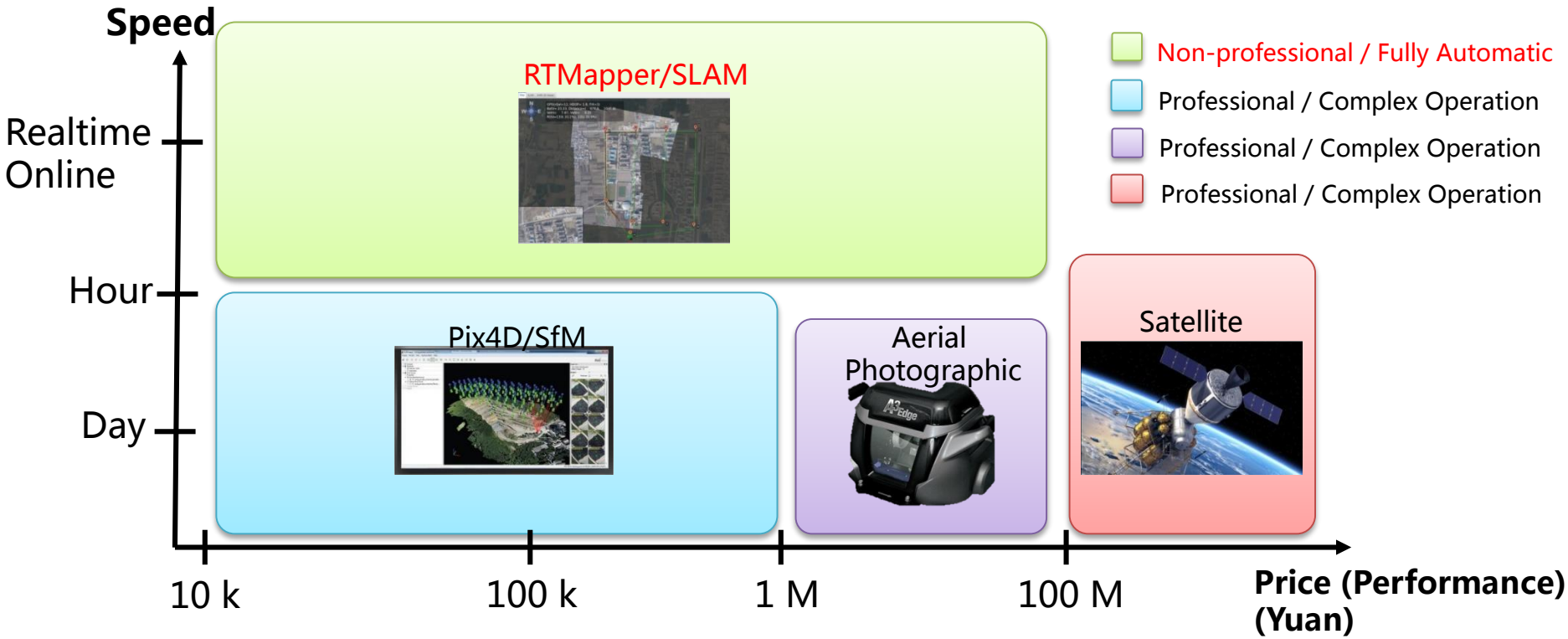




Pengcheng Han, et al., Aerial Image Change Detection using Dual Regions of Interest Networks, 2019

Contents

Market - Target



Market – Feature Comparison

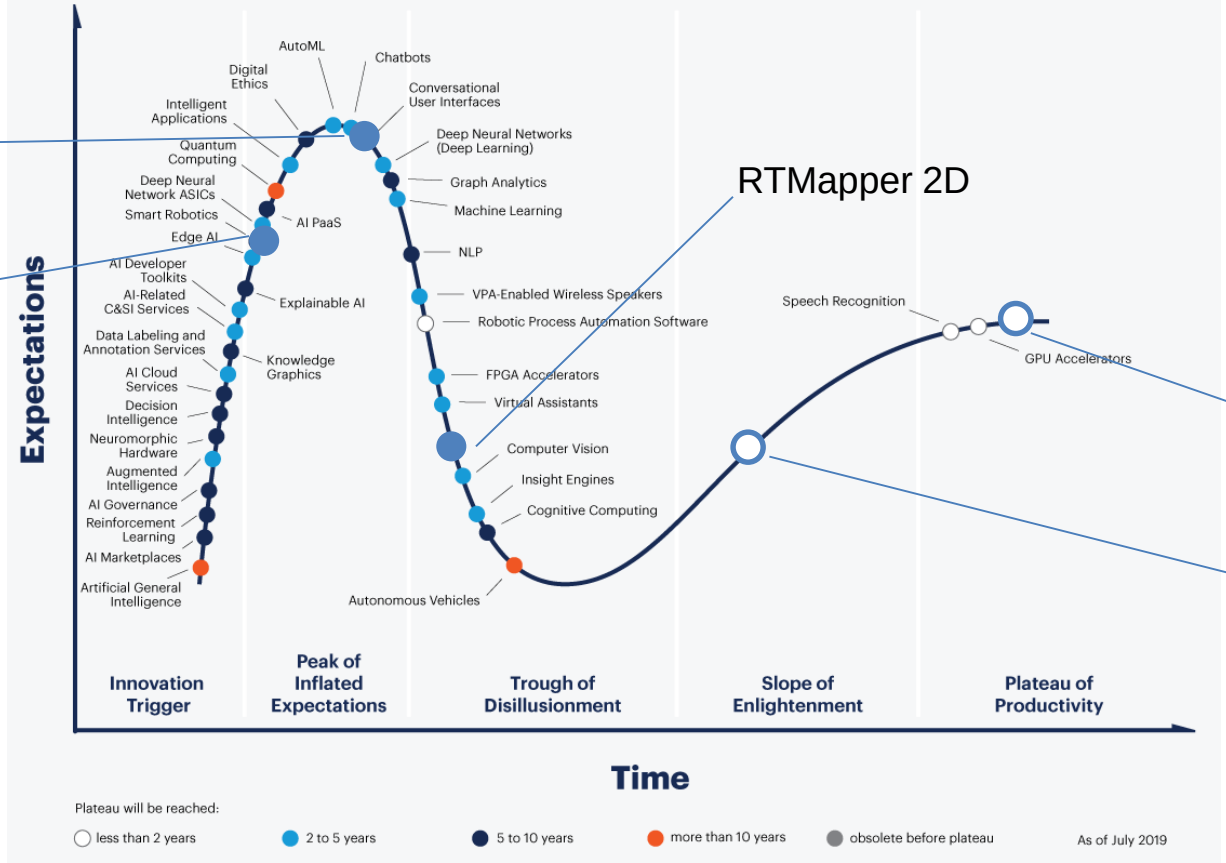
	Satellite / Aerial Photographic	Pix4D PhotoScan	RT MAPPER
Speed	Offline / Batch	Offline / Batch	Online / Realtime
Security	High	Normal	High
Accuracy	High	Normal	Normal
Multi Information Fusion	No	No	Yes
Integration	No	No	Yes
Hardware Requirements	High	High	Low
SDK	No	No	Yes
Cost	High	High	Low
Functions	DEM, DOM, 3D	DEM, DOM, 3D	DEM, DOM, 3D, Navigation

Photoscan: http://www.agisoft.com/
Pix4D: https://pix4d.com/

Market – Hype Cycle

RTMapper 3D

RTMapper SmartAnalysis



RTMapper 2D

Satellite
Aerial Photographic

UAV SfM

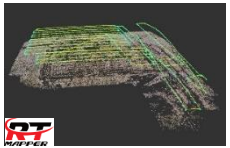
Market – Products

NWPU PI-Lab - Map2DFusion and prototype system

DroneDeploy - FieldScanner

Lockhead Martin – Hydra Fusion Tool

NWPU PI-Lab – RTMapper



Sibitu – Sibitu Desktop/Mobile

DJI – DJI-Terra

Pix4D – Pix4Dreact

2016 March

2017 April

2017 May

2017 June

2019 March

2019 April

2019 Nov

https://defensesystems.com/articles/2017/05/13/3d.aspx
https://www.dronedeploy.com/fieldscanner.html
https://www.dji.com/cn/dji-terra
https://www.pix4d.com/product/pix4dreact

http://www.adv-ci.com/blog/projects/map2dfusion
http://www.rtmapper.com
http://www.sibitu.cn

Application - Fields

Real time map creation, situation awareness, integrated surveillance and combat, intelligent navigation, collaborative navigation of cluster UAV

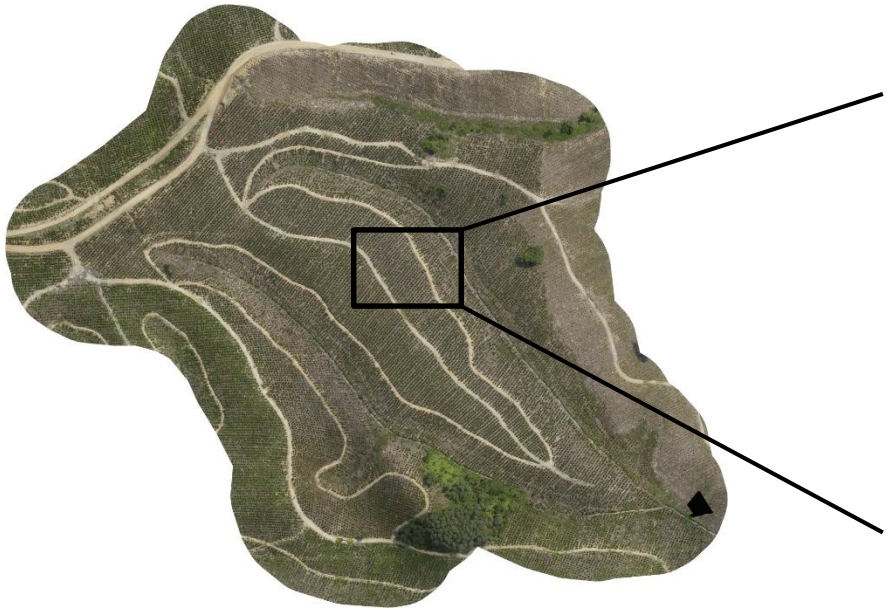
Simple and easy-to-use map creation with high performance, fully automatic control of plant protection UAV

Reliable planning, monitoring and analysis data support for exploration and mining

Efficient and global monitoring, and automatically data acquisition

Weekly and regular 2D/3D map for buildings construction, reliable technical means for construction progress and quality tracking

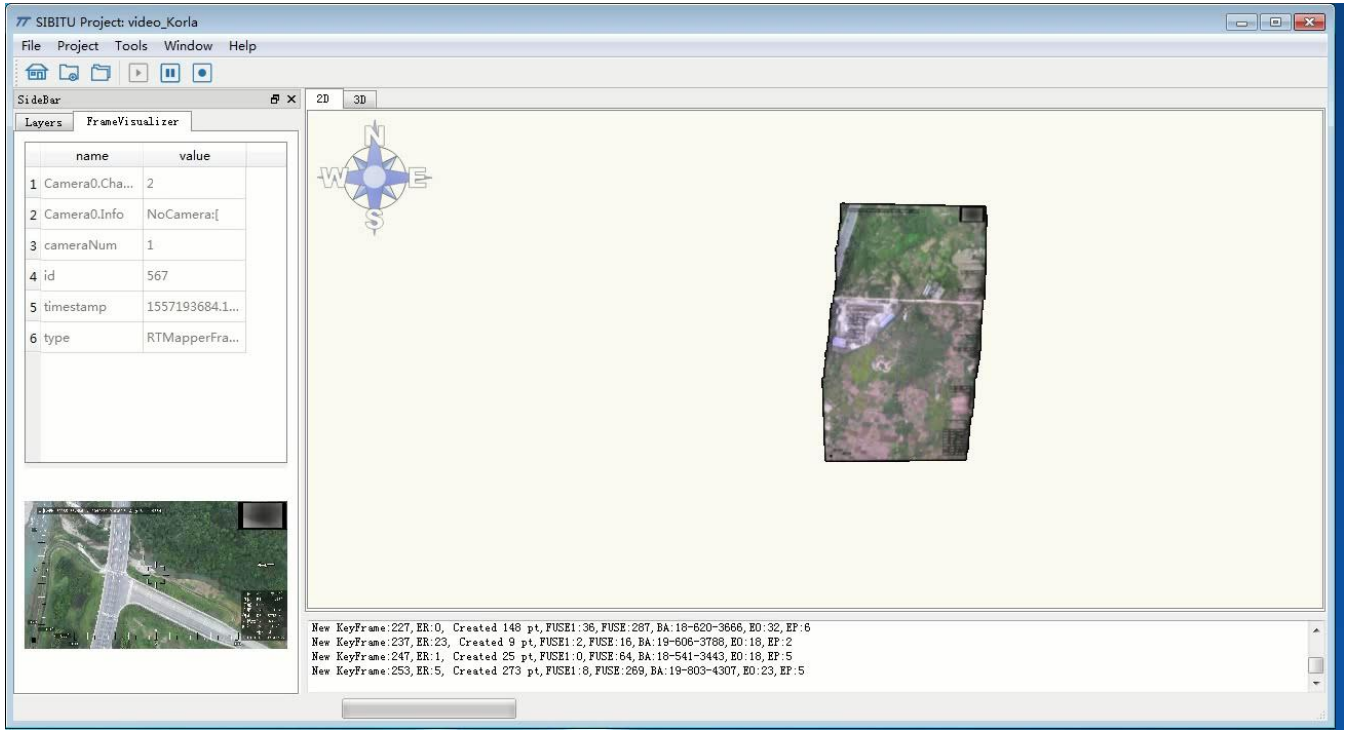
Application – Demo 1



Plantation mapping

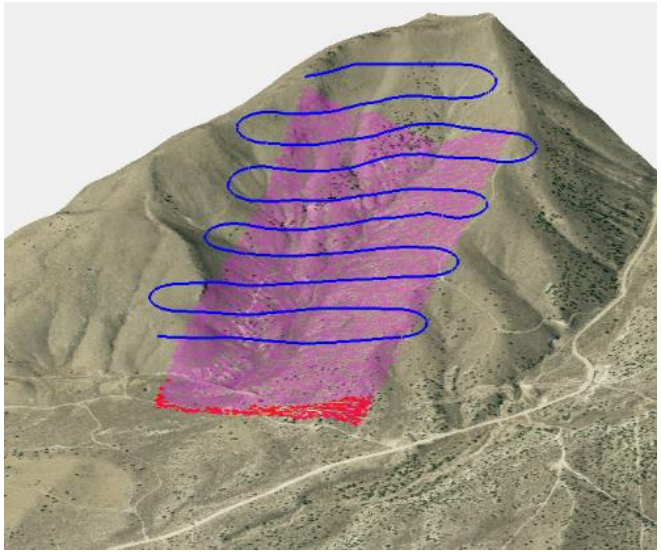
Tree detection and counting

Application – Demo 2

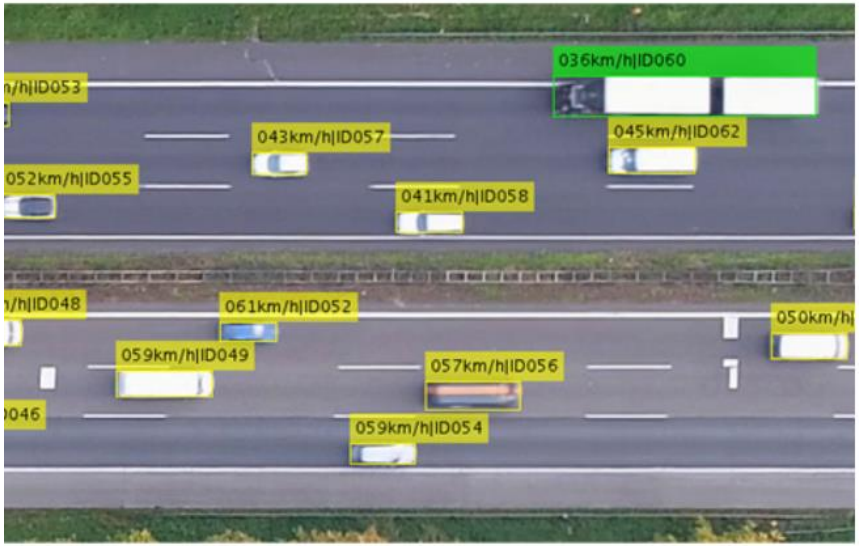


Video surveillance

Application – Demo 3



Path planning for
special environment



Safety / traffic analysis *1

*1R. Krajewski, et al., The highD dataset: a done dataset of naturalistic vehicle trajectories on German highways for validation of highly automated driving systems, 2018

Contents

- Background
- RTMapper
  - G-SLAM
  - MapFusion
  - SemanticAnalysis
- Market & Applications
- Conclusion

Future

- Realtime map plays import roles for navigation, GIS
- Realtime mapping and cooperation will bring interesting applications
- Integrating geometric information with semantic analysis will greatly improve the system intelligence

西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

THANK YOU

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