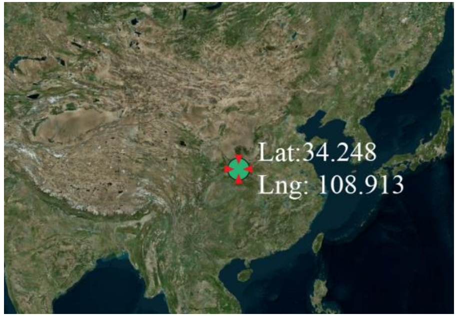
西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

Visual SLAM and Smart Navigation

Shuhui Bu
布树辉

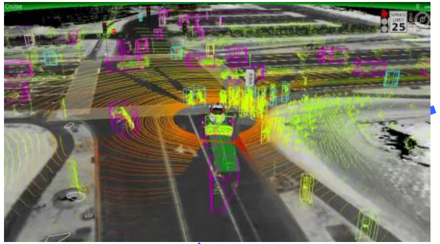
Northwestern Polytechnical University

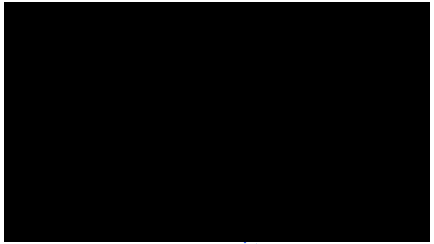


Focuses on science and technology of
aviation, aerospace, marine, and related fields.

Contents

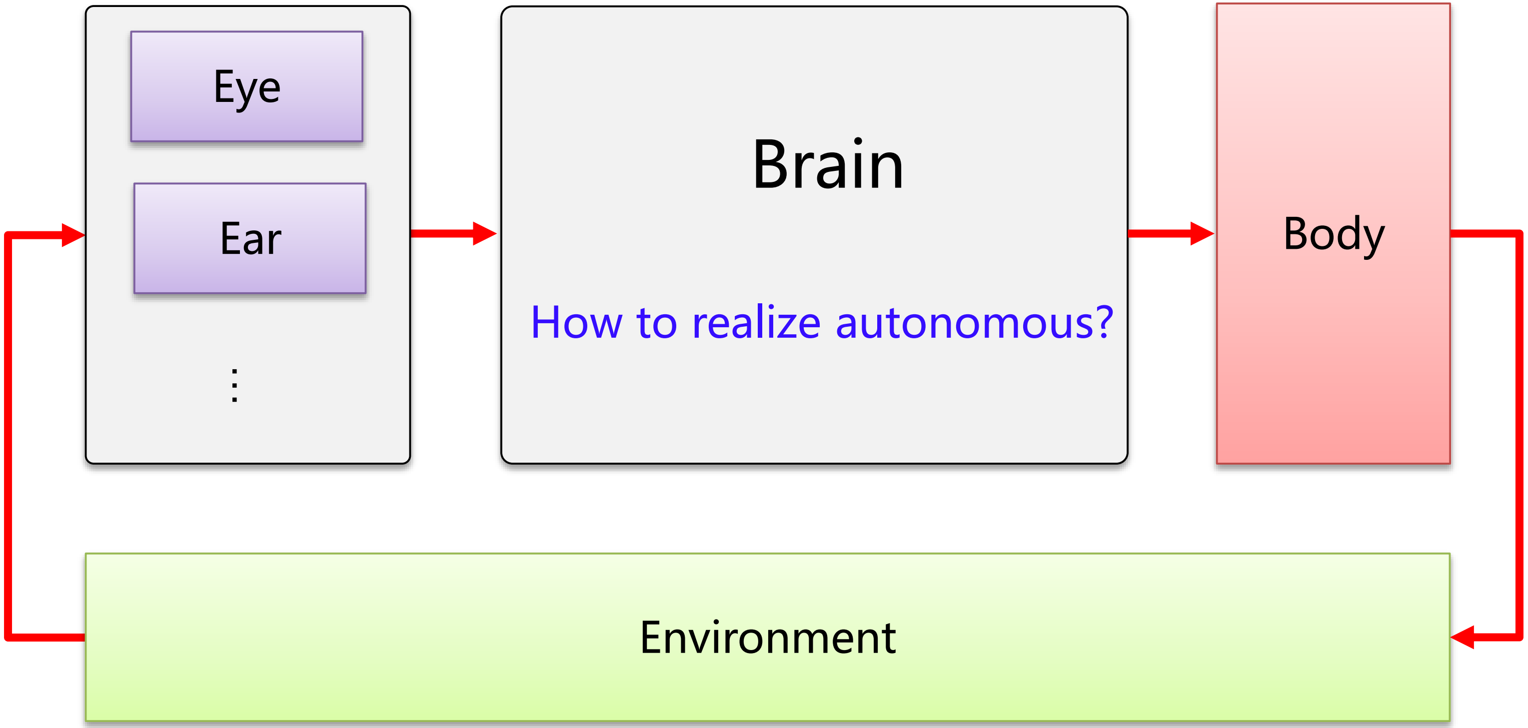
Future?



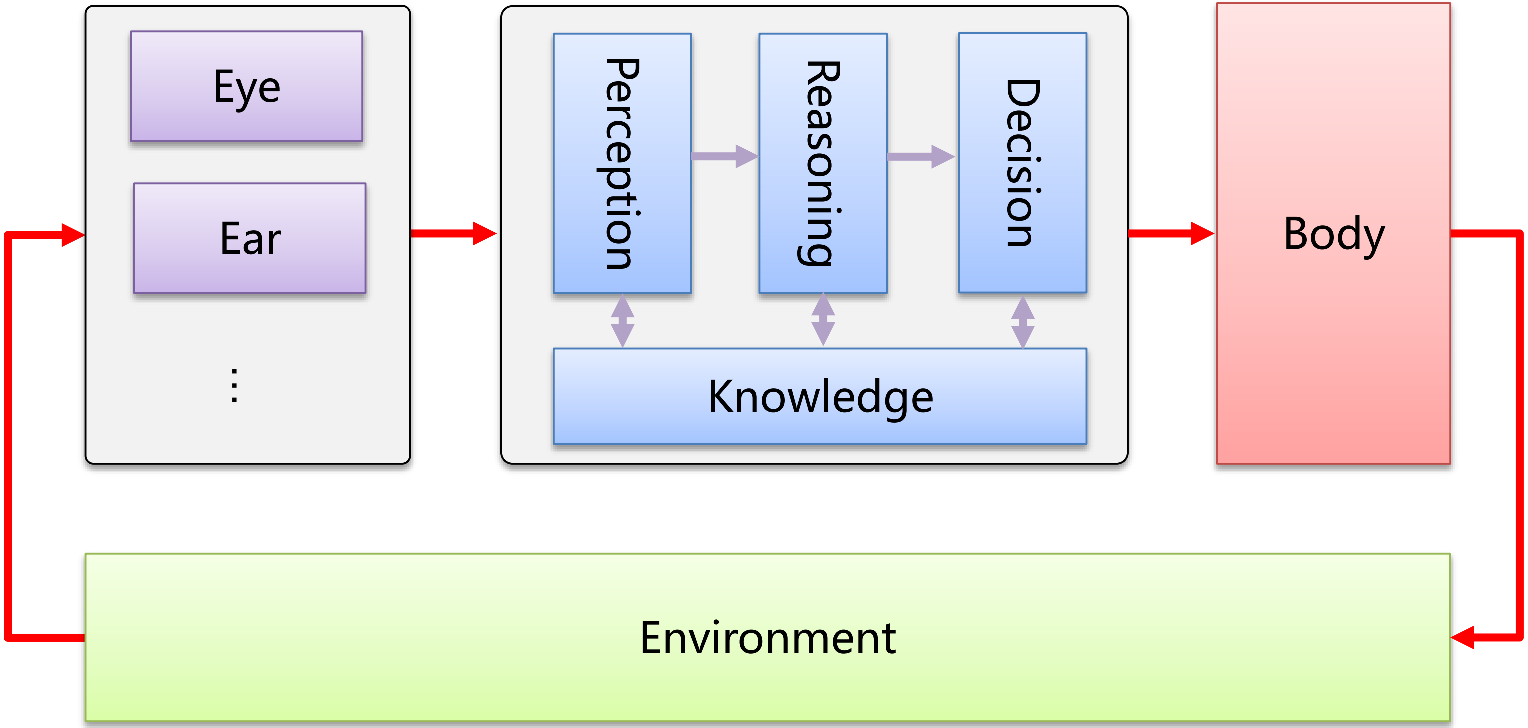


AI

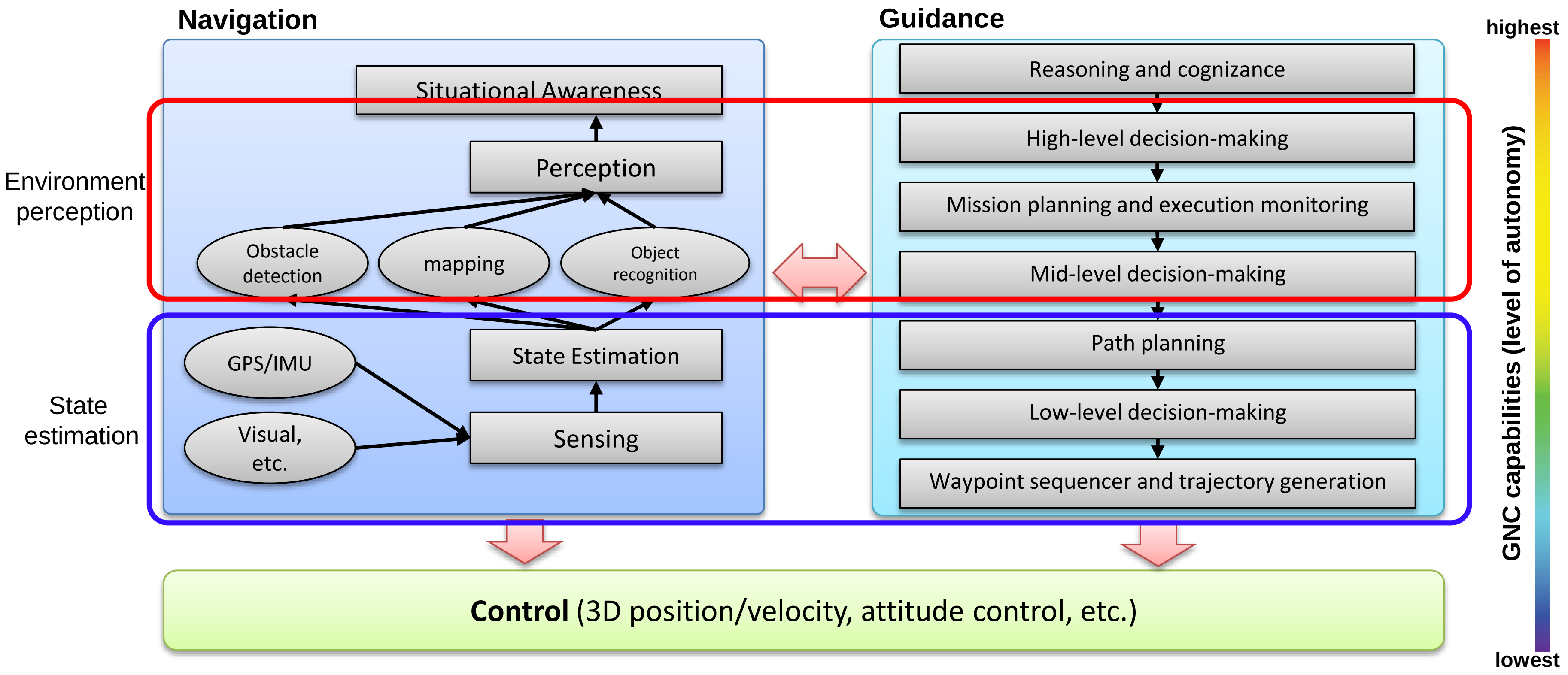
How to Realize Autonomous?



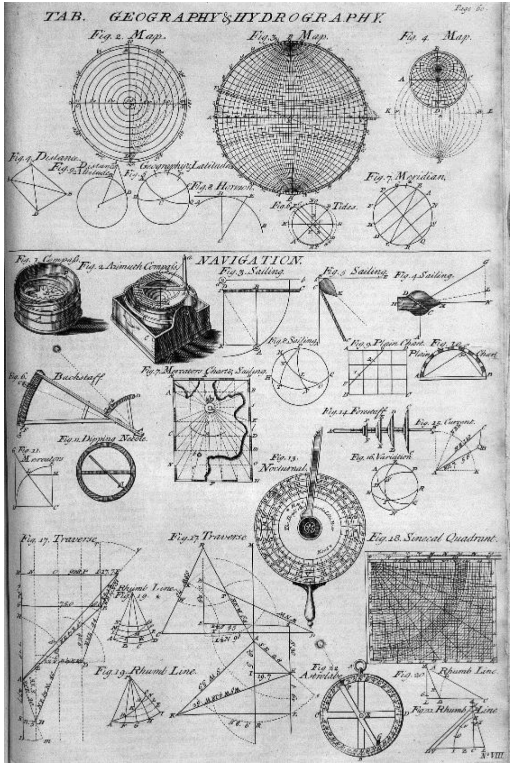
How to Realize Autonomous?



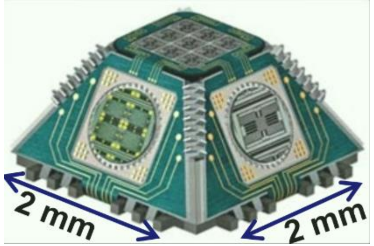
Architecture of GNC

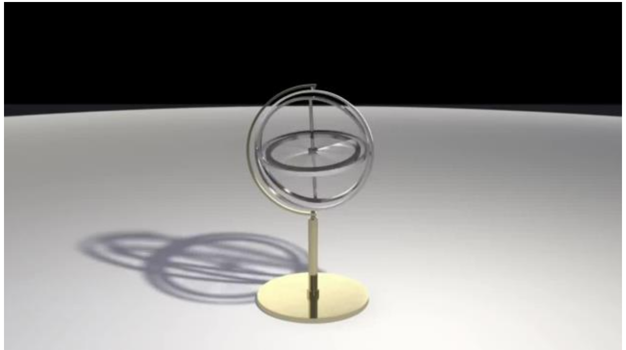


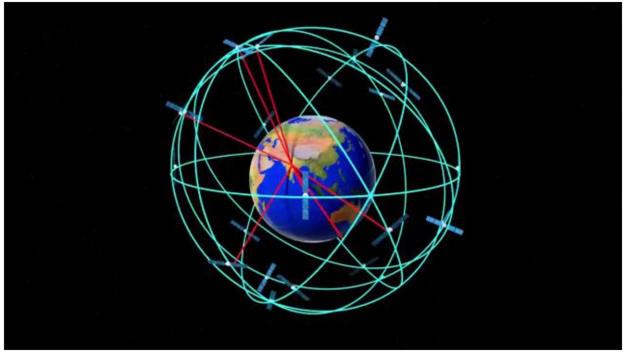
Traditional Navigation



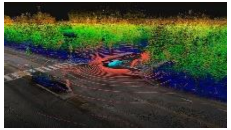
A microprocessor allows navigation to specific fixes or routes

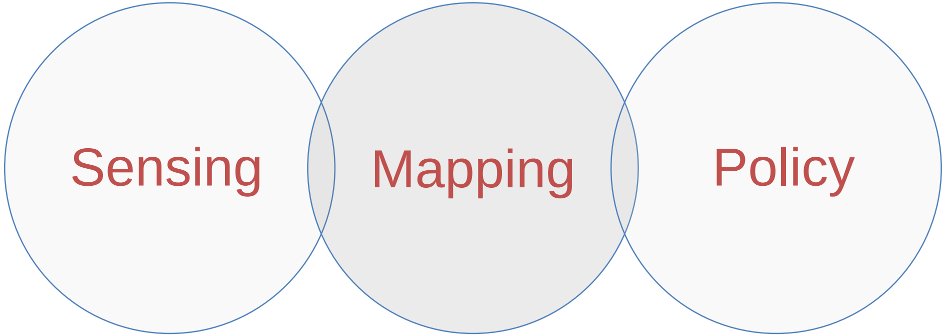






New Challenges



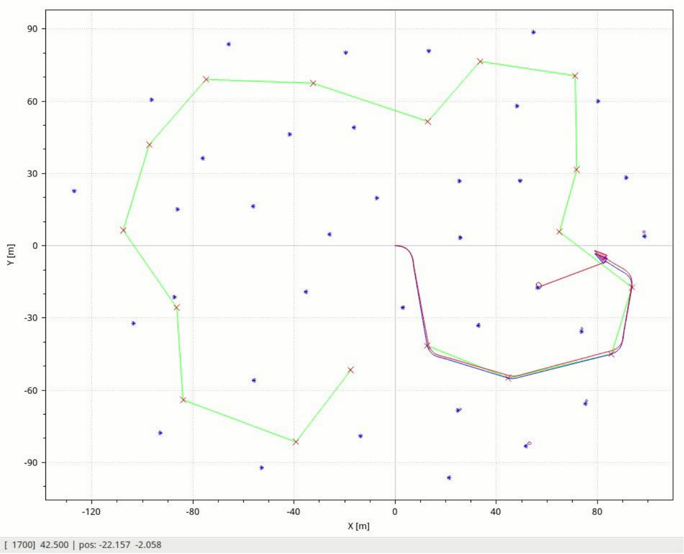


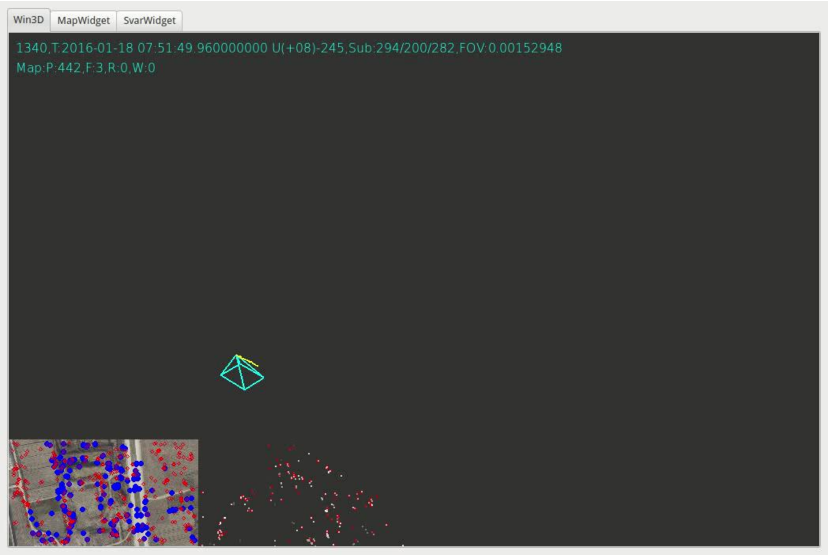
- Multi-type sensors: IMU, GPS, Image, LiDAR, RADAR …
- High quality and real-time speed required

SLAM ?

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

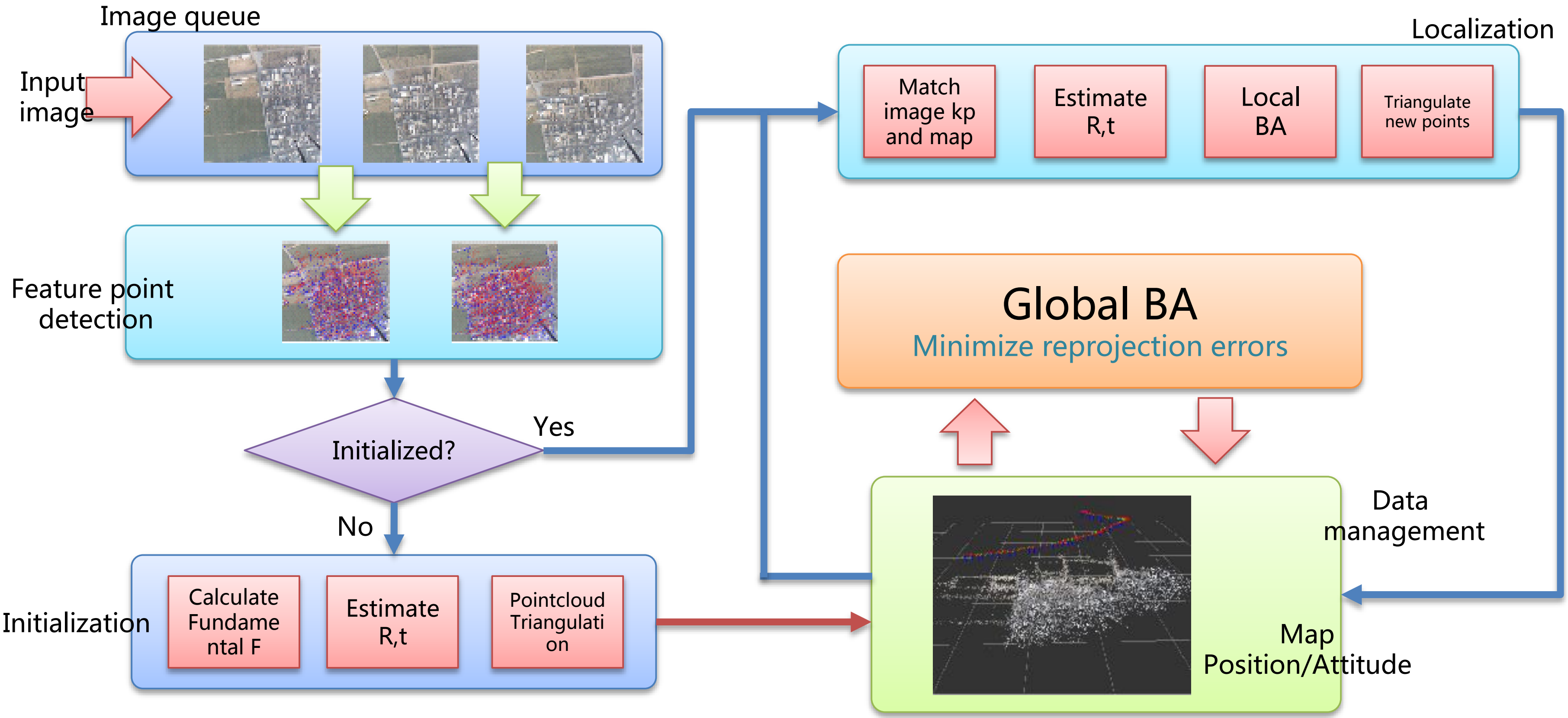
- Fusing & joint optimizing multiple-source data
- Providing position, attitude and environment map simultaneously





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

Visual SLAM – Keypoint Methods



Visual SLAM – Progress

Parallel Tracking and Mapping
(PTAM)

Large-scale Direct Monocular SLAM
(LSD-SLAM)

sfmLearner

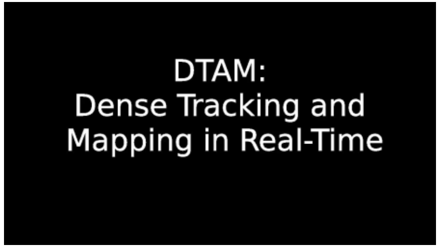
2007

2011

2014

2016

2018



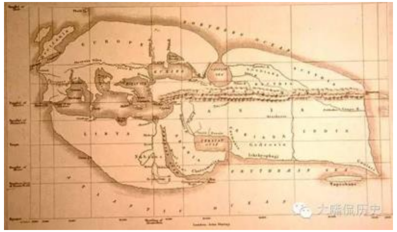
Dense Tracking and Mapping
(DTAM)

ORB-SLAM

Semi-direct Tracking and Mapping
(SDTAM)

Contents

Map ?



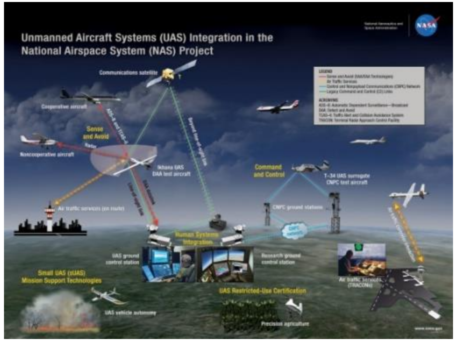
BC 276

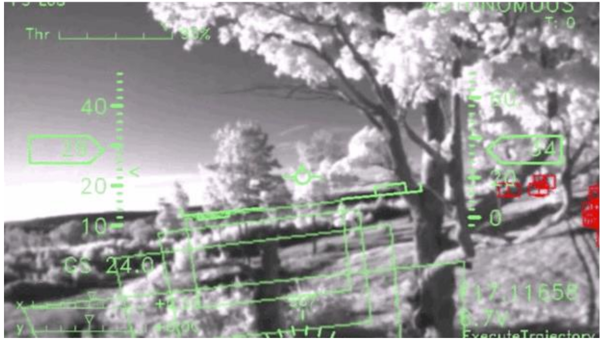
Middle Ages

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





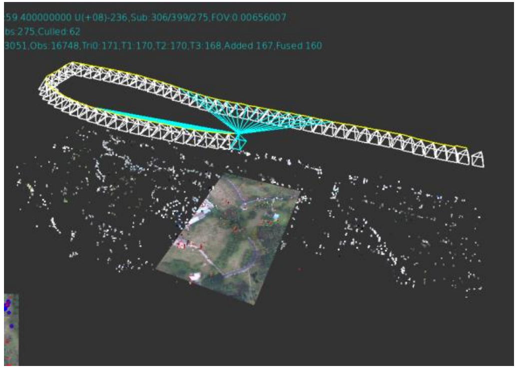
Problems in SLAM

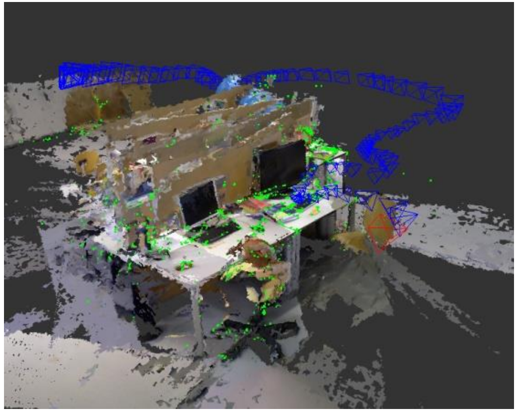
- Mapping just for fast localization
- Mainly output 3D sparse pointcloud
- Low environment representation
- Low storage efficiency
- Low re-localization accuracy for long time interval
- DOM, DEM, 3D Map, HD Maps are required

Enhance Mapping

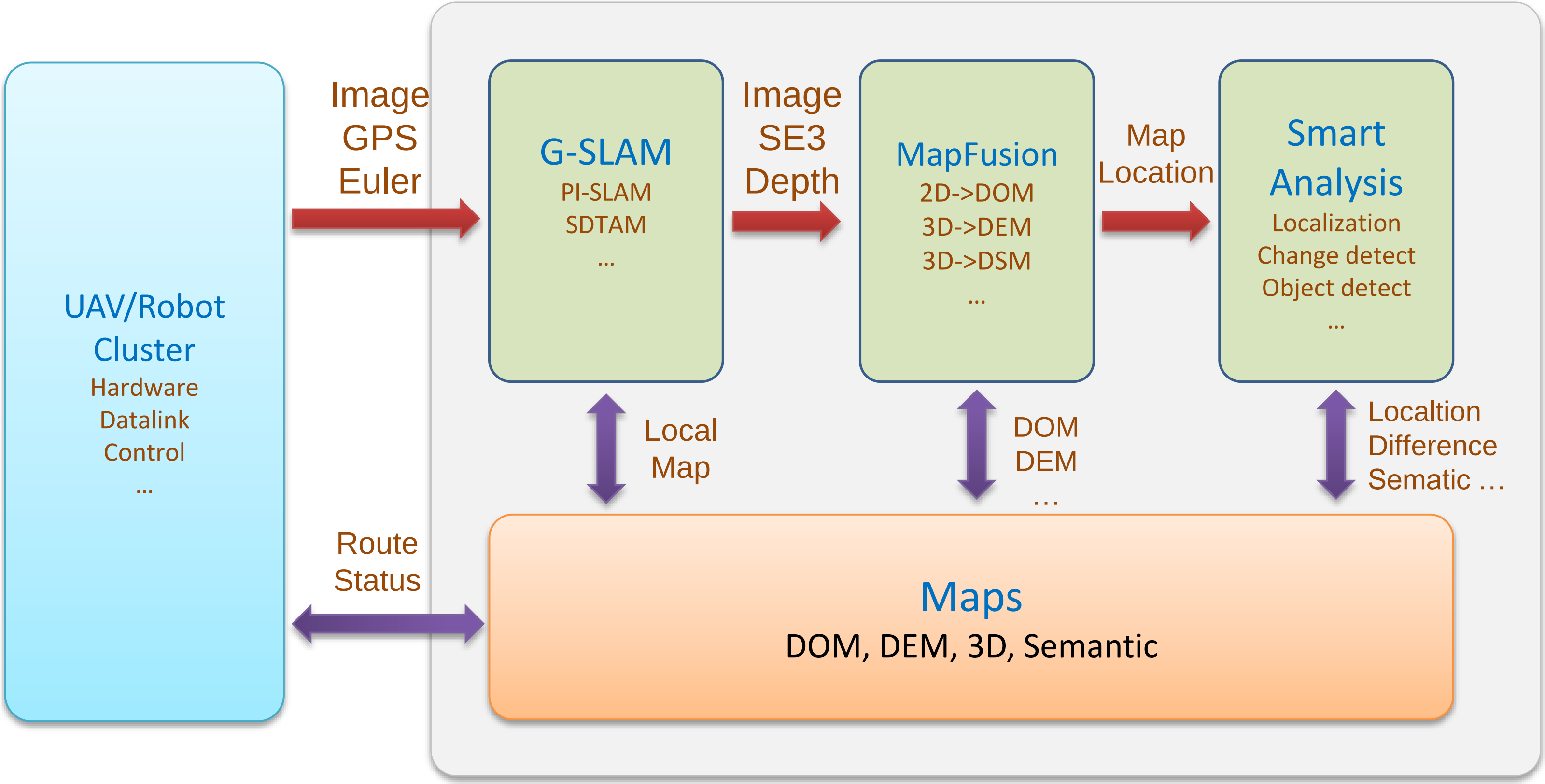
RT MAPPER

Realtime Mapper





Architecture of RTMapper

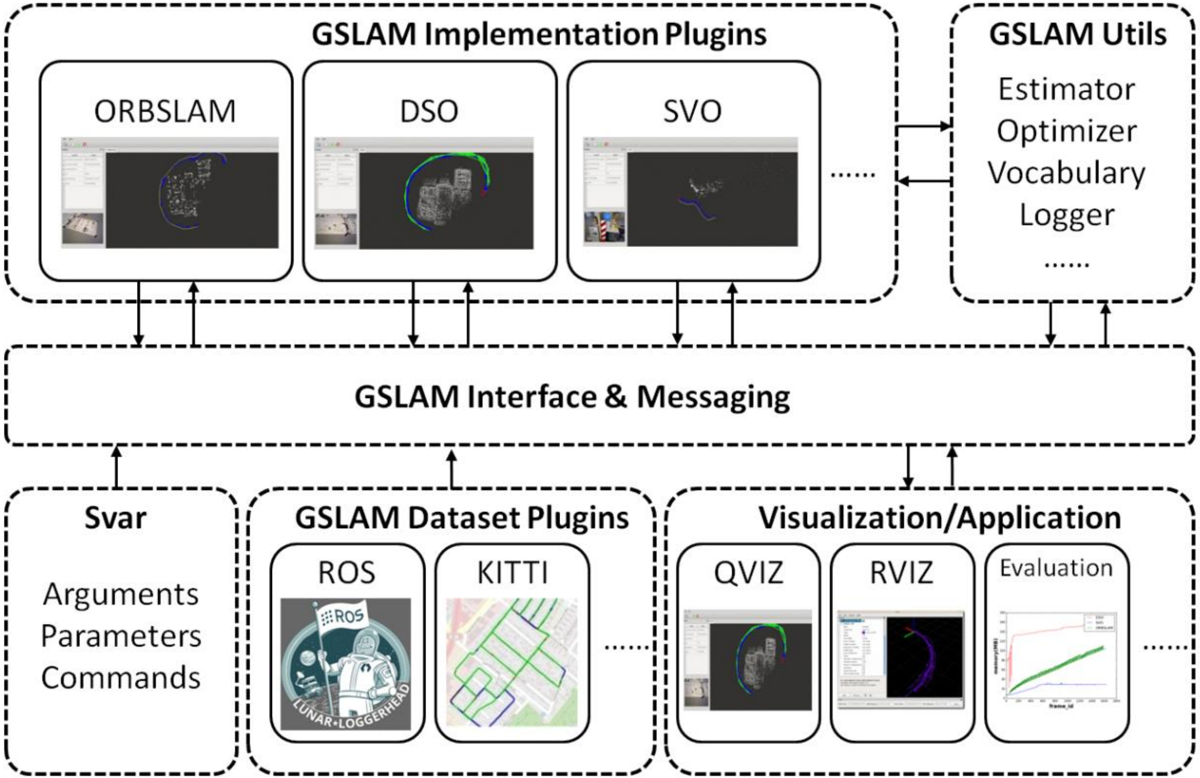


(1) UAV / Platform

- Robustness
- Simple Operation

- Realtime map creation
- G-SLAM/RTMapper

（2）G-SLAM



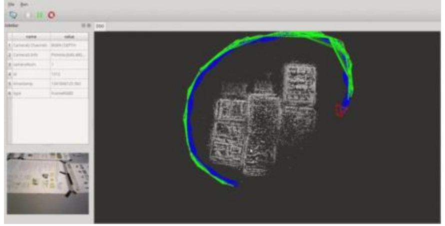
- General platform for SLAM development
- Plugin architecture
- High performance components/utils
- C++ 11
- Python/Javascript bindings

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

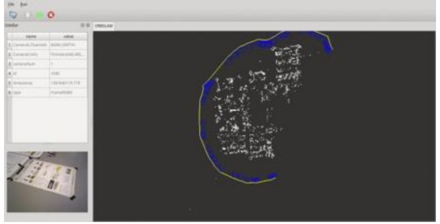
https://github.com/zdzhaoyong/GSLAM

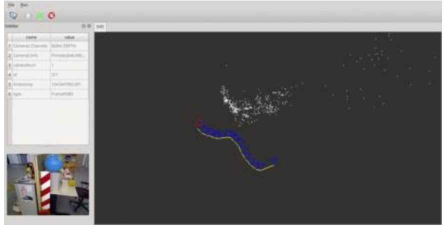
（2） G-SLAM – Implemented SLAMs

DSO

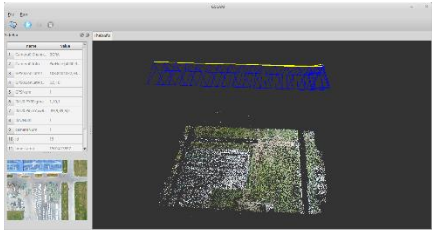


ORB-SLAM

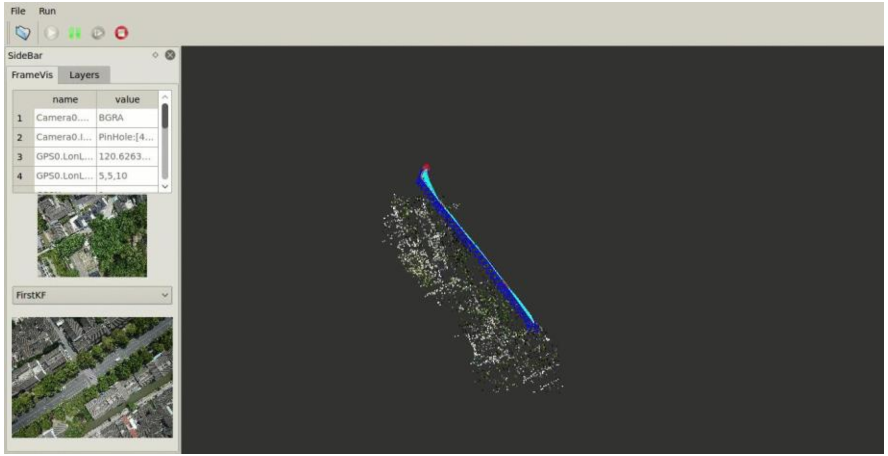




SVO



TheiaSfM



PI-SLAM

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

https://github.com/zdzhaoyong/GSLAM

（2） G-SLAM – 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	-

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]	-	-	-

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

Visual Vocabulary

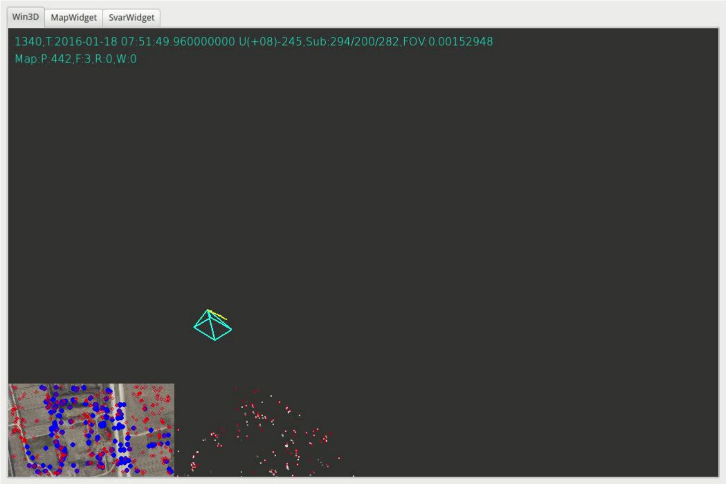
Implementation		Ours	DBoW2	DBoW3	FBoW
Load	*ORB-4*	**67.3us**	47.2ms	7.1ms	72.3us
	ORB-6	**7.2ms**	6.8 s	1.1 s	9.5ms
	SIFT-4	**1.0ms**	436.1ms	5.1ms	1.1ms
Save	*ORB-4*	**437.9us**	40.4ms	1.7ms	553.1us
	ORB-6	34.4ms	4.8 s	632.4ms	**20.6ms**
	SIFT-4	4.4ms	437.6ms	6.7ms	**2.7ms**
Train	*ORB-4*	**7.6 s**	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

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

https://github.com/zdzhaoyong/GSLAM

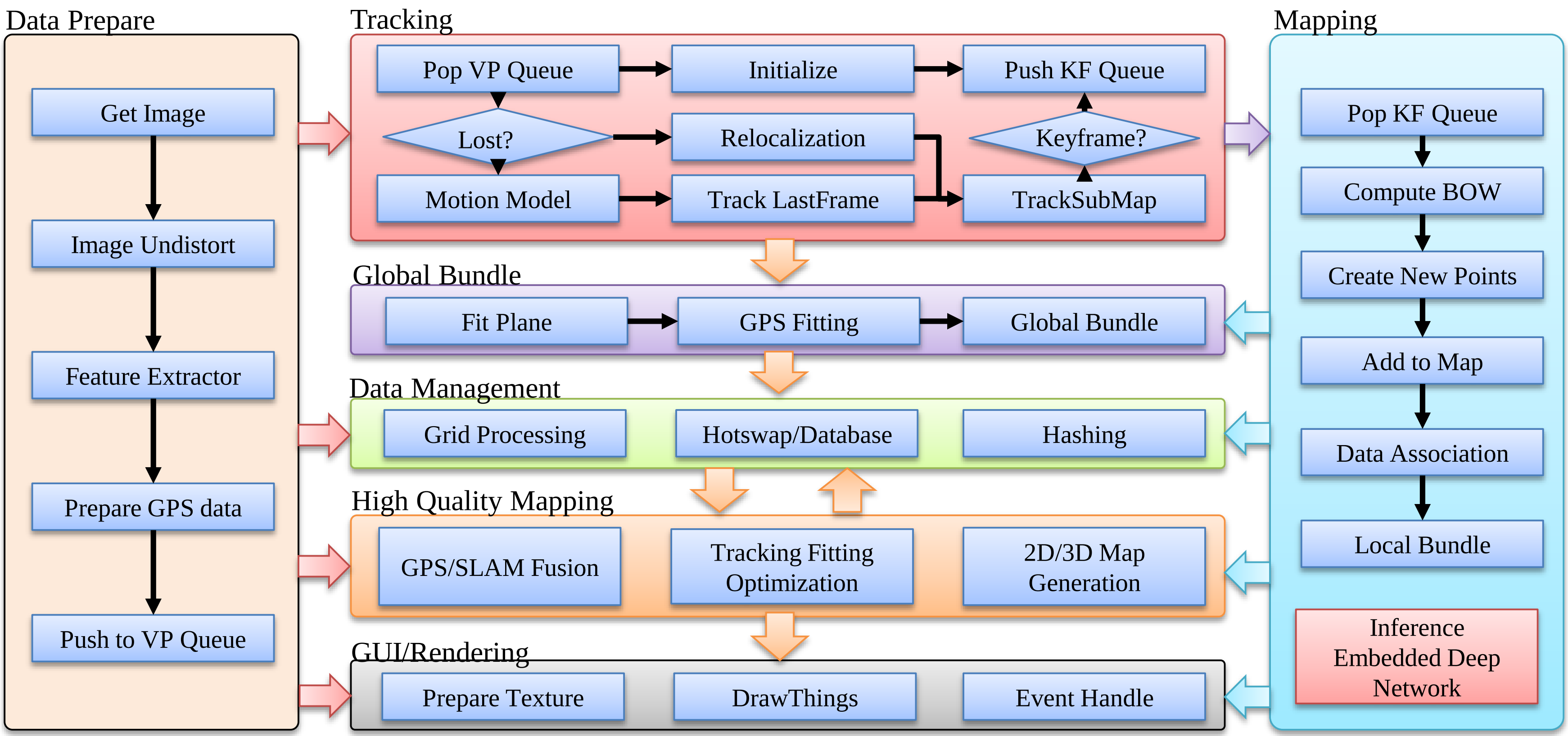
（2） G-SLAM： PI-SLAM

Pilot Intelligent SLAM
（PI-SLAM）



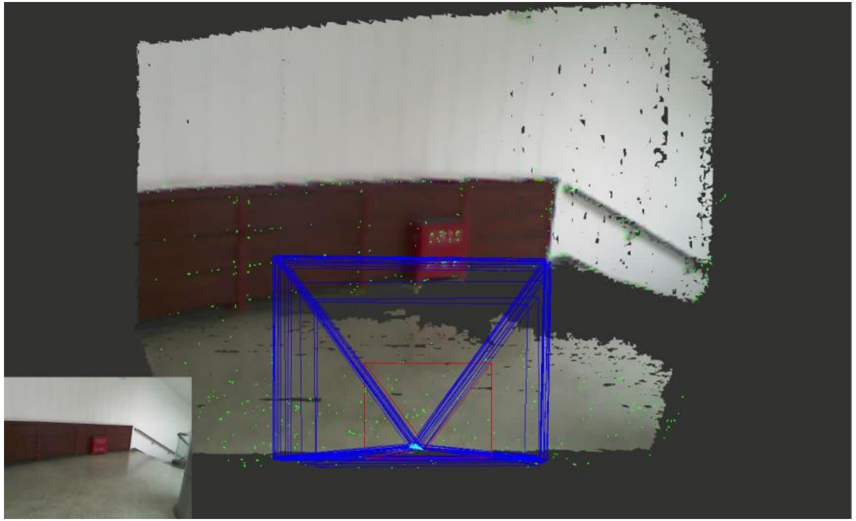
- **High processing speed**： 30 FPS for 1080p images
- **Balance between SLAM and SfM:** Support 40M pixel photo with high processing speed
- **Multisource fusion**： Vision and GPS data can be joint optimized
- **Realtime DOM/DSM**: Adaptive multi-band method for realtime DOM generation
- **large area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

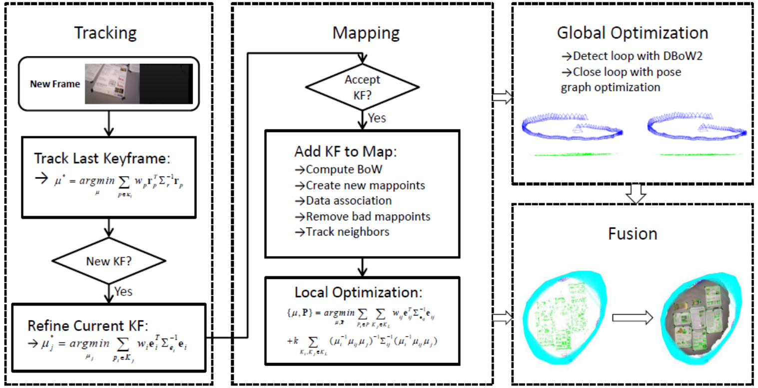
（2）G-SLAM： PI-SLAM



（2） G-SLAM： SDTAM

Semi-direct Tracking and Mapping

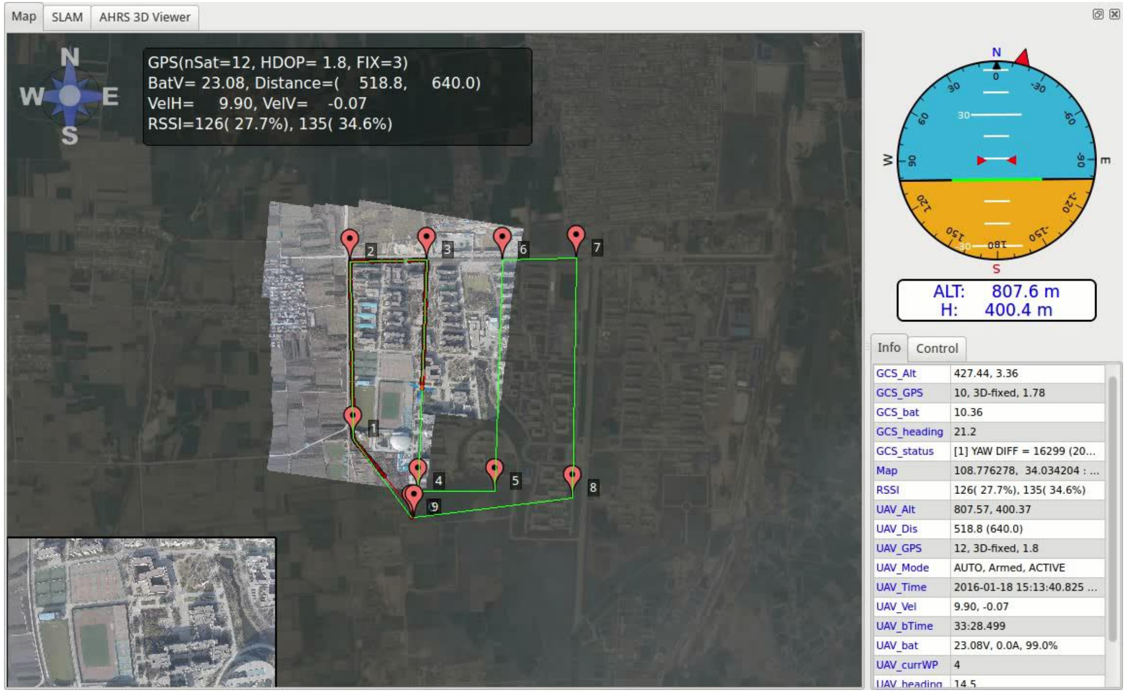




- Use direct method to fast tracking new frame’s position, and then use keypoint method to realize precisely optimization
- Define a novel error function which incorporate depth and geometric measures
- Speed and accuracy balance can be achieved

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

（3） MapFusion

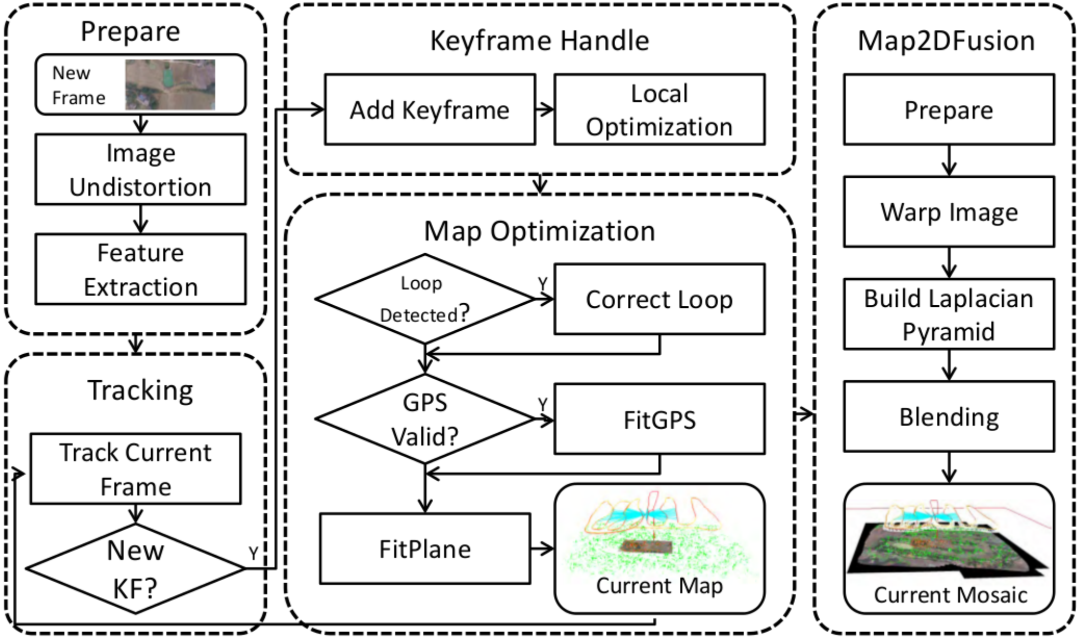


- Realtime fuse 2D maps (DOM), 2.5D maps (Terrain), 3D (Mesh)
- Capability of extension
- Integrating data process / analysis

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

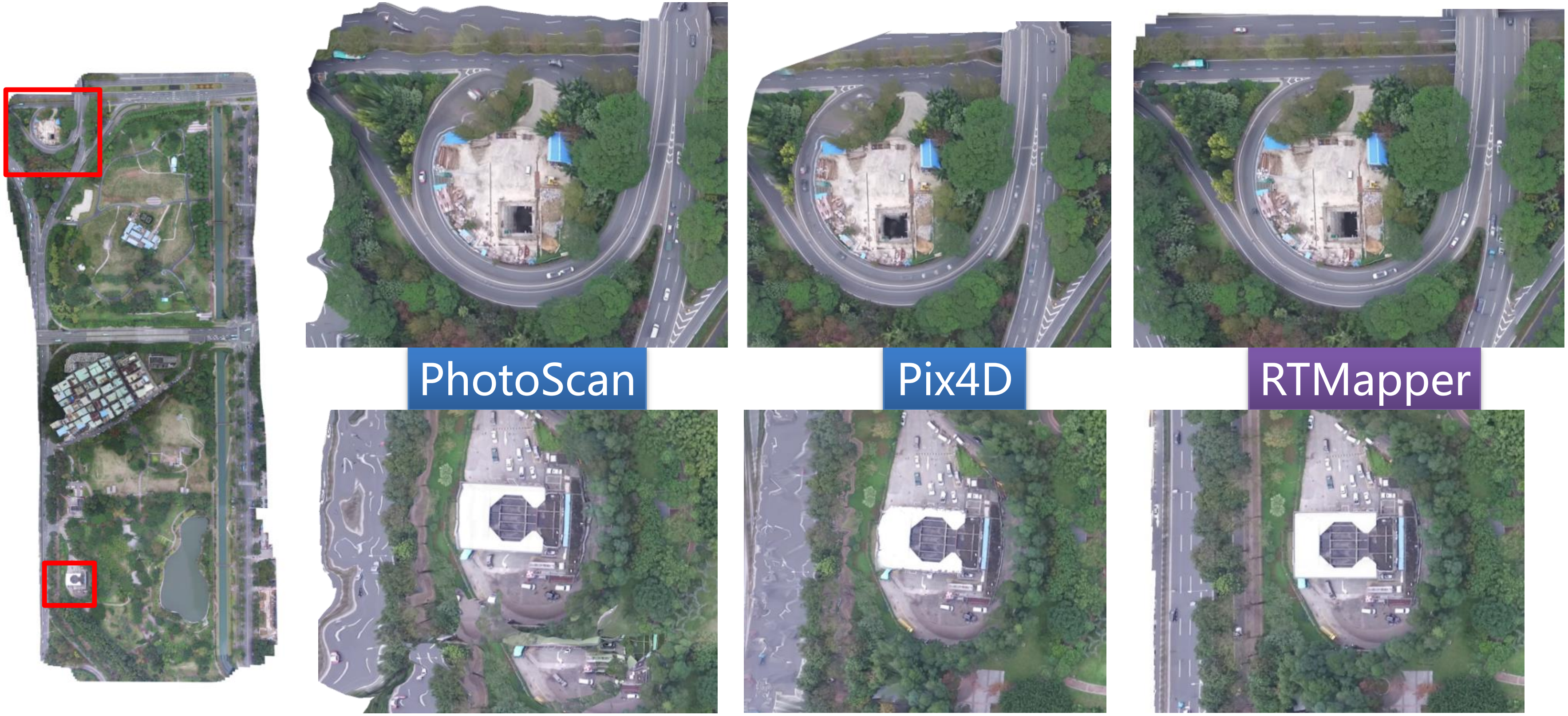


- **Feature based Visual SLAM System: PI-SLAM**
- **Automatic GPS and video synchronization**: a graph based optimization is proposed to synchronize video time with GPS time from coarse to fine.
- **Real-time orthoimage blender**: an adaptive weighted multi-band method to blend and visualize images incrementally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

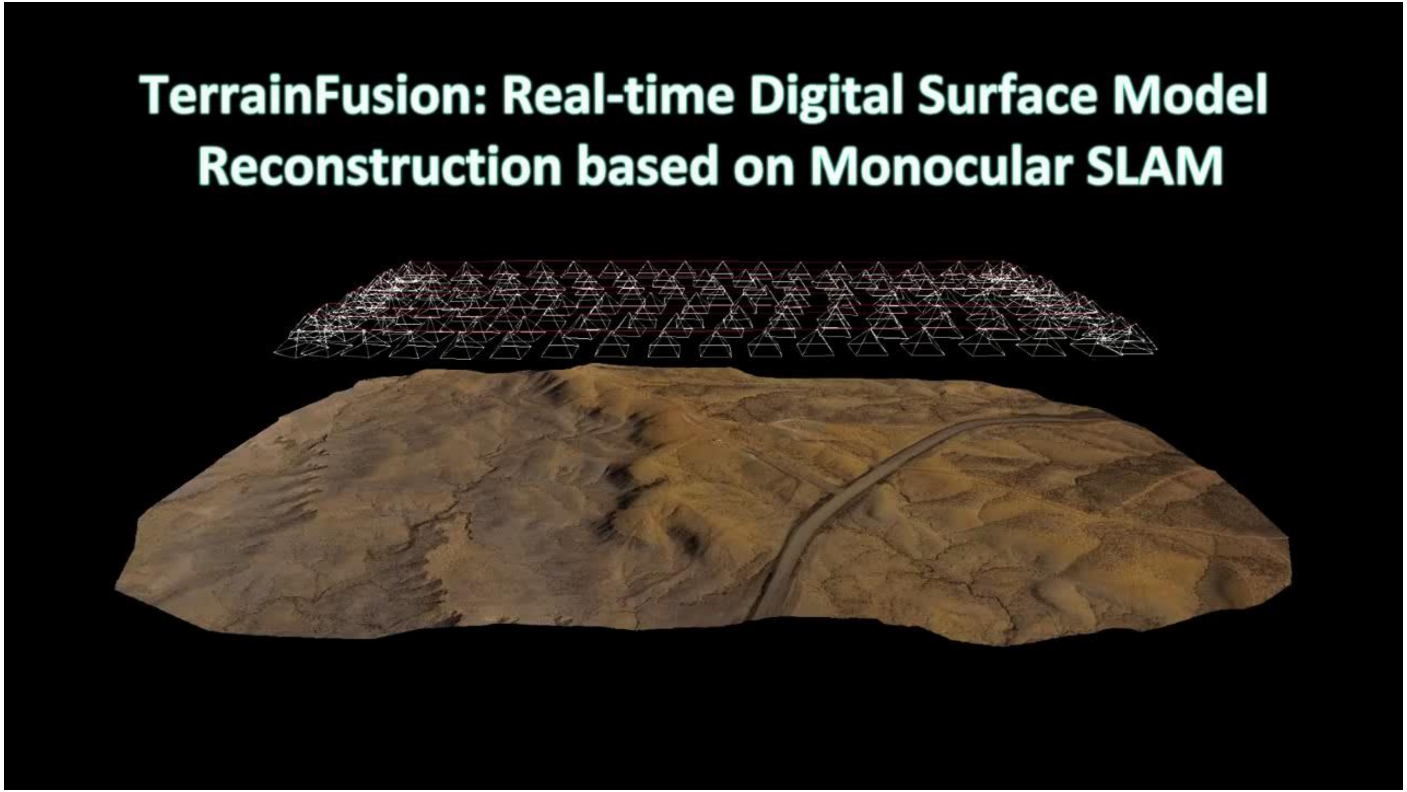
Shuhui Bu, Yong Zhao, et al., Map2DFusion: Real-time Incremental UAV Image Mosaicing based on Monocular SLAM, IROS, 2016

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

（3） MapFusion – Map2DFusion

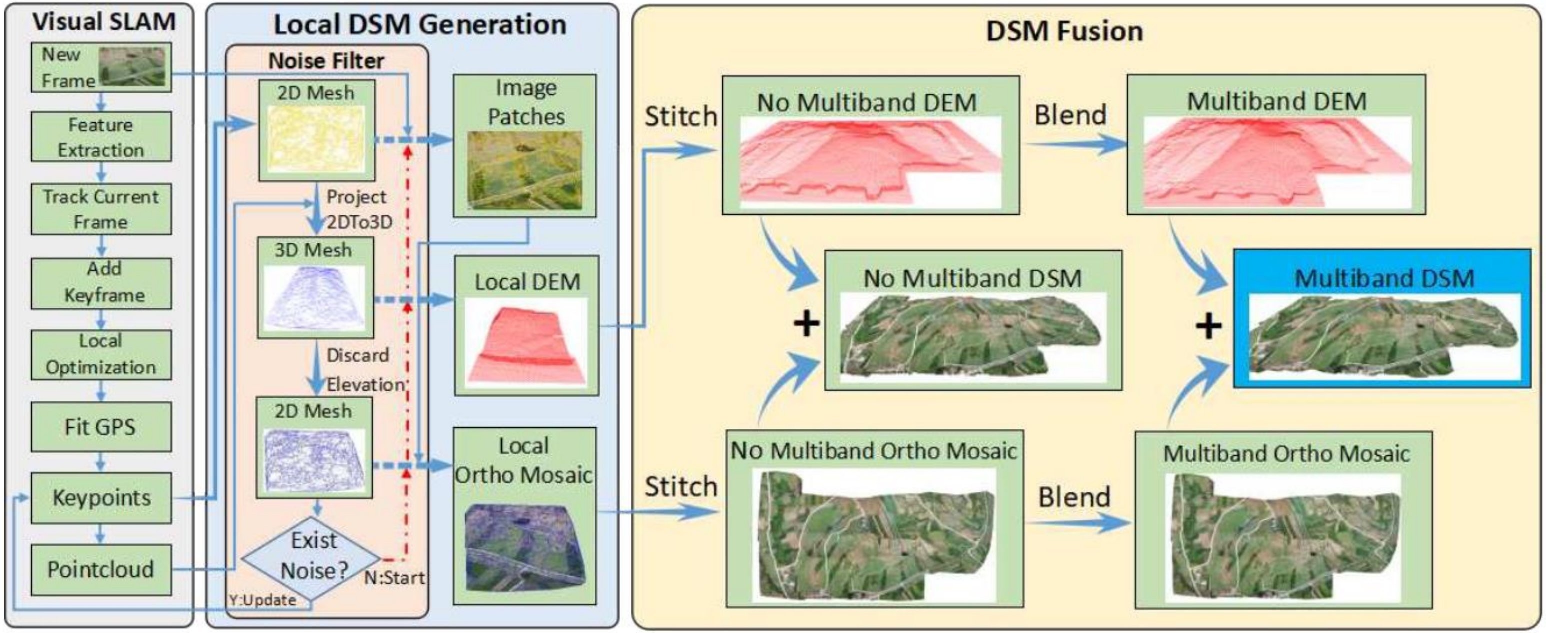


（3） MapFusion – TerrainFusion



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

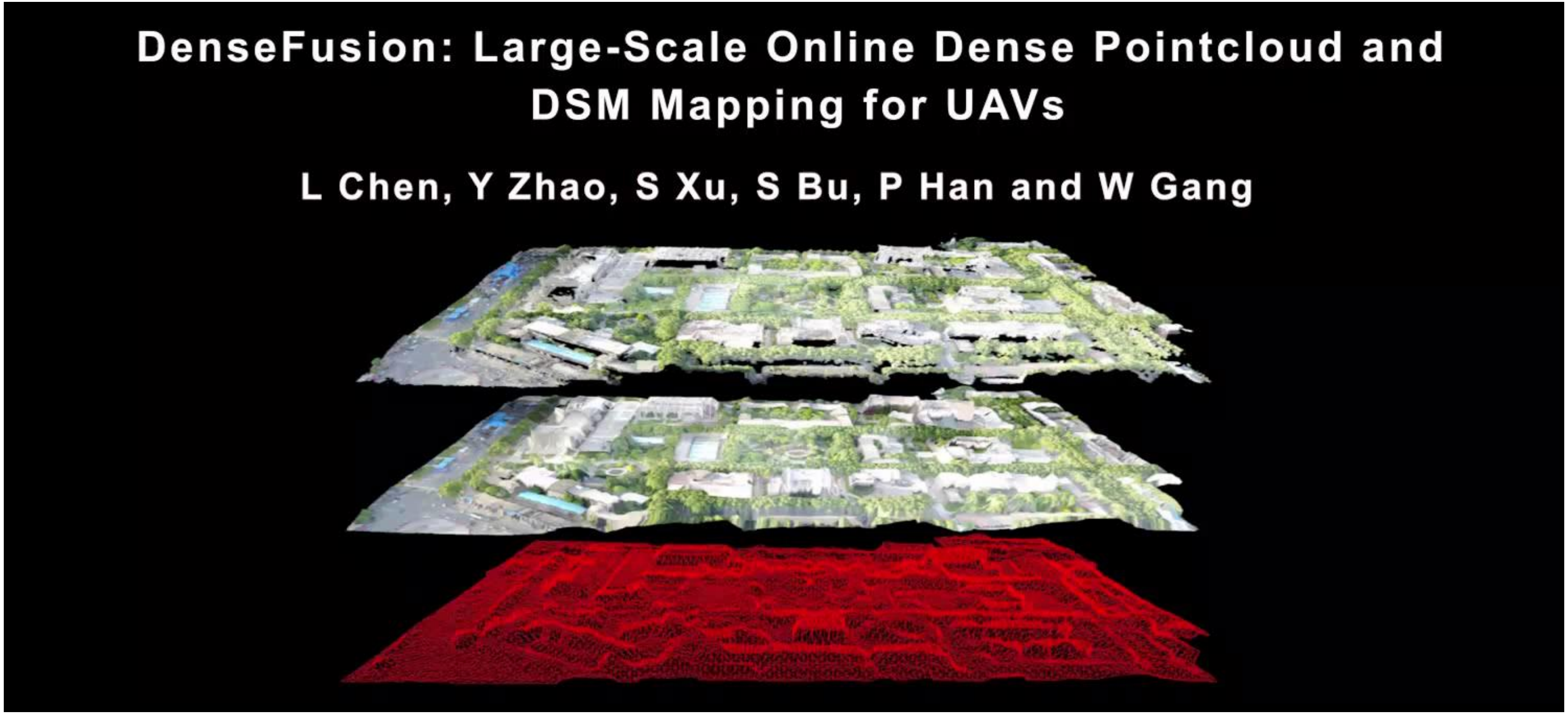
（3） MapFusion – TerrainFusion



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

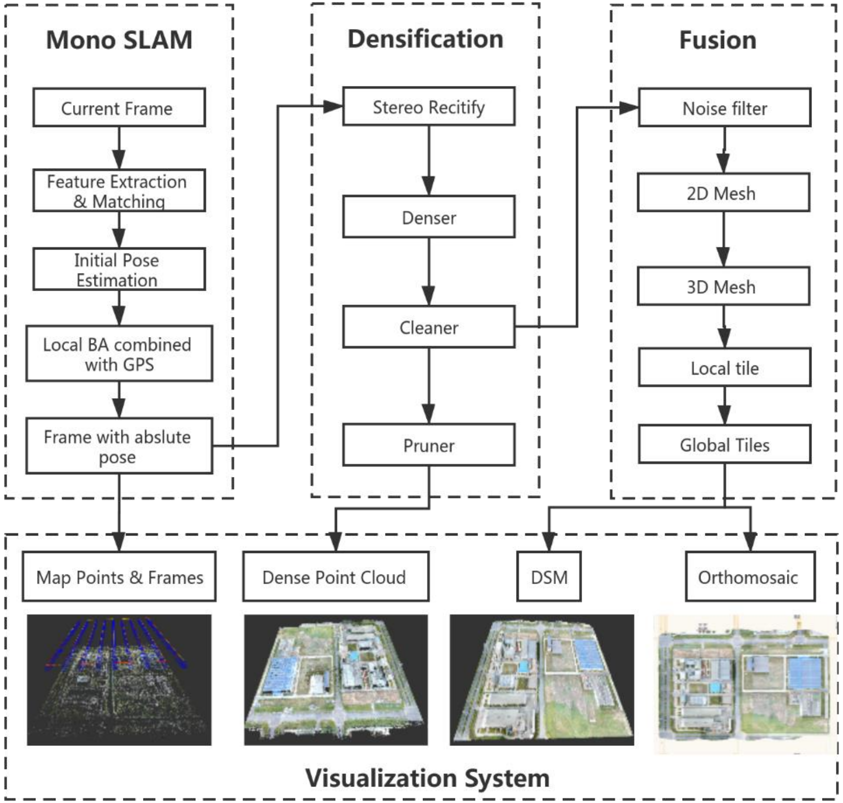
Wei Wang, et al., TerrainFusion:Real-time Digital Surface Model Reconstruction based on Monocular SLAM, iROS 2019

（3） MapFusion – DenseFusion



Lin Chen, et al., DenseFusion: Large-scale Online Dense Pointcloud and DSM Mapping for UAVS, iROS 2020

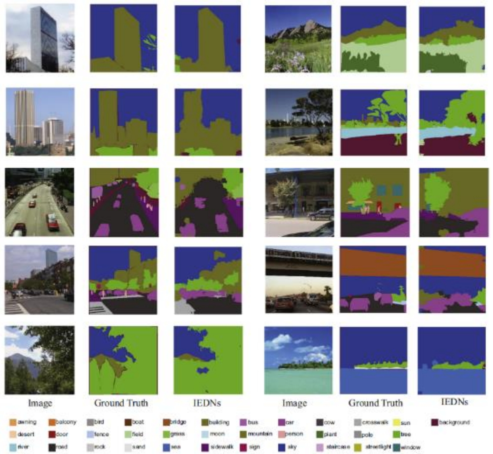
（3） MapFusion – DenseFusion



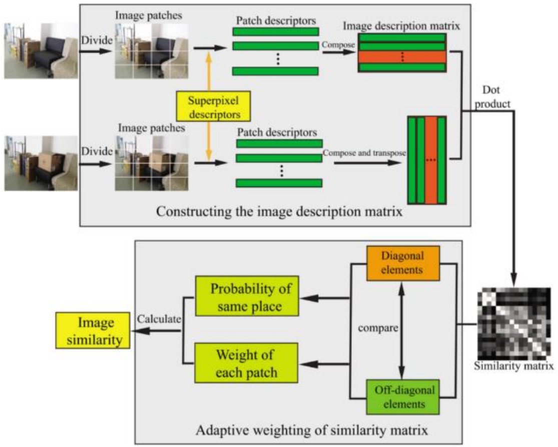
- Realtime and fast 3D dense pointclound and DSM generation
- Improved DOM quality
- Large area support

Lin Chen, et al., DenseFusion: Large-scale Online Dense Pointcloud and DSM Mapping for UAVS, iROS 2020

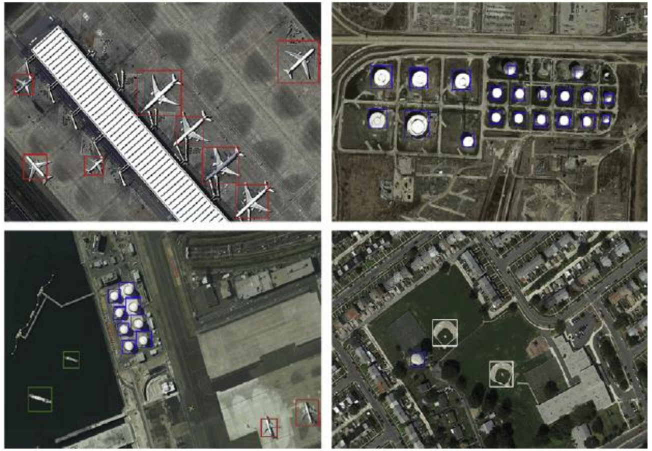
(4) SmartAnalysis



Scene Segmentation



Scene Recognition

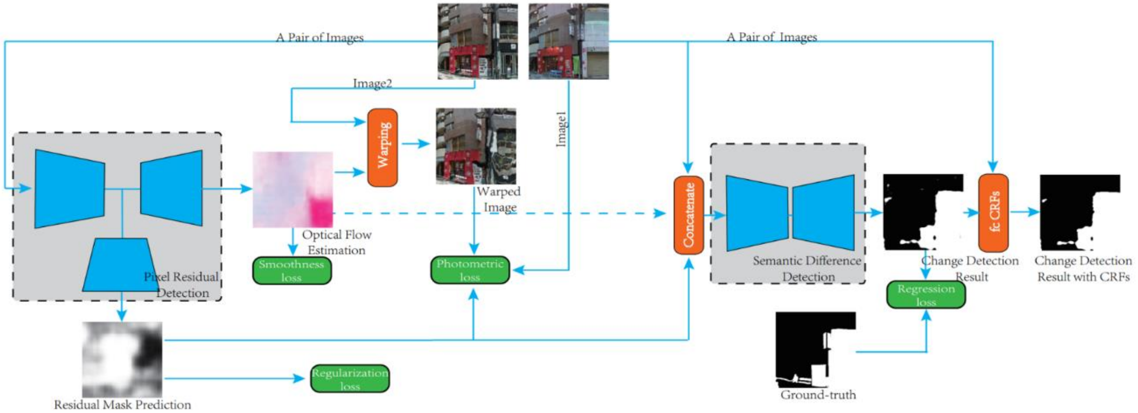


Object Recognition

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) SmartAnalysis – Change Detection

Input 1 Input 2 Detected Changes

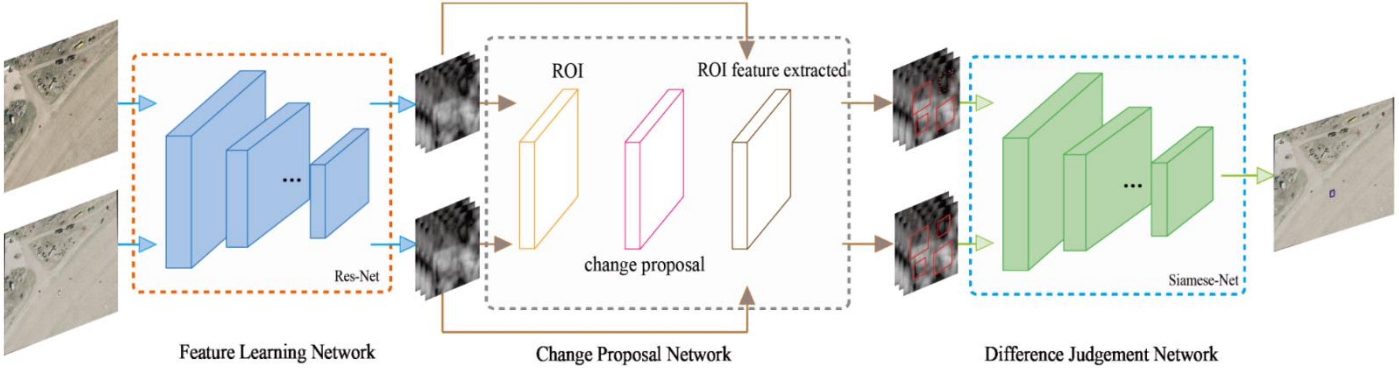


Shuhui Bu, et al., Pixel-level Semantic Change Detection using Mask-CDNet

(4) SmartAnalysis – Change Detection

Input 1 Input 2 Detected Changes

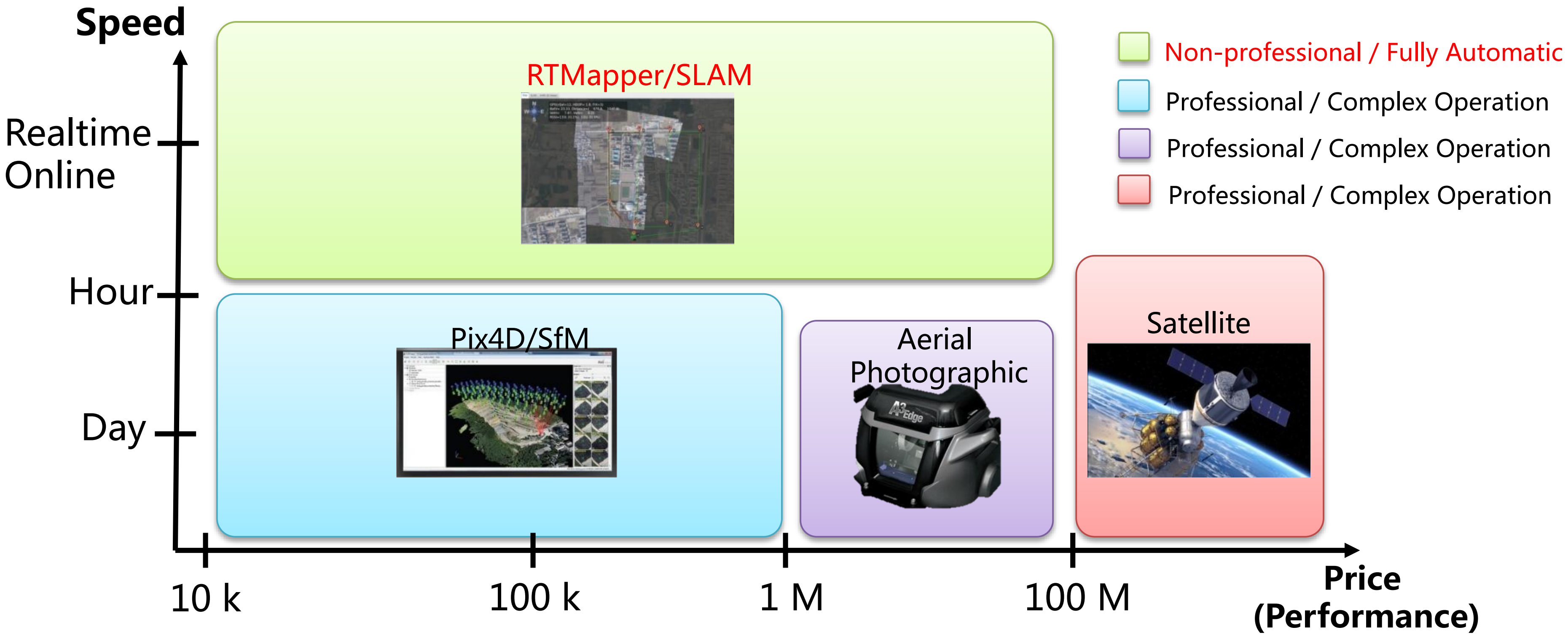
Input 1 Input 2 Detected Changes



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

Contents

Application - Targets

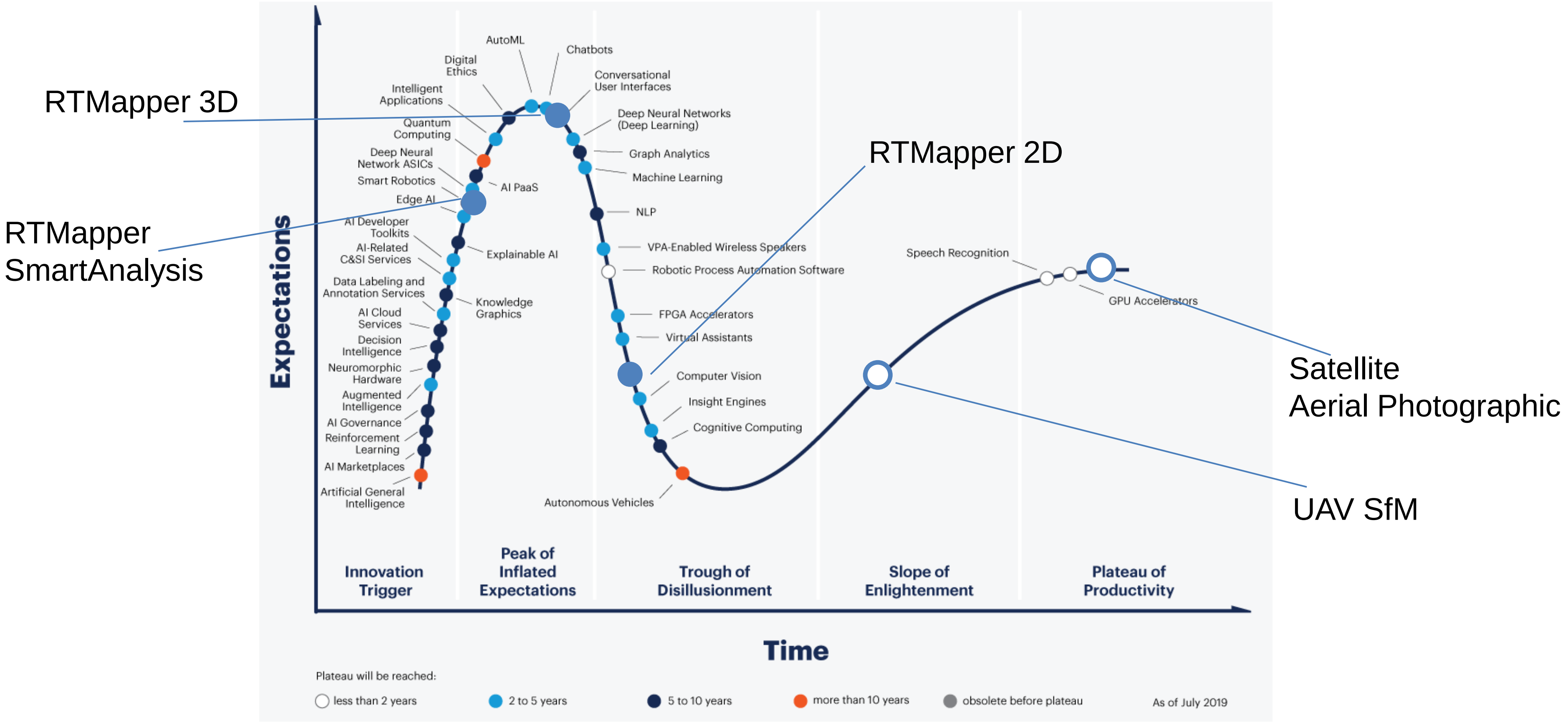


Feature Comparison

	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/

Hype Cycle



RTMapper 3D
RTMapper SmartAnalysis
RTMapper 2D
Satellite Aerial Photographic
UAV SfM
Expectations
AutoML
Chatbots
Digital Ethics
Conversational User Interfaces
Intelligent Applications
Deep Neural Networks (Deep Learning)
Quantum Computing
Graph Analytics
Deep Neural Network ASICs
Machine Learning
Smart Robotics
AI PaaS
Edge AI
NLP
AI Developer Toolkits
AI-Related C&SI Services
Explainable AI
VPA-Enabled Wireless Speakers
Robotic Process Automation Software
Speech Recognition
GPU Accelerators
Data Labeling and Annotation Services
Knowledge Graphics
AI Cloud Services
FPGA Accelerators
Virtual Assistants
Decision Intelligence
Neuromorphic Hardware
Computer Vision
Augmented Intelligence
Insight Engines
AI Governance
Cognitive Computing
Reinforcement Learning
AI Marketplaces
Artificial General Intelligence
Autonomous Vehicles
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Time
Plateau will be reached:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau
As of July 2019

Related Technologies

NWPU PI-Lab - Map2DFusion and prototype system

2016 March

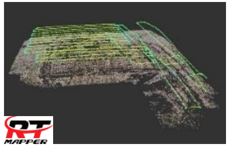
DroneDeploy - FieldScanner

2017 April

Lockhead Martin – Hydra Fusion Tool

2017 May

NWPU PI-Lab – RTMapper



2017 June

Sibitu – Sibitu Desktop/Mobile

2019 March

DJI – DJI-Terra

2019 April

Pix4D – Pix4Dreact

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

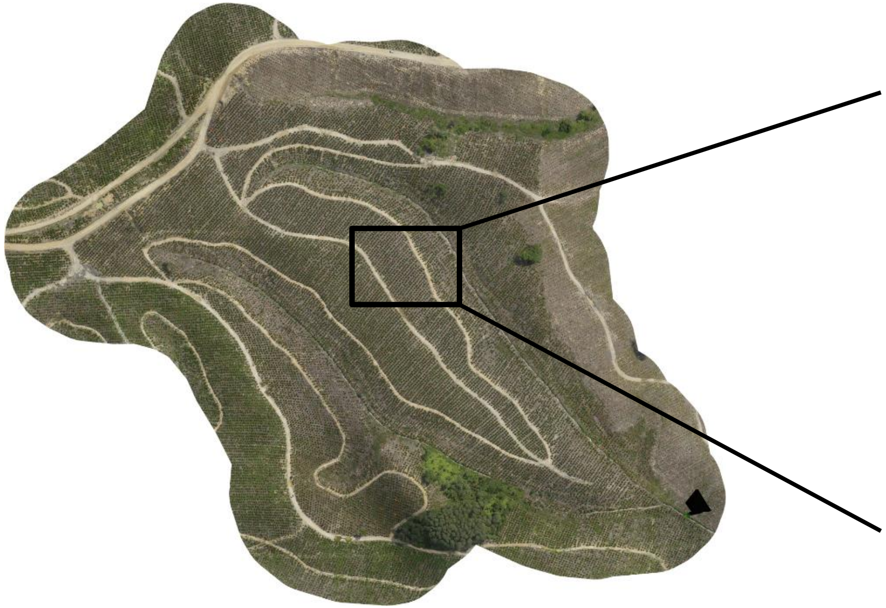
Simple and easy-to-use map creation with high performance, fully automatic control of plant protection UAV

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

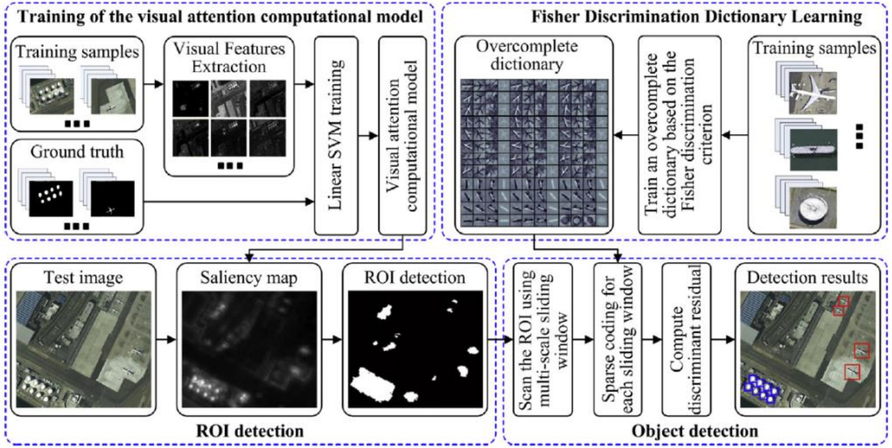
Application – Object Detection & Analysis (1)

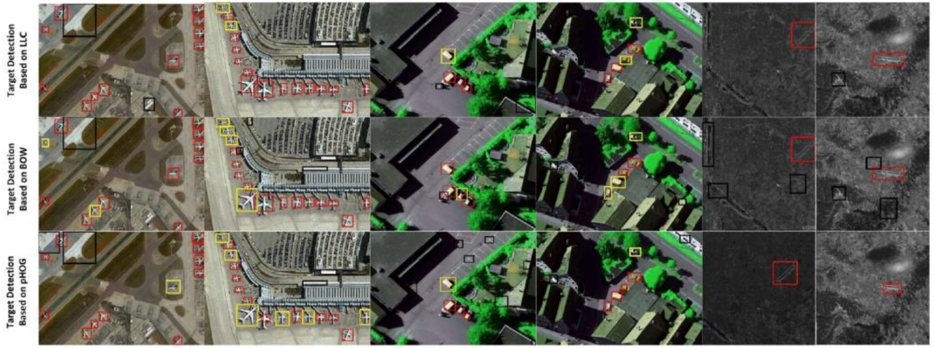


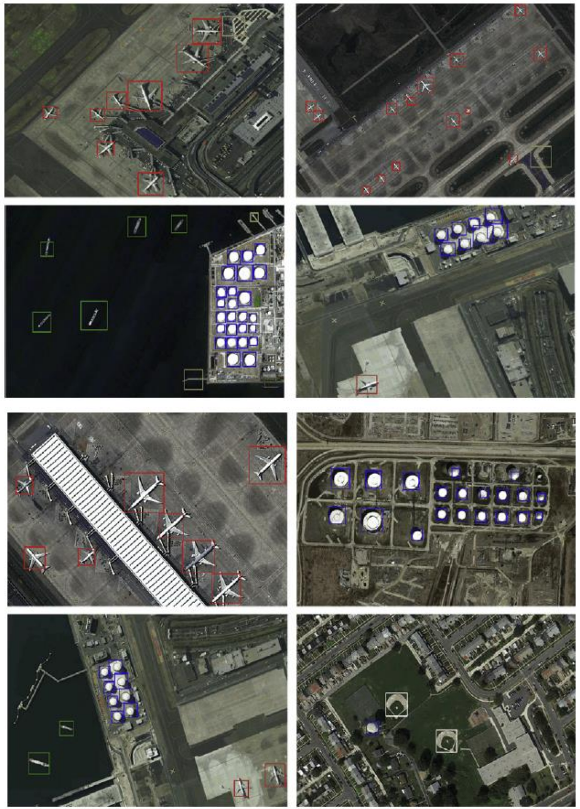
Plantation mapping

Tree detection and counting

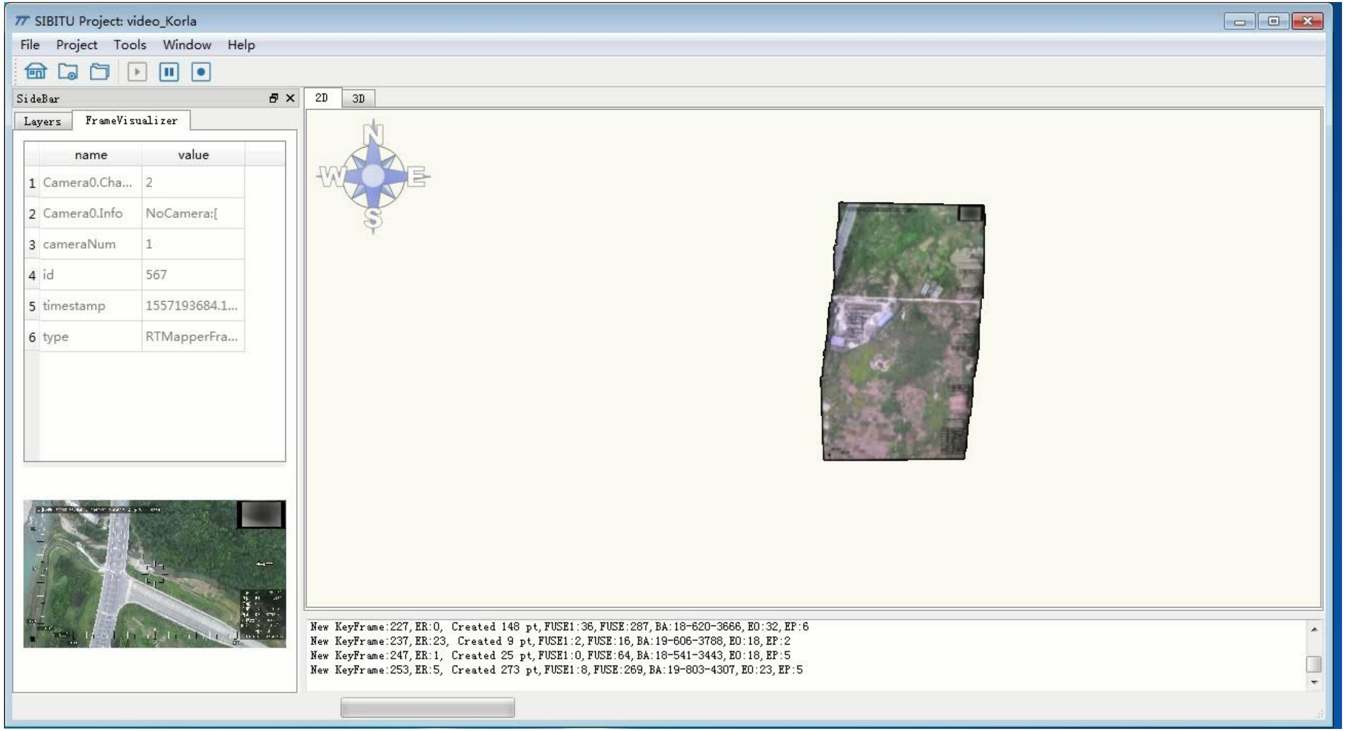
Application – Object Detection & Analysis (2)







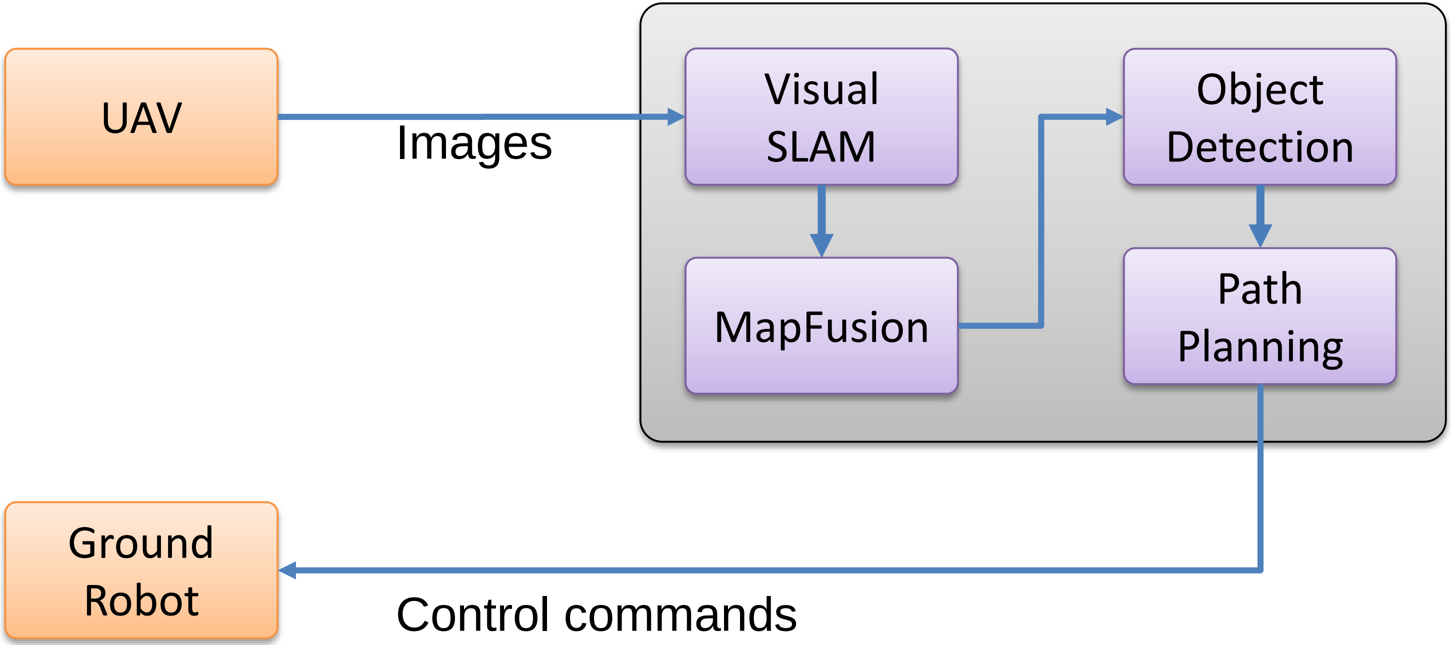
Application – Surveillance



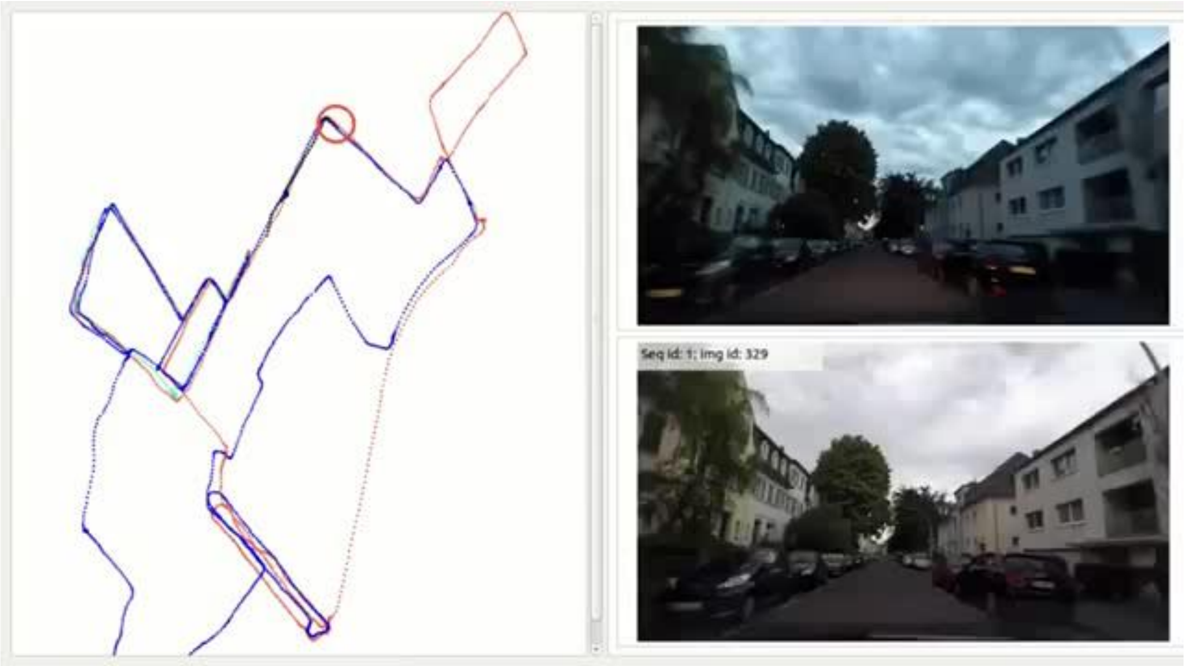
Video surveillance

Application – Cooperation

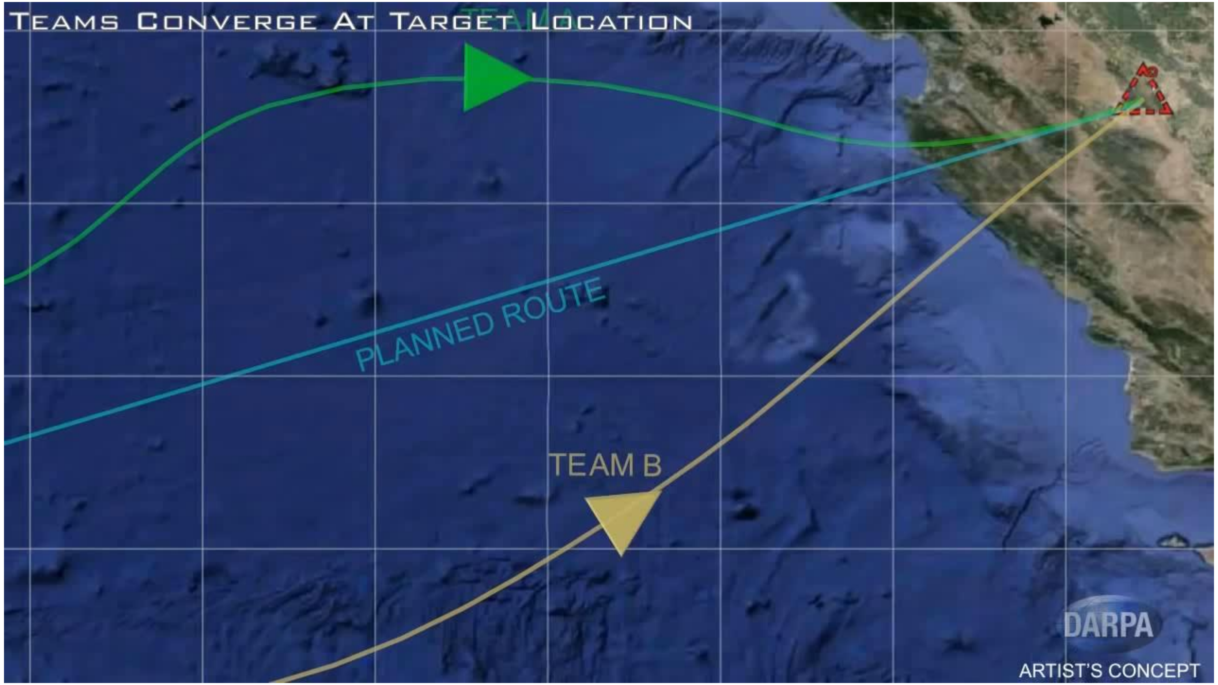
Application – Cooperation



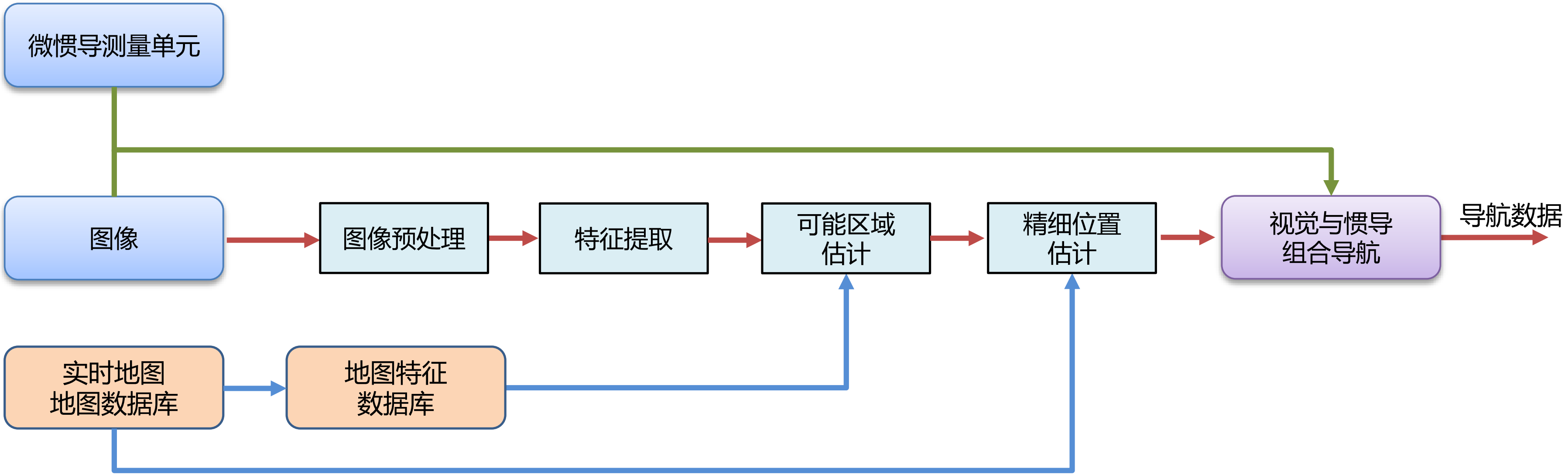
Application – Smart Navigation



Application – Smart Navigation



Application – Smart Navigation



Application – Autonomous Control

Color & Depth Images

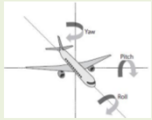
Flight Control

Path Planning

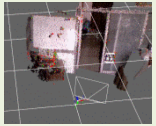
Obstacle Avoidance

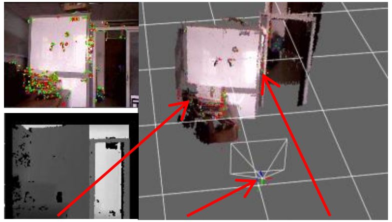
Align color and depth image

Estimate position and attitude



Select keyframe and update map



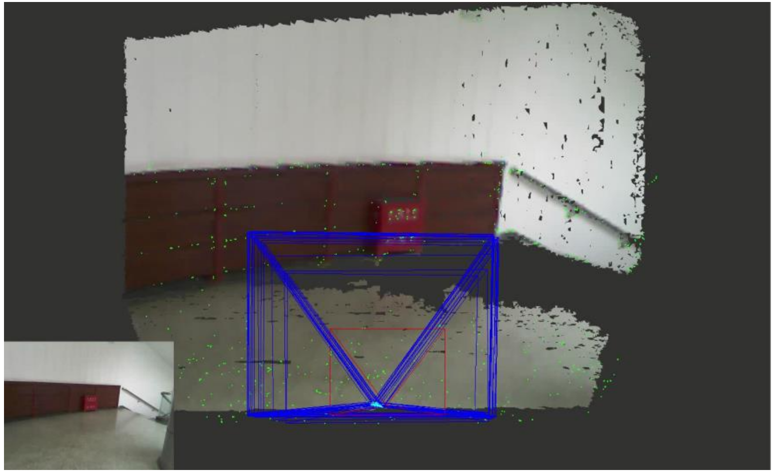


Feature point

Keyframe

Point cloud

Application – Autonomous Control



Application – Key Technologies

Platforms	UAV / Robot Cluster and Cooperation

Applications

Situational Awareness	Complex Environment / Cluster Navigation	Target Localization	Surveillance	Damage Assessment

Key Technologies

- IMU & SLAM for robust estimating position and attitude.
- Realtime and fast 2D/3D environment mapping.
- Object detection / segmentation / change detection / localization from realtime maps.
- Multi-sensor fusion and integration.
- Mapping architecture for cluster / edge platforms.

Contents

- Background
- RTMapper
  - G-SLAM
  - MapFusion
  - SmartAnalysis
- Applications
- Conclusion

Future

- Realtime mapping 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