

N L P R

# 城市场景三维重建与结构化表达

申抒含

中国科学院自动化研究所  
模式识别国家重点实验室

<http://vision.ia.ac.cn/Faculty/shshen/index.htm>



# 城市场景三维感知的**共性需求**

航拍  
图像

车载  
图像

全景  
图像

航空  
LiDAR

车载  
LiDAR

背包  
LiDAR

北斗

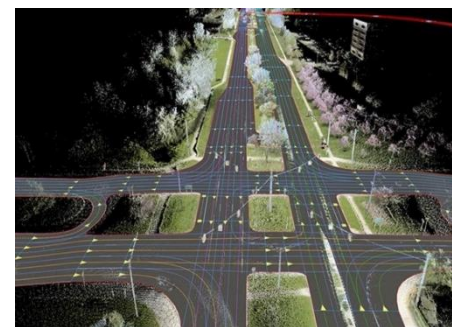
组合  
惯导



数字城市



增强/虚拟现实



无人系统

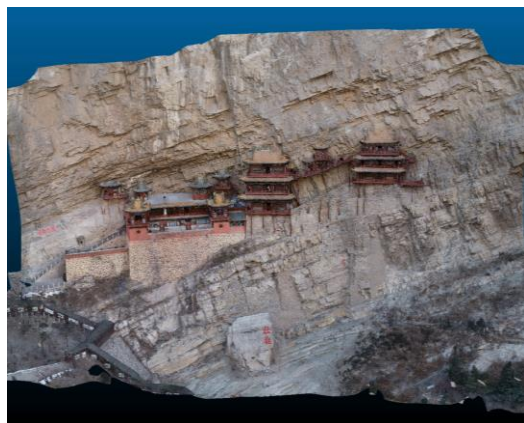
**共性需求：**室内外场景三维表达（低成本、高精度、全自动、高效率）

**关键技术：**以图象为主、其他传感器为辅的数据采集和三维感知技术

# 城市场景三维感知的**特定需求**

影视娱乐  
文化遗产数字化  
虚拟现实

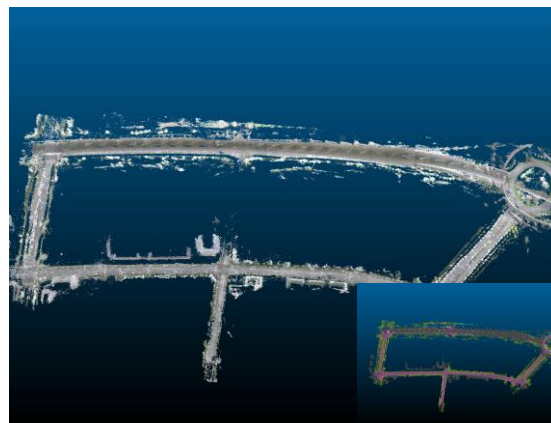
...



场景完整  
几何精确  
细节保持

无人系统  
三维场景理解  
增强现实

...



类别丰富  
语义精确  
更新及时

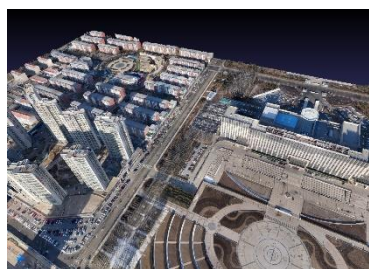
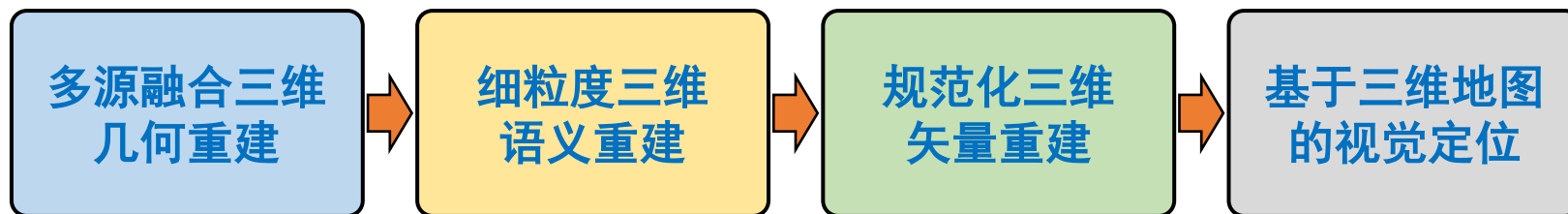
数字城市  
建筑信息管理  
国土资源

...

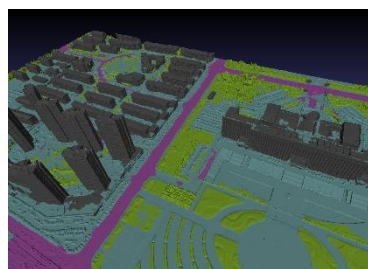


高度结构化  
高度语义化  
合标合规

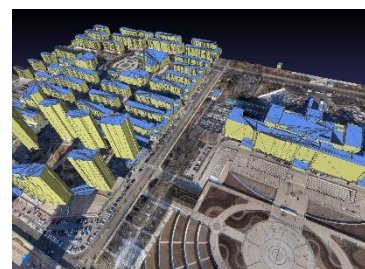
# 城市场景三维重建和视觉定位系统



3D几何模型



3D语义模型

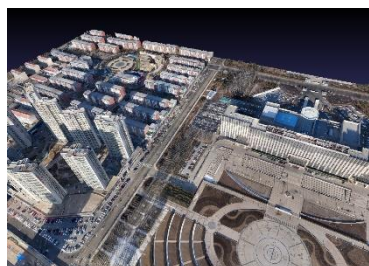
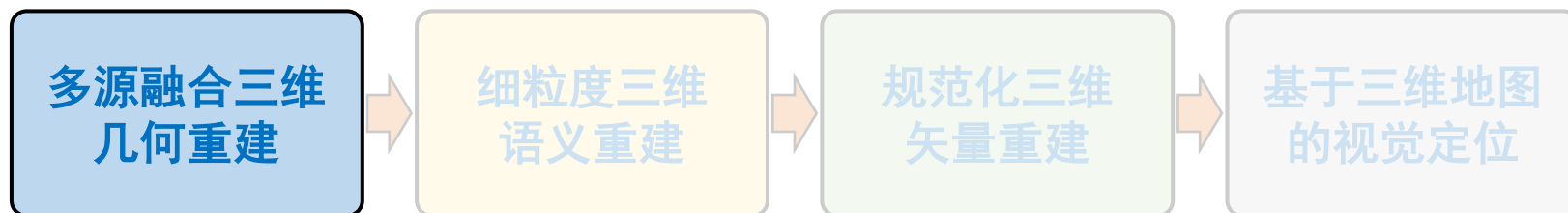


3D矢量模型

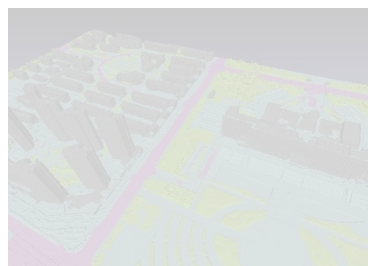


6DoF视觉定位

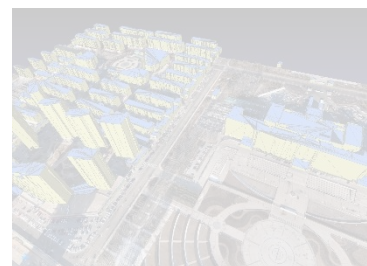
# 多源融合三维几何重建



3D几何模型



3D语义模型



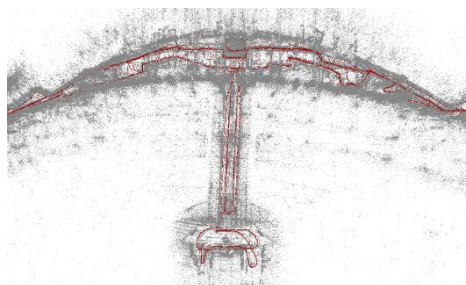
3D矢量模型



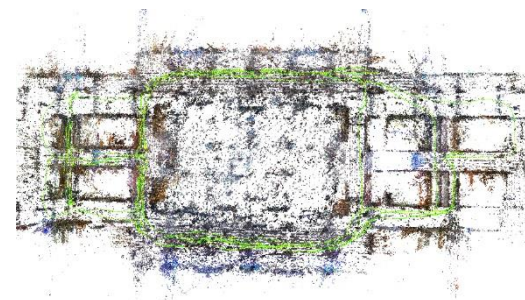
6DoF视觉定位



陕西建华镇倾斜摄影 (1.3万幅)



首都机场T3到达层 (3.7万幅)

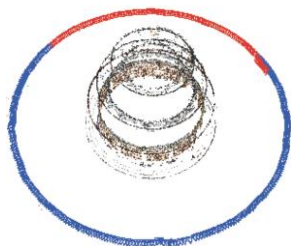


北京南站B1层 (1.7万幅)

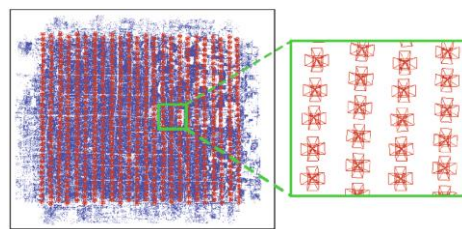
# 多源融合三维几何重建



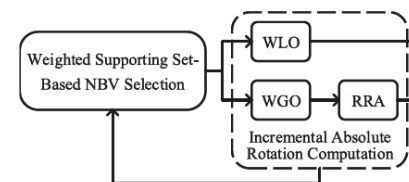
**Hybrid SfM**  
CVPR 2017  
混合稀疏重建



**Progressive SfM**  
3DV 2018  
增量稀疏重建



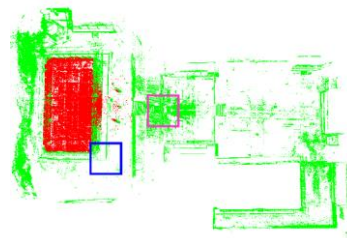
**Tracks Selection in SfM**  
ISPRS P&RS 2019  
增量稀疏重建



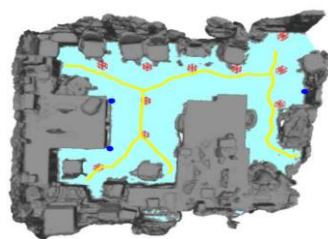
**Incremental RA**  
IJCV 2021  
全局稀疏重建



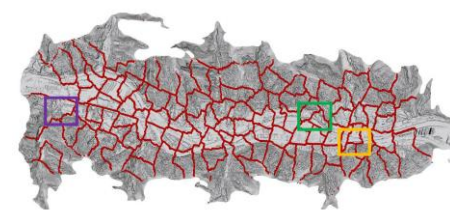
**Aerial and Ground Fusion**  
ISPRS P&RS 2018  
多源融合稠密重建



**Image and Laser Fusion**  
IEEE T-CSVT 2020  
多源融合稠密重建



**Mini Drone and Robot Fusion**  
IEEE Sensor Journal 2021  
多源融合稠密重建



**Large Meshing**  
3DV 2019  
分布式点云网格化

# 多源融合三维几何重建

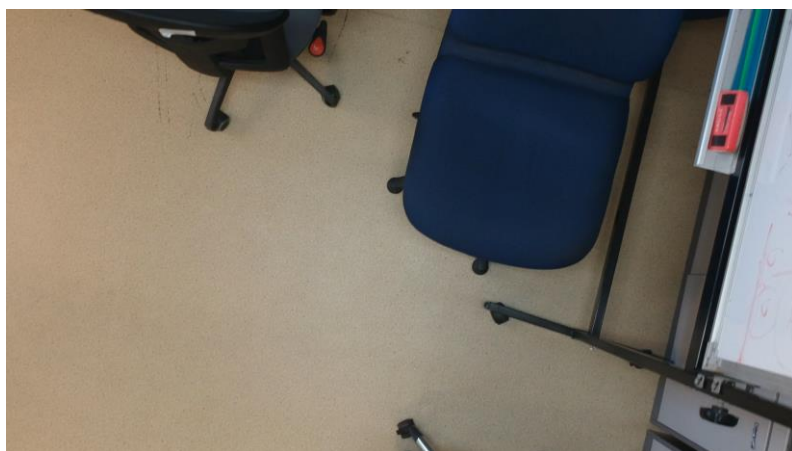
## Complete and Accurate Indoor Scene Capturing and Reconstruction Using a Drone and a Robot

*IEEE Sensor Journal 2021*

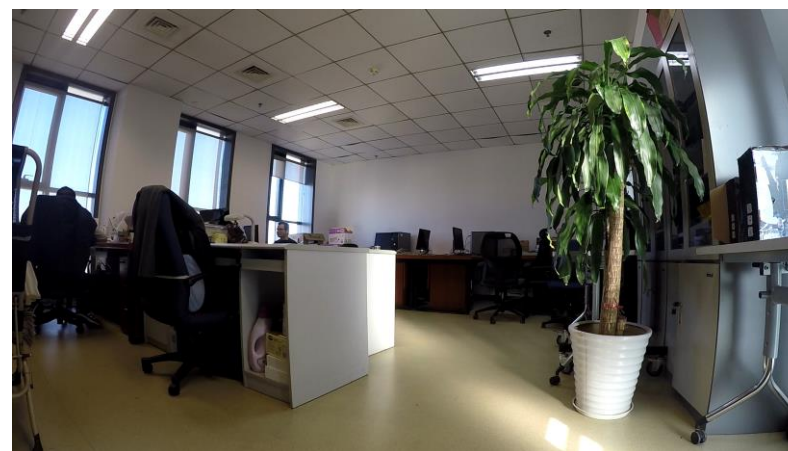


UAV: DJI Spark

Robot: TurtleBot

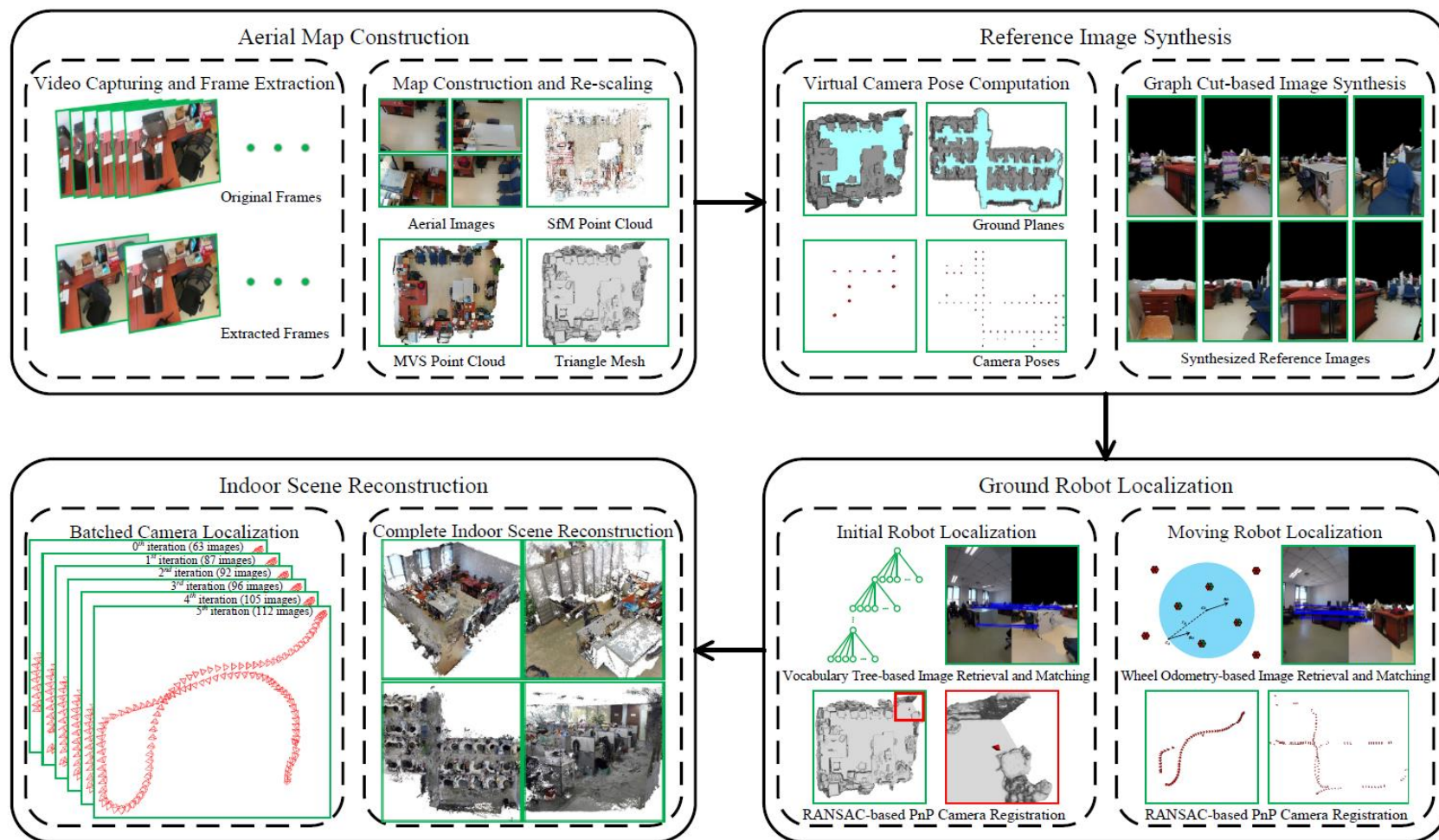


**DJI Spark Video**



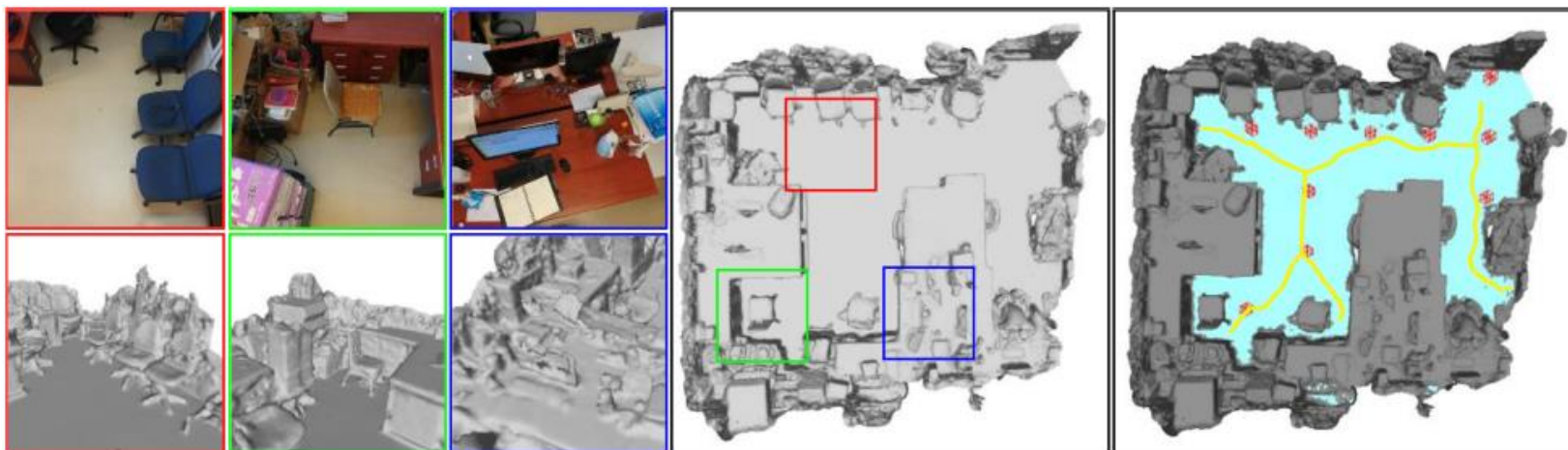
**TurtleBot (GoPro) Video**

# 多源融合三维几何重建

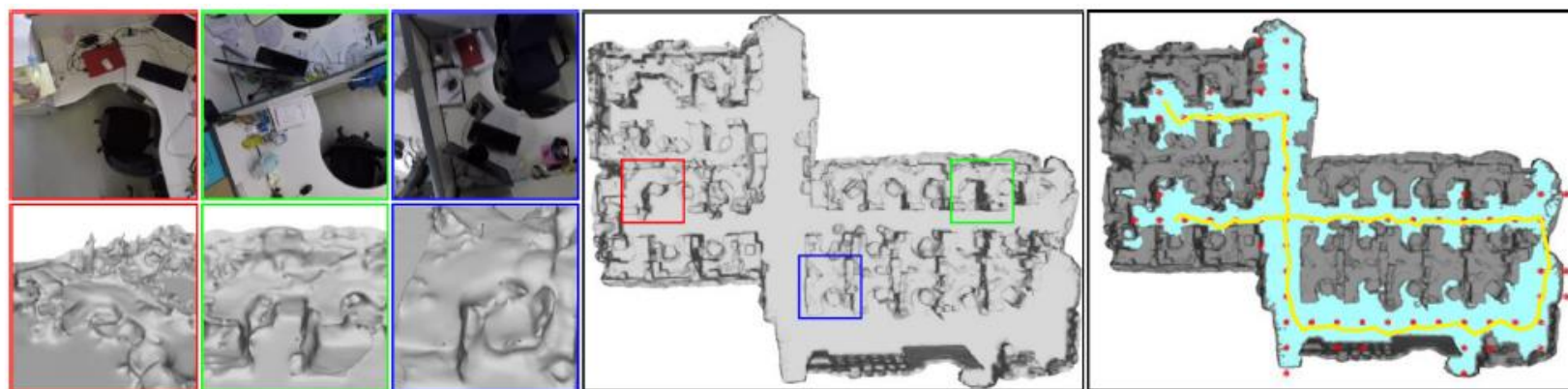


**Pipeline:** 1) aerial map construction, 2) reference image synthesis, 3) ground robot localization, and 4) indoor scene reconstruction

# 多源融合三维几何重建

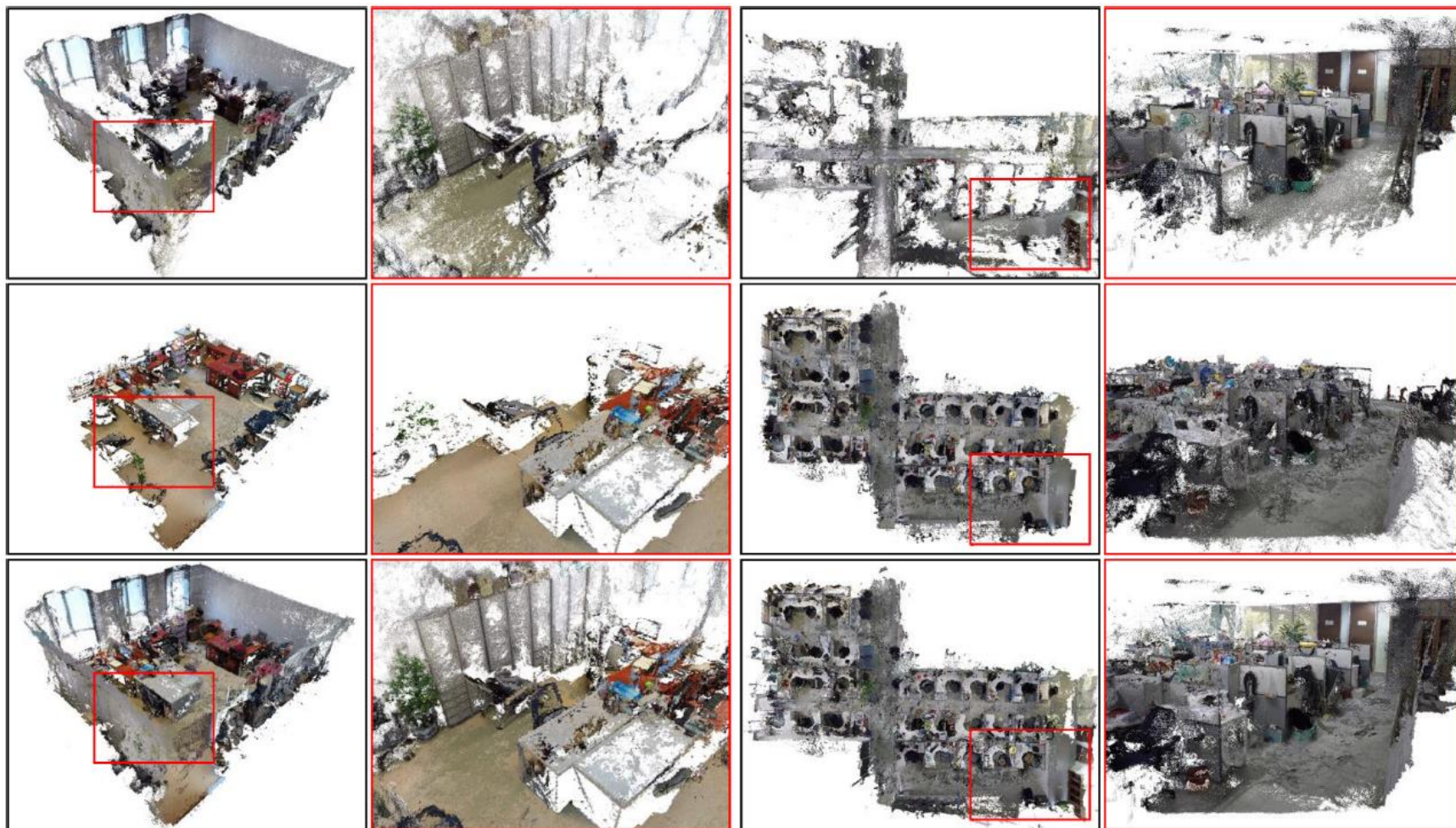


30平方米，218秒视频



130平方米，494秒视频

# 多源融合三维几何重建

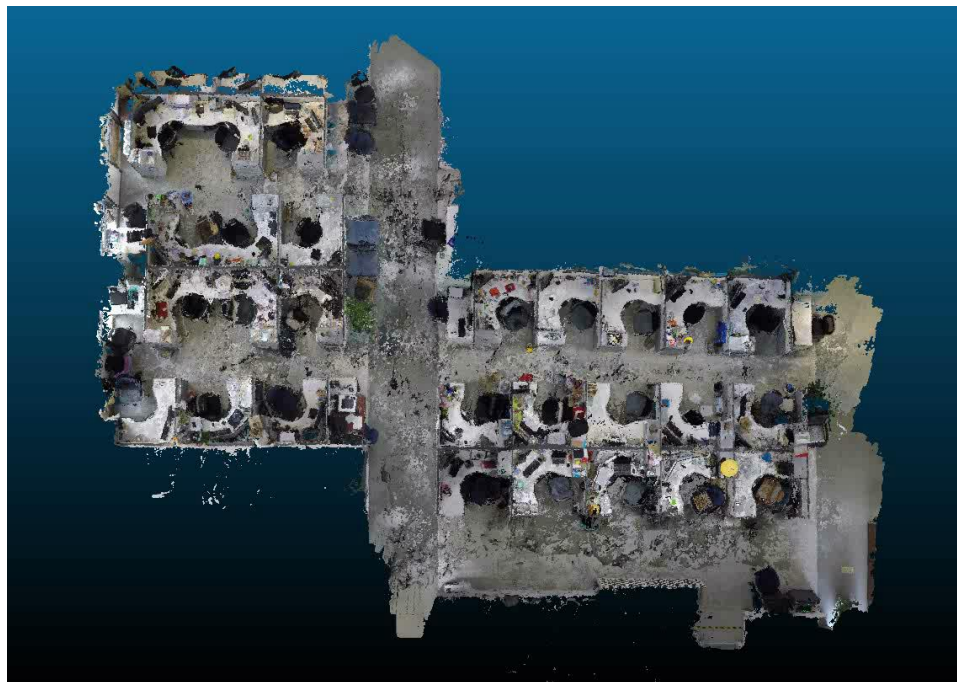


航拍与地面图像融合三维重建

# 多源融合三维几何重建

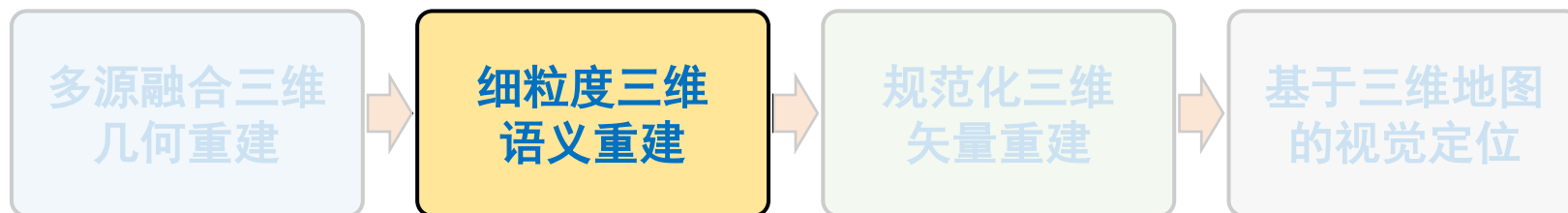


30平方米

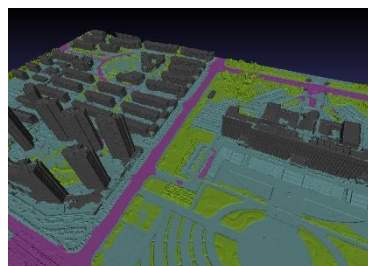


130平方米

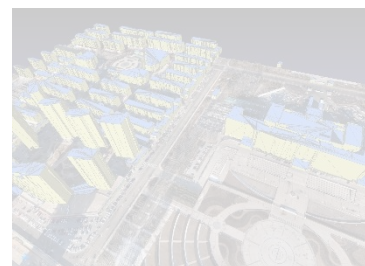
# 细粒度三维语义重建



3D几何模型



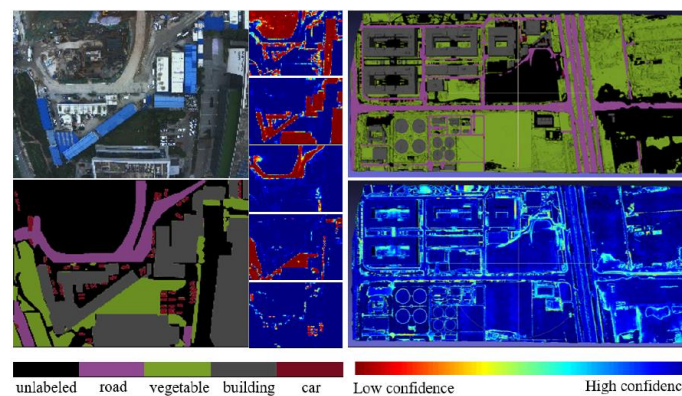
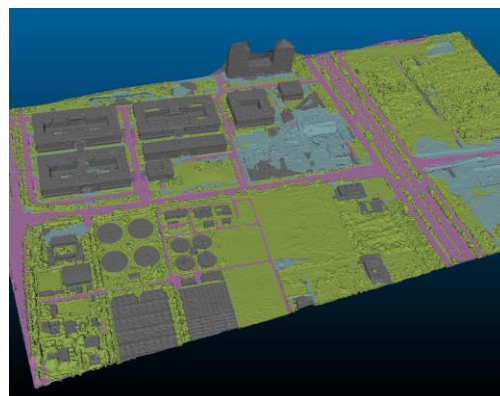
3D语义模型



3D矢量模型

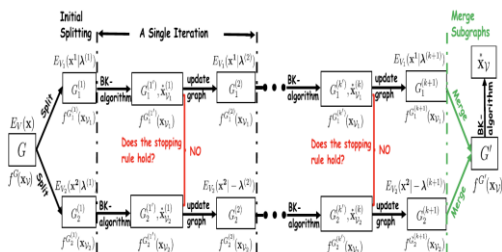


6DoF视觉定位

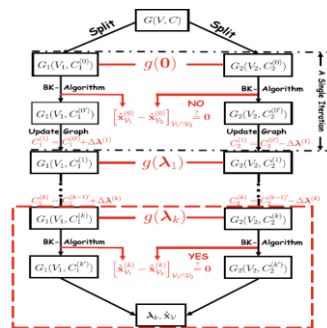


unlabeled road vegetable building car Low confidence High confidence

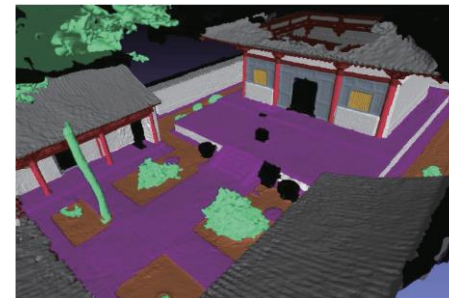
# 细粒度三维语义重建



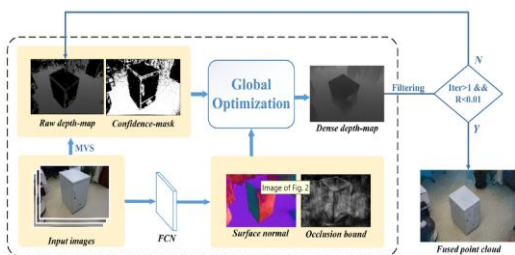
**Distributed Graph Cuts**  
*IEEE TIP 2016*  
 分布式图割优化



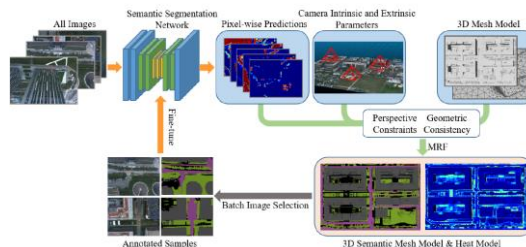
**Parallel Graph Cuts**  
*IEEE TIP 2017*  
 并行图割优化



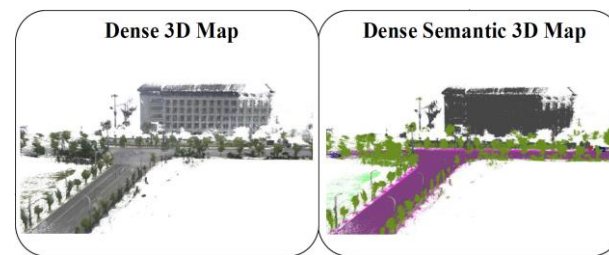
**AL for Fine-Level Scene Parsing**  
*3DV 2018*  
 三维场景细粒度分割



**Semantic Depth Completion**  
*PR 2020*  
 场景语义补全



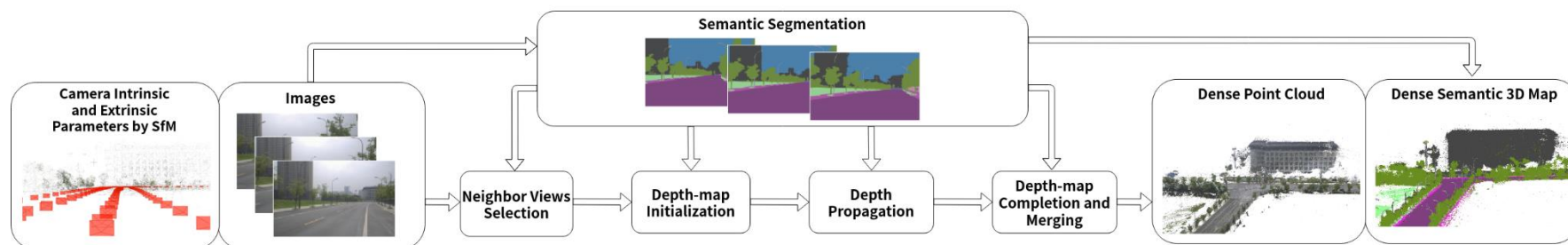
**AL for Large 3D Scenes**  
*IEEE T-CSVT 2021*  
 主动学习场景分割



**Semantic Road Mapping**  
*ICRA 2021*  
 道路三维语义地图

# 细粒度三维语义重建

## Semantically Guided Multi-View Stereo for Dense 3D Road Mapping ICRA 2021

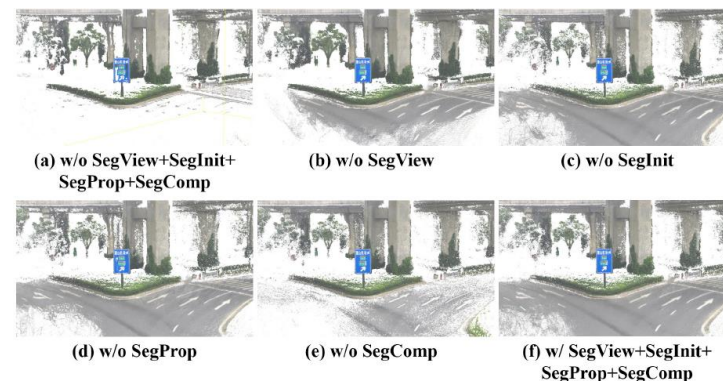


A) Semantically Guided Neighbor Views Selection

B) Semantically Guided Depth Map Initialization

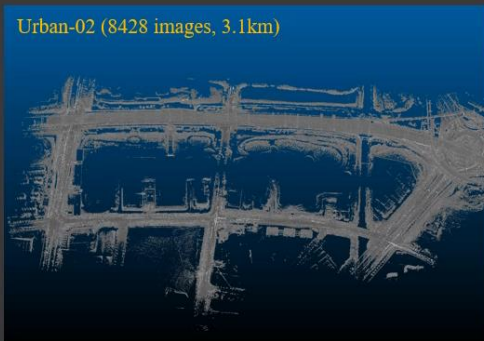
C) Scale-Adaptive Depth Propagation

D) Semantically Guided Depth Completion and Merging



# 细粒度三维语义重建

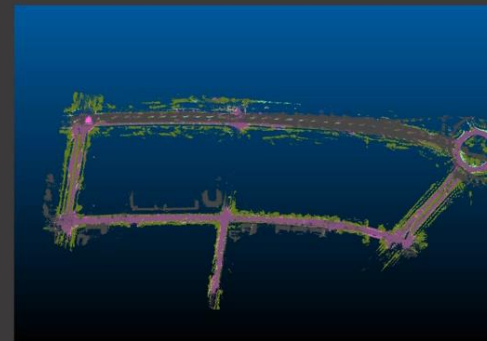
Urban-02 (8428 images, 3.1km)



LiDAR Map



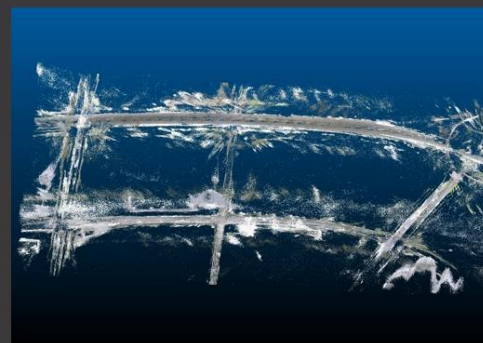
Ours (Dense 3D Map)



Ours (Dense Semantic 3D Map)



OpenMVS [42]



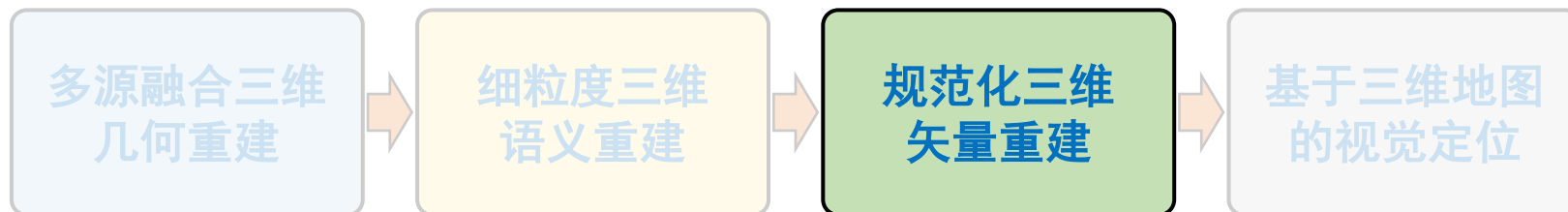
CasMVSNet [32]



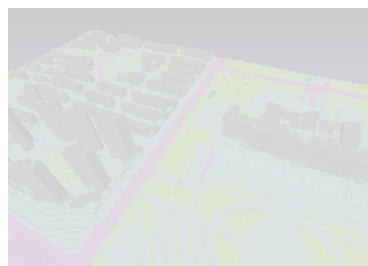
VisMVSNet [33]

杭州萧山区无人驾驶测试路段三维语义地图  
(8428幅前向车载图像, 3.1公里路段)

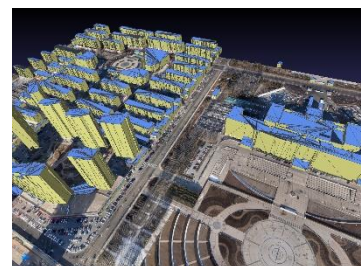
# 规范化三维矢量重建



3D几何模型



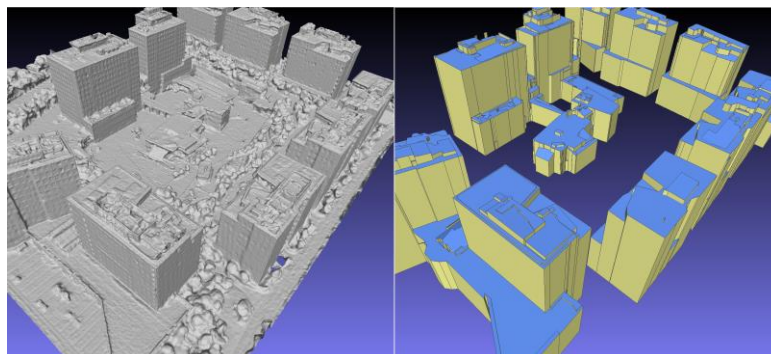
3D语义模型



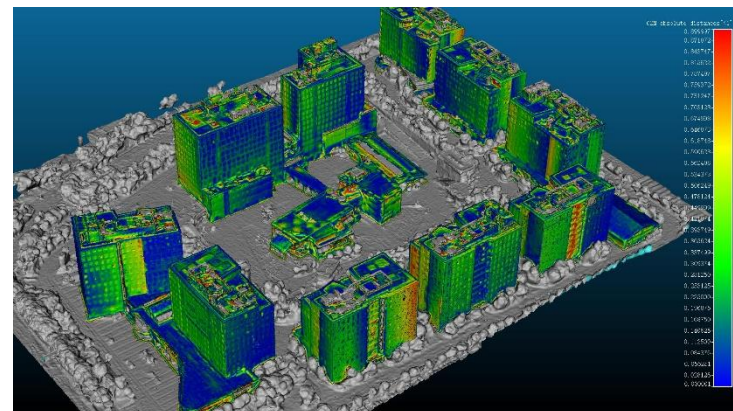
3D矢量模型



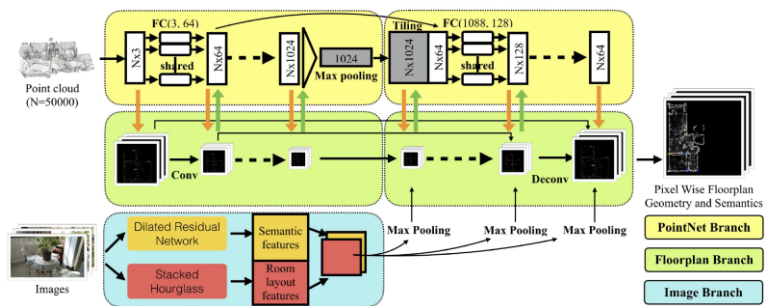
6DoF视觉定位



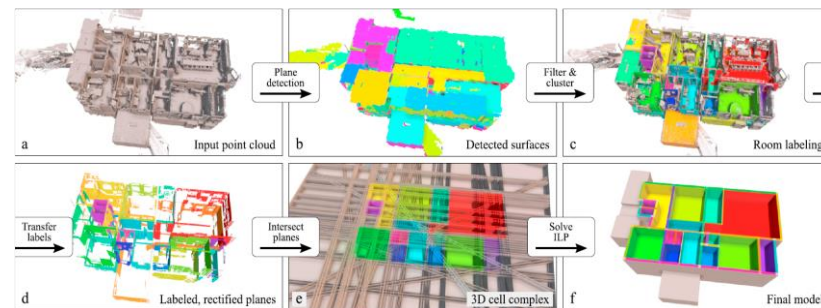
Mesh Model (9M facets) LOD2 Model (8K facets)



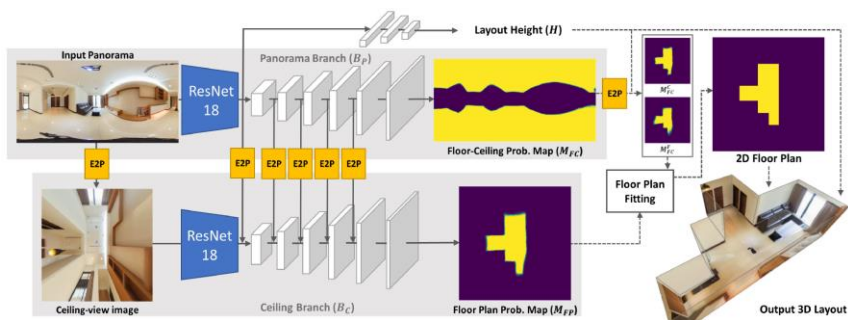
# 规范化三维矢量重建



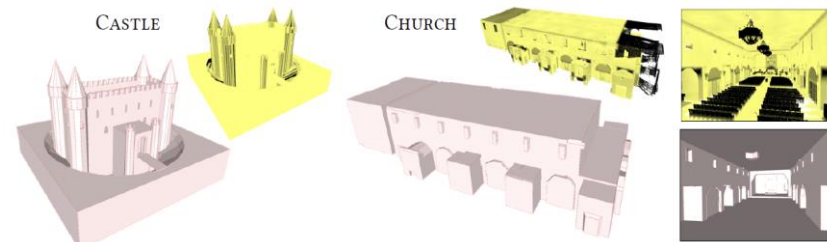
FloorNet, ECCV 2018



Volumetric Modeling, ISPRS P&RS 2019



DuLa-Net, CVPR 2019



Kinetic Shape Reconstruction, SIGGRAPH 2020

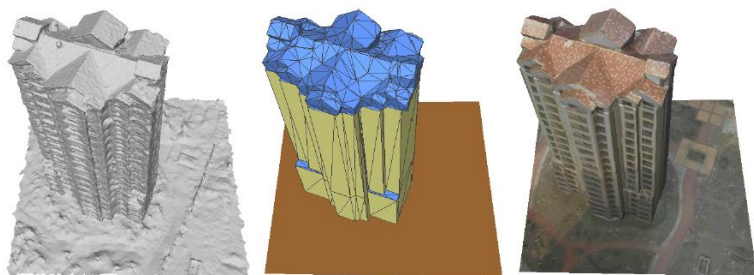
SOTA structured modeling in CV

*Prefer data driven approach*

SOTA structured modeling in CG

*Prefer direct points processing*

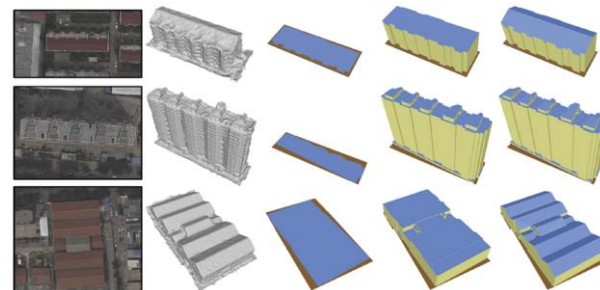
# 规范化三维矢量重建



**Variational Building Modeling**

*3DV 2017*

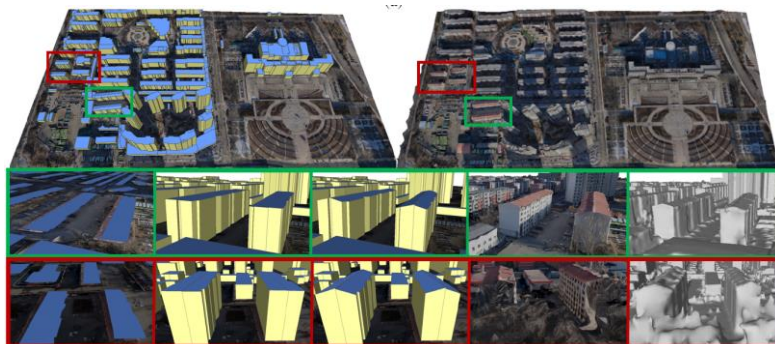
*LOD2室外矢量建模*



**Urban Scene Modeling**

*ECCV 2018*

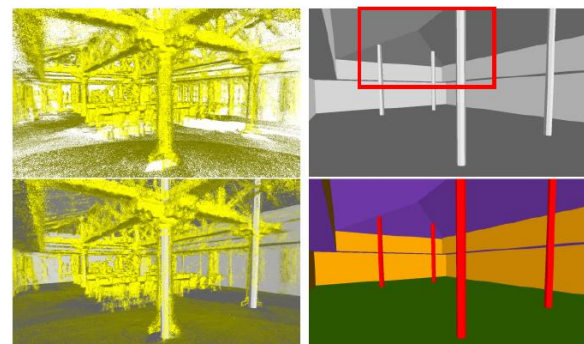
*LOD2室外矢量建模*



**Non Manhattan LOD Modeling**

*IEEE TIP 2021*

*LOD2室外矢量建模*



**Multistep Indoor Modeling**

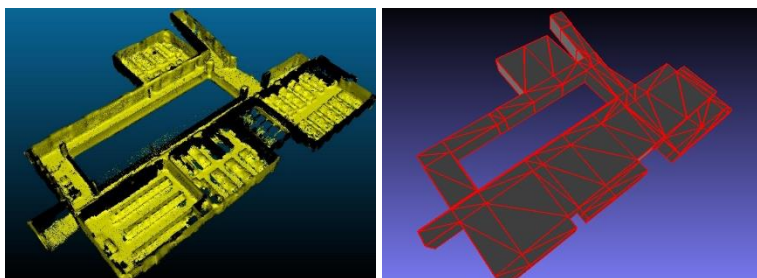
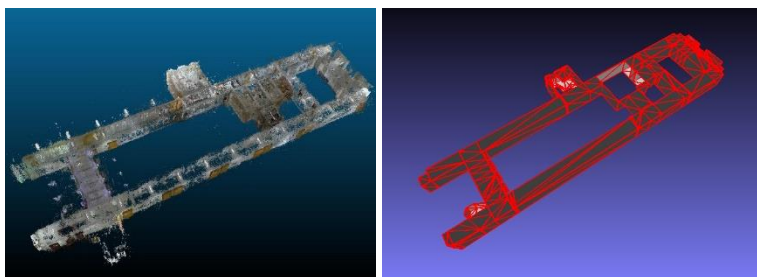
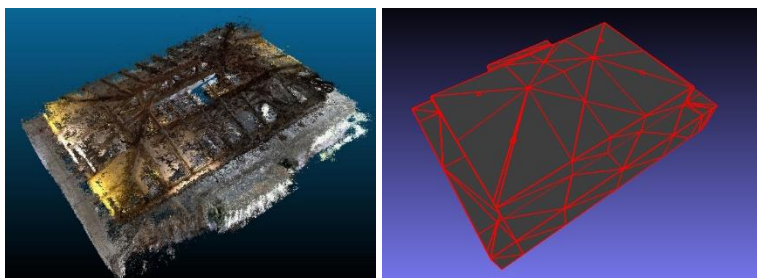
*ISPRS P&RS 2021*

*LOD2室内矢量建模*

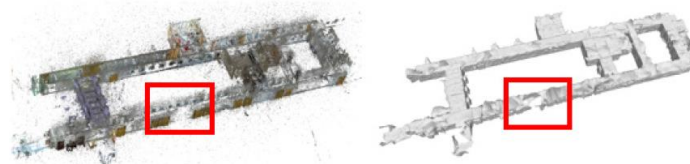
# 规范化三维矢量重建

## Vectorized Indoor Surface Reconstruction from 3D Point Cloud with Multistep 2D Optimization

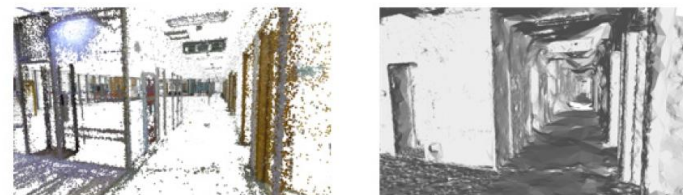
*ISPRS Journal of Photogrammetry and Remote Sensing 2021*



(a) Example images of Office\_MVS scene

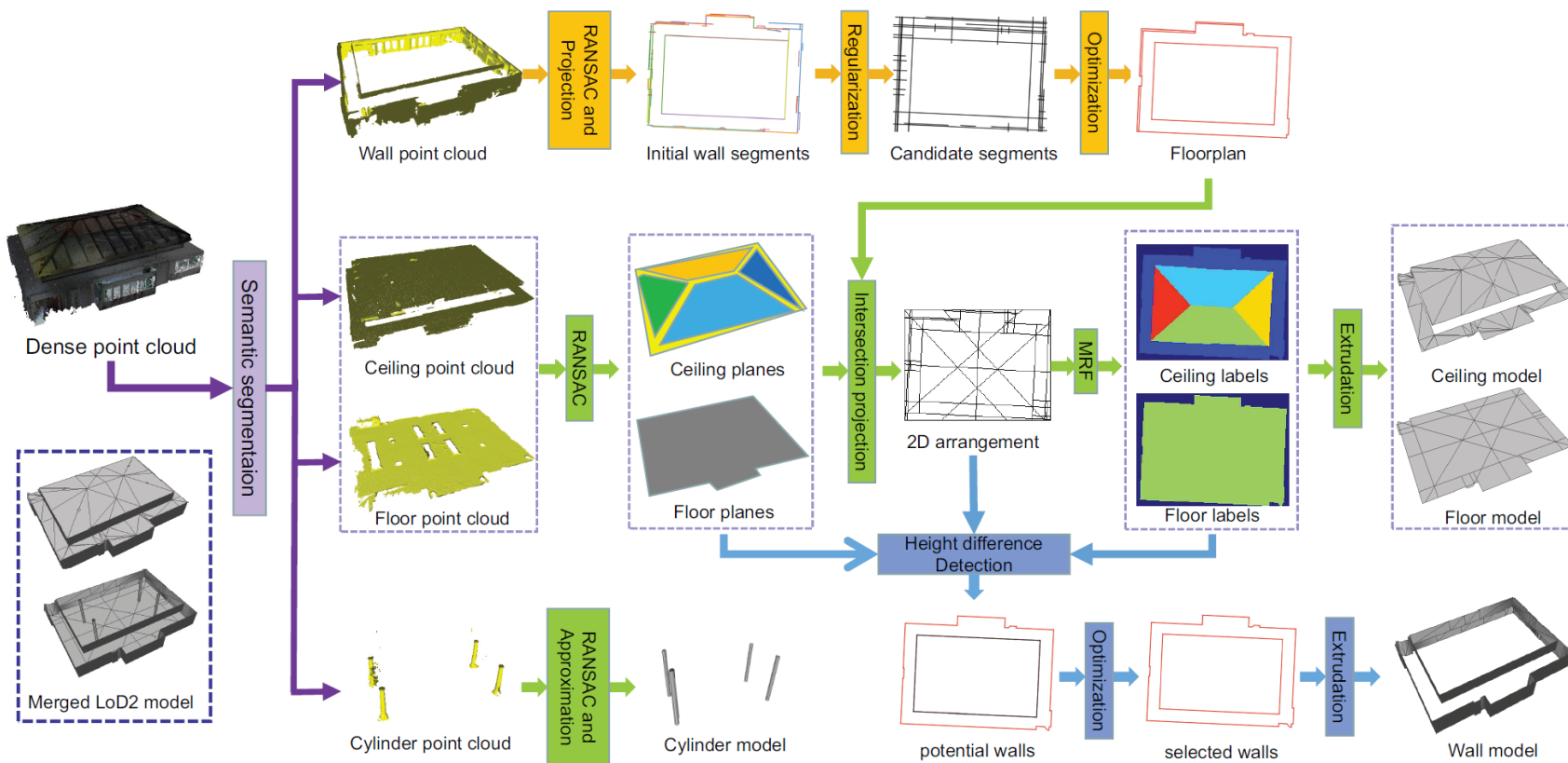


(b) MVS point cloud (left) and MVS mesh (right)



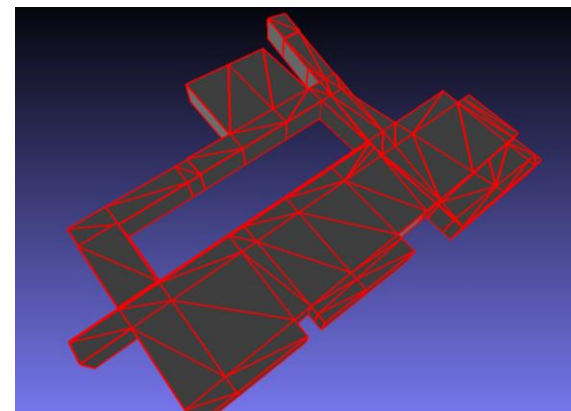
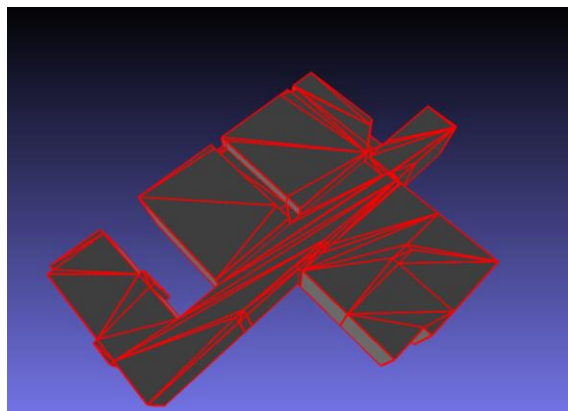
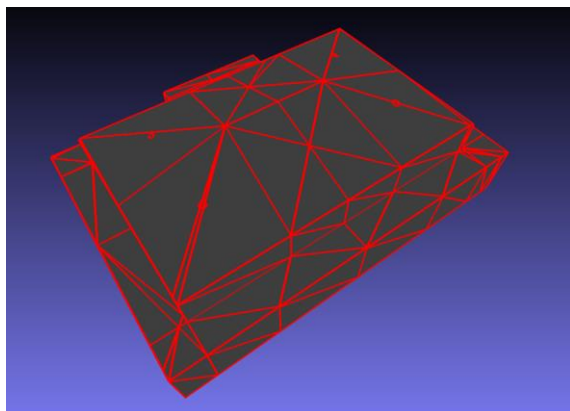
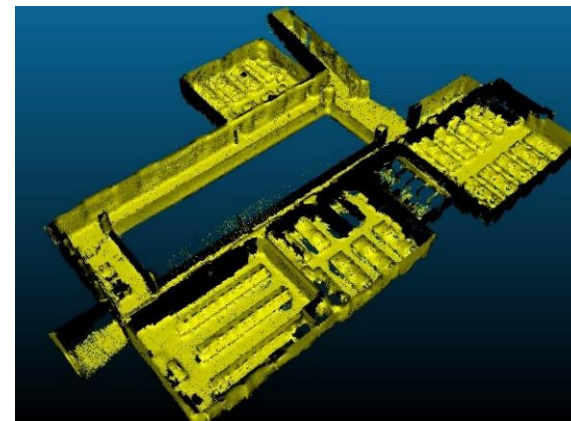
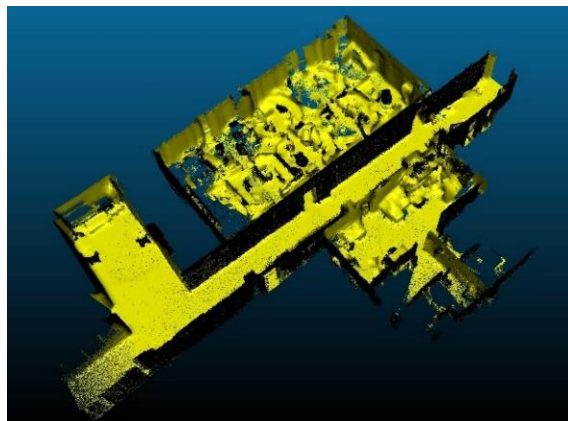
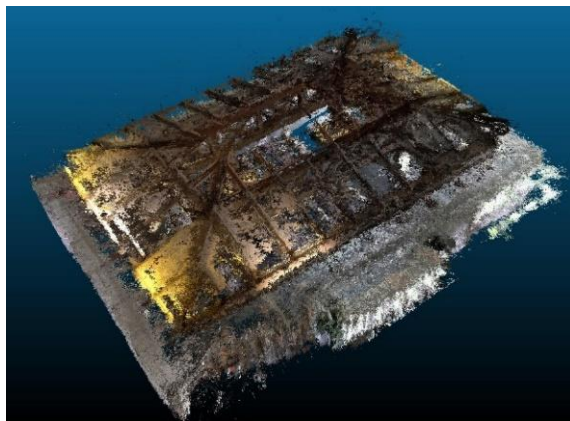
(c) Close-up of point cloud (left) and mesh (right)

# 规范化三维矢量重建



**Pipeline:** 1) scene segmentation, 2) floorplan generation, 3) non-wall structure reconstruction, 4) wall structure reconstruction, and 5) LOD2 model assembly

# 规范化三维矢量重建



**Meetingroom LOD2**  
366 facets

**Mimap\_bim\_01 LOD2**  
262 facets

**Mimap\_bim\_02 LOD2**  
560 facets

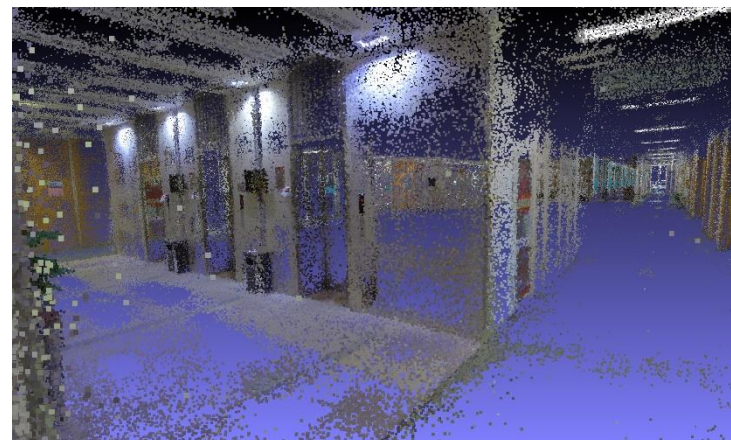
# 规范化三维矢量重建



Insta360 Pro2



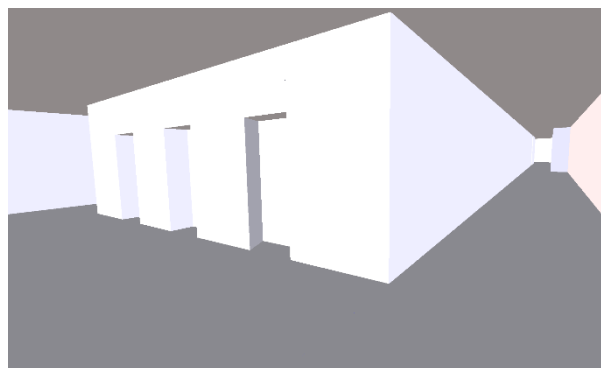
6 minutes pano-video, 960 m<sup>2</sup>



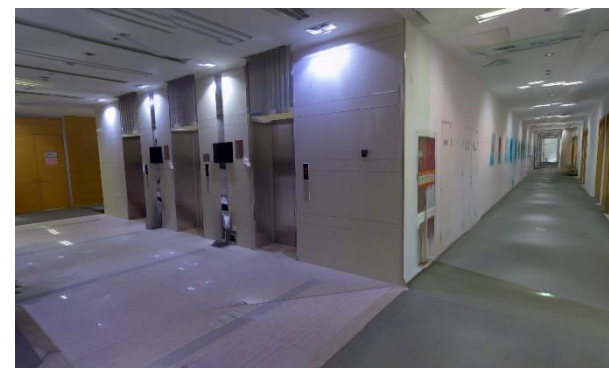
Dense point cloud, 10M points



Mesh model, 3M facets



LOD2 model, 930 facets



Textured LOD2 model

# 城市场景三维重建系统应用

系统应用一：城市实景三维建模



系统应用二：无人车三维地图



系统应用三：AR三维定位地图



# 系统应用一：城市实景三维建模



航拍三维建模系统（西安世博园）



全景三维建模系统（自动化所园区）



道路三维建模系统（杭州萧山）



室内三维建模系统（自动化所大厦三层）

多类型城市场景实景三维建模（航拍、车载、全景）

# 系统应用一：城市实景三维建模



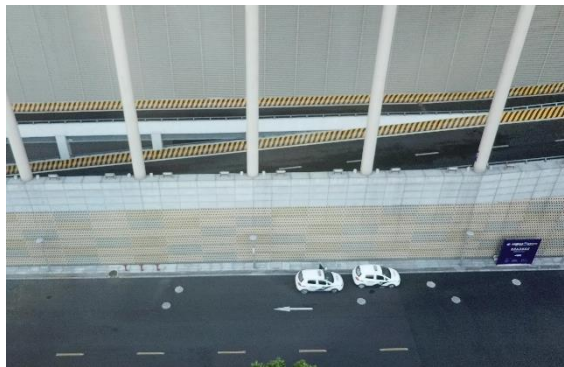
陕西省苏坊镇三维房地一体确权（倾斜摄影，4900幅图像）

# 系统应用一：城市实景三维建模



陕西省苏坊镇三维房地一体确权（倾斜摄影，4900幅图像）

## 系统应用二：无人车三维地图



基于小型无人机的无人车仿真环境自动构建（2600幅无人机图像）

# 系统应用二：无人车三维地图



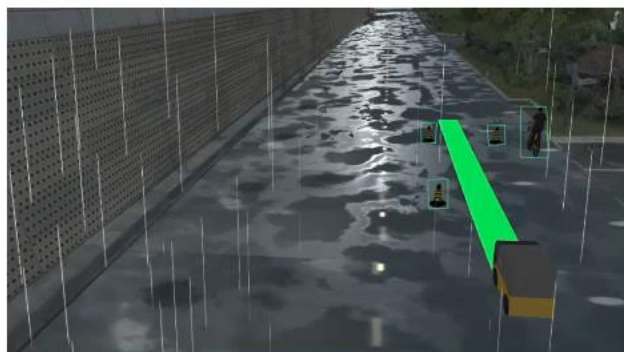
白天



夜晚



雾天



雨天



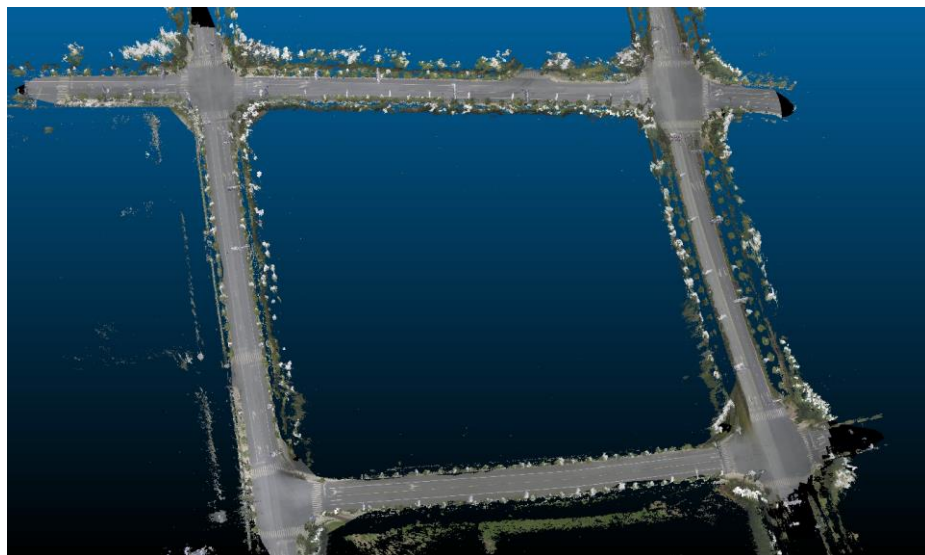
语义



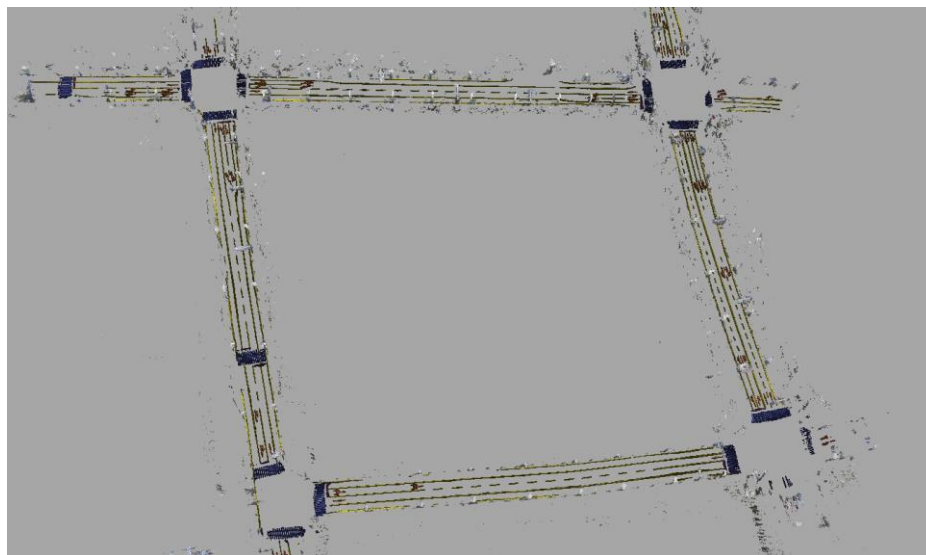
天眼

基于小型无人机的无人车仿真环境自动构建（2600幅无人机图像）

# 系统应用二：无人车三维地图



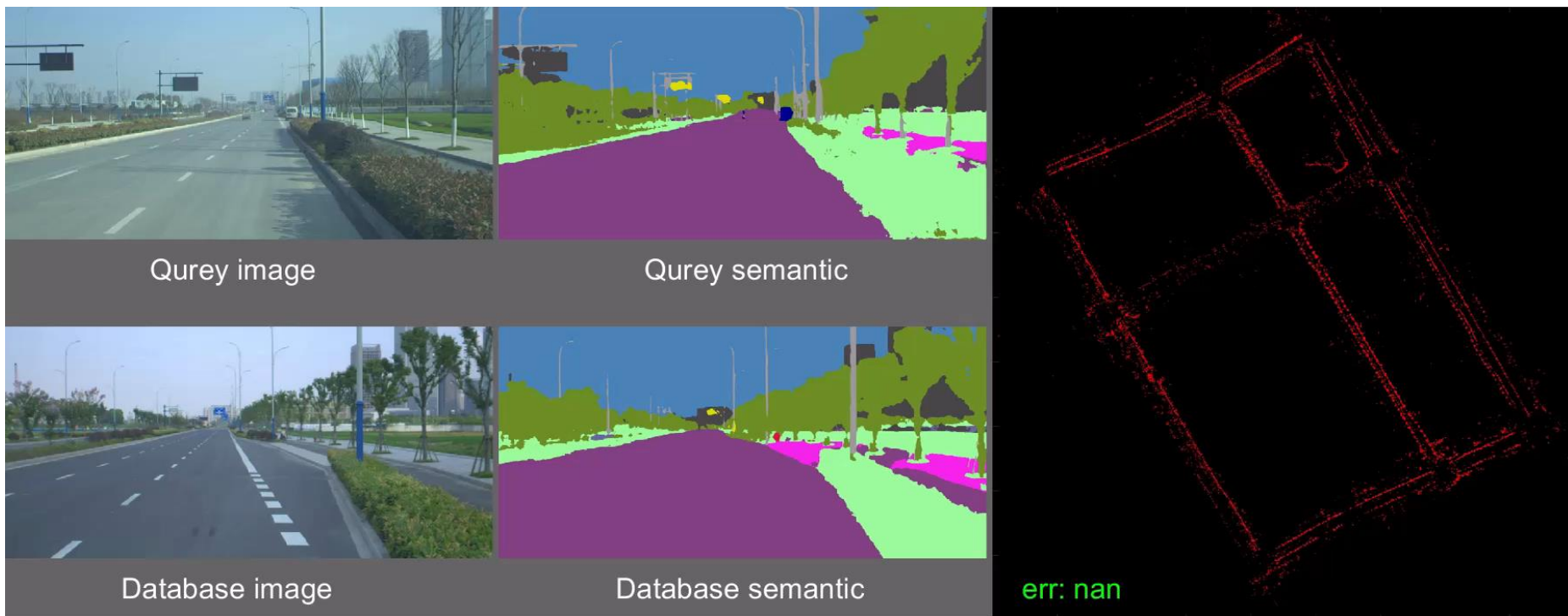
三维稠密点云地图



三维语义地图（交通设施、车道线）

杭州萧山区无人驾驶测试路段视觉三维地图  
(2700幅无人车前向车载图像, 1.1公里路段)

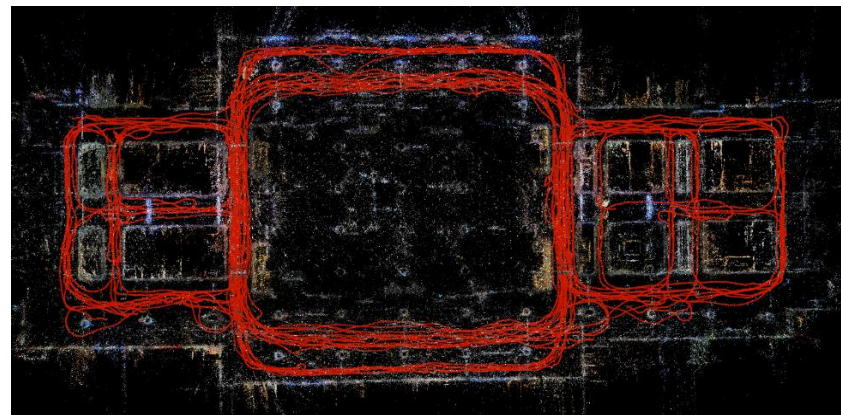
# 系统应用二：无人车三维地图



单幅图像定位成功率：92.1%，定位中值误差：0.41m

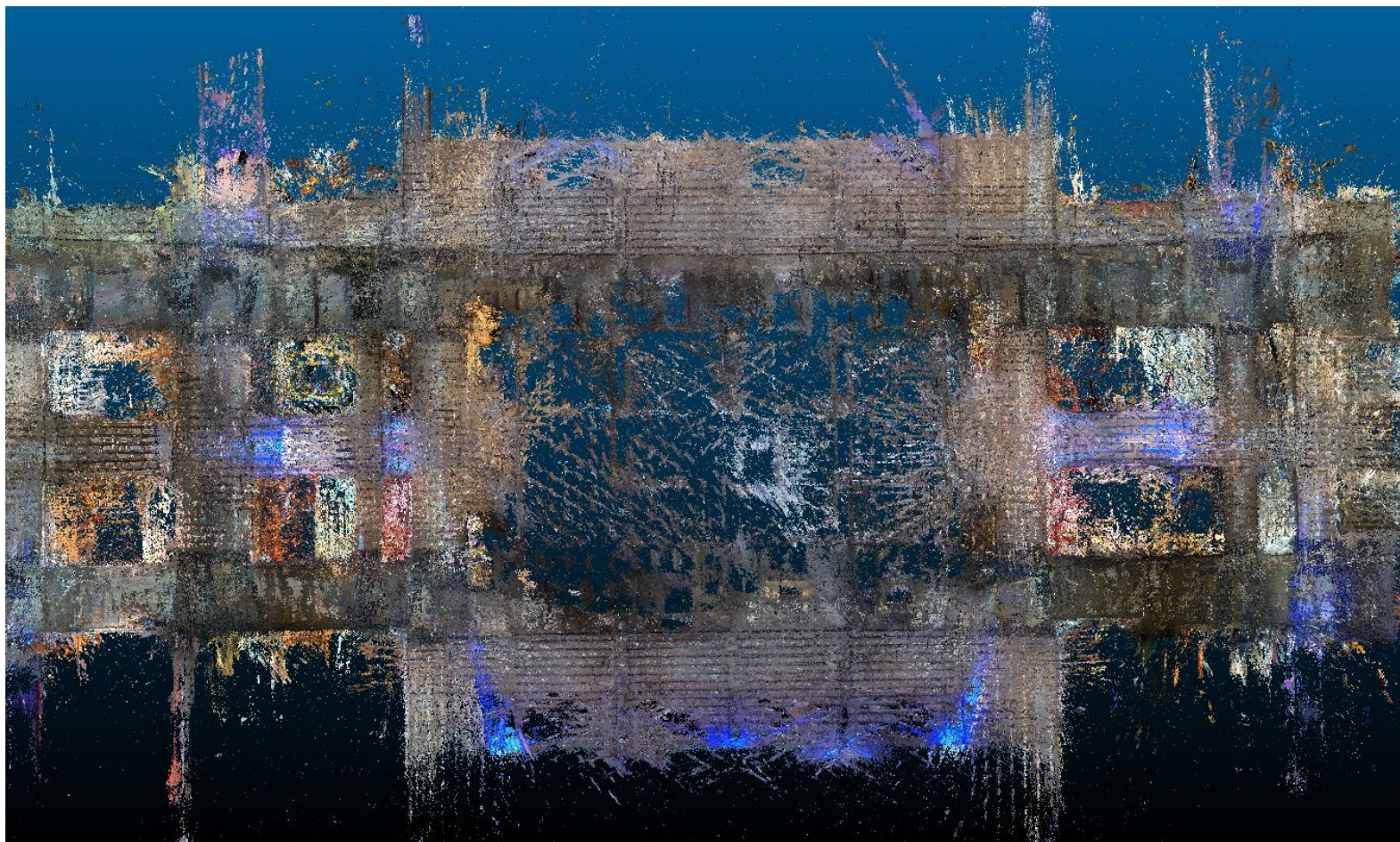
无人车单目视觉定位  
(前向单目相机，2600幅定位图像，3.5公里路段)

# 系统应用三：AR三维定位地图



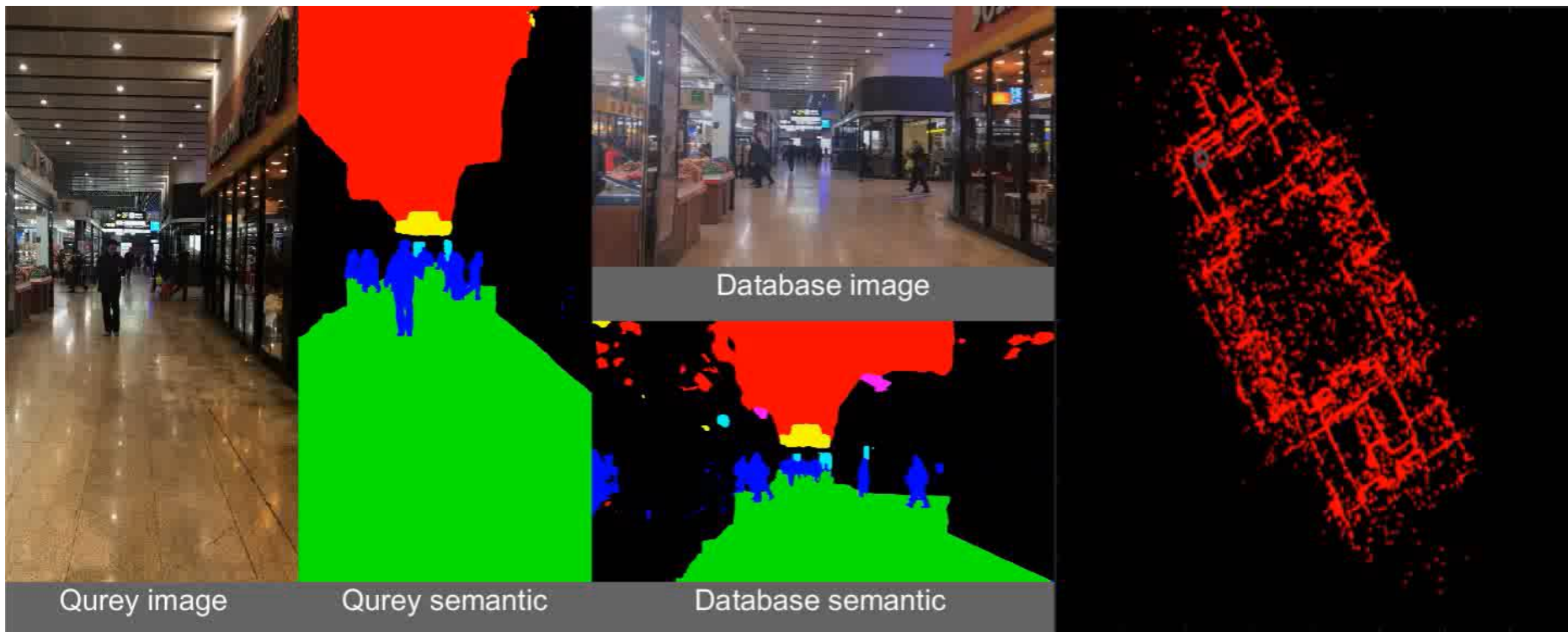
北京南站B1层到达区（17750帧图像，6万平方米室内区域）

# 系统应用三：AR三维定位地图



北京南站B1层到达区（17750帧图像，6万平方米室内区域）

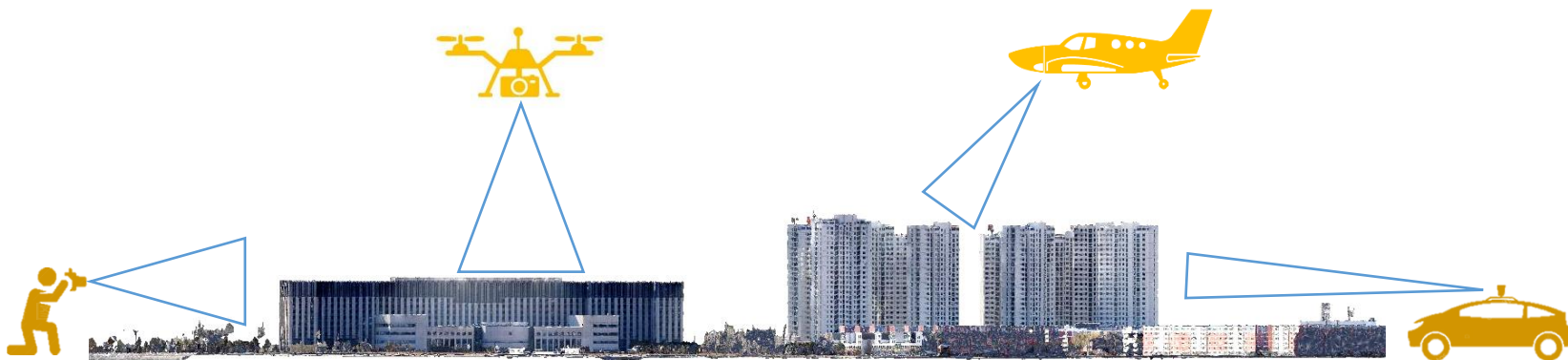
# 系统应用三：AR三维定位地图



定位图象数：1236，定位成功数：1229（99.43%），定位连续数：1156（93.5%）

北京南站B1层到达区（17750帧图像，6万平方米室内区域）

# 总结



以航拍、车载、全景、手机图像为主要数据源，低成本、高精度、全自动、高效率的获取从天空到地面、从室外到室内的城市场景三维表达。



大兴航天星汉小区实景三维



五台山佛光寺三维VR漫游



丰台小屯路三维道路地图

# 主要合作者和主要合作企业



汪国平 教授  
北京大学



刘红敏 教授  
北京科技大学



崔海楠 副研究员  
中科院自动化所



中航工业



高翔 博士  
中国海洋大学





N L P R

**Thanks !**