

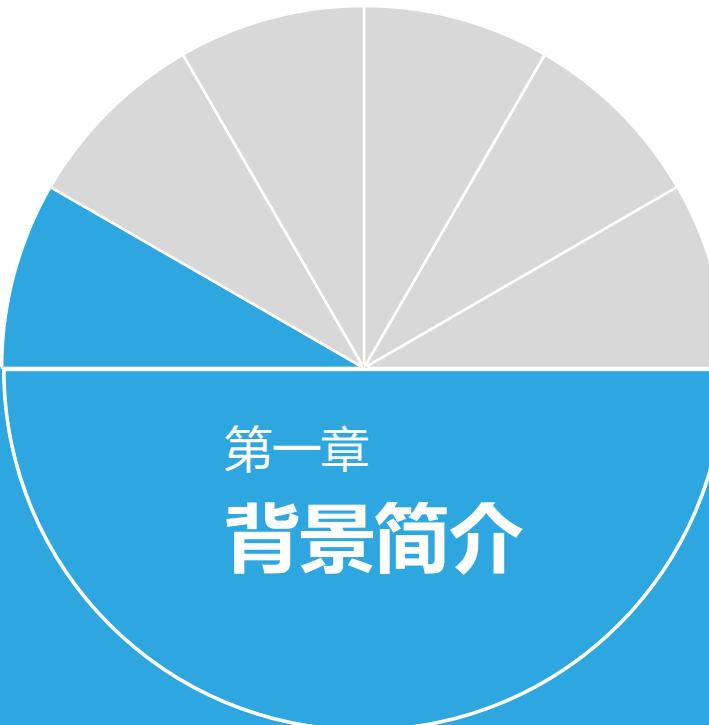


三维激光点云中向量场的构建与分割研究

信息科学技术学院

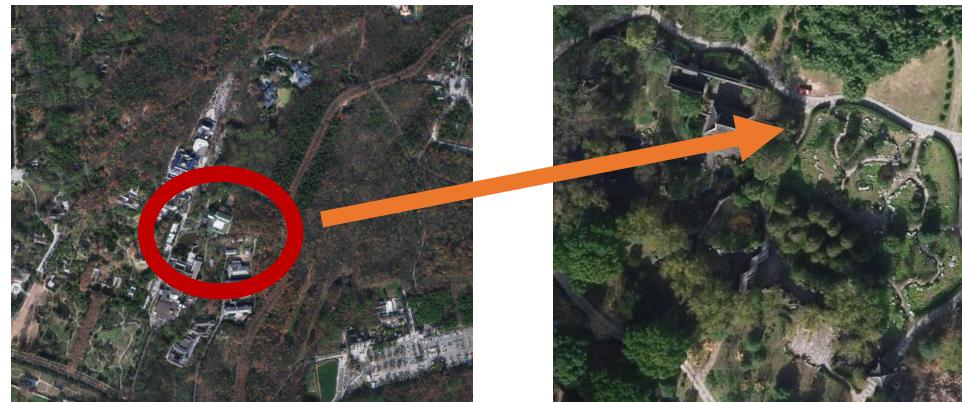
徐昇 · 副教授





第一章 背景简介

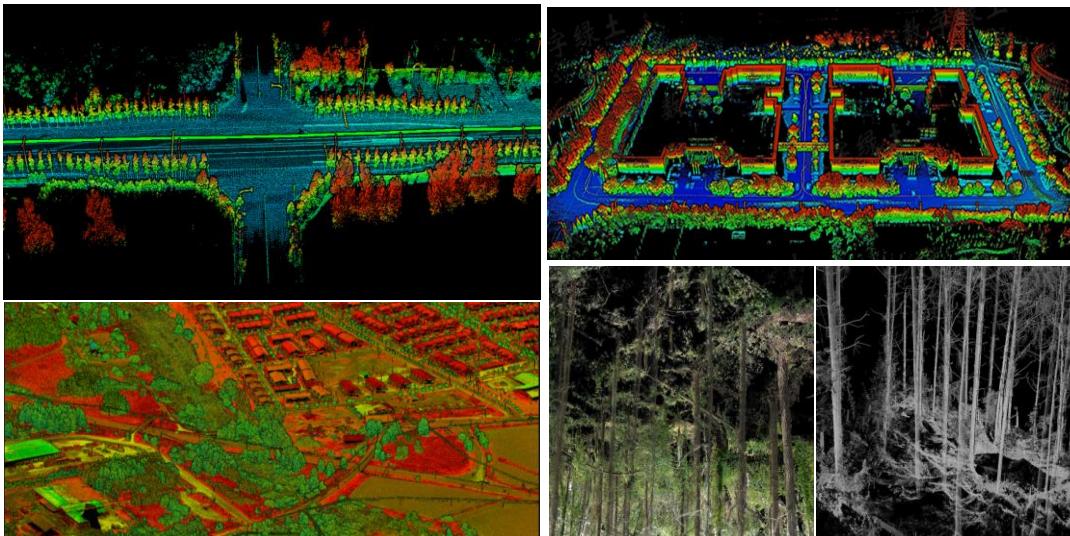
- 遥感技术：运用现代光学、电子学探测仪器，不与目标物相接触，从远距离把目标物的电磁波特性记录下来，通过分析、解译揭示出目标物本身的**特征、性质及其变化规律**



- 点云：单个空间三维坐标被称为一个点，**三维坐标的集合**被称之为点云
- 摄影测量技术（双目视觉）
 - RGB-D深度相机（kinect）
 - 激光扫描技术



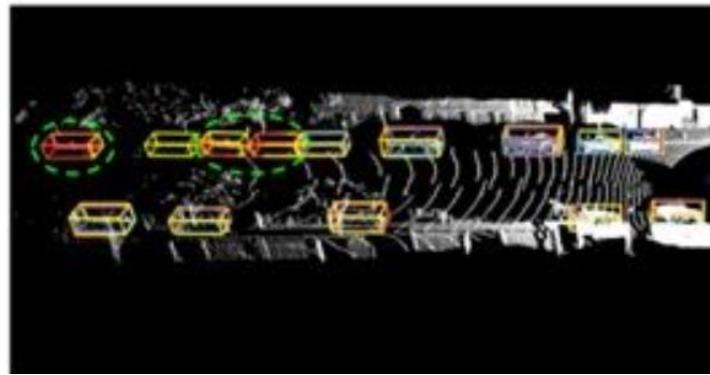
- 激光扫描技术：利用激光测距的原理，通过记录被测物体表面大量的密集的点的三维坐标，复建出目标的**三维模型**
 - 车载，机载，地基，手持式
- 扫描仪构成
 - 激光测距仪，惯性测量系统（IMU），全球定位系统（GPS），高分辨率数码相机
- 扫描数据



1.2研究内容

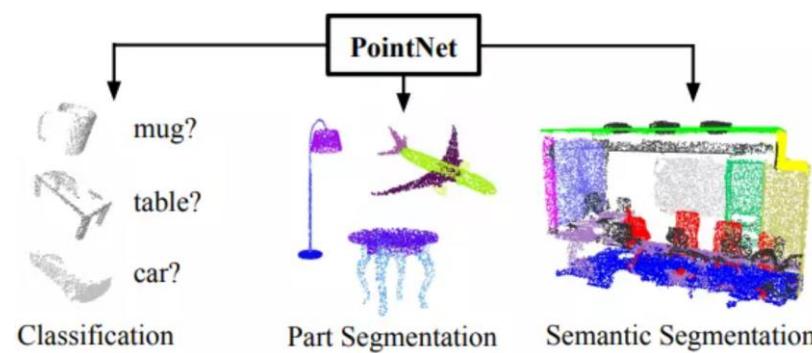
➤ 目标检测

- 三维空间目标的位置估



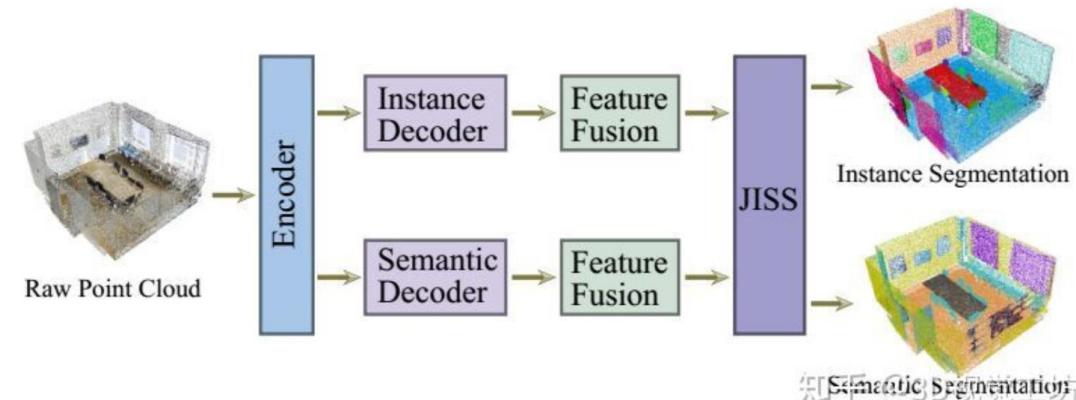
➤ 目标识别

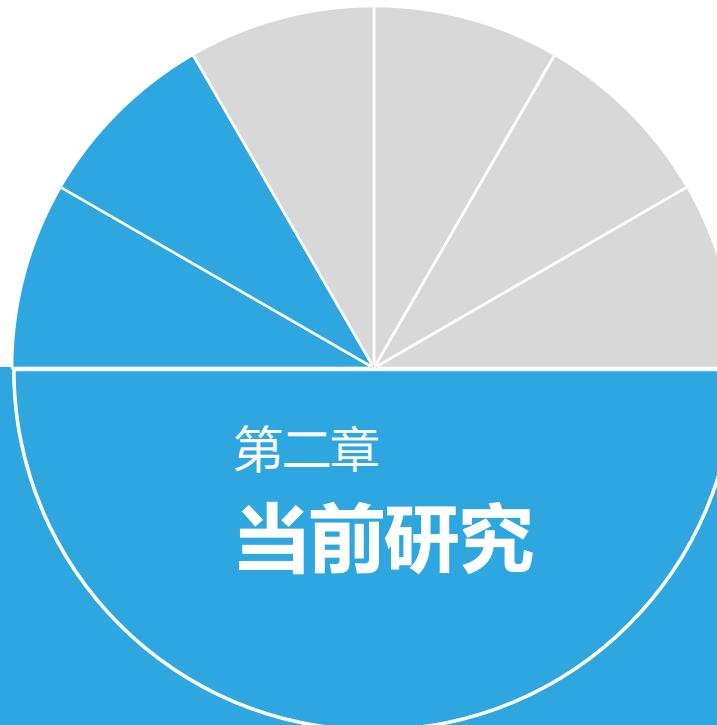
- 三维空间目标分类



➤ 点云分割

- 根据分割粒度，点云分割分为三类：
 - 语义分割（场景级别）
 - 实例分割（对象级别）
 - 部件分割（部件级别）

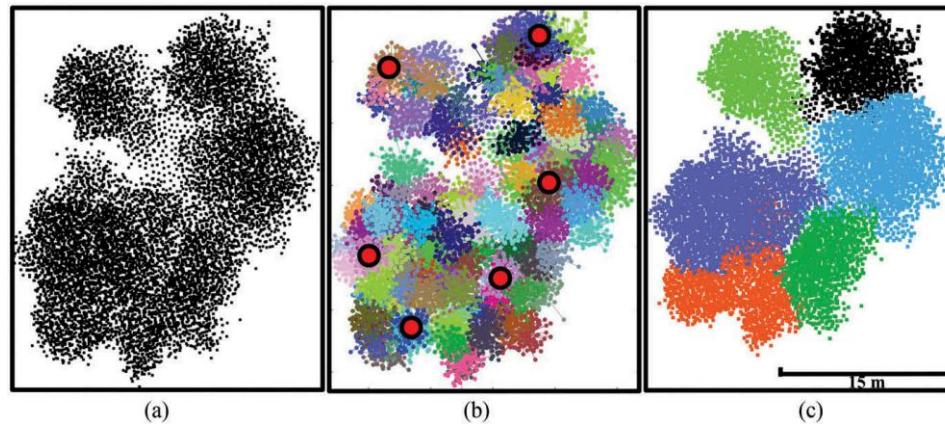




2.1研究方法 (Process of Partitioning Input Data into Multiple Regions)

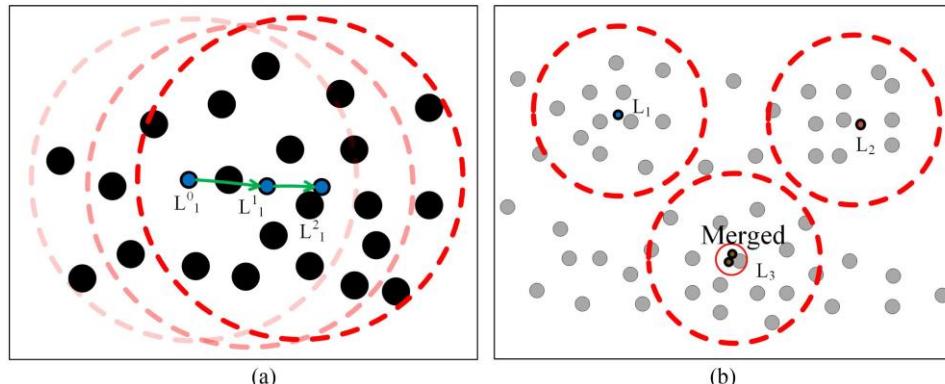
● Region Growing

- 设置种子点 - 基于局部信息 (平面方程、平面法向量) - 区域增长



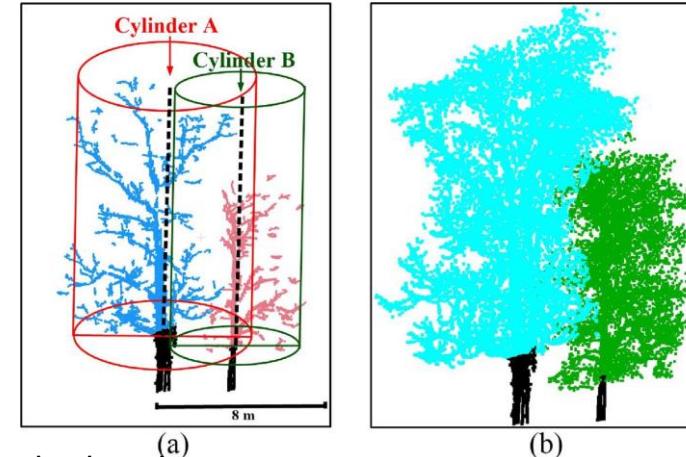
● Clustering

- 计算邻近矩阵 - 合并 - 计算邻近矩阵 - 合并



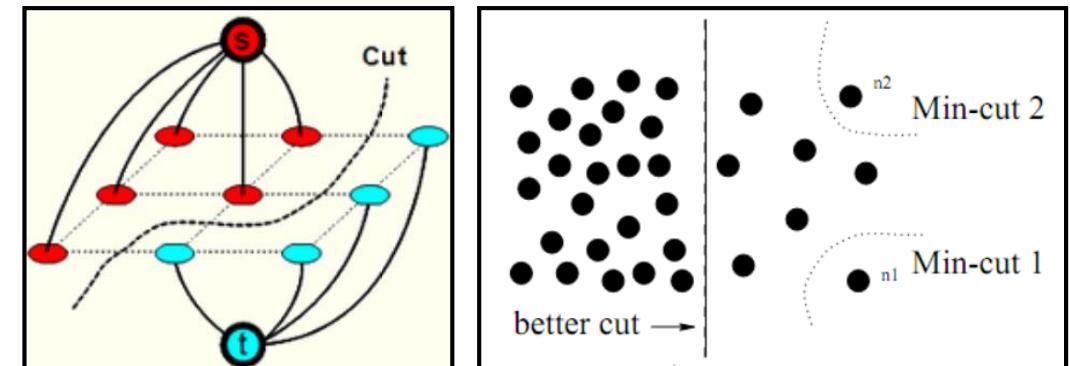
● Shape Fitting

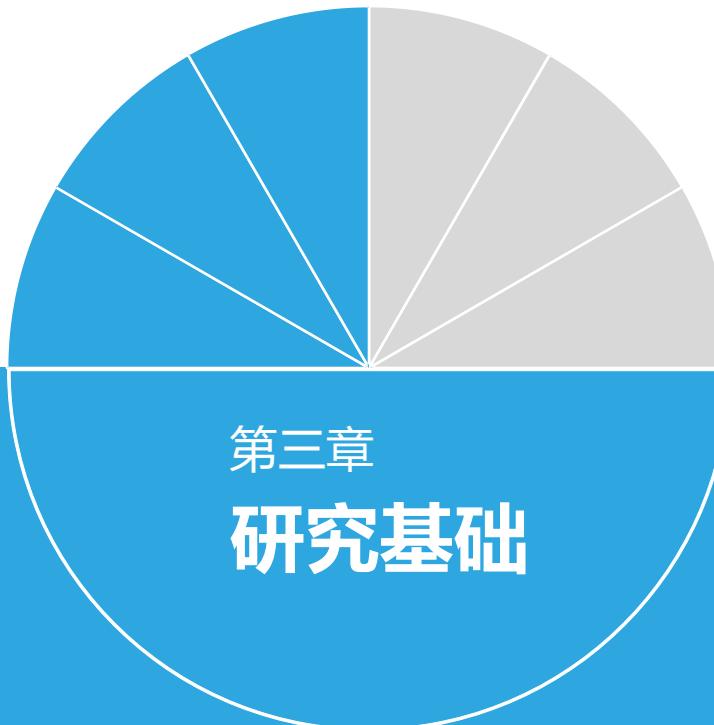
- 定义元模型 (primitive model) - 构造模型方程 (柱面、球面、线状等) - 曲面拟合



● Global Optimization

- 能量函数构建 - 能量函数优化





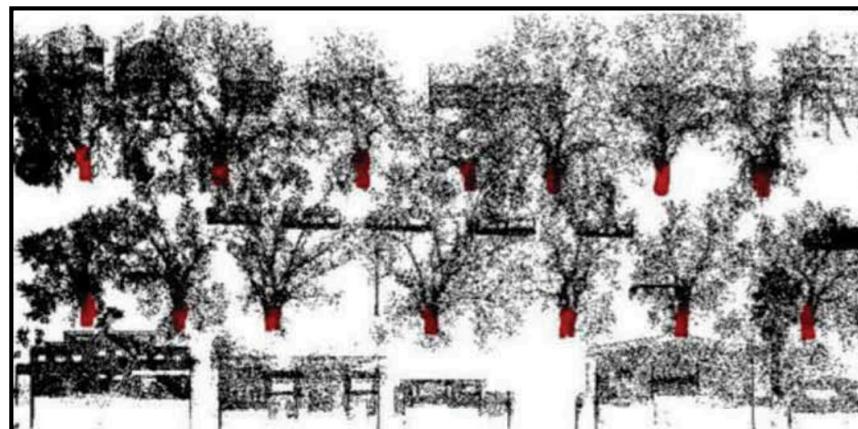
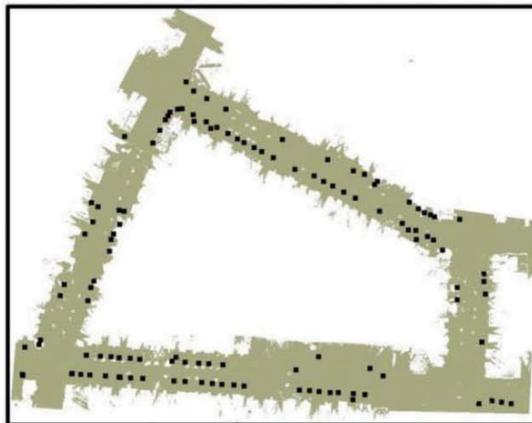
➤ 目前发表国内外期刊**30**篇，包括

- SCI期刊**16**篇，EI期刊或会议**3**篇，国内期刊**11**篇，
- 近五年一作录用或发表点云相关SCI期刊**10**篇(4篇1区):

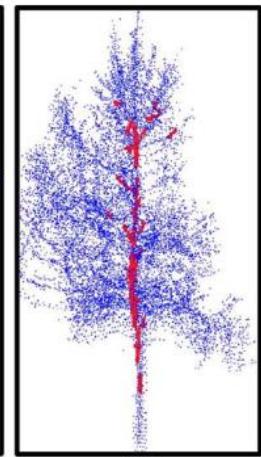
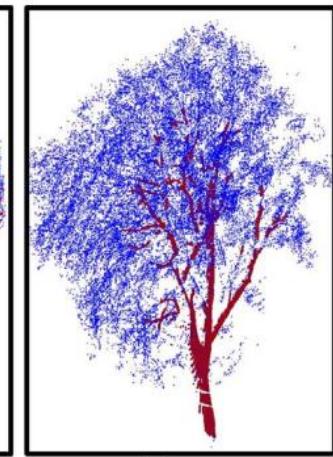
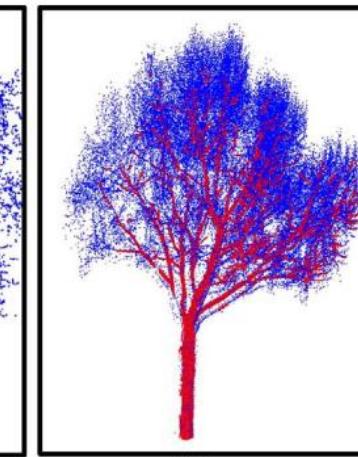
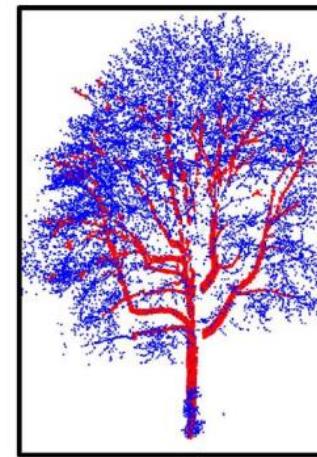
1. **Sheng Xu**, R. Wang, H. Wang and R. Yang, "Plane Segmentation Based on the Optimal-vector-field in LiDAR Point Clouds," in IEEE Transactions on Pattern Analysis and Machine Intelligence, doi: 10.1109/TPAMI.2020.2994935. **(1区)**
2. **Sheng Xu**, R. Wang(*), H. Wang and H. Zheng, An Optimal Hierarchical Clustering Approach to Mobile LiDAR Point Clouds, IEEE Transactions on Intelligent Transportation Systems. 2020.07, 21(7):2765-2776 **(1区)**
3. **Xu Sheng(*)**; Wang Ruisheng; Zheng Han, Road Curb Extraction From Mobile LiDAR Point Clouds , IEEE Transactions on Geoscience and Remote Sensing, 2017. 02, 55(2): 996~1009 **(1区)**
4. **Xu Sheng**; Xu Shanshan(*); Ye Ning; Zhu Fa, Automatic extraction of street trees' nonphotosynthetic components from MLS data , International Journal of Applied Earth Observation and Geoinformation, 2018.07, 69: 64~77 **(1区)**
5. **Sheng Xu**, Xinyu Sun, Jiayan Yun, and Hao Wang(*), " A New Clustering-Based Framework to the Stem Estimation and Growth Fitting of Street Trees from MLS data," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2020. 07,13:3240-3250. **(2区)**
6. **Sheng Xu**; Ruisheng Wang(*), Power Line Extraction From Mobile LiDAR Point Clouds, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2019.2.13, 12(2): 734 ~743 **(2区)**
7. **Xu Sheng**; Xu Shanshan(*); Ye Ning; Zhu Fa, Individual stem detection in residential environments with MLS data , Remote Sensing Letters, 2018, 9(1): 51~60 **(4区)**
8. **Xu Sheng**; Ye Ning; Xu Shanshan(*); Zhu Fa, A supervoxel approach to the segmentation of individual trees from LiDAR point clouds , Remote Sensing Letters, 2018, 9(6): 515~523 **(4区)**
9. **Sheng Xu**; Shanshan Xu(*). A Minimum-Cost Path Model to the Bridge Extraction from Airborne LiDAR Point Clouds , Photonirvachak-Journal of the Indian Society of Remote Sensing, 2018.9, 46(9): 1423~1431 **(4区)**
10. **Sheng Xu**; Ning Ye; Shanshan Xu(*), A new method for shoreline extraction from airborne LiDAR point clouds, Remote Sensing Letters, 2019.02.08, 10(5): 496~505 **(4区)**

➤ 植被场景提取与分割

- 车载激光点云中树木主干分割（2017.10）



- 车载激光点云中树木非光合作用部分分割（2018.10）

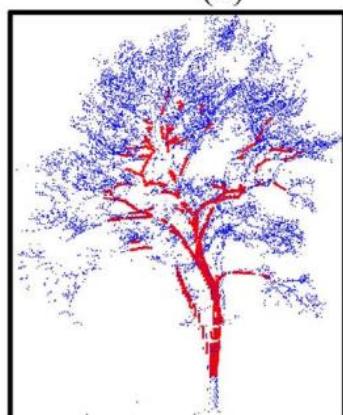
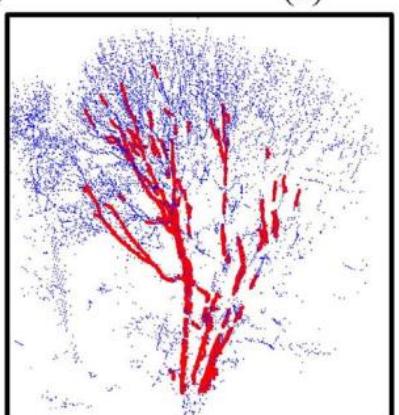
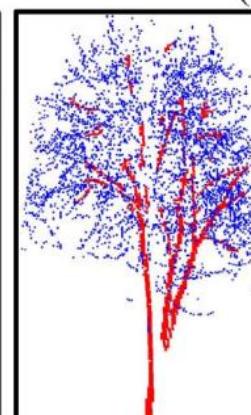
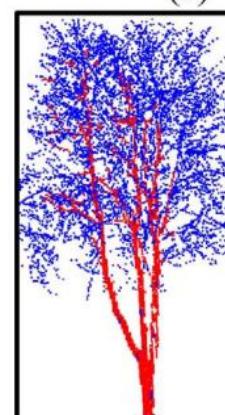


(a)

(b)

(c)

(d)



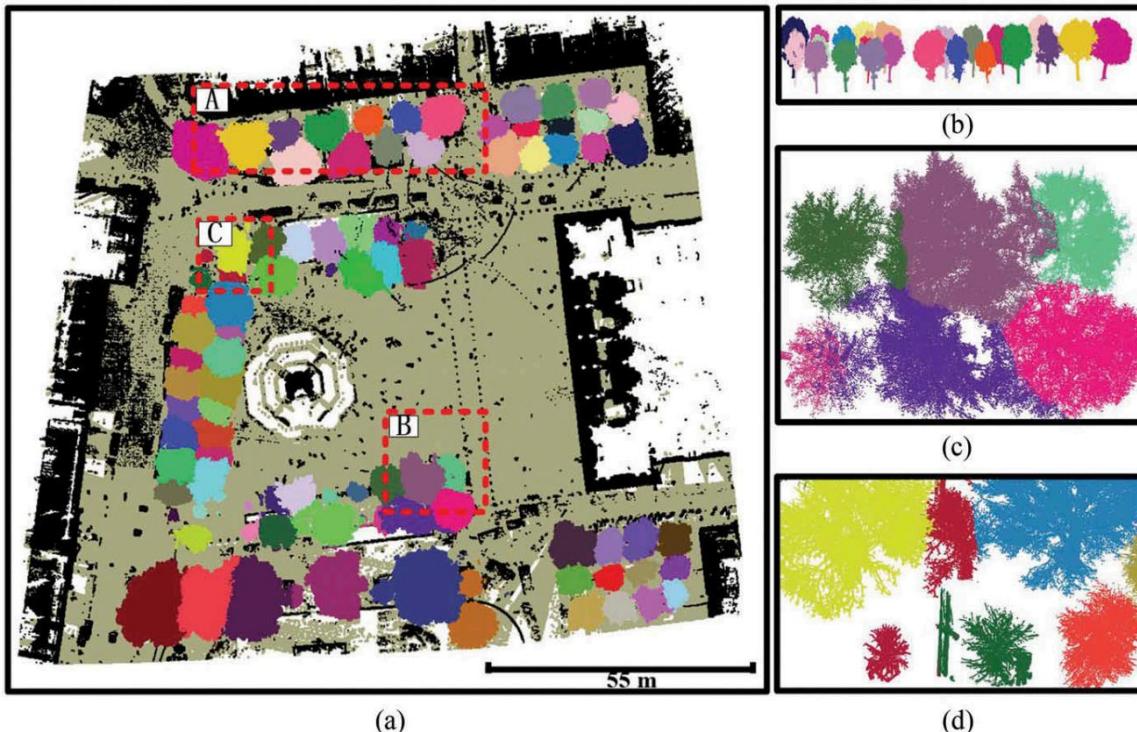
(e)

(f)

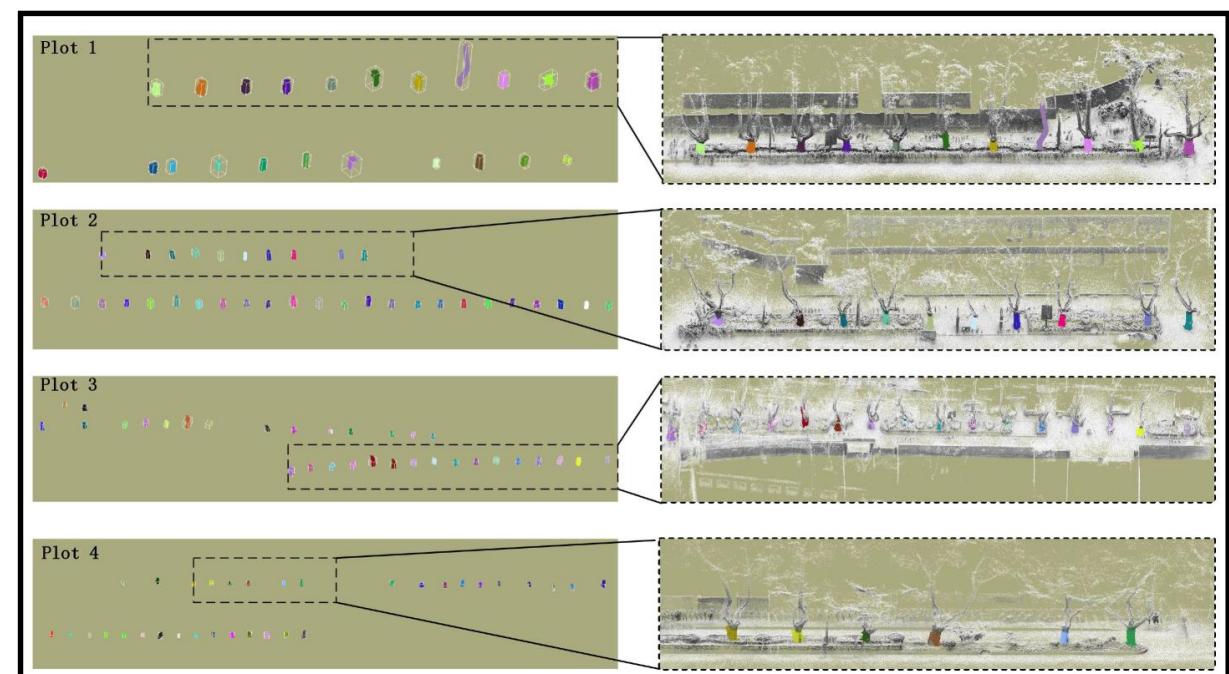
(g)

(h)

- 机载激光点云中树冠分割（2018.02）

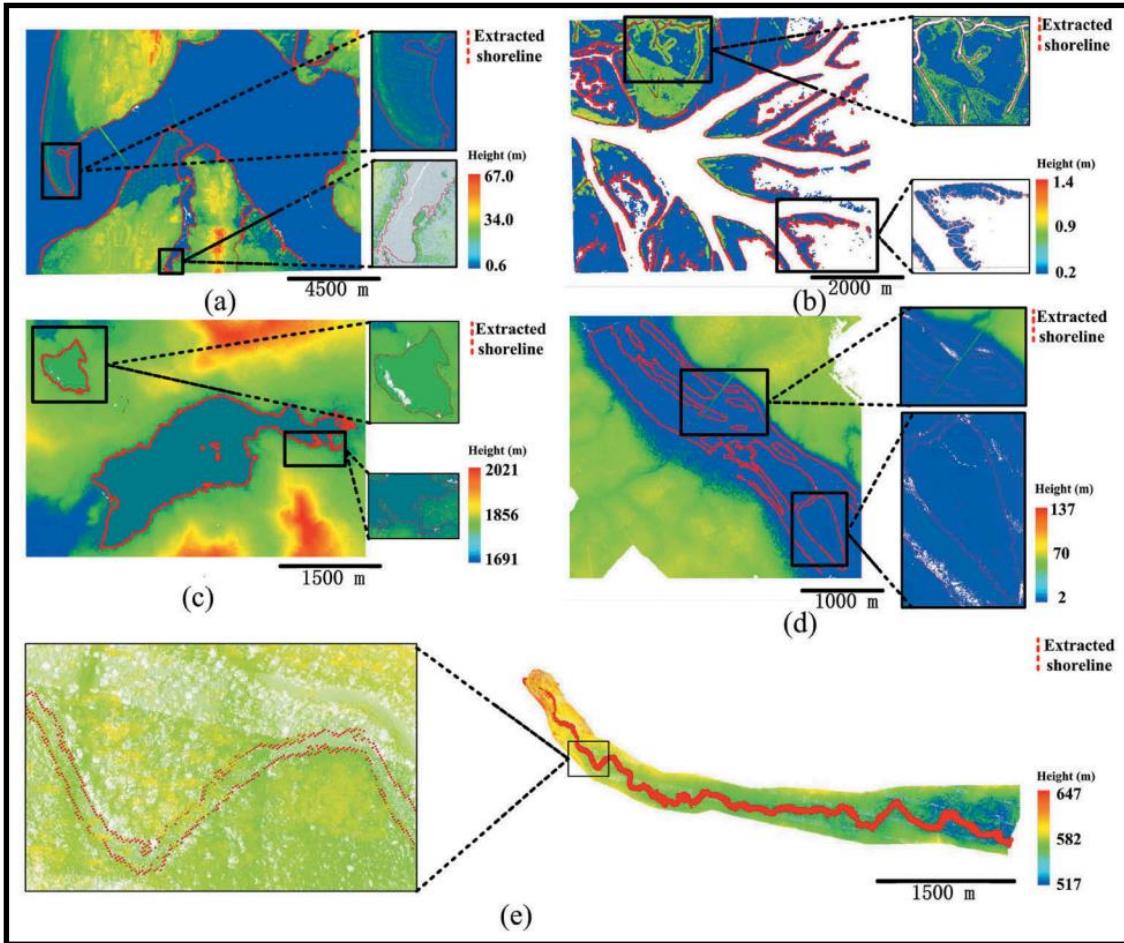


- 手持式激光点云中树干分割（2020.07）

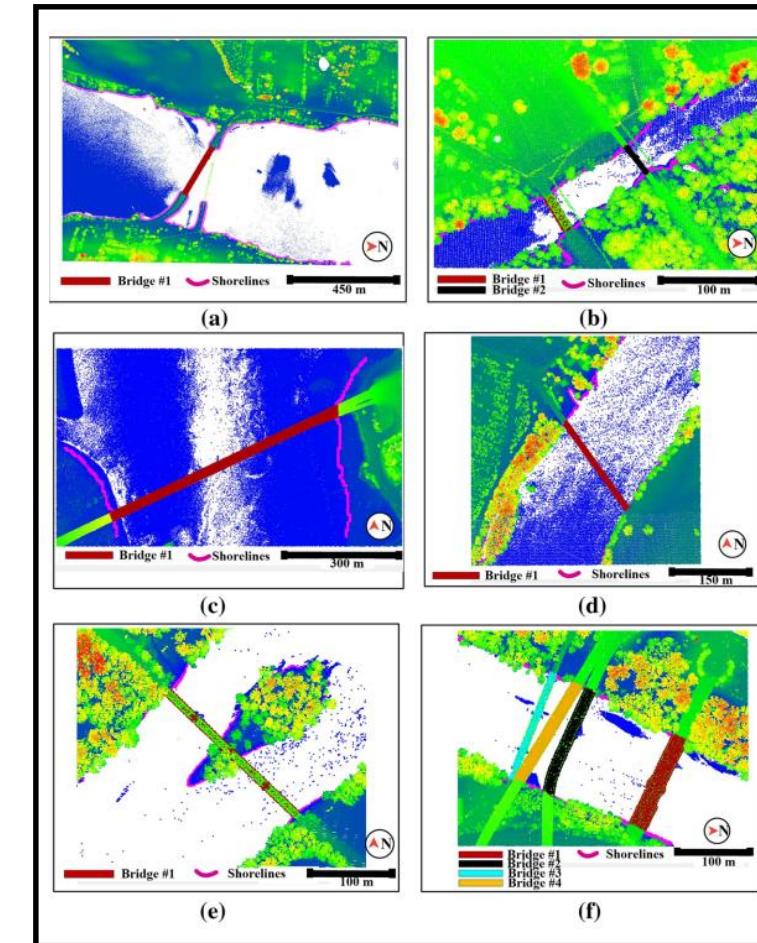


➤ 湖泊场景提取与分割

● 机载激光点云中海岸线分割（2019.02）

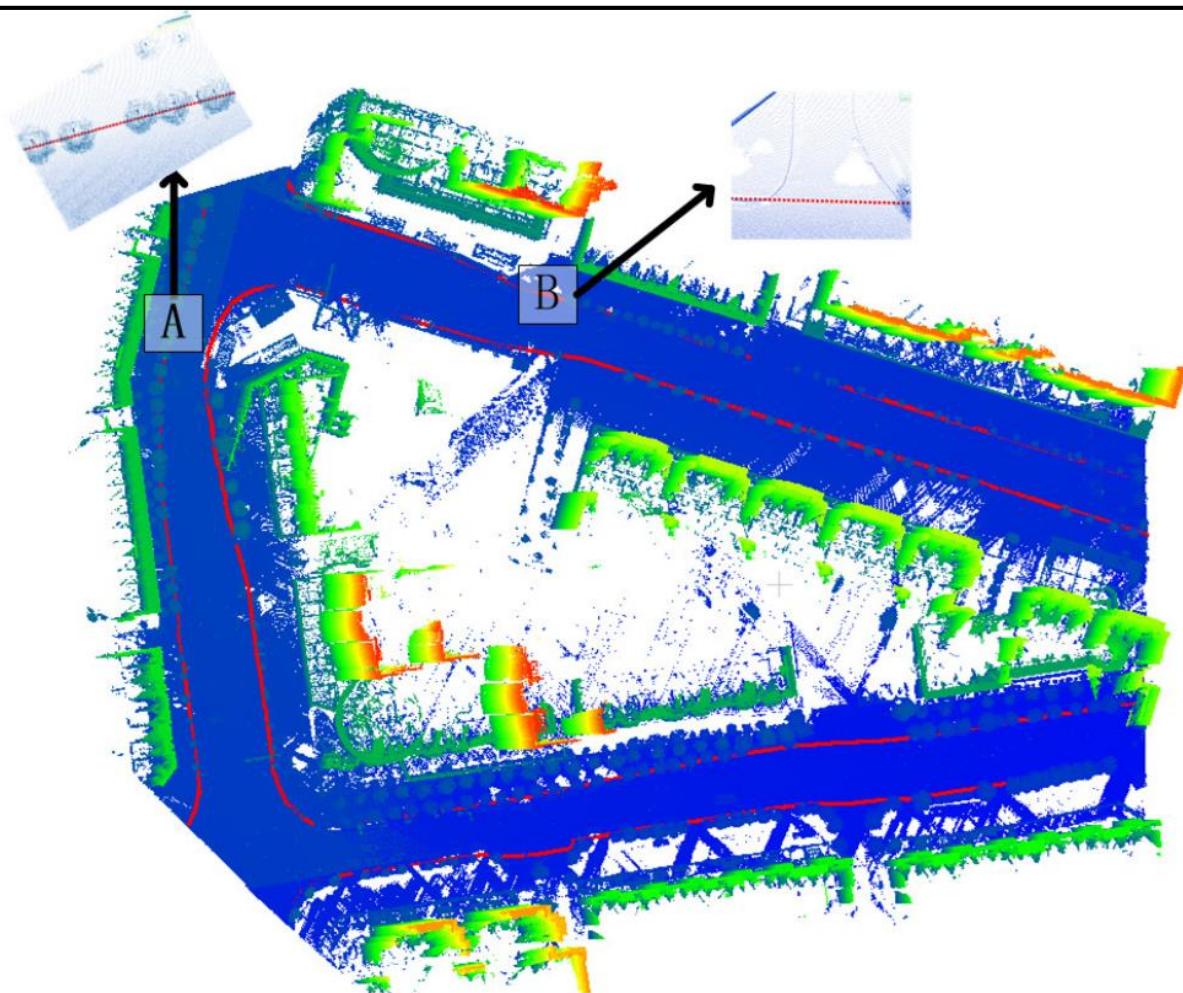


● 机载激光点云中桥梁分割（2018.09）

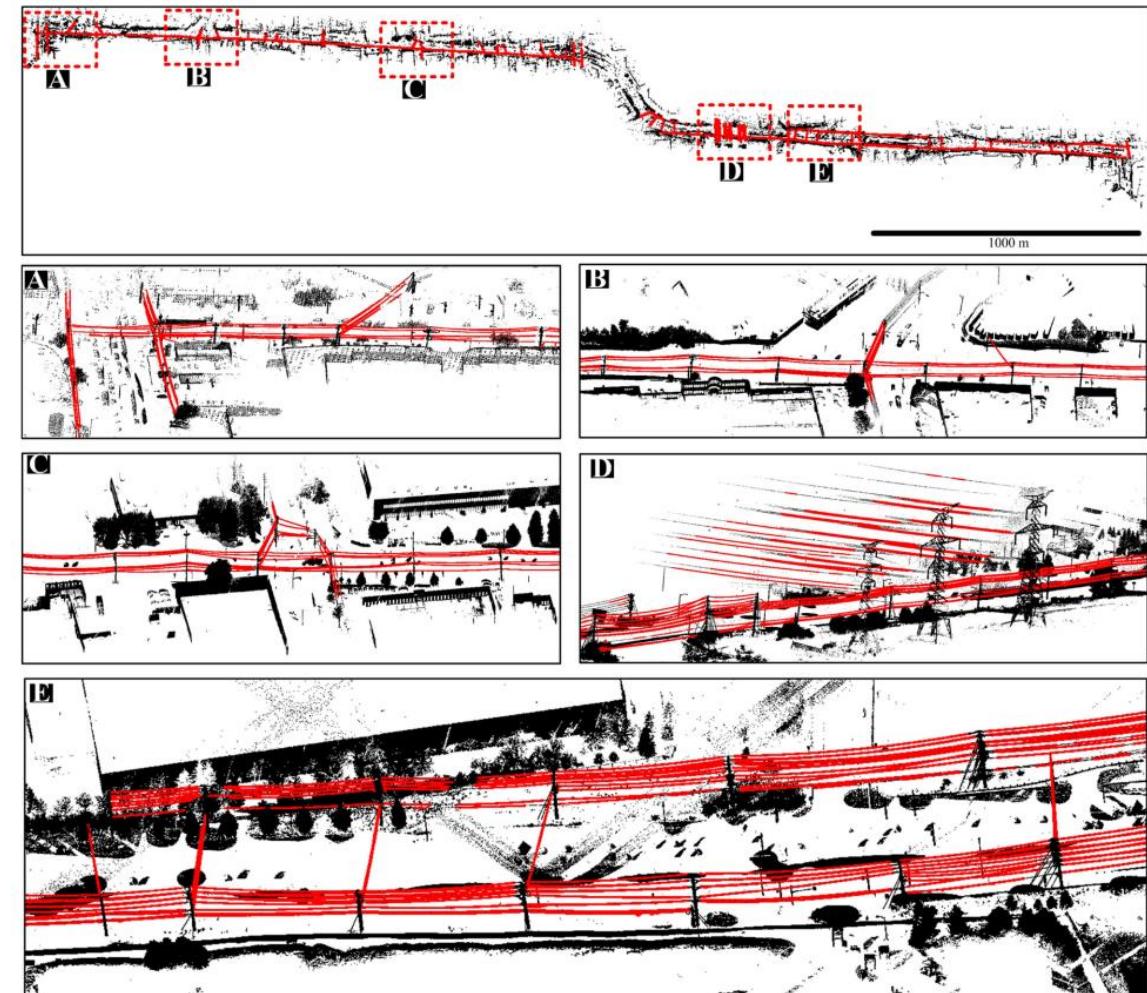


➤ 道路场景提取与分割

- 车载激光点云中道路提取（2017.02）

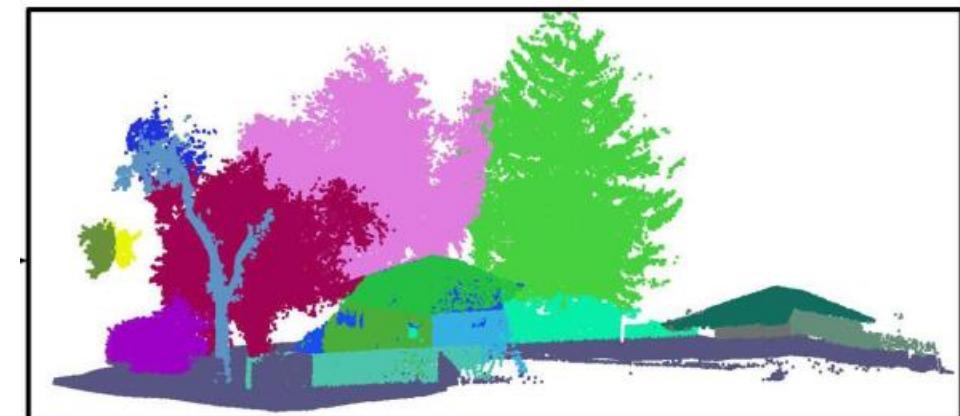
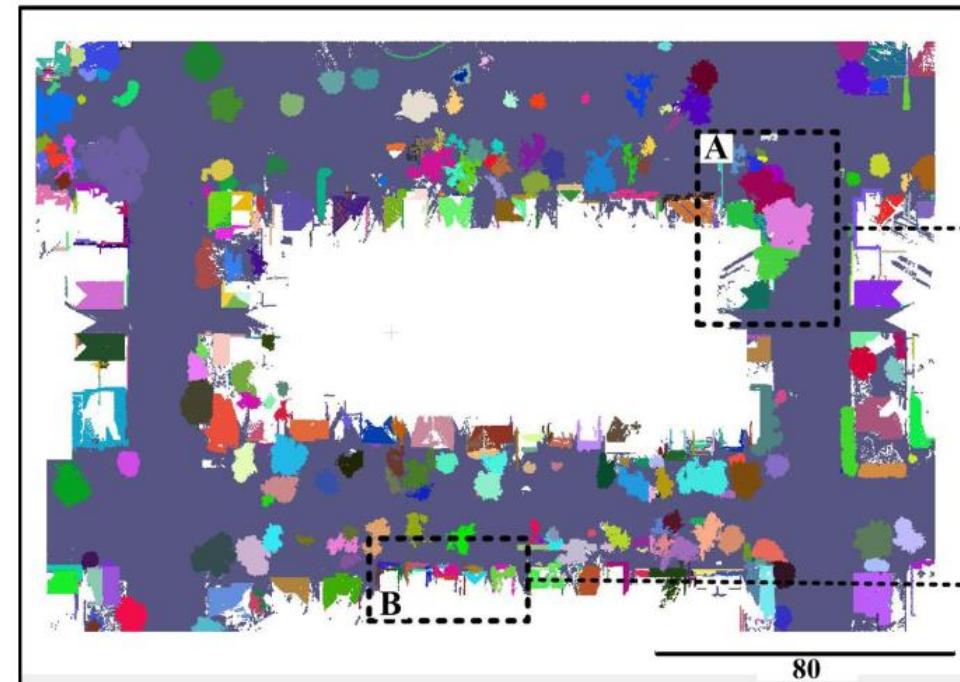
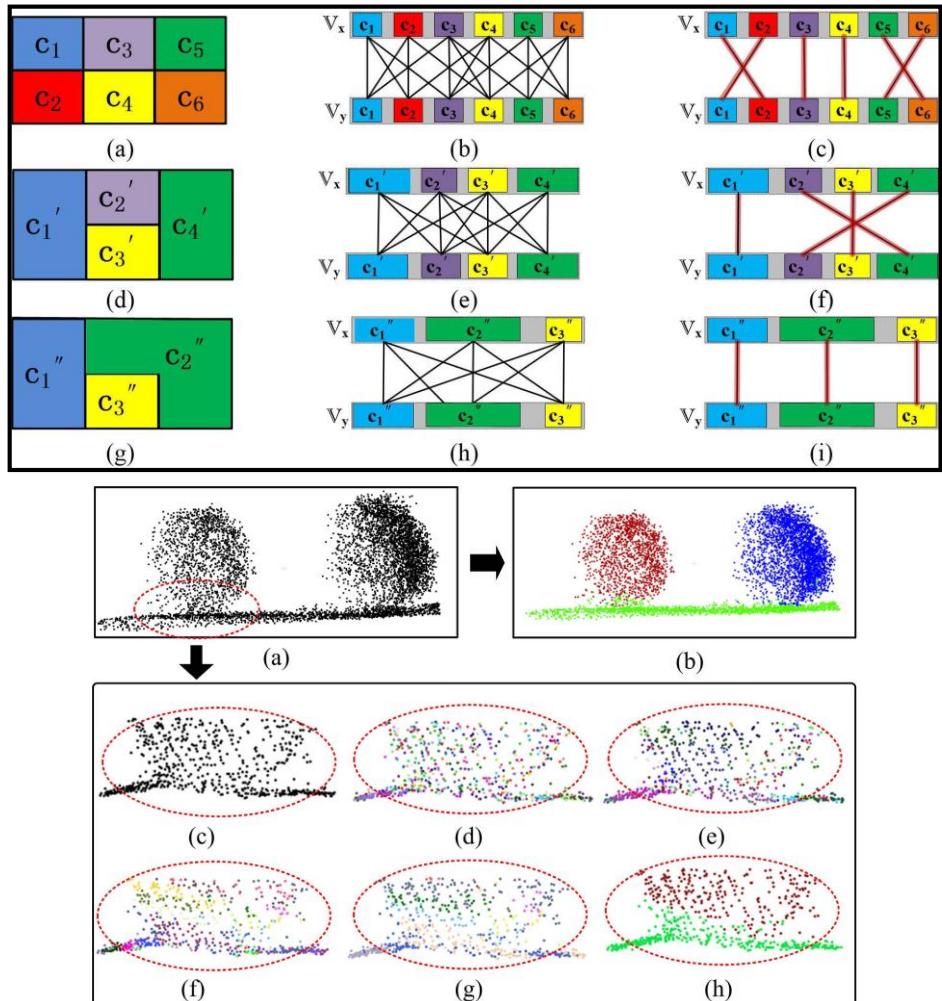


- 车载激光点云中电力线分割（2019.02）



➤ 道路场景提取与分割

● 车载激光点云中地物分割 (2020.07)



➤ 问题与方法

- 基于物体的分割(Object-based Division)
- 基于区域的分割 (Region-based Division)

➤ 区域划分

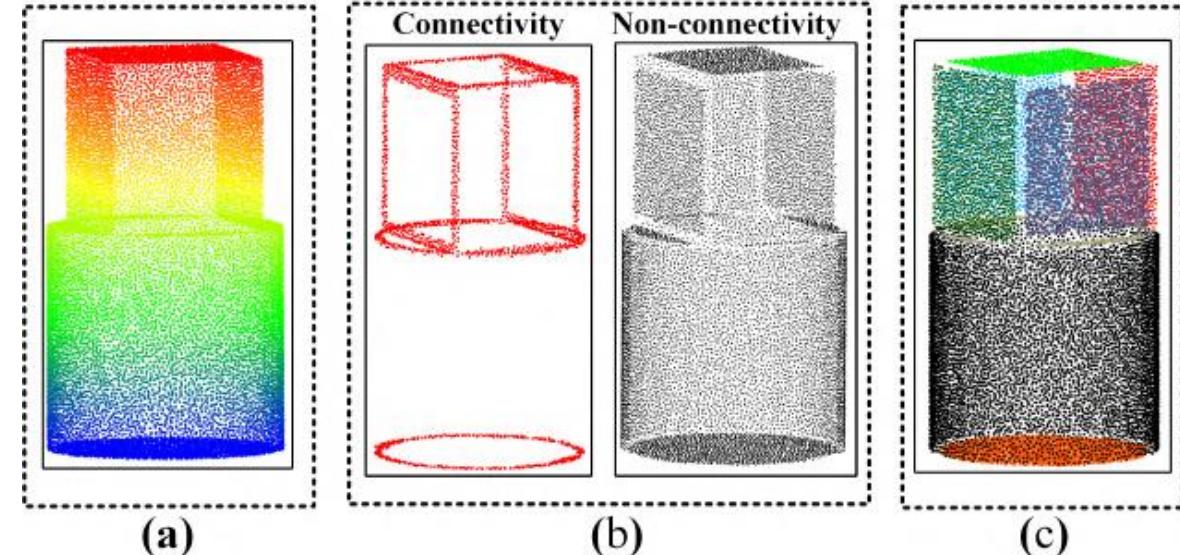
- 前景和背景
- 连通区域和非连通区域

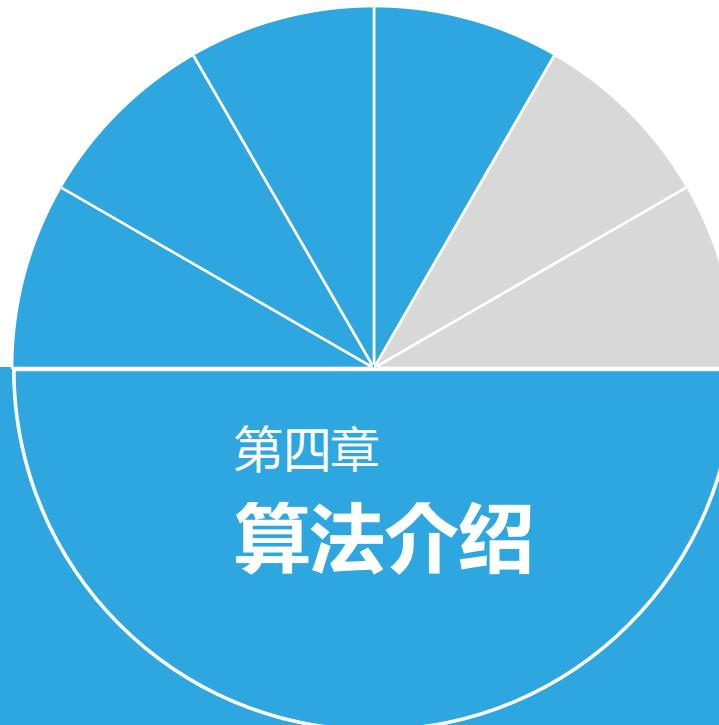
➤ 思路

- 数据划分为Connectivity和Non-connectivity Region
- 去除所有Connectivity Regions
- 聚类点云成Disjoint Clusters

➤ 难点

- 如何检测出Connectivity区域
- 如何分割开Connectivity和Non-connectivity Region



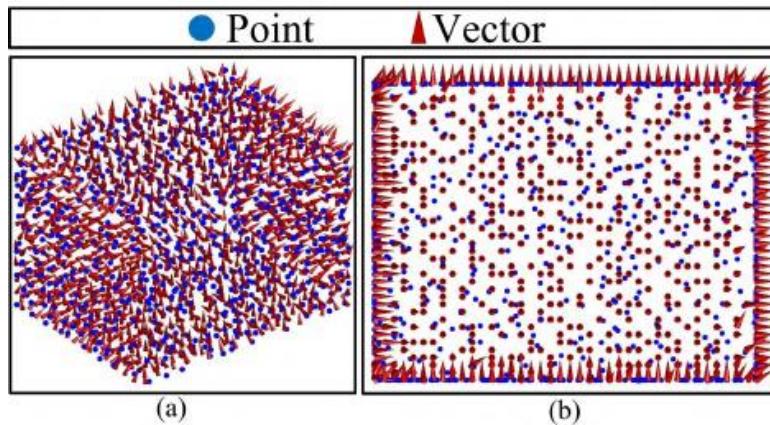


第四章 算法介绍

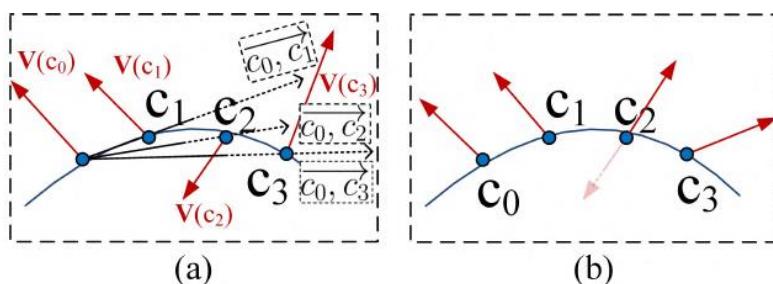
➤ 点云法向量一致化 (consistency)

- 法向量估计

$$\begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \dots & \dots & \dots \\ x_k & y_k & z_k \end{bmatrix} = \mathbf{D}_{k \times 3} = \mathbf{U}_{k \times k} \mathbf{S}_{k \times 3} \mathbf{V}_{3 \times 3}^\top$$



- 一致化

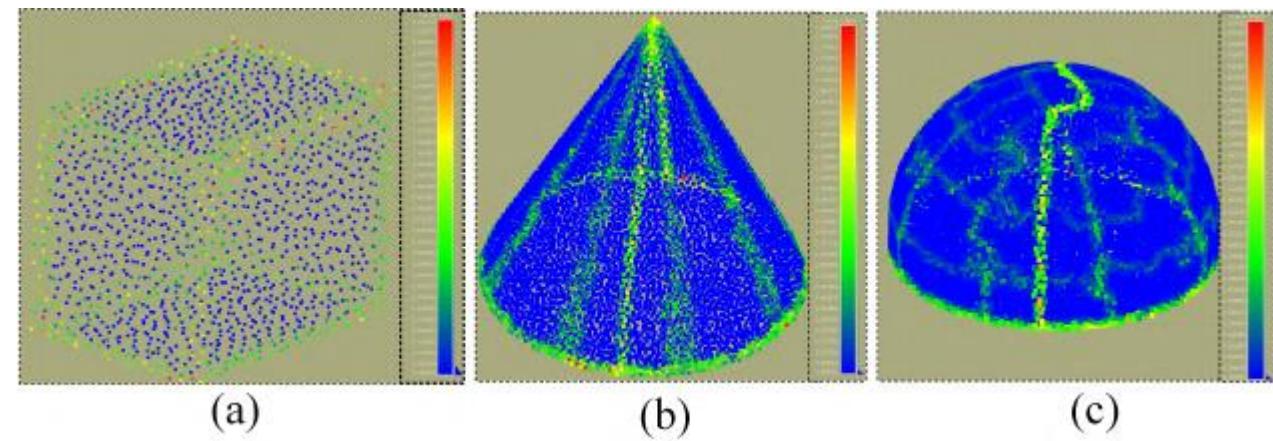


➤ 点云中的Connectivity Score

- Connectivity Region: $h(x,y,z) \nearrow$
- Non-connectivity Region: $h(x,y,z) \searrow$

$$h(x, y, z) = \frac{1}{\sum_{c_j \in c_i^s} |\mathbf{V}(c_i) \cdot \mathbf{V}(c_j)|}, \quad (2)$$

➤ 基于 h 值得区域分割



➤ 向量场的构建

$$F(u, v, w) = [u(x, y, z), v(x, y, z), w(x, y, z)], \quad (3)$$

➤ 能量函数

$$\begin{aligned} E &= \iiint (\lambda E_g + E_h) dx dy dz \\ &= \iiint \{\lambda (\nabla u \cdot \nabla u^\top + \nabla v \cdot \nabla v^\top + \nabla w \cdot \nabla w^\top) \\ &\quad + h \times (F - h)^2\} dx dy dz, \end{aligned} \quad (4)$$

➤ 函数最小化 (Euler equation) - 解析解

$$\lambda \Delta u - h \times (u - h) = 0, \quad (5a)$$

$$\lambda \Delta v - h \times (v - h) = 0, \quad (5b)$$

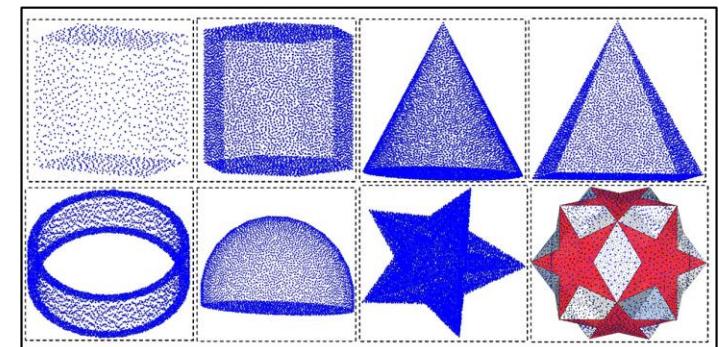
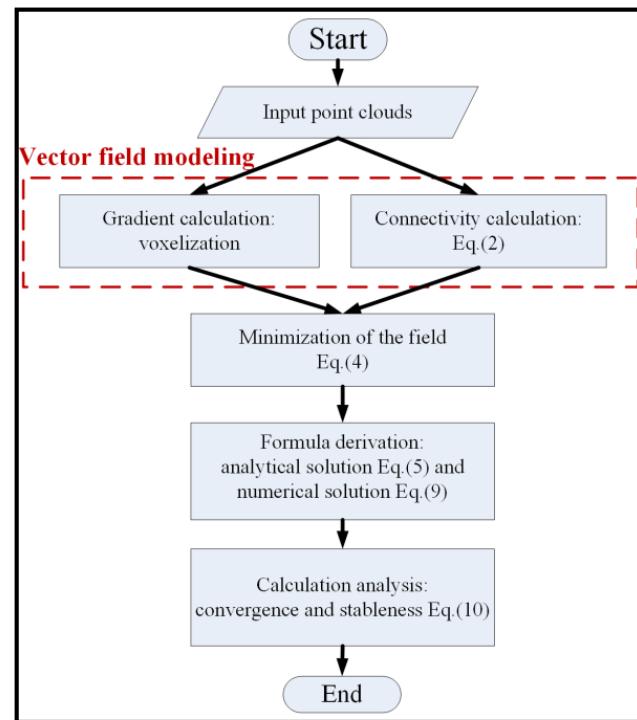
$$\lambda \Delta w - h \times (w - h) = 0, \quad (5c)$$

➤ 数值解

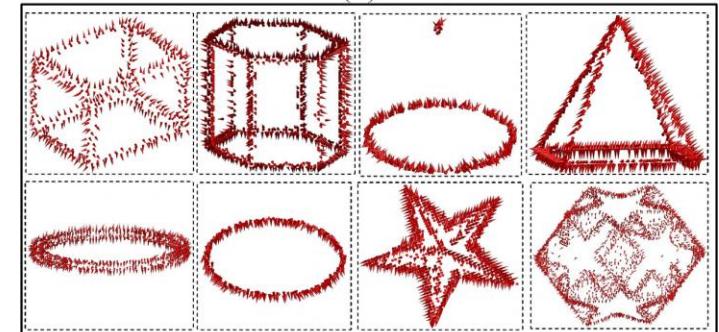
$$\begin{aligned} u_{x,y,z}^{t+1} &= (1 - h_{x,y,z} \Delta t) u_{x,y,z}^t \\ &\quad + \frac{\lambda \Delta t}{\Delta x \Delta y \Delta z} \cdot (u_{xx}^t + u_{yy}^t + u_{zz}^t) + \Delta t h_{x,y,z}^2. \end{aligned} \quad (9)$$

➤ 收敛性和稳定性

$$\Delta t \leq \frac{\Delta x \Delta y \Delta z}{6\lambda} \quad (10)$$



(a)



(b)

➤ 分割 (2 labels)

● 能量函数

$$E(C, L) = D(C, L) + \gamma S(C, L), \quad (11)$$

● Data term

$$D(C, L) = \sum_{c \in C} d(c, l_c), \quad (12)$$

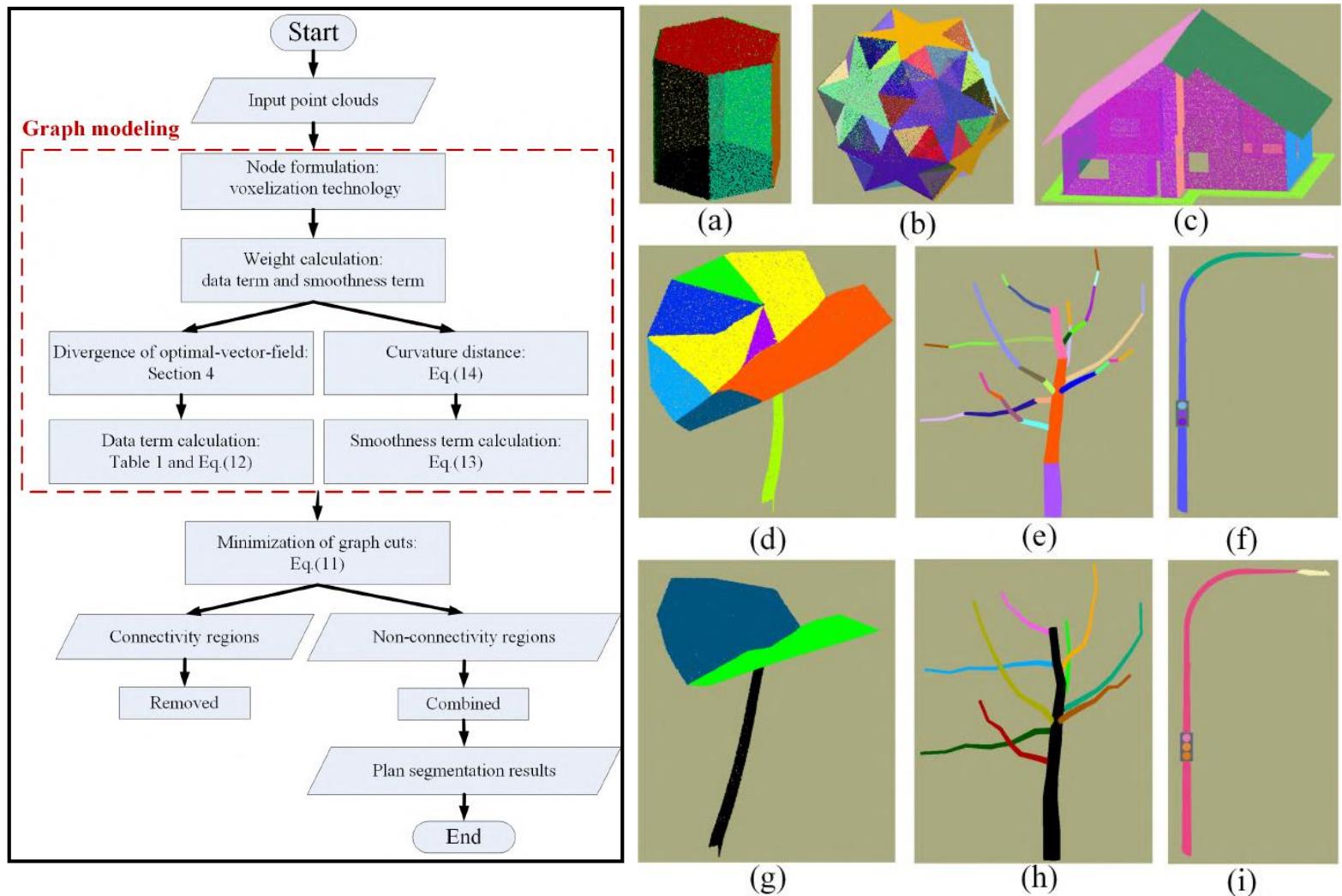
$div(c)$	$l_c=0$	$l_c=1$
$> \epsilon$	$d(c, l_c)=0$	$d(c, l_c)=1$
$\leq \epsilon$	$d(c, l_c)=1$	$d(c, l_c)=0$

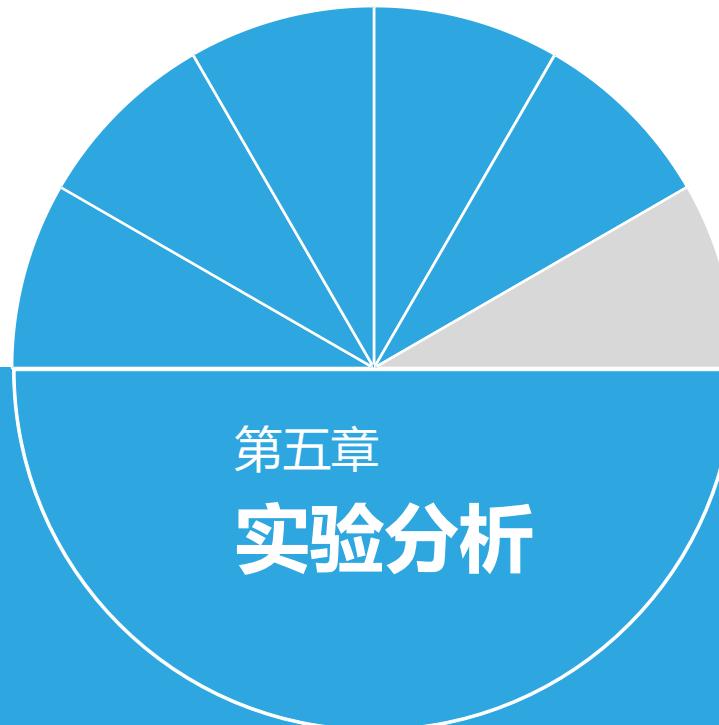
● Smoothness term

$$S(C, L) = \sum_{\{c, c' \} \in N} \beta_{c, c'} \cdot \delta(l_c, l_{c'}), \quad (13)$$

$$l_c \neq l_{c'}, \delta(l_c, l_{c'}) = 1$$

$$\beta_{c, c'} = e^{-(r_c - r_{c'})^2}, \quad (14)$$

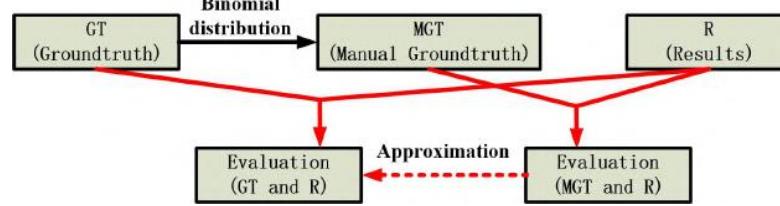




5.1分割算法对比 (部件级别)

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Ground Truth



$$\begin{aligned}
 & Pro(R|GT) \\
 &= \frac{Pro(R|MGT)Pro(MGT)Pro(GT|MGT, R)}{Pro(GT)Pro(MGT|GT, R)} \\
 &= Pro(R|MGT) \cdot \frac{Pro(MGT|GT)}{Pro(GT|MGT)} \cdot \frac{Pro(GT|MGT, R)}{Pro(MGT|GT, R)} \\
 &= \Phi \cdot Pro(R|MGT).
 \end{aligned}$$

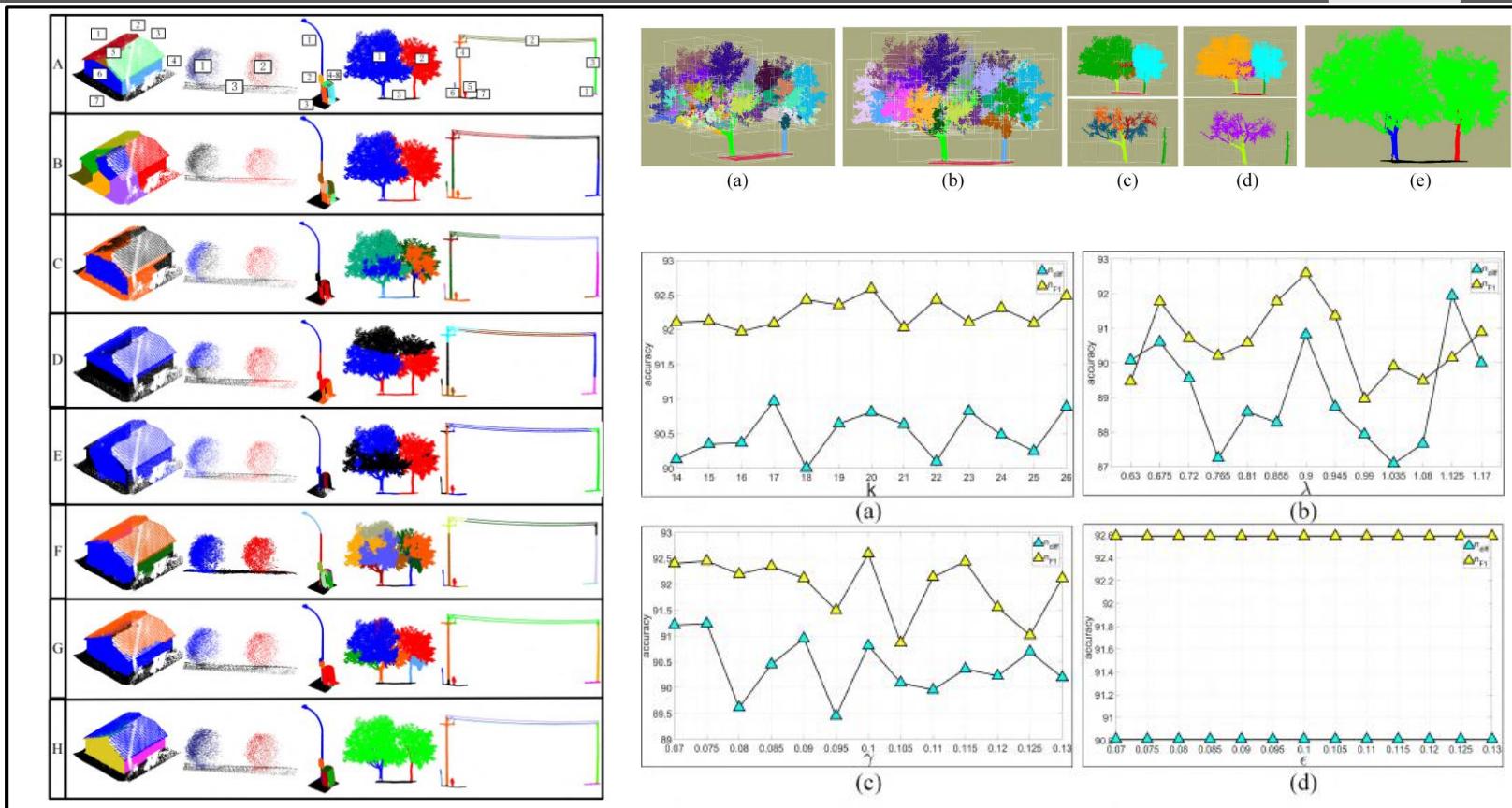
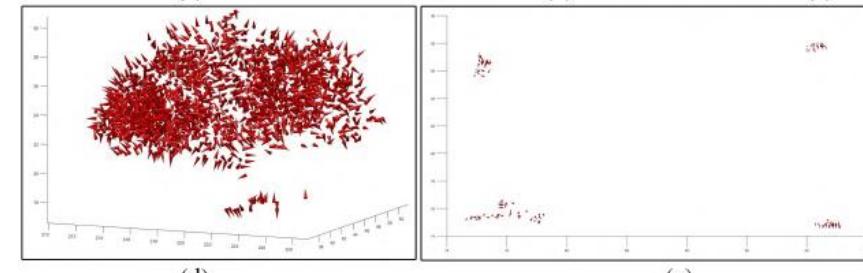
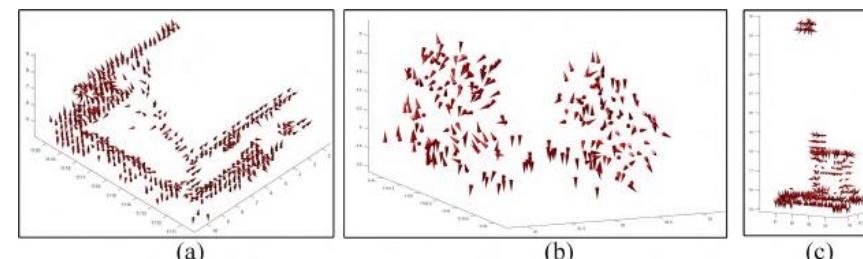
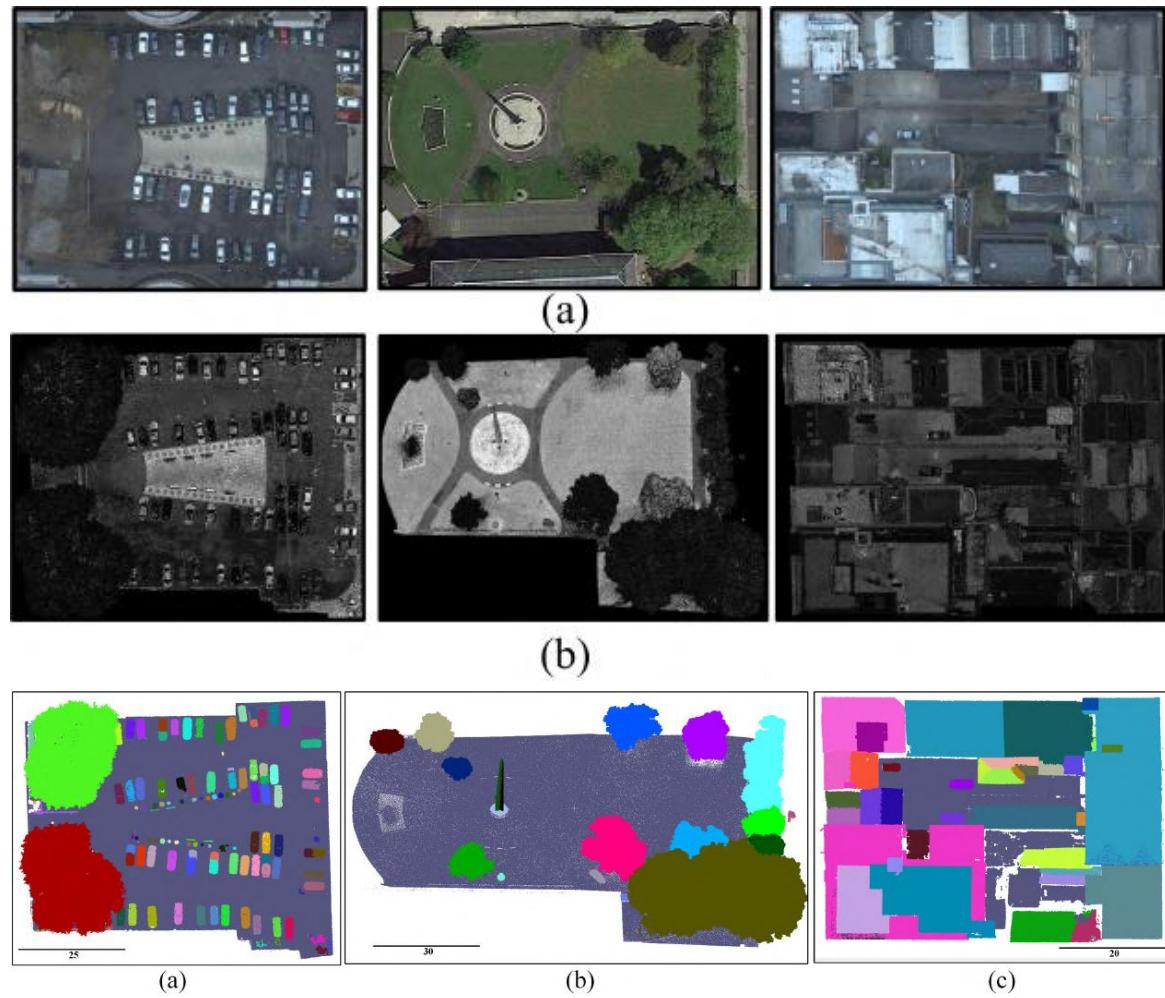
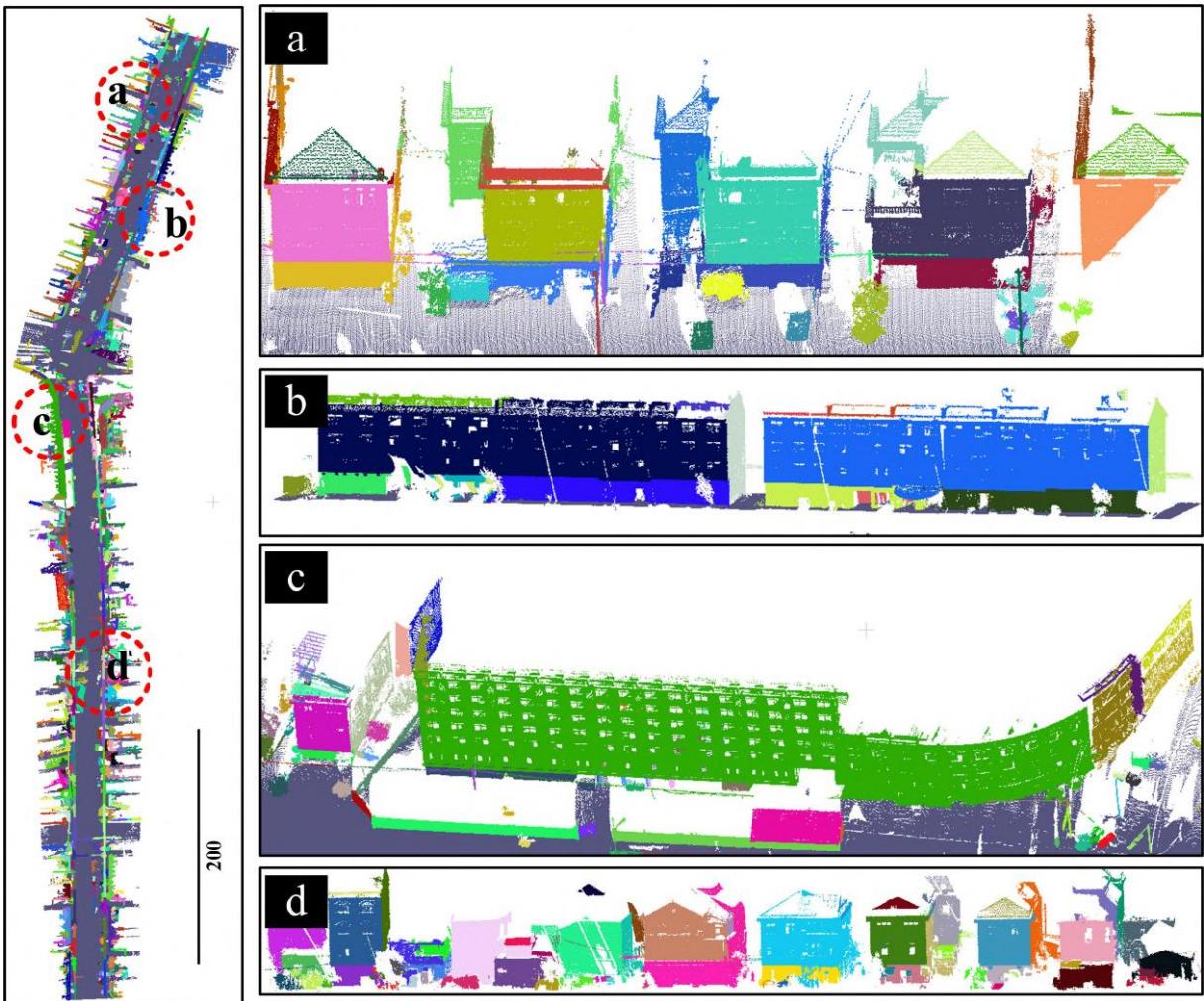


Fig. 10. Performance of different segmentation methods. A.Ground-truth. B.KMiPC. C.KNNiPC. D.3DNCut. E.MinCut. F.PEAC. G.OHC. H.The proposed algorithm.

Dataset	Number of points	Density (points/m ²)	Time cost (seconds)						
			KMiPC	KNNiPC	3DNCut	MinCut	PEAC	OHC	Proposed
HouseSet	73899	821	0.72	0.76	61.67	15.99	4.92	10.63	6.65+10.45
BushesSet	7046	793	0.04	0.04	0.60	3.16	0.24	1.63	0.40+1.61
LamppostSet	52403	4645	0.46	0.21	29.96	31.92	3.02	9.91	2.10+9.82
TreesSet	257469	858	1.86	1.84	520.14	122.21	111.32	35.96	16.15+60.47
PowerlinesSet	154307	1836	1.07	0.58	234.35	139.53	33.65	16.23	9.75+35.07

5.2 点云分割结果 (部件级别)

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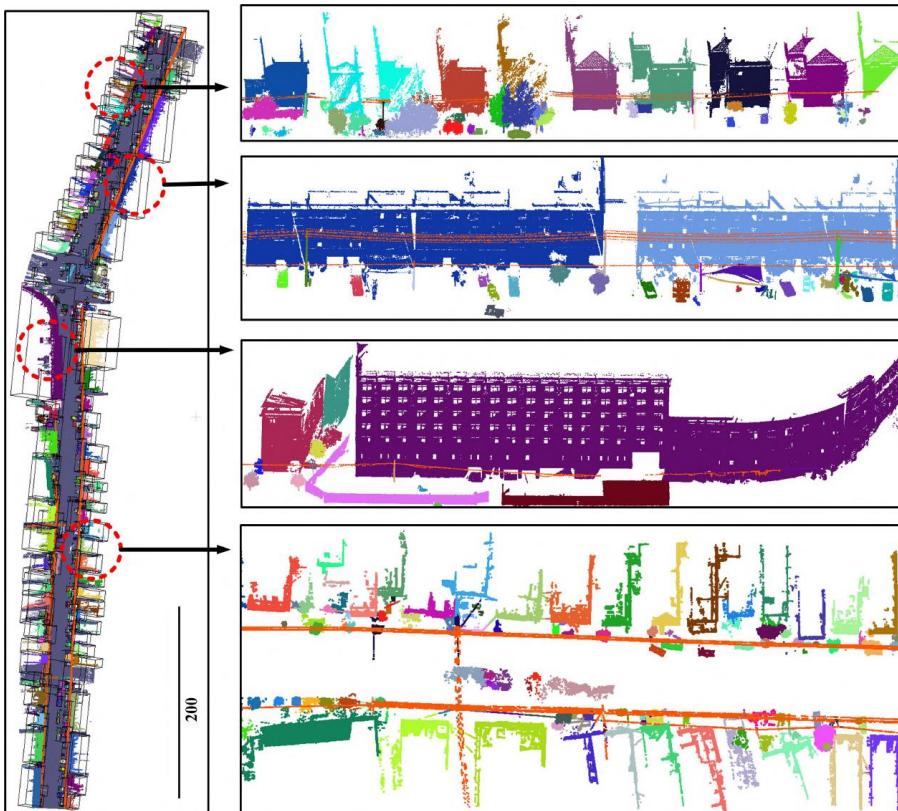


➤ Compatibility of Information

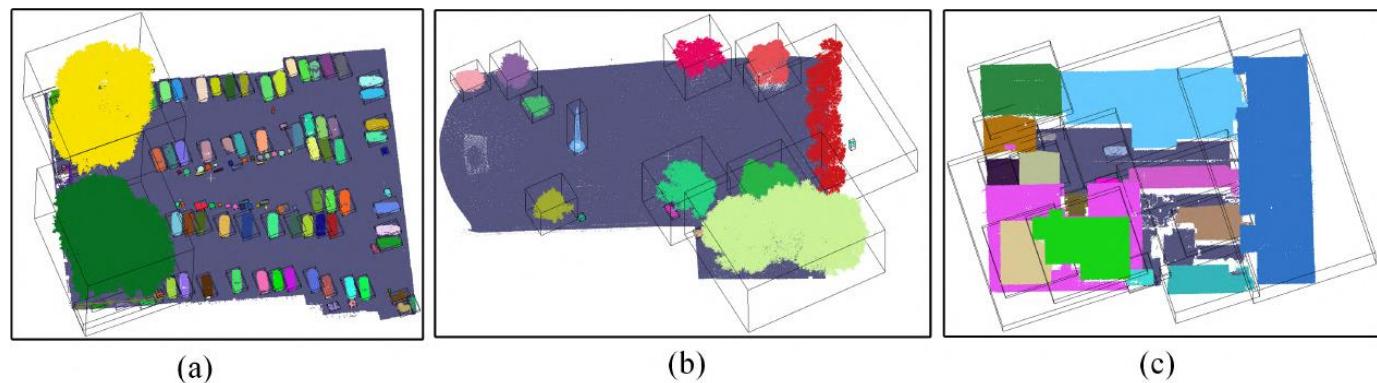
- Property (e.g. the material, color, texture)
- Structure (e.g. topology, shape)

$$|\overline{\phi_A} - \overline{\phi_B}| < T$$

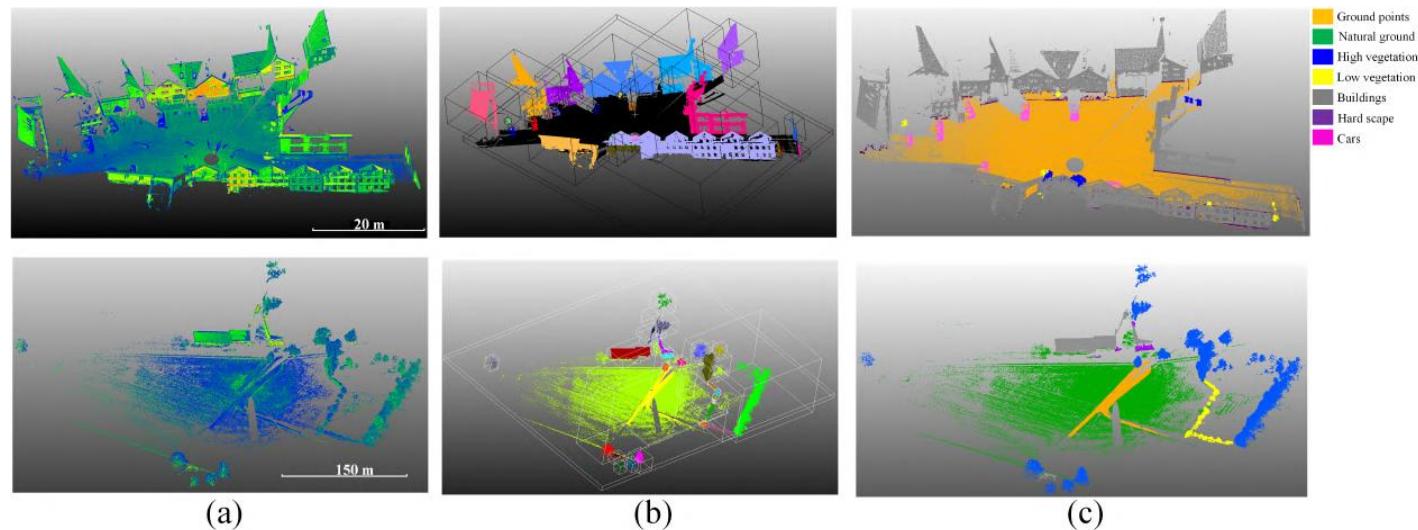
➤ RGB+MLS

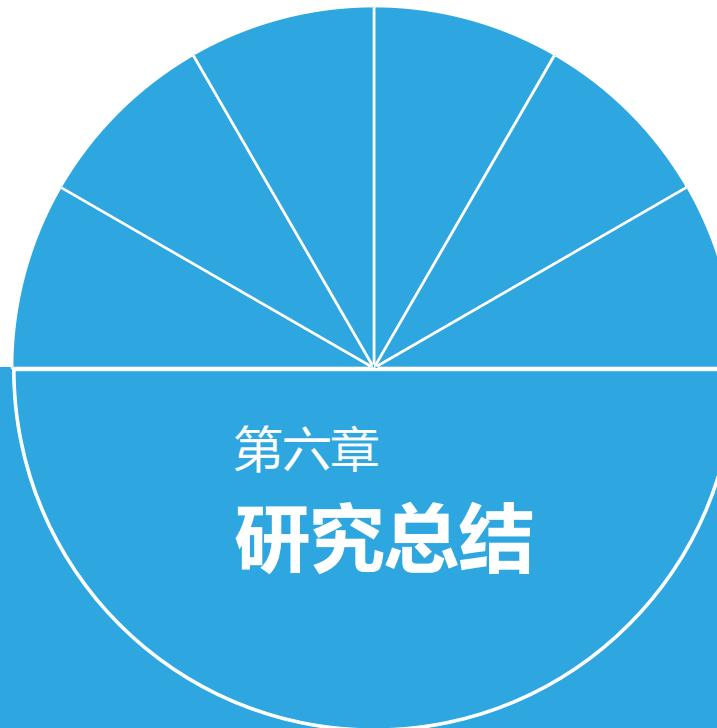


➤ Intensity + ALS



➤ Object Detection

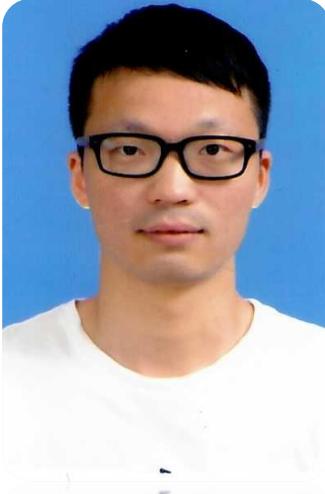




- **Contributions:** 提出一个点云分割算法(**Component Level**)
 - Phase 1: Local Phase 构造向量场来检测平面相交处
 - Phase 2: Global Phase 采用**Graph Cut** 来分割**Connectivity and Non-connectivity Region**
- **Advantages**
 - 采用**Binary Segmentation**方法来解决多目标分割问题
 - 分割过程中，无需迭代操作
- **Limitations**
 - 分割前后点云不一致
 - 向量场构建与图割优化都依赖于点云体素化构造
 - **Fine Segmentation**效果较差
 - **Instance Level** 分割需要实用额外信息
- **Future Works**
 - 主动轮廓方法 (**active models**) 计算空间中平面的相交曲线
 - **Dualist Vector Foil** (“二向箔”)



谢谢



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教育经历:

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研究兴趣: 采用计算机视觉技术, 对点云数据进行研究, 包括:
三维空间信息处理, 点云数据分析, 点云场景分割与识别等。目前发表国内外期刊会议30余篇, 近五年一作发表SCI期刊10篇(4篇1区), 包含IEEE TPAMI, IEEE TITS, IEEE TGARS等顶刊。