刘鸿雁

中国科学院大学博士，曾在王天然**院士**（中国工程院院士）团队攻读博士学位，师从**曲道奎教授**（新松机器人创始人，国家机器人标准化总体组组长），长期致力于移动机器人定位与建图以及运动规划等研究工作，发表SCI/EI论文10余篇，包括机器人与自动化领域顶刊***IEEE T-VT*，*Intell Robot Syst***和顶会***IEEE ITSC (CCF-B)***等

2023年初进入之江实验室担任助理研究员（**博士后**），负责静态环境感知以及自主代客泊车等算法研发工作。21年入职之江实验室担任**定位与建图组负责人**，主持**国自然青年基金项目**一项，聚焦于面向具身智能的通用基础模型研究，**骨干**参与之江实验室科研攻关项目等多个国家/省部级项目。

156-2055-6702 ghm@mail.nankai.edu.cn https://ghm0819.github.io

教育背景

- **2015.09-2020.06 南开大学**-人工智能学院-控制科学与工程 博士 GPA: 91.04/100 (**1**/38)
- **2011.09-2015.06 河海大学**-机电工程学院-机械工程及自动化 学士 GPA: 4.64/5.0 (**8**/285)

工作经历

2021.07-至今 **之江实验室**-智慧交通研究中心/智能制造计算研究中心 高级研究专员/副研究员

- 国自然青年基金项目**负责人**，面向**场景图谱**和**具身智能**等前沿领域开展研究
- 无人车项目定位与建图组**负责人**，面向无人车和移动机器人**感知**、**定位与建图**开展研究

2020.07-2021.07 **华为**(上海)-智能汽车解决方案BU-感知融合项目组 高级算法工程师

- 自动驾驶系统**静态环境感知**、**可行驶区域检测**等算法研发
- **AVP**（自动代客泊车）和**APA**（自动泊车辅助）算法研发

科研项目

- **2024.01-2026.12**: **项目负责人**，负责**项目申报**，包括**研究内容**、**技术路线**以及**方案实施**
  国家自然科学青年基金项目：动态歧义环境下面向移动机器人全局定位的自组织时空场景图谱构建
- **2021.09-2023.12**: **主要参与人**，定位与建图组**负责人**，**定位建图**与**感知融合**等算法预研和实车部署
  之江实验室科研攻关项目：车路协同自主交通系统及示范工程建设
- **2019.06-2022.05**: **主要参与人**，制定**研究内容**、**技术路线**以及**项目申报**，**自主行为与遥操作**融合
  “智能机器人”国家重点研发项目：面向高海拔科考环境的机器人移动与作业技术研究
- **2021.01-2024.12**: **主要参与人**，基于激光/视觉传感器的**地面机器人SLAM算法**开发
  国家自然科学基金面上项目：多重异构源的空地协作紧耦合环境感知与建图
- **2016.01-2019.12**: **主要参与人**，基于激光传感器的**自主探索**、**环境建模**以及**全局定位**算法开发
  国家自然科学基金：面向场景监控的全方位移动机器人最短时间覆盖
  南开大学学科项目：基于视觉与激光的无人平台环境感知与自主导航共性理论方法与应用研究
  天津市杰出青年科学基金：智能移动机器人
- **2015.12-2016.06**: **主要参与人**，移动机器人**鲁棒定位**与**导航规划**算法研发
  横向课题：酒店服务机器人校企合作项目

获奖情况

- 2023.12, 之江实验室年度**绩效优秀**
- 2021.01, 华为大学**最佳学员**，智能汽车解决方案BU**优秀新员工**
- 2020.06, 南开大学研究生**优秀毕业生**，公能**一等奖学金**，研究生**三好学生**
- 2019.05, 首届中国光谷人工智能大会——**最佳论文奖**
- 2018.08, **Finalist for the Best Paper Award, IEEE RCAR**, Maldives, Aug. 2018
- 2018.07, **Best Conference Paper Finalist, IEEE ARM**, Singapore, July 2018
- 2015.06, 河海大学**优秀毕业生**, **校长奖学金**
- 第十五届**全国机器人锦标赛**半自主型足球机器人5vs5、11vs11**一等奖**
- 2013中国机器人大赛暨**RoboCup公开赛**FIRA小型组3vs3**一等奖**
- 2013~2014, **国家奖学金**
- 2011~2015, 优秀学生、优秀学生标兵、优秀学生干部

研究兴趣

- 智能机器人**通用基础模型**、**具身智能**算法研究
- 自动驾驶**定位与建图**、**感知融合**算法研究
- 移动机器人**全局定位**、**自主探索**和**SLAM**算法研究

论文发表

【共发表SCI/EI论文20余篇(IEEE汇刊7篇)；第一/通讯作者发表SCI/EI论文8篇(IEEE汇刊4篇)】

[1] **H. Gao**, Q. Qiu, W. Hua*, X. Zhang, Z. Su, and S. Zhang. CVR-LSE: Compact vectorized representation of local static environments for reliable obstacle detection, ***IEEE Transactions on Industrial Electronics***, 2024, 71(8): 9309-9318. **[SCI 一区TOP，影响因子7.7]**

[2] **H. Gao**, X. Zhang*, J. Yuan, and Y. Fang. NEGL: Lightweight and efficient neighborhood encoding-based global localization for unmanned ground vehicles, ***IEEE Transactions on Vehicular Technology***, 2023, 72(6): 7111 - 7122. **[SCI 二区TOP，影响因子6.8]**

[3] **H. Gao**, X. Zhang*, J. Wen, J. Yuan, and Y. Fang. Autonomous indoor exploration via polygon map construction and graph-based SLAM using directional endpoint features, ***IEEE Transactions on Automation Science and Engineering***, 2019, 16(4): 1531-1542. **[SCI 二区TOP，影响因子5.6]**

[4] **H. Gao**, X. Zhang*, J. Yuan, J. Song, and Y. Fang. A novel global localization approach based on structural unit encoding and multiple hypothesis tracking, ***IEEE Transactions on Instrumentation and Measurement***, 2019, 68(11): 4427-4442. **[SCI 二区TOP，影响因子5.6]**

[5] Q. Qiu, W. Wang, H. Ying, D. Liang, **H. Gao*(通讯)**, and X. He. SelFLoc: Selective feature fusion for large-scale point cloud-based place recognition, ***Knowledge-based System***, 295: 111794, 2024. **[SCI 一区TOP，影响因子8.8]**

[6] **H. Gao**, X. Zhang*, Y. Fang, and J. Yuan. A line segment extraction algorithm using laser data based on seeded region growing, ***International Journal of Advanced Robotic Systems***, 2018, 15(1): 1-10.

[7] **H. Gao**, Q. Qiu, S Zhang, W. Hua*, Z. Su, and X. Zhang. MPC-MF: Multi-point cloud map fusion based on offline global optimization for mobile robots, ***2023 Chinese Control Conference***, pp. 4237-4242, 2023.

[8] **H. Gao**, X. Zhang*, C. Li, X. Chen, Y. Fang, and X. Chen. Directional endpoint-based enhanced EKF-SLAM for indoor mobile robots, ***IEEE/ASME International Conference on Advanced Intelligent Mechatronics***, pp. 978-983, 2019.

[9] J. Wen, X. Zhang*, **H. Gao**, J. Yuan, and Y. Fang. CAE-RLSM: Consistent and efficient redundant line segment merging for online feature map building, ***IEEE Transactions on Instrumentation and Measurement***, 2020, 69(7): 4222-4237. **[SCI 二区TOP，影响因子5.6]**

[10] C. Li, X. Zhang*, **H. Gao**, R. Wang, and Y. Fang. Bridging the gap between visual servoing and visual SLAM: A novel integrated interactive framework, ***IEEE Transactions on Automation Science and Engineering***, 2022, 19(3): 2245-2255. **[SCI 二区TOP，影响因子5.6]**

[11] J. Wen, X. Zhang*, **H. Gao**, J. Yuan, and Y. Fang. E³MoP: Efficient motion planning based on heuristic-guided motion primitives pruning and path optimization with sparse-banded structure, ***IEEE Transactions on Automation Science and Engineering***, 2022, 19(4): 2762-2775. **[SCI 二区TOP，影响因子5.6]**

[12] Q. Qiu, **H. Gao**, W. Hua, G. Huang, and X. He. PriorLane: A prior knowledge enhanced lane detection approach based on transformer, ***IEEE International Conference on Robotics and Automation (ICRA)***, pp. 5618-5624, 2023. **[机器人领域顶级会议]**

[13] 周光召,苑晶*,**高海明**,孙沁璇,张雪波,俞诗卓. 结构化环境下基于结构单元软编码的3维激光雷达点云描述子[J]. 机器人, 2020, 42(06): 641-650.

[14] J. Song, **H. Gao**, X. Zhang*, W. Lin, and J. Liu. A global localization algorithm for mobile robots based on grid submaps, ***IEEE International Conference on Advanced Robotics and Mechatronics***, pp. 201-206, 2018. (**Best Conference Paper Finalist**)

[15] J. Wen, X. Zhang*, **H. Gao**, J. Yuan, and Y. Fang. A novel 2D laser scan matching algorithm for mobile robots based on hybrid features, ***IEEE International Conference on Real-time Computing and Robotics***, pp. 366-371, 2018. (**Finalist for the Best Paper Award**)

[16] J. Wang, X. Zhang*, **H. Gao**, and Y. Fang. Time-optimal motion planning for a nonholonomic mobile robot on a barcode map, ***IEEE International Conference on Robotics and Biomimetics***, pp. 215-220, 2017.

[17] H Liu, **H. Gao***, J. Shi, C. Xu, D. Qu, and W. Hua. APMC-LOM: Accurate 3D LiDAR odometry and mapping based on pyramid warm-up registration and multi-constraint optimization. ***IEEE Transactions on Vehicular Technology***, Minor Revision, 2024. **[SCI 二区TOP，影响因子6.8]**

...

专利申报

[1] **高海明**；华炜；邱奇波；张顺；史进；刘鸿雁. 场景识别方法、装置和电子装置，已授权(CN202311256742.6), 2024-01-09.

[2] **高海明**；华炜；张顺；邱奇波；张霄来；史进. 一种无人车主动全局定位方法和系统，已授权(CN202310320547.9), 2023-09-29.

[3] **高海明**；华炜；邱奇波；张霄来；张骞. 车道线地图生成方法、装置、电子装置和存储介质，已授权(CN202310444818.1), 2023-07-18.

[4] **高海明**；华炜；邱奇波；张骞；张顺；姜峰. 在线俯仰角估计的BEV下鲁棒车道线生成方法及装置，已授权(CN202310016576.6), 2023-06-20.

[5] 华炜；**高海明**；张顺；胡艳明；马也驰；邱奇波. 一种基于离线全局优化的多点云地图融合方法和装置，已授权(CN202210228899.7), 2022-07-01.

[6] 张雪波；**高海明**；苑晶；宋剑超；方勇纯. 基于结构单元编码和多假设跟着的线激光全局定位方法，已授权(CN201811306776.0), 2022-04-22.

学术兼职

➢ 校外导师
- 大连理工大学研究生企业导师

➢ 评审专家
- 国家自然科学基金委员会项目评审专家

➢ 审稿专家
- IEEE Transactions on Automation Science and Engineering
- IEEE-ASME Transactions on Mechatronics
- IEEE Transactions on Industrial Informatics
- IEEE Transactions on Instrumentation and Measurement
- IEEE Robotics and Automation Letters
- IEEE Transactions on Intelligent Vehicles
- IEEE Transactions on Intelligent Transportation Systems
- IEEE Sensors Journal
- IEEE ICRA

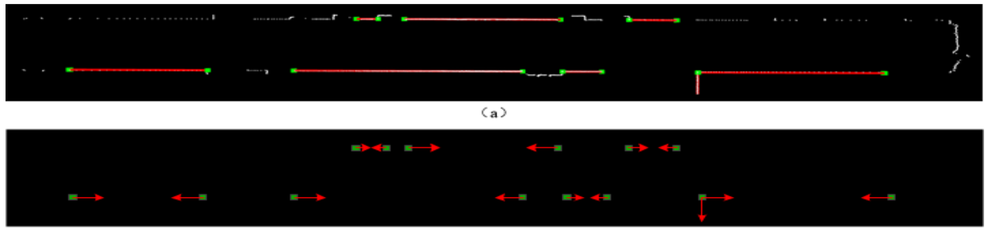
代表作介绍

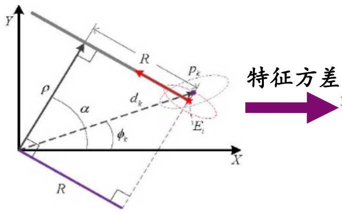
代表作1：有向端点特征定义、提取与环境表征

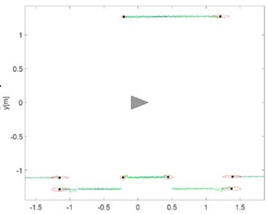
利用新型特征实现紧凑、有效、快速的环境描述和特征方差模型构建，运行时间减少**90%**，准度提升**20%**

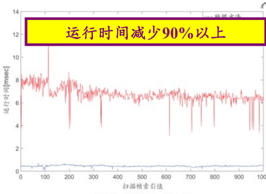
线段特征提取

有向端点提取









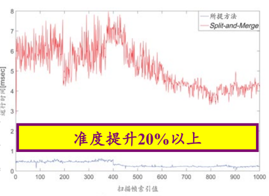
(a) 实验室环境运行时间对比

表 2.4: 线段提取运行时间对比 [msec]

	平均值	方差	最小值	最大值
所提方法	**0.445**	**0.057**	**0.130**	**0.695**
Split-and-Merge	6.762	0.672	3.084	12.00
所提方法	**0.329**	**0.129**	**0.073**	**0.631**
Split-and-Merge	5.193	1.039	2.848	7.971

表 2.5: 准度对比

		TR[%]	FR[%]
实验室环境	所提方法	**93.55**	**2.59**
	Split-and-Merge	68.55	7.06
走廊环境	所提方法	**94.20**	**0**
	Split-and-Merge	71.01	4.08



(b) 走廊环境运行时间对比

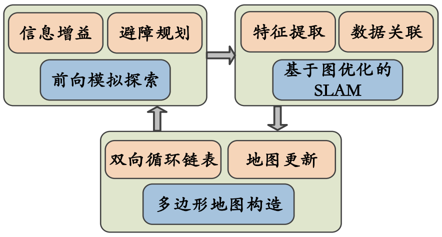
H. Gao(高海明), X. Zhang*, Y. Fang, and J. Yuan. A line segment extraction algorithm using laser data based on seeded region growing, ***International Journal of Advanced Robotic Systems***, 2018, 15(1): 1-10.

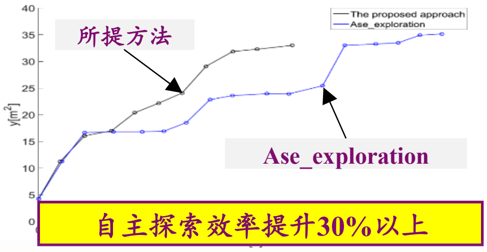
H. Gao(高海明), X. Zhang*, C. Li, X. Chen, Y. Fang, and X. Chen. Directional endpoint-based enhanced EKF-SLAM for indoor mobile robots, ***IEEE/ASME International Conference on Advanced Intelligent Mechatronics***, pp. 978-983, 2019.

代表作2：未知环境下移动机器人自主探索与地图构建

利用有向端点特征完成未知环境下，移动机器人紧凑且高效的地图构建与自主探索，探索效率提升**30%**

- **科学问题**：对于未知新环境，需手工遥控机器人遍历。**如何合理衡量未知区域潜在的信息量，引导机器人对未知环境自主探索？**
- **学术贡献**：以有向端点特征构建环境地图，**提出一种**针对该类地图的**新型信息熵计算方法，提高了机器人自主探索的效率。**

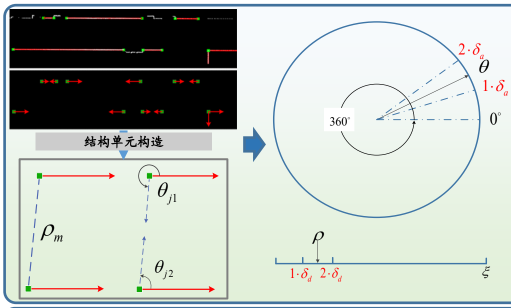




H. Gao(高海明), X. Zhang*, J. Wen, J. Yuan, and Y. Fang. Autonomous indoor exploration via polygon map construction and graph-based SLAM using directional endpoint features, ***IEEE Transactions on Automation Science and Engineering***, 2019, 16(4): 1531-1542.

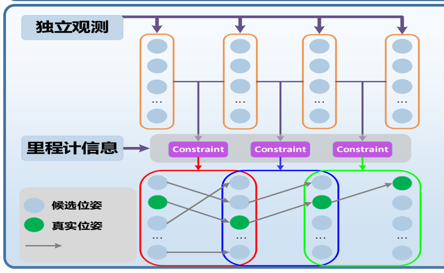
代表作3：复杂环境下移动机器人全局重定位与回环检测

提出复杂环境下全局重定位与回环检测方法，相比于传统基于滤波和优化的方法，全局定位更加**高效准确**



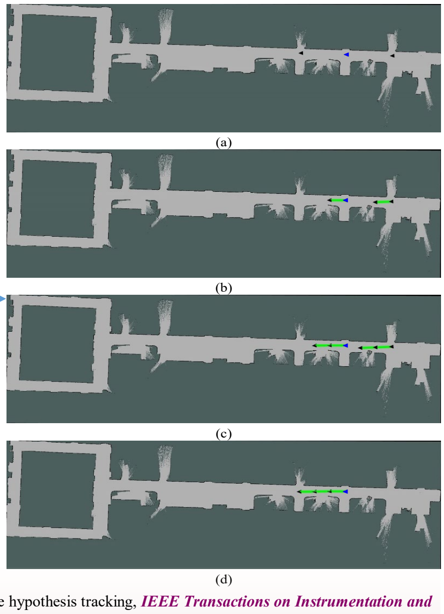
软编码机制：
- 保证结构单元可区分
- 相似结构单元保证**一致性**

结构单元编码机制SUES：
- ✓ 无需训练产生**结构词汇**
- ✓ 不依赖于结构词汇质量



先验项：观测获得的候选位姿
似然项：离散的候选位姿变化，里程计增量信息

扩展-多假设跟踪E-MHT：
- **保证信息对等，**最终获得的候选位姿与特征数量无关。
- **收敛速度快**



H. Gao(高海明), X. Zhang*, J. Yuan, J. Song, and Y. Fang. A novel global localization approach based on structural unit encoding and multiple hypothesis tracking, ***IEEE Transactions on Instrumentation and Measurement***, 2019, 68(11): 4427-4442.

代表作引用情况

陈启军

同济大学教授，中国（上海）数字城市研究院执行院长，中国自动化学会集成自动化技术专业委员会主任，科技部重点研发计划首席科学家，教育部新世纪优秀人才

在2023年的*IEEE Transactions on Instrumentation and Measurement*论文中论文中多次引用并感谢了代表作1，强调了所提直线段特征提取的有效性和高效性

To detect line segments from multiple 2-D laser scans, we take a seeded RG method from [35] for its fast processing speed. However, our MPS framework is not limited to this algorithm, and various line extraction approaches for 2-D range data can be found in the literature [34]. Here, we briefly introduce the major steps of the selected line extraction approach, and for more technical details, we refer readers to the original report. Gao et al. [35] extract line segments with a two-stage strategy. Detecting 2-D line segment seeds from a small number of consecutive points is followed by the seeded line growing process. Those two steps are executed recursively until all points are visited. Finally, overlapped line segments are refined by merging and absorption operations.

The scheme of our MPS method is illustrated in Fig. 2. The point cloud is first preprocessed into organized 2-D laser scans in vertical and horizontal directions. Then, line segments along two directions are detected with an efficient RG algorithm [35]. With those line primitives, we gen-

ACKNOWLEDGMENT

The authors would thank Gao et al. who provide source codes for line segment extraction and Geneva et al. for providing LIPS which facilitates our simulation experiment design.

Kerstin Thurow

德国罗斯托克大学教授，CELISCA国家重点实验室主任，德国工程院院士，汉堡科学院创始成员

在2023年*Robotics*室内机器人定位综述论文中引用了代表作2并给出良好的评价，表示论文利用有向端点特征的图优化SLAM具有更优的性能

subjected to motion filtering, it is superimposed to form a submap. Finally, all subgraphs are formed into a complete environment map through loop closure detection and back-end optimization [76]. Deng et al. divided the environment into multiple subgraphs, reducing the computational cost of the Cartographer [77]. Sun et al. improved Cartographer's boundary detection algorithm to reduce cost and error rate [57]. Gao et al. proposed a new graph-optimized SLAM method for orientation endpoint features and polygonal graphs, which experimentally proved to perform better than Gmapping and Karto [78].

朱向阳

上海交通大学教授,机械系统与振动国家重点实验室主任，国家杰青，上海交通大学机器人研究所所长，IEEE T-Cyber的AE

在2022年的*IEEE/ASME Transactions on Mechatronics*论文中引用代表作3，强调了多假设跟踪解决方案

when experiences of the robot accumulate [10], [13]. As it is impossible to determine which hypothesis is definitely right or wrong, one needs to maintain as many hypotheses as possible [20]–[22]. This strategy is the so-called multihypothesis method, which is commonly utilized in accumulated works to evaluate the correct map configuration probabilistically [23], [24].

孟庆虎

Clarence W. de Silva

- 香港中文大学教授，IEEE Fellow，加拿大工程院院士，香港工程师学院院士，广东省高尖端人才，深圳市杰出人才
- 英属哥伦比亚大学大学教授，IEEE Fellow，ASME Fellow，加拿大皇家学会院士，加拿大工程学院会士

在 2023 年的 *IEEE Transactions on Automation Science and Engineering* 论文中引用了代表作2关于在机器人场景感知和建图方面的代表性工作

Implementing mobile sensing robots to map out an environmental field involves: 1) characterizing the studied environment with a regression tool; 2) generating a sampling planner to navigate the robots to make observations; and 3) reconstructing the map using the observed data and the established regression scheme. In the robotics literature, a large amount of methods has been proposed for robotic field sensing and mapping, such as learning-based SLAM methods [19]–[21] and adaptive/attractive potential field methods [22]–[24]. Although addressing similar terminologies, it is

罗仁权

台湾大学讲座教授，IEEE Fellow，IEEE工业信息期刊总主编，IEEE国际工业电子协会杰出讲师，欧盟产业发展指导委员会委员

在 2022 年的 *IEEE/ASME Transactions on Mechatronics* 论文中引用代表作3，突出了全局定位方法无需离线训练的优势

established online. Gao *et al.* [30] use geometrical relationship as construction element, and use multiple hypothesis tracking as architecture. The advantage is that this method does not need offline training for vocabulary. And it does not effect with the quality of vocabulary. However, due to the use of specific

王郸维

新加坡南洋理工大学教授，IEEE Fellow，新加坡工程院院士，IEEE国际工业电子协会杰出讲师，欧盟产业发展指导委员会委员

在 2021 年的 *IEEE Transactions on Instrumentation and Measurement* 论文中多次提及代表作3，突出了所提方法在全局领域领域的代表性

fails or when the robot is lost/kidnapped. The existing solutions rely on either: 1) infrastructures, such as radio beacons [7], [29], artificial landmarks [25], [26], and QR-codes [8], [22] or 2) onboard sensors, such as camera [11], [28], Light Detection and Ranging (LiDAR) [5], [10], and magnetic sensor (a.k.a. magnetometer) [28]. For infrastructure-based

LBL approaches are commonly used for mobile robot localization. Previous works including probabilistic-based multiple hypothesis tracking [2], [10] and PF-based [1]–[3], [6] methods were proposed to solve mobile robot global localization problem with 2-D LiDAR. Meanwhile, place recognition [5]

Il Hong Suh

汉阳大学教授，IEEE Fellow，韩国首尔人工智能机器人初创公司CogAplex Company的联合创始人兼首席执行官，首尔汉阳大学智能机器人工程系和电子与计算机工程系的名誉教授

also to autonomously position the agents within it. However, to obtain reliable map information of the surroundings through navigation, a large portion of developed SLAM systems rely on human operators or a pre-described plan [16]–[18]. Also, many autonomous exploration approaches are developed based on previously available map [19]–[21]. POI for exploration

在 2023 年的 *IEEE Robotics and Automation Letters*论文中引用了代表作2在未知环境下移动机器人自主环境探索的相关工作

沈劭劼

Cyrill Stachniss

- 香港科技大学副教授，HDJI实验室创始主任，IEEE T-RO和IEEE ICRA 2019-2022的AE，IEEE IROS 2020-2022的高级编辑
- 波恩大学教授，摄影测量和机器人实验室负责人，牛津大学工程客座教授，IEEE T-RO和IEEE RA-L的AE

Table 2 Representative Works of Sequential Global LiDAR Localization

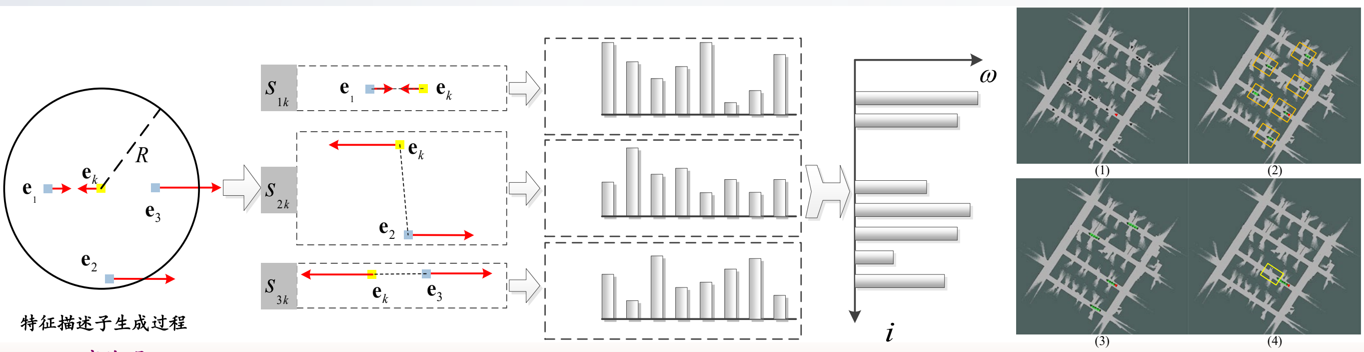
在 2024 年的 *International Journal of Computer Vision*论文中引用代表作3，突出了全局定位方法在机器人领域内的代表性

We also notice that there exist other frameworks that can achieve sequential-metric global localization. Multiple hypotheses tracking (MHT) Thrun (2002) is a possible solution to the global localization problem. An improved MHT framework is proposed in Gao et al (2019), and authors design a new structural unit encoding scheme to weight hypotheses. Hendrikx *et al.* Hendrikx et al (2022) propose to build

项目工作介绍

利用邻域编码机制克服全局定位的视角受限问题

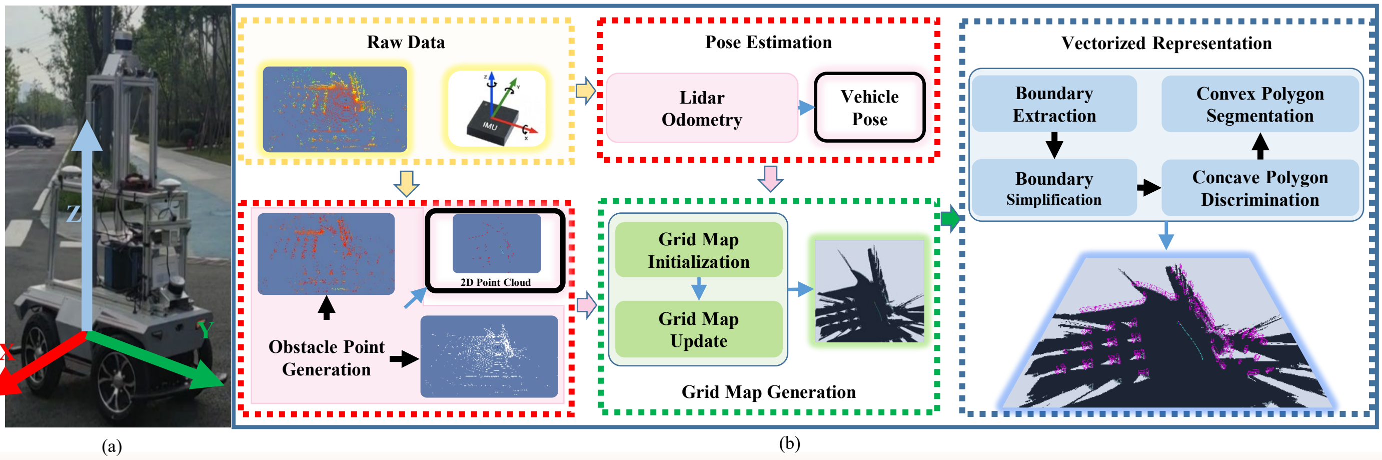
1）基于邻域编码机制，对有向端点特征进行描述；2）利用分层聚类和距离驱动-多假设跟踪实现全局定位；3）克服动态歧义场景下，全局定位过程中的传感器视角约束问题



H. Gao(高海明), X. Zhang*, J. Yuan, and Y. Fang. NEGL: Lightweight and efficient neighborhood encoding-based global localization for unmanned ground vehicles, *IEEE Transactions on Vehicular Technology*, 2023, 72(6): 7111 - 7122.

面向智能驾驶的紧凑轻量静态环境矢量化表征

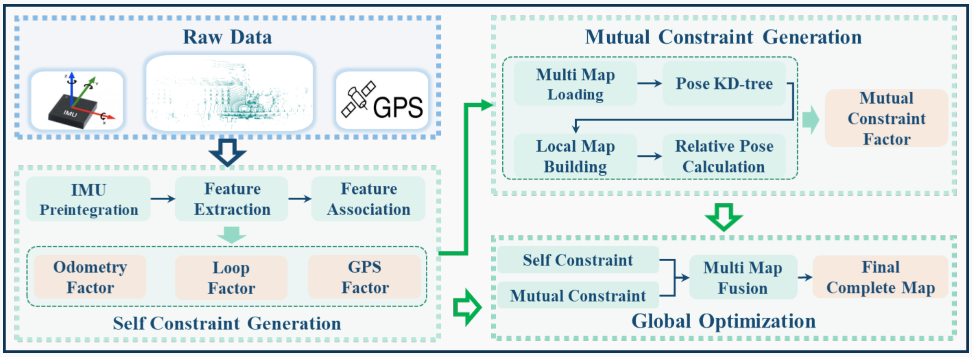
1）结合地面提取和最近障碍物选择，通过多帧融合实现周边障碍物的可靠检出；2）首次利用多个凸多边形来表示局部静态环境，更加紧凑和轻量化，目前已成功应用于无人驾驶项目



(a) (b)

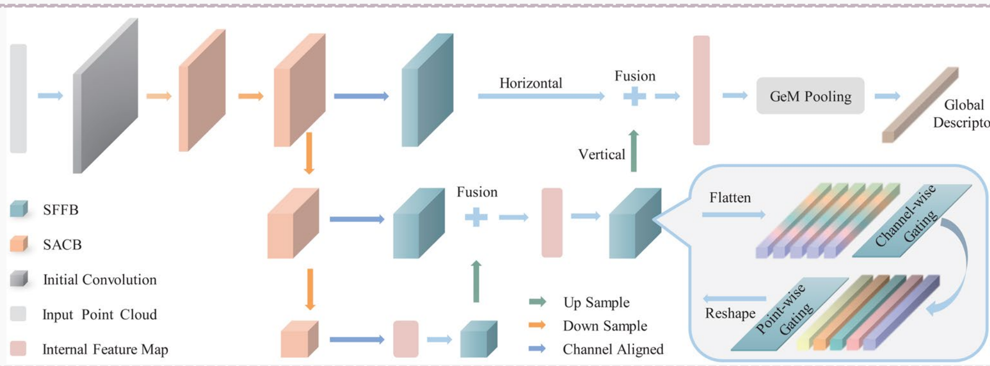
H. Gao(高海明), Q. Qiu, W. Hua*, X. Zhang, Z. Su, and S. Zhang. CVR-LSE: Compact vectorized representation of local static environments for reliable obstacle detection, *IEEE Transactions on Industrial Electronics*, 2024, 71(8): 9309-9318.

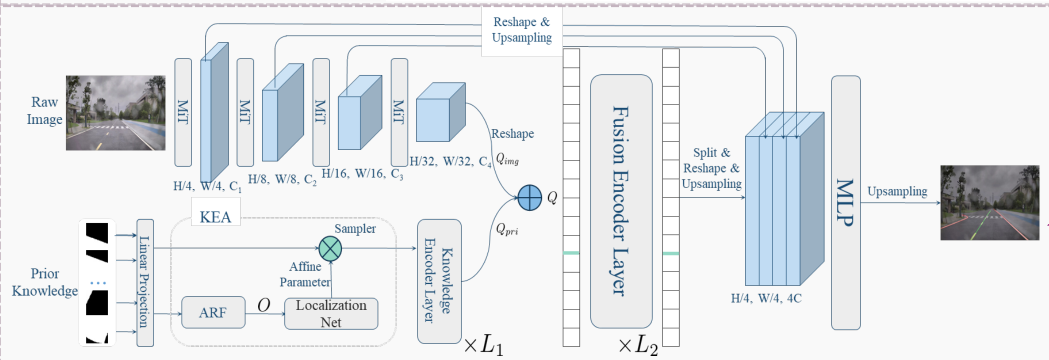
当前机器人/无人车其他工作介绍



基于离线全局优化的多点云地图融合方法

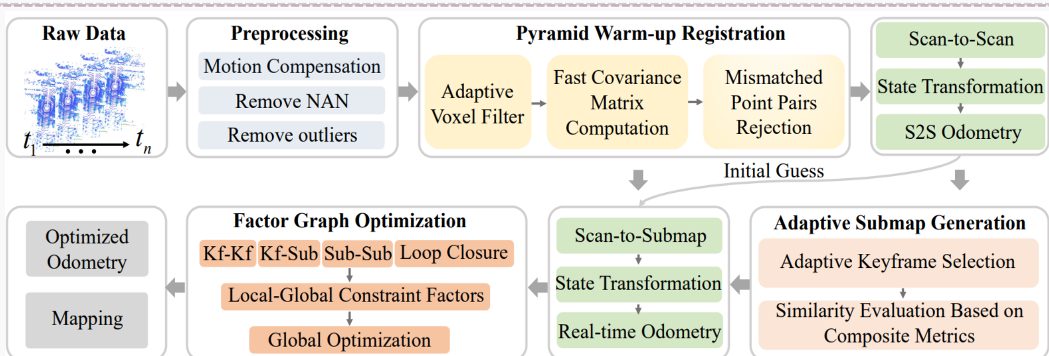
基于堆叠非对称卷积和选择性特征融合的大尺度场景识别

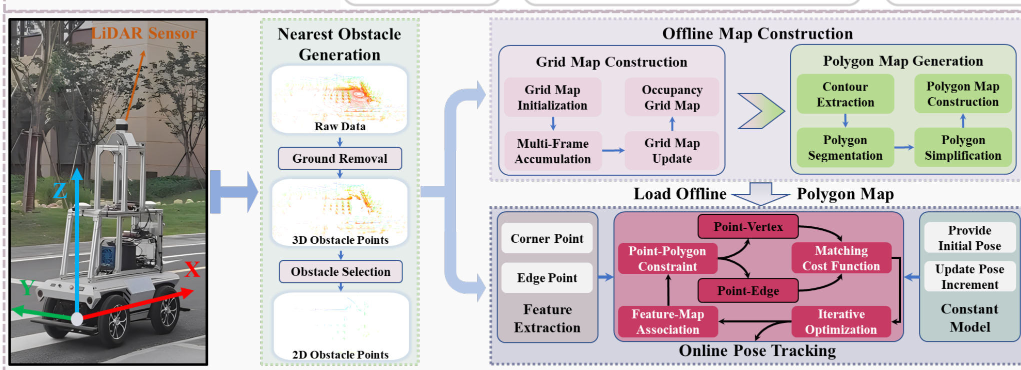




一种基于transformer的先验知识增强车道检测方法

基于金字塔预热匹配与多约束优化的精准激光SLAM





基于轻量级紧凑多边形地图的移动机器人快速有效位姿跟踪

[1] H. Gao, Q. Qiu, S Zhang, W. Hua*, Z. Su, and X. Zhang. MPC-MF: Multi-point cloud map fusion based on offline global optimization for mobile robots, *2023 Chinese Control Conference*, pp. 4237-4242, 2023.

[2] Q. Qiu, H. Gao, W. Hua*, G. Huang, and X. He. PriorLane: A prior knowledge enhanced lane detection approach based on transformer, *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 5618-5624, 2023.

[3] Q. Qiu, W. Wang, H. Ying, D. Liang, H. Gao*, and X. He. SelFLoc: Selective feature fusion for large-scale point cloud-based place recognition, *Knowledge-based System*, 295: 111794, 2024.

[4] H Liu, H. Gao, J. Shi, C. Xu, D. Qu, and W. Hua. APMC-LOM: accurate 3D LiDAR odometry and mapping based on pyramid warm-up registration and multi-constraint optimization. *IEEE Transactions on Vehicular Technology*, Under Second Review, 2024.

[5] H. Gao, *et al.* F3PT: Fast and effective pose tracking for mobile robots based on lightweight and compact polygon maps. *Awaiting Submission.*