Gengyu GE, Yi ZHANG, Wei WANG, Lihe HU, Yang WANG, Qin JIANG, 2023. Visual-feature-assisted mobile robot localization in a long corridor environment. *Frontiers of Information Technology & Electronic Engineering*, 24(6):876-889. https://doi.org/10.1631/FITEE.2200208

Visual-feature-assisted mobile robot localization in a long corridor environment

Key words: Mobile robot; Localization; Simultaneous localization and mapping (SLAM); Corridor environment; Particle filter; Visual features

Corresponding author: Yi ZHANG
E-mail: zhangyi@cqupt.edu.cn
ORCID: https://orcid.org/0000-0001-6935-5721

Motivation

In real-world scenes, especially in man-made structures, there are many areas with similar, repeated, or symmetrical geometrical features. The mobile robot will fail to estimate its pose in these areas without a known initial pose or the assistance of third-party tools.

To solve the above problems, we propose an alternative scheme that uses a monocular camera to extract visual features of the indoor environment to assist mobile robot localization. In addition, if necessary, it can be extended to object detection and pedestrian tracking tasks using semantic visual information. A coarse-to-fine paradigm is used in our method. It uses image retrieval to obtain a coarse position candidate and then an improved Monte Carlo localization (MCL) algorithm (Thrun et al., 2001) to achieve a fine pose.

Main idea

1. A hybrid map consisting of screened images and an occupancy grid map is built when the mobile robot moves from one end of the corridor to the other. The screened images are keyframes that are selected based on a selection strategy. Compared with conventional visual SLAM methods, our strategy can achieve dense and stable keyframes.

2. Each keyframe is associated with a mobile robot's pose relative to the global metric map. The associations or geo-tagged indexes are associated with each other by timestamps. A compound two-tuple data structure is used to store the associated information and is convenient for later image-pose searching.

Main idea (Cont'd)

3. A coarse-to-fine paradigm is used to achieve two-stage localization. According to the moving strategy, the mobile robot can find the best perspective to capture images and match them with the image database, to obtain a coarse localization. Based on the approximate location, an improved particle filtering approach is used to scatter the particles in a small range, instead of spreading them over the whole map. Experimental results show that our proposed approach is efficient and achieves a 98.8% successful localization rate where traditional MCL methods fail.

Method

1. Framework: In the mapping phase, an image database consisting of keyframes and visual words is created along with the building of an occupancy grid map. In the localization phase, according to our proposed moving strategy, a coarse localization is obtained using an image retrieval method, and then a fine localization is performed by employing an improved MCL approach

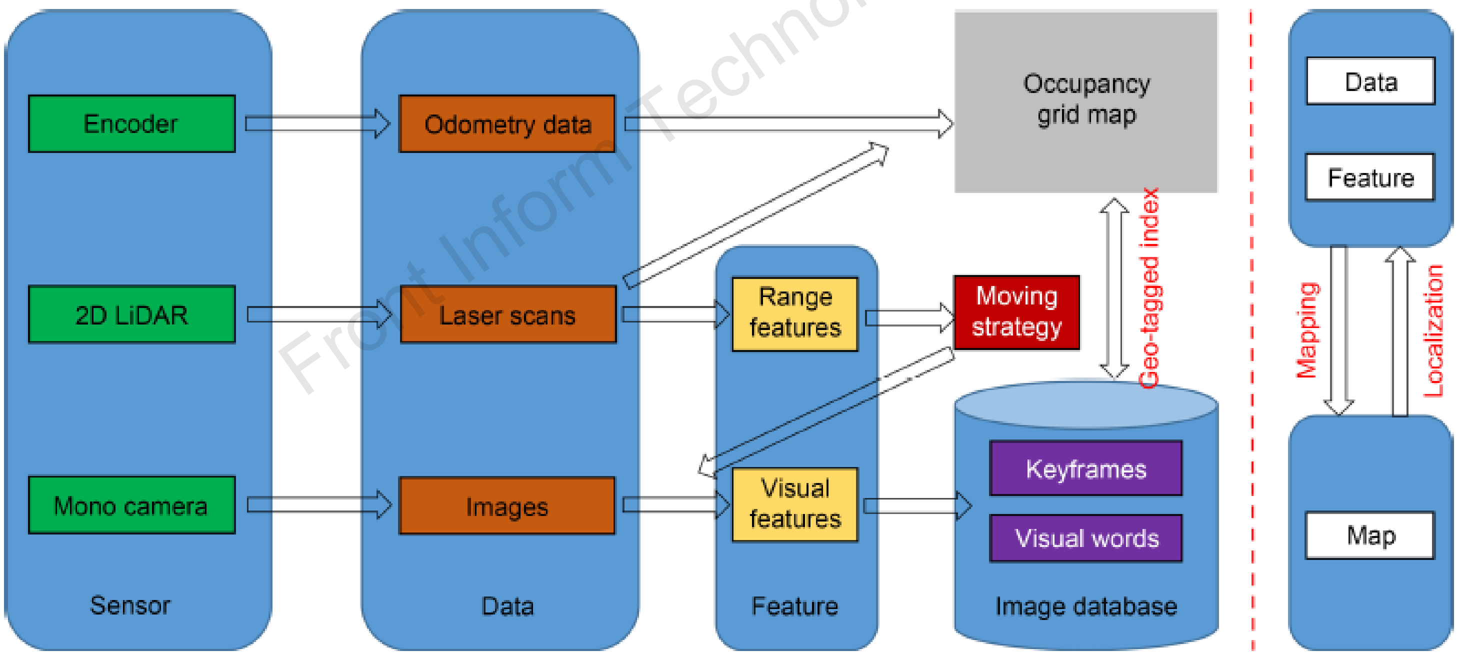
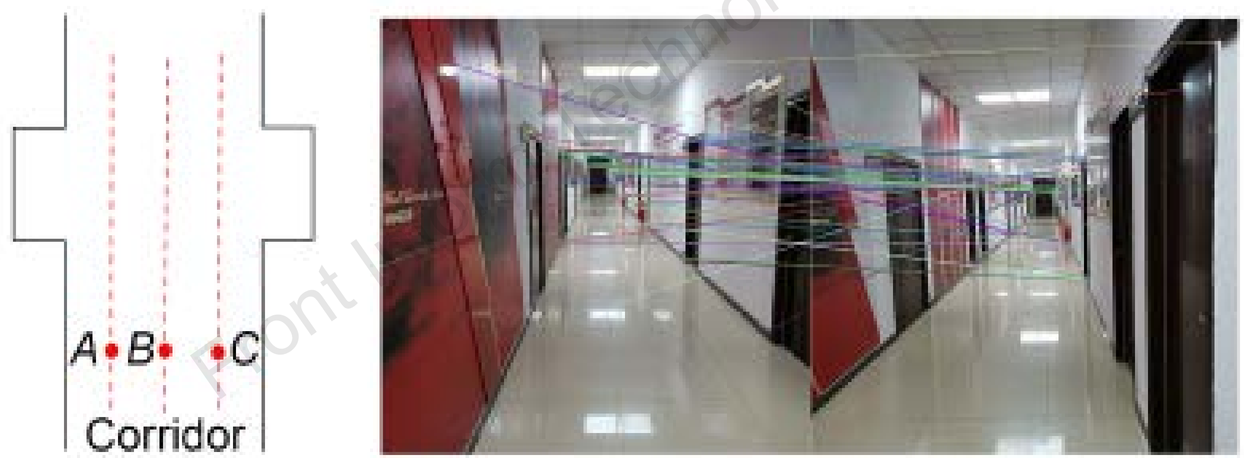


Diagram of the framework

Method (Cont'd)

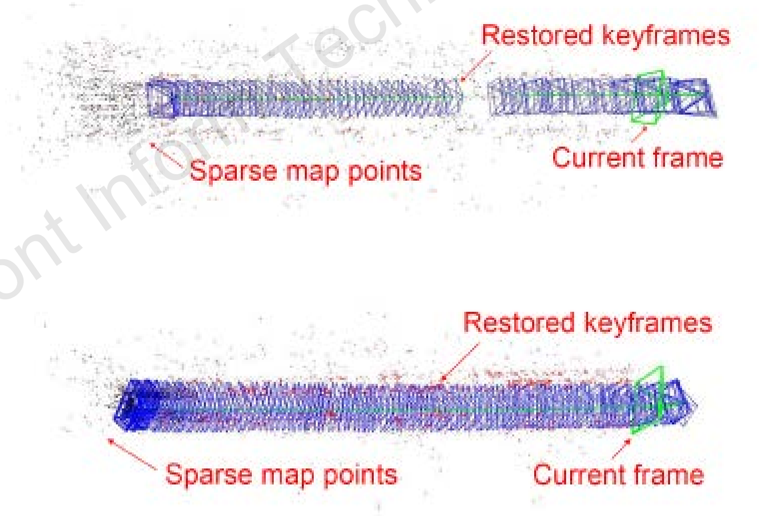
2. Moving strategy: The result of changing the moving route is that the mobile robot fails to track the visual features built previously. Consequently, the mobile robot needs to move within a fixed route range, preferably the middle line of the corridor, like the middle red dashed line.



Perspective of different lines

Method (Cont'd)

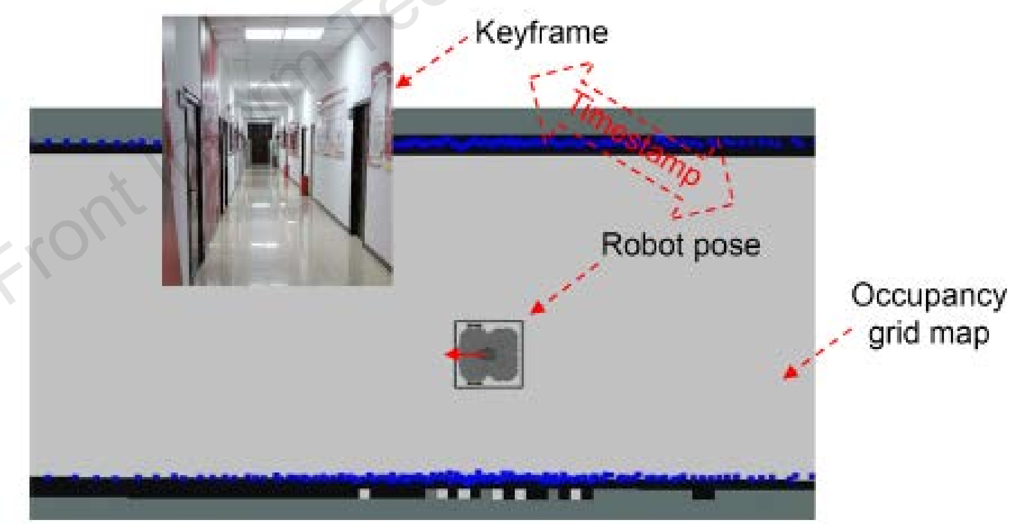
3. Keyframe selection: The main work is to decide which image can be thought of as a keyframe. Different from the monocular camera visual SLAM system which needs map initialization, the first image captured by the robot in our proposed method is treated as a keyframe by default. After that, a new image that is considered a keyframe should meet several conditions.



Keyframes and map points

Method (Cont'd)

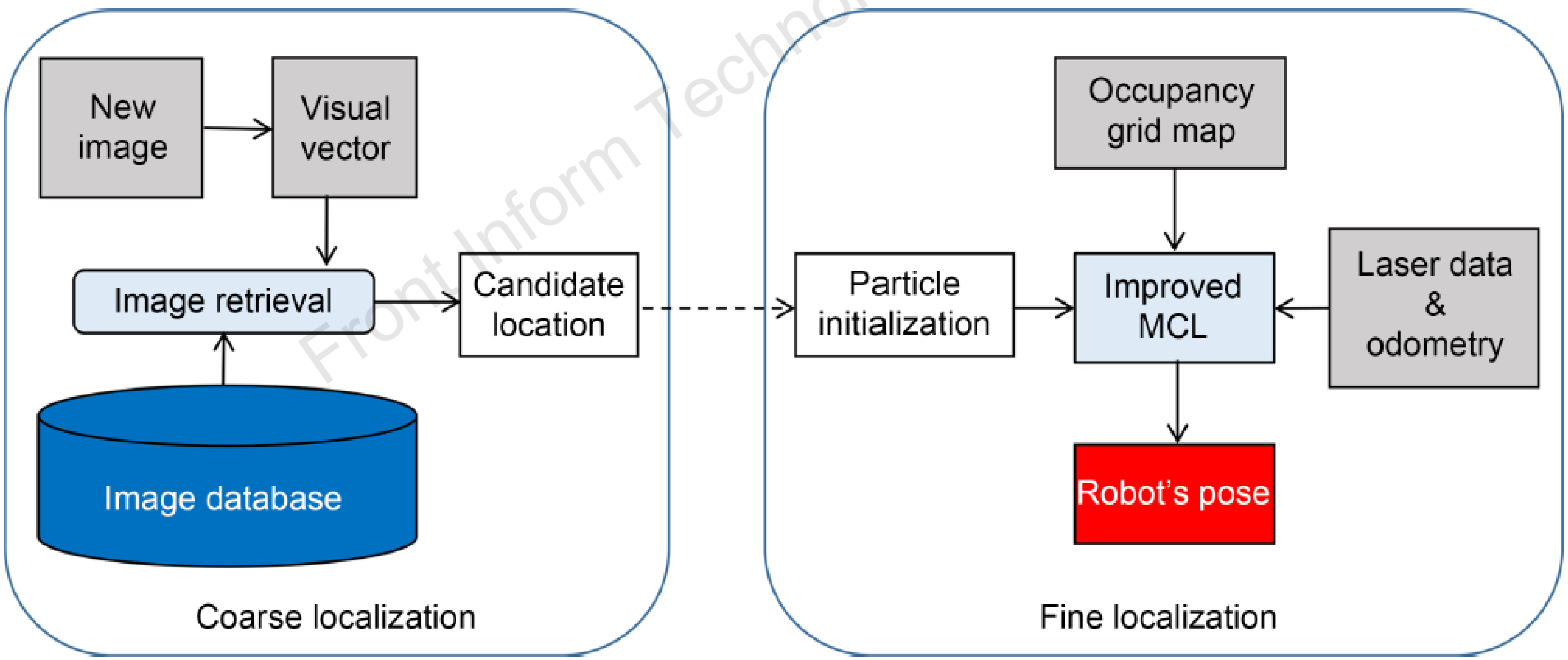
4. Building a hybrid map: The hybrid map consists of an image map and an occupancy grid map. The former consists of keyframes and visual words. The latter is a probability-occupied grid map constructed by the laser SLAM method. The link between these two is the timestamp which can be achieved by the robot operating system (ROS) software. Through time alignment, a keyframe can be associated with the pose coordinates of the robot.



Hybrid map

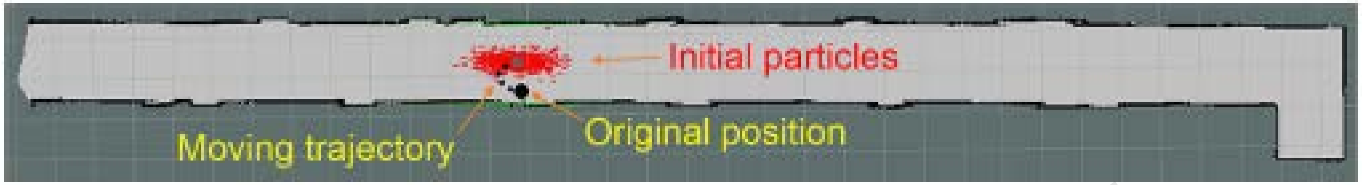
Method (Cont'd)

5. Localization mode: Given a known map, the localization mode uses a coarse-to-fine paradigm to achieve the mobile robot's pose. The figure below gives a framework of the paradigm: the left part is a visual image retrieval process that can acquire a coarse candidate location, and the right part is a fine pose estimation process that combines laser data, odometry data, and the occupancy grid map.

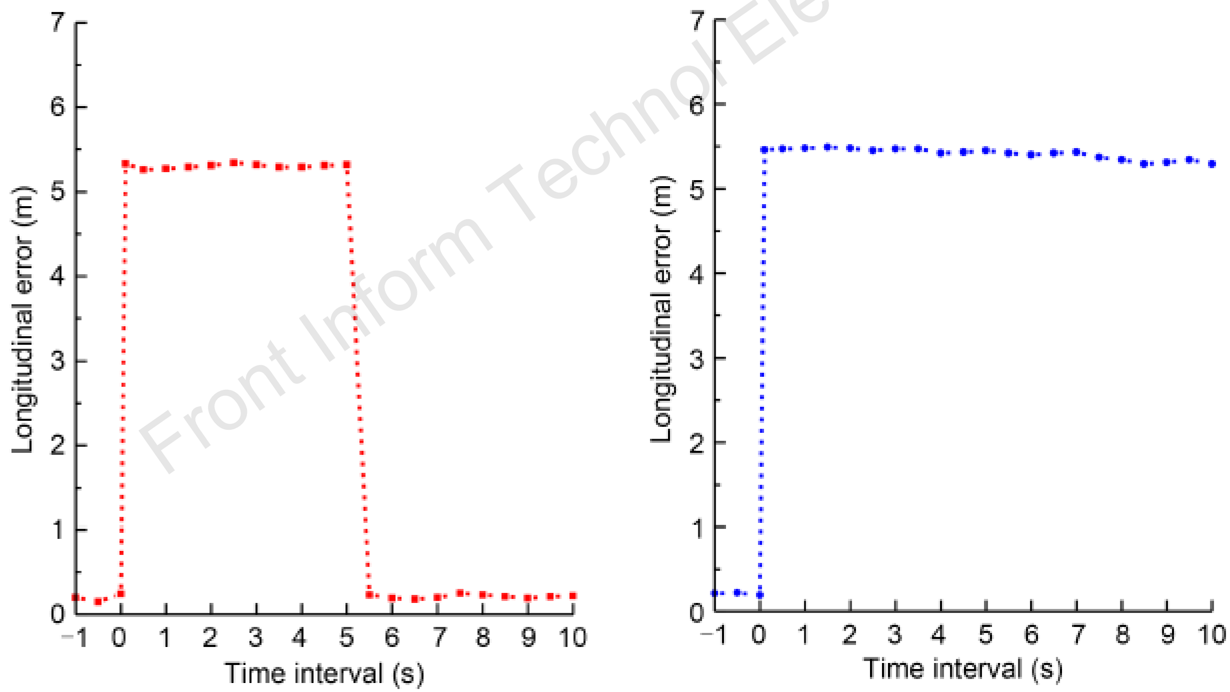


Localization mode

Major results



Particle initialization of the proposed method



Kidnapped robot problem (left: proposed method; right: the AMCL method)

Conclusions

A coarse-to-fine paradigm is used to realize the localization task, and the system is divided into two phases. In the mapping phase, we control the mobile robot moving along the middle line from the entry position to the end of the corridor. A hybrid map consisting of an occupancy grid map and an image database is built in the moving process. The image database includes keyframes which are screened according to an image selection strategy and visual words that are converted from the features of keyframes using the bag-of-words approach. The geo-tagged index between a keyframe and the associated robot's pose is decided by the timestamp. In the localization phase, the mobile robot adjusts its pose to find the best perspective to capture images and match them with the image database. The matching result provides a rough initial position candidate which is a coarse localization. Then, an improved AMCL method is used to realize a fine localization by scattering particles according to the reference position. The results indicate that our proposed method performs well in a corridor environment and can solve both global localization and kidnapped robot problems.