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A novel qualitative motion model based probabilistic indoor global localization method

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ABSTRACT

This paper presents a novel global localization approach based on a qualitative motion model to address the weakness in traditional probabilistic localization methods. To represent the occupancy global grid map for efficient localization, we generate a global hypothetical pose set on the grid map. Then the map is represented as a set of virtual observations associated to the poses. The online global localization is implemented based on the proposed enhanced particle filter. First, the particle set is obtained by a sampling process in the generated candidate hypotheses set where the robot may be located. Second, the particle set is propagated using a qualitative motion model and the negative effect of the motion model uncertainty are eliminated. Third, in the particle tracking process, the historical information and current observation are incorporated in the belief of the particles. The robot pose is estimated as the particle with the highest weight. In addition, the localization accuracy can be adjusted by sampling hypothetical poses with different densities. The results of the experiments show that the proposed method is robust to motion model uncertainty and can perform accurate global localization.

1. Introduction

The goal of mobile robot localization is to estimate a robot pose with respect to a map of its environment. It is a basic requirement for the mobile robot to implement given tasks. Local pose tracking and global localization are two paradigms of robot localization [19,24]. Local pose tracking involves robot pose tracking with an initial state estimation. Meanwhile, global localization focuses on estimating the global pose using only sensor data without knowing the initial pose. It provides the robot with the ability to deal with initialization at start-up and recovery in case of local pose tracking failure [17].

The general approach to address the global localization problem is to match the current observed surroundings with a prior global map. Typically, the matching procedure is implemented by measuring similarities between the sensor data and virtual observations of hypothetical poses. The performance of global localization is determined by the hypotheses generating strategy. Current global localization methods can be classified into two approaches according to their hypotheses generating strategies: probabilistic filter-based and heuristic searching-based. In probabilistic filter-based methods [2,3,7,24], the hypotheses are generated randomly. Then, the conditional probabilistic distribution is approximated and updated in a discrete way over the state space of a robot pose. In heuristic searching-based methods [13,15,17], robot pose estimation is formulated as an optimization problem and the hypotheses are generated according to the heuristic information.

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These methods have inherent weaknesses for mobile robot practical navigation. A robot using a probabilistic filter-based global localization method should generate as many multiple pose hypotheses as possible to increase the success rate of pose recovery. However, under conditions of motion model uncertainty, pose hypotheses could converge on an incorrect location if there are too few particles to cover the correct area [17]. The performance of heuristic searching-based methods is heavily dependent on the convergence rate, which is affected by many factors.

In this paper, we propose a novel global localization method. The proposed method aims to overcome the previous weakness described above. Without using the raw grid map, we represent the map with a set of observations associated to the hypothetical poses offline. With this map representation, we select particles from the hypothetical poses during the online localization. The candidate hypotheses sets are constrained by the odometry error bounds. Then the particle sets are obtained through a sampling process in the candidate hypotheses sets. To obtain a global consistent trajectory estimation, a hypotheses tracking process is implemented. The particles are able to converge on the correct location since the motion uncertainty is well considered.

The contributions of this study include three aspects as follow. First, the global grid map is represented in a localization-oriented way. The global localization efficiency can be improved as the virtual observations are computed offline. Second, instead of sampling and updating particles in the whole state space, the proposed enhanced particle filter employs a qualitative motion model to constrain the possible areas. In these areas, the samples with high weights are selected as particles. With this mechanism, we do not maintain large scale particles to track the robot pose. Furthermore, the accumulative error is eliminated. Third, we present a scheme that the global localization accuracy can be predesigned as expected. In the proposed method, the increasing of pose estimation precision has small effect on the localization efficiency.

2. Related work

Global localization on 2D grid map is a classic yet still popular research subject. We briefly review some significant researches on the two major categories: probabilistic filter-based and heuristic searching-based methods.

Probabilistic filter-based methods aim to compute and evaluate a probabilistic distribution over the space of pose states. The Bayes filter algorithm provides a general approach to compute the belief distribution [17]. Grid-based Markov localization [2,7] and Monte Carlo localization (MCL) [3,24] are the two most popular global localization methods. Grid-based Markov localization methods approximate the posterior using histogram filter over grid decomposition of the pose space [6,31]. These algorithms are robust but suffer from computational complexity that grows exponentially with the number of grid cells [14]. In MCL methods [4,9,12,21,22,30], the framework of a traditional particle filter is employed and the posterior probabilistic distribution is represented by a set of weighted samples. These methods can represent arbitrary probabilistic densities. However, particle filter may fail to keep track of the robot pose if most samples are far away from the robot location. In the probabilistic framework, more particles are required to ensure the success rate of pose estimation, while the localization efficiency would drop substantially. Several researches attempt to provide effective solutions to this shortcoming. Kullback–Liebler distance-sampling (KLD-Sampling) localization method [8] is proposed, which adapts the number of samples based on the KullbackLiebler divergence between the belief and posterior distributions. Without applying observations to refine the possible areas, this method fails to improve the efficiency greatly. Biswas et al. [1] use state space gradients of the observation model to improve localization accuracy while maintaining low computational requirements.

The main idea of heuristic searching-based methods is to prompt the optimal pose estimation searching speed using heuristic information. A coarse-to-fine mechanism is commonly employed to improve localization efficiency. Xie et al. [28] propose a pyramid grid-map based coarse-to-fine matching approach. The initial pose is obtained by a map matching algorithm between local map and global map. Park et al. [18] propose a localization process composed of two stages: coarse localization with a fast, but not precise scan-matching method and fine localization with a comparatively slow, but more accurate scan-matching method. Park et al. [17] merge SVM-based place recognition and particle filter into a coarse-to-fine framework. These methods greatly improve global localization performance by modifying the scan-matching method, while more computing resource is required. Zhang et al. [31] propose an improved Monte Carlo localization algorithm using a pre-caching technique to reduce the online computational burden. This method refines the meaningful areas efficiently, but it suffers from motion model uncertainty. Park et al. [20] propose a vision-based global localization, in which coarse pose estimation is performed by object recognition and SVD-based point cloud fitting, and then refined by stochastic scan matching. Wang et al. [27] introduce an indoor global localization method by extending and matching features. An extended map of the current local environment is established during movement and matched with an extended map set. By partitioning the environment into convex subdivisions, the method can perform fast global localization. Instead of using extra heuristic information to enhance global localization performance, heuristic searching strategy is applied. Artificial intelligent (AI) algorithms, which have been applied to various domains, including image classification [10], photo event recognition [29] and state estimation [11,13,15,16,26], are applied to global localization. Several global localization methods combine the Markov chain Monte Carlo sampling technique and the DE method [11,13,16]. Instead of relying on a quadratic fitness function to define the similarity between two scans, Martin et al. [13] introduce Kullback–Leibler divergence to the cost function, which makes different types of occlusions possible. Moreno et al. [15] use evolutionary filter to search for the best robot pose estimation.