Computers and Electrical Engineering 000 (2017) 1–12

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

A novel relocation method for simultaneous localization and mapping based on deep learning algorithm☆

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ARTICLE INFO

Article history:
Received 31 October 2016
Revised 15 March 2017
Accepted 15 March 2017
Available online xxx

Keywords:
SLAM
Relocation
Deep learning
Cloud robotics
Classification

ABSTRACT

Relocation is one of the most common problems in Simultaneous Localization and Mapping (SLAM). This paper presents a novel relocation method, using unsupervised deep learning algorithm to extract the feature of Light Detection and Ranging (LiDAR) data, and narrows the scope of relocation by classifying these features to reduce the randomness of the relocation. Compared with the other methods which is based on matching the manual feature points, this method avoids some limitations of manual features. We modify the Particle Filter SLAM (PF-SLAM), and use our relocation method to replace the original method for experimentation. The experimental results demonstrate that this method can be relocation whit high success rate only use a small amount of computational resource in a short time. Training neural network will consume a lot of computing resources, we also propose a cloud computing framework to the implementation of this method for the mobile robot which computational resources are limited.

1. Introduction

Robotics and cloud computing has been an important part of the Industry 4.0 [1] since its inception. In intelligent factories and intelligent manufacturing, the robot undertakes most of the manufacturing and transportation work, and cloud servers provide a powerful computing resource. Cloud robotics [2,3] are the perfect combination of robotics and cloud computing, solving the problem of limited computational power of robots, especially mobile robots, and providing basic conditions for multi-robot collaboration.

SLAM is the process by which a mobile robot uses environmental information obtained from sensors mounted on the robot to actively locate itself and simultaneously build a map of the environment [4]. It is one of the prerequisites of autonomous and intelligent navigation [5]. And it has become the most basic function of industrial transport robots [6]. In a practical scenario, the application of SLAM involves solving several challenges. The first challenge is the determination of the initial location of the mobile robot on a global map without any priori information of the environment. Since continuous accurate data acquisition and association is an important pre-requisite for SLAM [7,8], when the robot is moved artificially that it will destroy the data continuity may cause the localization process to fail. In such cases, the robot needs to be relocated [9].

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. Jiafu Wan.

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http://dx.doi.org/10.1016/j.compeleceng.2017.03.015
0045-7906/

The relocation problem as known as global location on the global map can be described as: When the robot first locates in an environment which the global map was known, or the robot fails to locate in the course of moving. How to find the possible position scope of the robot on the global map accurately is the key to solve this problem. The most basic way to solve the relocation problem is to include all positions on the global map as possible positions with a high randomness [10]. The possible position scope of the robot on the global map is gradually reduced by matching the current sensor data with the global map information at a continuous time, and finally converge to the correct position. However, this approach will consume a great deal of computational resources and computational time, and computational power will have a degree of impact on the success rate of relocation. A more reasonable approach is to reduce the initial scope of relocation by matching the first frame sensor data with the global map information.

In this paper we focus on using the deep learning algorithm to solve the relocation problem of SLAM in large environments. We use a deep learning algorithm to automatically extract features from the environmental data obtained by LiDAR sensor, and narrows the relocation scope by classifying these features to reduce the randomness of the relocation. Compared with the other methods, this method allows us to avoid the limitations of manual features, making it suitable for applying to more complex environments [11]. In order to adapt to the application environment of SLAM, where the autonomous robot must start in an unknown environment, and work with the data obtained from the sensor without any labels. We use a Stacked Auto-Encoder (SAE) [12] to extract the feature of the LiDAR data obtained in the process of building a map, classification by data segmentation to label these data as training set to train a classifier [13]. However, performing such complex computations is resource intensive, hence it can be difficult to execute locally in the robot due to low on-board computational resources. Since modern network transmission speeds are fast [14,15], moving the complex operations of the robot to a cloud server is an effective approach to solving this problem, and the training step of this method can be done offline. Therefore, to solve the problem that computers equipped on robot are not suitable for deep learning training, we describe a cloud-based version of this method.

This paper is organized as follows: Section 2 describe the details of several common relocation methods. Section 3 explains the theory of PF-SLAM [16] which is a common SLAM algorithm. We will also discuss the relocation problem in the PF-SLAM in this section. In Section 4, we analyze the data characteristics in SLAM, and provides a classification method of LiDAR data for the relocation problem. Section 5 provides a relocation method base on classification of LiDAR data and a cloud computing framework of this method. The experimental result and numerical comparisons are shown in Section 6. Finally, conclusions of this work is give in Section 7.

2. Related works

Previous methods that approaches the relocation problem of SLAM can be divided into two categories according to whether only use the LiDAR sensor or use multiple sensors. When robot can get more information of environment by multiple sensors (GPS, magnetic, radio etc.) [17,18], the relocation problems relatively easy to solve. However, these sensors can not use in certain operating environments (indoor, manufacturing plant etc.). So relocation with the robot which only equipper LiDAR sensor has a greater research value.

PF-SLAM addresses the relocation problem by randomly generating a wide scope of particles to create a particle swarm where the current location is in the scope of the sampled particles. This method will cost a lot of computational resources and time.

Most of the improved relocation methods are based on the matching of manual feature points. These manual feature points are extracted by traversing each frame of LiDAR data to find data points that conform to the preset pattern in the data. In [19], Weerakoon et al. extract the line segmentation and feature points of LiDAR data by data points segmentation and straight line iterative fitting, and use these feature represent the walls and corners. This method can effectively extract the indoor feature, but only used for the regular indoor environments. The article [20] propose a prediction-based method to extract the geometric feature quickly which only traversing the LiDAR data once. This method is fast and compact, but the feature extracted by prediction-based method is still limited to geometric features such as lines, arcs, and circles.

In [9], Rocchi et al. propose an algorithm which is based on the expansion of algorithm [21] to search the relocation scope by matching the geometric feature of the room which obtained from the sensor data and the information from the global map. In [22], Fallon and Folkesson et al. use a priori designated features from sonar data to relocate autonomous underwater vehicles in a shallow-water ocean environment. In [23], the authors incremental the Random Sample Consensus Algorithm (RANSAC) for Relocation. This algorithm generates a set of relocation candidate regions randomly by matching sets of feature between LiDAR data and global map, and using the position of the matching pair as the relocation result. Since RANSAC has a well performance in the features outlier, this method can be use in dynamic environments. Though, there are significant limitations [11] in using manual features for relocation which cannot be applied to different environments.

3. Relocation in particle filter SLAM

SLAM is a process of build a map of an unknown environment incrementally, whereas simultaneously estimating the location and orientation of a robot which relying on this map. The SLAM problem is generally represented by a probabilistic model. Because the SLAM problem has an independence condition, and the localization process satisfies the first order