Implementation Issues and Experimental Evaluation of D-SLAM

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Summary. D-SLAM algorithm first described in [1] allows SLAM to be decoupled into solving a non-linear static estimation problem for mapping and a three-dimensional estimation problem for localization. This paper presents a new version of the D-SLAM algorithm that uses an absolute map instead of a relative map as presented in [1]. One of the significant advantages of D-SLAM algorithm is its $O(N)$ computational cost where $N$ is the total number of features (landmarks). The theoretical foundations of D-SLAM together with implementation issues including data association, state recovery, and computational complexity are addressed in detail. Evaluation of the D-SLAM algorithm is provided using both real experimental data and simulations.

Keywords: Decoupled SLAM, Extended Information Filter, Sparse Matrix, Computational Complexity

1 Introduction

Simultaneous localization and mapping (SLAM) is the process of building a feature based map of an environment while concurrently generating an estimate for the location of the robot. The SLAM problem has been the subject of extensive research in the past few years, most of which make use of estimation-theoretic techniques (see for example [2], [3], [4], [5], [6], [7] and the references therein).

In traditional SLAM, the state vector contains the location of the robot and all the feature locations. Some convergence properties of the traditional SLAM algorithm using Extended Kalman Filter are proved in [2]. However, traditional SLAM algorithms lead to a heavy computation burden for large scale problems. Many researchers have exploited the special structure of the SLAM algorithm in order to reduce the computational effort required in the SLAM process thereby make large scale SLAM more tractable. For example,
In [3], a compressed algorithm is presented to store and maintain all the information gathered in a local area, and then the information is transferred to the rest of the global map. In a recent publication [7], Thrun et al. used the Extended Information Filter to exploit the relative sparseness of the information matrix to reduce the computational effort required in SLAM.

Another way to reduce the computational complexity is to decouple the mapping and localization processes in SLAM. Different groups of researchers have been discussing the possibility of the decoupling. Most of them have made use of the idea of constructing a relative map using the observation information. For example, Newman [4] introduced a relative map in which the map state contains the relative locations among the features. Csorba et al. [8], Deans and Herbert [9], and Martinelli [10] have made use of relative map where the map state only contains distances among the features, which are invariants under shift and rotation. However, all the above approaches have redundant elements in the state vector of the relative map. If no further constraint is applied, it may result in inconsistent map. If constraints are applied, the computation complexity will be increased dramatically. Moreover, how to extract the information about the relative map from the observations and the possible information loss in the decoupling of localization and mapping have not been fully addressed.

In our recent research work [1], a novel decoupled SLAM algorithm, D-SLAM using compact relative maps, is proposed. The state vector for the mapping in D-SLAM is a $2n - 3$ dimensional vector containing distances and angles among the features (where $n$ is the total number of features). It is shown that the new formulation retains the significant advantage of being able to improve the location estimates of all the features from one local observation. When Extended Information Filter is applied, D-SLAM results in a sparse information matrix.

This paper provides a D-SLAM algorithm where the state vector for mapping is the absolute locations of the features ($2n$ dimension for $n$ features). The new algorithm is easier to implement than the D-SLAM algorithm using relative map, yet maintains the sparseness of the information matrix and the resulting computational savings. Some discussion on the implementation issues and further evaluation of D-SLAM using experimental data is presented in this paper. The paper is organized as follows. In Section 2, the key idea of D-SLAM and the details of the mapping and localization algorithms are provided. Section 3 addresses some implementation issues in D-SLAM including data association, state recovery and computational complexity. Experimental and simulation results are presented and compared with the results using traditional SLAM in Section 4. Section 5 concludes the paper and addresses future research directions.