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An Approach to Reduce Computational Cost for Localization Problem

Nur Aqilah Othman and Hamzah Ahmad
Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
(E-mail: aqilah,hamzah@ump.edu.my)

Abstract – One of the biggest factors that contribute to the computational cost of extended Kalman filter-based SLAM is the covariance update. This is due to the multiplications of the covariance matrix with other parameters and the increment of its dimension, which is twice the number of landmarks. Therefore a study is conducted to find a possible technique to decrease the computational complexity of the covariance matrix without minimizing the accuracy of the state estimation. This paper presents a preliminary study on the matrix-diagonalization technique, which is applied to the covariance matrix in EKF-based SLAM to simplify the multiplication process. The behaviors of estimation and covariance are observed based on three case studies.

Keywords – covariance, diagonalization, extended Kalman filter, simultaneous localization and mapping.

1. Introduction

Simultaneous localization and mapping (SLAM) of a mobile robot is one of the navigation techniques which enable the robot to move autonomously in an unknown environment. SLAM does not require a priori map, but with the aid of exteroceptive and proprioceptive sensors on board, the mobile robot is able to incrementally build a feature map of the environment and use this map to localize its position. The position of mobile robot and landmarks are determined by means of estimation method such as the Kalman filter [1], the particle filter [2] or the $H\infty$ filter [3]. These methods provide estimations based on the measurement data that are recursively recorded by the sensors. SLAM has been applied in a wide range of mobile robot applications such as underwater, mining, space exploration and in home appliances [4-6].

Extended Kalman filter (EKF) has been widely used to solve the estimation problem in SLAM due to simplicity of the algorithm, its robustness and its ability to apply the algorithm online compared to other approaches such as particle filter. However, the whole covariance matrix in EKF-based SLAM needs to be updated each time a new landmark is detected. This process involves lots of mathematical operation, thus will increase the computational cost. Moreover the dimension of covariance matrix will increase to twice the number of landmark, as more landmarks are detected. The classical EKF-based SLAM algorithm is known to have a cost of $O(m^2)$, in which m is a total landmark of the map. This limits the use of EKF in a large environment.

Therefore researchers have been trying to find the solution to minimize the computational cost by focusing on the simplification of the covariance structure. Guivant and Nebot [7] introduced a decorrelation algorithm to simplify the covariance matrix. The algorithm will decorrelate a subset of the states that is weakly correlated and cancel the weakly cross-correlation terms in the covariance matrix. A positive semi definite matrix is added to the covariance matrix to reduce both computational and storage costs in SLAM. However this technique has some drawbacks that lead to filter instability. For that reason the cross-correlation of the structure needs to be preserved [8, 9]. A Study has been conducted to improve the technique through diagonalization of only part of the state error covariance [10]. The technique is known as covariance inflation method, in which a pseudo-noise covariance is added to the covariance matrix to maintain the suboptimality of the filter, given that SLAM is considered as a partially observable system [11, 12]. Besides covariance inflation, Julier and Uhlmann introduced a covariance intersection method for SLAM, a fusion technique that combines two covariances when the correlations between them are unknown [13], and this technique has been implemented not only in SLAM, but also in other applications [14]. In this technique, the update process is carried out in two independent steps; updating the robot, then updating the landmark. However there exists a new parameter ω in the algorithm that needs to be chosen through an optimization process.

This preliminary study is conducted to find an alternative technique in diagonalizing the covariance matrix of EKF-based SLAM. As an initial approach, the matrix will be diagonalized using the technique of finding its eigenvalues and rebuilding a new diagonal-covariance from these values. The preliminary results of the effect on the estimation and covariance behavior are presented, which have been obtained through simulations.

This paper is structured as follows: the next section contains a brief explanation on the EKF-based SLAM models, diagonalization technique and the structure of covariance matrix. Section 3 explains the diagonalization process based on three case studies. The simulated results are presented and discussed in Section 4. Finally, the conclusion is drawn in Section 5.

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