Delayed vs Undelayed Landmark Initialization for Bearing Only SLAM

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1 Introduction

The Simultaneous Localization And Mapping problem (SLAM) is one of the fundamental ones in mobile robotics. It concerns the incremental construction of an environment model from the fusion of sensory data (laser range finder, vision,...) and proprioceptive data acquired by an inertial measurement unit or by odometry. Sensory data are processed to extract features (interest points, segments, planar patches...) used as landmarks to locate the robot. A SLAM algorithm incrementally builds a Stochastic Map: at every data acquisition, it estimates the robot pose from the matchings between observed and previously perceived landmarks, and updates the map, fusing the matched informations and adding the new ones. The resulting model can be used by path-planning algorithms or other higher decisional layers.

Using a sensor such that a video camera has many assets over the commonly used laser range finder with only horizontal scanning: *a)* Vision is a 3D sensor. Even for indoor robots for which pose can be represented in 2D $[x, y, \theta]$, 3D information is crucial; *b)* CCD cameras are of common use by now on embedded systems; they are cheap, light and small, power-saving and reliable; and *c)* Many algorithms are available from the vision community. They can be used to extract high level features from an image, and match them with previously perceived features included in the map using perceptual informations.

Nevertheless, depth information cannot be retrieved using a single image. The classic Extended Kalman Filter (EKF) SLAM algorithm [8] cannot be directly applied as the landmark addition into the stochastic map requires a full gaussian estimation of its state. A special landmark initialization process must therefore be used which combines at least two observations of the same features from far enough robot poses. Moreover, whereas many authors make use of the Mahanalobis distance and the χ^2 test to match observed landmarks with landmarks in the map, this method is not appropriate in the bearing-only case, as several candidates in the map can lay on the same optical ray in 3D space.

This problem is known as Landmark Initialization in Bearing-Only SLAM. Bearing only SLAM using vision is very similar to the Structure From Motion (SFM) problem which is usually solved with Bundle Adjustment. The main difference is that robotic applications require an incremental and computationally tractable solution whereas SFM algorithm can run in a time consuming batch process. Links between non linear optimization algorithm for SFM and standard Kalman filter for bearing-only SLAM are studied in [6].

2 Related work

This Initialization problem in Bearing-Only SLAM is a specific case of a more general *Partially Measurable* SLAM where the sensor does not give enough information to compute the full state of the observed landmark. For example, the use of sonar sensors raises the problem of *Range-Only*

SLAM. A solution to this problem was proposed by Leonard *et al.* In [5]: since a single observation is not enough to estimate a landmark, multiple observations are combined from multiple poses.

Several articles propose different solutions for the Initialization problem in Bearing-Only SLAM. Bailey *et al.* [1] compute the initial landmark estimation using observations from two robot poses; the gaussianity of this estimation is tested using the Kullback distance, the computation time of which is too high to be integrated on a real time system. Davison *et al.* [2, 3] propose a method based on a particle filter to represent the initial depth of a landmark; the number of particles does not scale nicely for large environments. Deans *et al.* [4] propose a combination between a bundle adjustment to initialize the landmark estimation and a Kalman filter to update it; the complexity of the initialization step is greater than a Kalman filter but theoretically gives more optimal results. All these works propose a delayed initialization of a landmark in the map, either with a sub optimal solution (with respect to the Kalman Filter), or with high complexity.

To our knowledge, only the work presented in [7] proposes an *undelayed* landmark initialization. The initial state is approximated with a sum of gaussians and is explicitly added to the state of the Kalman filter. The method is sub-optimal. The sum of gaussians is not described and the convergence of the filter when updating a multi gaussian landmark is not proved, not even discussed.

3 Bearing Only SLAM: landmark initialization

Two solutions of the problem are proposed. First, a *delayed* solution which is optimal and computationally light. Second, an *undelayed* method inspired by the Federated Filter. Both algorithms keep using the EKF-SLAM framework and are intended for real time implementation.

3.1 Efficient delayed nearly-optimal initialization

Several aspects make this algorithm innovative: the initial probability density of a landmark is approximated with a special weighted sum of gaussians. This initial state is expressed in the robot frame, and not in the global map frame so that it is not correlated with the current stochastic map. The current robot pose as well as some past poses, must be carefully estimated. The corresponding extra poses will be required when a landmark is added to the map, for computing in a consistent way, the landmark state in the map frame, as well as the correlations with the robot poses and the other landmarks. Moreover any number of past observations with corresponding robot poses can also be stored and then used to update the newly added landmark. The complexity of our algorithm is no more than the complexity of usual EKF SLAM ($O((k+N)^2)$) taking into account the number of estimated poses (k). It is also as optimal as the EKF (the EKF is not the very optimal solution because of the linearizations).

3.2 Undelayed Initialization via Federated Information Sharing

The theoretically optimal solution to the undelayed initialization implies the abandon of the EKF. It rather leads to untreatable algorithms such as the Gaussian Sum Filter (GSF), for which computational load grows exponentially.

The presented method is an approximation of the GSF that permits undelayed initialization with simply an additive growth of the problem size. At the first landmark observation, the robot only knows the optical ray on which it is located. This ray, with associated covariances, define a conic probability distribution function (PDF) for its position. A minimal representation of this PDF is introduced as a geometric series of gaussians; they are all included in one single EKF-SLAM map. As with all approximations, the involved risks of *inconsistency* and *divergence* have to be minimized. For that, an innovative strategy named Federated Information Sharing, is proposed to perform all the subsequent updates and to define criteria for pruning the less likely members of the PDF.

3.3 Undelayed vs Delayed

At a controlled computational cost and a limited loss of optimality, the Federated Information Sharing approach can be used for undelayed feature initialization. Avoiding initialization delay is an interesting issue: having information of the landmark in the map, even without knowing its distance, permits its immediate use as an angular reference. It also allows the use of landmarks that lie close to the direction of travel of the robot, for which baseline would take too long to grow. This is crucial in outdoor navigation where straight trajectories are common and vision sensors will naturally look forward.

On the other hand the ability to track many uninitialized features at low computational cost may be of great interest when working with cluttered data from real environment. The delay can be used to select best features and add them as landmarks into the map.

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