Online Constraint Network Optimization for Efficient Maximum Likelihood Map Learning

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Abstract— **In this paper, we address the problem of incrementally optimizing constraint networks for maximum likelihood map learning. Our approach allows a robot to efficiently compute configurations of the network with small errors while the robot moves through the environment. We apply a variant of stochastic gradient descent and use a tree-based parameterization of the nodes in the network. By integrating adaptive learning rates in the parameterization of the network, our algorithm can use previously computed solutions to determine the result of the next optimization run. Additionally, our approach updates only the parts of the network which are affected by the newly incorporated measurements and starts the optimization approach only if the new data reveals inconsistencies with the network constructed so far. These improvements yield an efficient solution for this class of online optimization problems.**

Our approach has been implemented and tested on simulated and on real data. We present comparisons to recently proposed online and offline methods that address the problem of optimizing constraint network. Experiments illustrate that our approach converges faster to a network configuration with small errors than the previous approaches.

I. INTRODUCTION

Maps of the environment are needed for a wide range of robotic applications such as search and rescue, automated vacuum cleaning, and many other service robotic tasks. Learning maps has therefore been a major research focus in the robotics community over the last decades. Learning maps under uncertainty is often referred to as the simultaneous localization and mapping (SLAM) problem. In the literature, a large variety of solutions to this problem can be found. The approaches mainly differ in the underlying estimation technique. Typical techniques are Kalman filters, information filters, particle filters, network based methods which rely on least-square error minimization techniques.

Solutions to the SLAM problem can be furthermore divided into online an offline methods. Offline methods are so-called batch algorithms that require all the data to be available right from the beginning [1], [2], [3]. In contrast to that, online methods can re-use an already computed solution and update or refine it. Online methods are needed for situations in which the robot has to make decisions based on the model of the environment during mapping. Exploring an unknown environment, for example, is a task of this category. Popular online SLAM approaches such as [4], [5] are based on the Bayes' filter. Recently, also incremental maximum-likelihood approaches have been presented as an effective alternative [6], [7], [8].

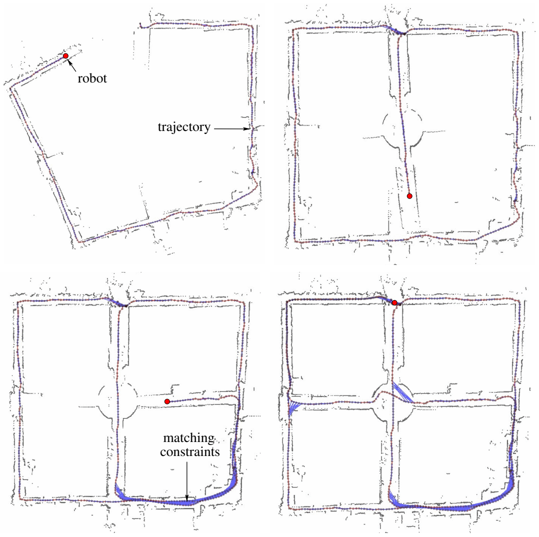

Fig. 1. Four snapshots created while incrementally learning a map.

In this paper, we present an efficient online optimization algorithm which can be used to solve the so-called "graph-based" or "network-based" formulation of the SLAM problem. Here, the poses of the robot are modeled by nodes in a graph and constraints between poses resulting from observations or from odometry are encoded in the edges between the nodes. Our method belongs to the same class of techniques of Olson's algorithm or MLR [8]. It focuses on computing the best map and it assumes that the constraints are given. Techniques like the ATLAS framework [9] or hierarchical SLAM [10], for example, can be used to obtain the necessary data associations (constraints). They also apply a global optimization procedure to compute a consistent map. One can replace these optimization procedures by our algorithm and in this way make them more efficient.

Our approach combines the ideas of adaptive learning rates with a tree-based parameterization of the nodes when applying stochastic gradient descent. This yields an online algorithm that can efficiently compute network configurations with low errors. An application example is shown in Figure 1. It depicts four snapshots of our online approach during a process of building a map from the ACES dataset.

II. RELATED WORK

A large number of mapping approaches has been presented in the past and a variety of different estimation techniques have been used to learn maps. One class of approaches uses constraint networks to represent the relations between poses and observations.

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