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A Novel Particle Filter Formulation with Application to Terrain-Aided Navigation ⋆

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Abstract: Terrain-aided navigation (TAN) holds high potential for integration with classical dead-reckoning methods in underwater vehicles that do not have access to the global positioning system (GPS). The TAN approach constitutes an economical solution for long-range oceanographic missions that cannot afford the cost of high-grade inertial navigation systems or the logistics associated to the deployment of long acoustic baselines. Successful implementations of the terrain navigation concept require efficient and robust algorithms for estimation of the vehicle kinematic states. Current implementations of terrain-based navigation rely essentially on a class of nonlinear filters commonly designated particle filters (PF) due to their versatility and robustness. However, there are some typical problems posed by TAN applications that require further investigation since they are not adequately solved by standard PF algorithms. The present paper addresses the problem of efficiency and robustness of particle filters in the context of terrain based navigation. To this effect, we present two new filter versions that are shown to be more robust and to achieve superior performance in terms of position and velocity estimation. When applied to TAN, the new PF formulations mitigate filter divergence problems frequently caused by terrain symmetries and are more robust than other well-known versions when used in scenarios with poor terrain information.

Keywords: Bayesian estimation; importance sampling; particle filter; terrain-aided navigation.

1. INTRODUCTION

Conventional navigation of autonomous underwater vehicles (AUVs) is performed by dead-reckoning based on inertial navigation systems (INS) complemented with discrete-time, possibly asynchronous position fixes provided by arrays of acoustic beacons. Since global positioning system (GPS) signals are not available underwater, acoustic long baselines (LBL) play a key role in the correction of INS inherent drifts in long range missions. However, the costs of navigation grade INS and the deployment of artificial beacons cannot be afforded in a large number of scientific and commercial applications. The need for reduction of operational costs and larger autonomy have motivated a surge of interest in the development of non-conventional navigation systems for autonomous underwater vehicles that rely mainly on the observation of environmental features. A well documented implementation of the former concept is the terrain-aided navigation (TAN) approach which consists essentially in matching a set of measurements obtained by the vehicle with a previously acquired map of the terrain to estimate its position.

In the context of terrain-aided navigation there are three main issues that must be addressed: feature observation, association of features with the map, and estimation of position based on the former two. These subjects are widely covered in the literature and have been addressed in our prior research. The current paper addresses theses issues but places the emphasis on the problem of position estimation using terrain information.

2. PRIOR WORK AND MAIN CONTRIBUTIONS OF THE PAPER

The application of sequential Bayesian estimation methods based on point-mass approximations of the probability distributions of interest is extensively documented in the literature. Included in this class of methods, particle filters (PFs) have been increasingly adopted in the last two decades to solve tracking and navigation problems. Among

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