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Complementary Terrain/Single Beacon-Based AUV Navigation ⋆

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Abstract:
This paper describes work done towards the development of advanced geophysical-based navigation systems for autonomous underwater vehicles (AUVs). The specific problem that we tackle is that of combining terrain-aided navigation (TAN) with single-beacon navigation (SBN) techniques. The resulting complementary TAN/SBN system has the potential to overcome some of the problems that arise with TAN navigation only, when an AUV undergoes motions that lead it temporarily across areas where the terrain below is not sufficiently "rich" in terms of topographic features. The key contribution of this paper is a formal analysis of the benefits of using complementary filtering, in opposition to TAN navigation only. To this effect, we exploit key tools of estimation theory, and in particular the Cramér-Rao lower bound inequality to obtain a lower bound on the minimum covariance of the estimation error that can be obtained with any unbiased estimator. For a real terrain profile we compute and compare the Cramér-Rao lower bounds for TAN only and TA/SB-based navigation. The increase in the expected performance that can be achieved with the second solution is clearly visible. The efficacy of the new solution proposed is illustrated with the help of computer simulations.

Keywords: Terrain-aided navigation; Single-beacon navigation; Cramér-Rao bounds; Monte Carlo methods; Particle filters.

1. INTRODUCTION

The advent of autonomous underwater vehicles (AUVs) has dramatically improved the quality of the tools available for ocean data acquisition. Equipped with advanced sensor suites, these vehicles have the capability to roam the oceans freely and acquire ocean data at unprecedented scales. Central to the operation of the vehicles is the availability of good navigation and positioning systems. While at the surface, autonomous marine vehicles may resort to the Global Positioning Systems (GPS). However, this is not an option for AUVs operating submerged.

Underwater navigation has a long and rich history and has proven to be a key ingredient in the operation of submerged vehicles for scientific, commercial, and military operations. In the case of AUVs, the solutions adopted include conventional navigation using dead-reckoning methods based on inertial navigation systems (INS) complemented with discrete-time position fixes provided by acoustic baseline systems, that permit the correction of the INS inherent drifts. The solutions come with different accuracy, cost, and complexity; see e.g. Kinsey et al. (2006). Recently, with a view to cost reduction, a trend was started on the development of single beacon navigation (SBN) systems to work in isolation or to complement the aforementioned navigation systems; Larsen (2000), Lapointe (2006), and Crasta et al. (2011). There is also a surge of interest in the development of reliable navigation systems for autonomous underwater vehicles that rely on information extracted from the surrounding environment (e.g. terrain information) without incurring in the cost of deploying artificial beacons. Map based navigation, also called Terrain-Aided Navigation (TAN), holds good potential to be used for long range missions without incurring in a cost escalate. However, to the best of our knowledge TAN has not yet realized its full potential as an integral part of underwater navigation systems.

As a contribution to the development of advanced, cost effective terrain based navigation systems, we propose a new architecture that brings together TAN and SBN. In this paper we consider a simple set-up that consists of a single echo-sounder looking downwards to measure the altitude of the AUV above the terrain, aided with measurements of the ranges between the vehicle and a single transponder (often referred to as beacon) at a known position. Our aim is to show analytically, via the computation of appropriate Cramér-Rao lower bounds (CRLB), that there is a clear advantage in complementing terrain data with range data. This is especially noteworthy when the vehicle goes temporarily over parts of the terrain that are not "sufficiently rich" in terms of topography.

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