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AUV Terrain-Aided Doppler Navigation using Complementary Filtering ⋆

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Abstract: This paper addresses the challenging problem of achieving truly autonomous long-range navigation of underwater vehicles relying on affordable navigation sensors. Terrain-aided navigation (TAN) is a methodology that holds potential to solve this problem by dispensing with the need to use high-grade, inertial navigation sensors and the deployment and calibration of acoustic beacons. To implement TAN without incurring the additional cost of expensive dedicated sensors, we propose the utilization of a Doppler velocity logger (DVL) which is an equipment of widespread utilization in oceanography and also a standard instrument in underwater navigation. We avail ourselves of a less exploited characteristic of DVL sensors that consists in the ability to acquire, simultaneously with the velocity data, a set of accurate range measurements relatively to a reflective interface. The combination of these sensing capacities enables Doppler units to be used not only in dead-reckoning navigation but also in terrain-based localization of underwater vehicles. The main contribution of the paper is the design of a complementary filter (CF) for fusion of TAN estimates with DVL measurements. The CF approach is motivated by the need to reduce the short-term variability of position estimates that is typically observed in conventional TAN. The solution proposed is analysed in comparison with a well-known Rao-Blackwellized particle filter set-up which is shown to implement a data fusion filter designed in a stochastic estimation framework. The results obtained in Monte Carlo simulations performed with real bathymetric data evidence the superior performance of the complementary filter approach in terms of position estimation accuracy and long term output signal stability.

Keywords: Doppler-based navigation; terrain-aided navigation; complementary filtering; particle filters.

1. INTRODUCTION AND MAIN CONTRIBUTION OF THE PAPER

Currently, there is widespread interest in the development of navigation systems for submerged robotic vehicles relying on inexpensive motion sensors. This research effort can be explained by the need to develop a new class of affordable, multi-purpose autonomous underwater vehicles (AUVs) capable of performing long-range navigation without incurring the costs of high-grade inertial navigation systems (INS) and the deployment of long acoustic baselines. Terrain-aided navigation (TAN) is a methodology that holds potential to solve this problem by relying on the observation of topographic features located in the area where a vehicle navigates that are matched against a previously acquired map of the environment. In the absence of global positioning system (GPS) signals, terrain-based navigation can be integrated with conventional dead-reckoning methods to achieve precise navigation in the short term combined with bounded localization errors in the long run. TAN is a cost-effective approach specially in applications that involve operations in a previously mapped area. It may also be an interesting approach for missions that require prolonged operations in the same area even if a prior map has to be acquired, since the cost of acquiring the prior map can be largely compensated by the investment reduction in terms of the navigation instrumentation.

With a few exceptions (see e.g. Newman (1999); Majumder (2001)), previous implementations of the TAN methodology for underwater vehicles rely exclusively on sonar to observe the environmental features of interest. The sensors most frequently proposed are conventional echo-sounders as well as pencil-beam and multi-beam sonars. In the latter case, due to the large computational burden of the cor-

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