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Magnetic Navigation and Target Tracking of Underwater Vehicles ⋆

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Abstract: This paper proposes novel methods with the potential to improve the performance of navigation and tracking systems in underwater environments. The work relies on well-established methods of potential field inversion and introduces a new analytic formulation designed to stabilize the solution of the inverse problem in real-time applications. The navigation method proposed exploits the terrain information associated with geomagnetic field anomalies, without the need of a priori maps. The procedure can also be applied to track a moving target based on its associated disturbance of the environmental magnetic field. We envision the integration of theses methods in terrain-aided navigation systems, simultaneous localization and mapping algorithms, and target tracking applications.

Keywords: Navigation; target tracking; magnetic methods; inverse problems; particle filters.

1. INTRODUCTION AND MAIN CONTRIBUTION OF THE PAPER

The execution of long-range and long-term missions by robotic underwater vehicles in a fully autonomous mode is still a challenging problem. Without the aid of external references, the position error of high-grade inertial navigation systems (INS) grows at a minimum rate of 0.1 percent of the distance traveled. Even with the integration of Doppler velocity loggers (DVL) with INS to improve the performance of dead-reckoning navigation systems, the positioning error grows unbounded at a considerable rate. Hence, efficient and affordable navigation methods are under development to afford underwater robotic vehicles the capacity of executing long-range missions with minimum human intervention. Among the novel methods proposed, the terrain aided navigation (TAN) and the Simultaneous localization and mapping (SLAM) approaches have great potential for the implementation of a new generation of reliable and affordable navigation systems. However, a fair assessment of the state of the art shows that TAN and SLAM implementations in the marine environment are still in a experimental phase. SLAM is a method rooted in the mobile robotics community where navigation problems have been solved relying on the extraction of geometric features and prominent landmarks or based on the utilization of artificial beacons. Normally, these conditions cannot be ensured in marine environments. On the other hand, TAN has already proved its efficacy in natural, unstructured environments but requires the existence of prior maps for navigation, a requirement that cannot be fulfilled easily in most applications. The terrain-based approach also assumes that the terrain is sufficiently rich in terms of topography to permit the estimation of position. It is well-known that this assumption is not valid in vast areas of the ocean floor. To solve this problem we proposed in prior works to complement the topographic information with geomagnetic data extracted from the terrain; Teixeira (2007); Teixeira and Pascoal (2008).

It is against this backdrop of ideas that this paper proposes the combination of different analytic methods of geopotential field inversion to implement 3D localization algorithms that can be employed in navigation and tracking. We propose its integration in TAN and SLAM to improve the navigation capabilities of autonomous underwater vehicles. Based on the same methods, we present a target tracking procedure that may find applications in civilian and military applications.

2. MAGNETIC METHODS IN NAVIGATION AND TRACKING PROBLEMS

The magnetic field of the Earth is a vector field characterized by very slow variations in its intensity and orientation due to geophysical phenomena in the interior of the planet and by higher frequency fluctuations caused by external influences such as the solar activity. In addition to these large-scale variations, there are local anomalies in terms of magnitude and orientation of the geomagnetic field that are introduced by natural and artificial objects with induced and remanent magnetization. The exploitation of these geomagnetic anomalies as a source of information for the navigation of AUVs has been proposed many years ago but the concept still requires practical demonstration.

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