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Research on the Underwater Vehicle Navigation Based on Bayesian Filter

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Abstract

The underwater multi-sensor integrated navigation technology provides guarantees for the long-term and large-scale execution of underwater vehicle diving missions. In multi-source navigation information fusion, observational models and navigation sensor noise are spatially and temporally complex. It is of great theoretical interest and practical value for constructing accurate functional and stochastic models. In this paper, we focus on the fusion of multi-source navigation information for underwater vehicles and work on high-precision long-baseline acoustic system filter design, nonlinear filtering, colored noise filtering, integrated navigation fault-tolerant design, and multi-vehicle coordinated navigation. The work and results of this study are as follows.

The paper is divided into seven chapters and is structured as follows:

Chapter 1 introduces the research status of common commercial underwater navigation sensors at home and abroad, the development status of filtering theory under the framework of Bayesian filtering and the research status of underwater integrated navigation filtering at home and abroad, introduces the research content and technical route of the paper, and gives the chapter division of the paper.

Chapter 2 presents the filtering principle for underwater multi-sensor integrated navigation. Definitions and transformation relations have been studied for commonly used underwater integrated navigation systems, Strapdown inertial navigation systems, Doppler logs, acoustic USBL systems, LBL systems, and pressure sensor and measurement error models. In this paper, we introduce the underwater navigation sensor noise analysis method and its mathematical foundations in the framework of Bayesian filtering.

In Chapter 3, sound velocity estimation and sound velocity error correction methods in LBL acoustic localization are investigated. Considering the delayed nature of acoustic propagation, we study the acoustic delay of LBL systems and analyze the PDOP problem in acoustic localization. The underwater carrier navigation filter algorithm is designed based on the LBL/INS loose-binding and tight-binding modes, and the simulation experiments are designed to validate it.

Section 4 presents the application of the Bayesian filtering algorithm to nonlinear systems

corresponding to the specific operational context of underwater integrated navigation. In this paper, we introduce SINS fast alignment problem under large misalignment angle, USBL/DVL integrated navigation under depth constraint, CKF based compact combination algorithm for SINS/USBL, and localization problem for nonlinear ranging equations when acoustic ranging is short, which are validated by simulations and experiments.

In Section 5, the effect of systematic errors on the integrated navigation filter is analyzed and colored noise treatments including augmented state methods, measurement difference methods, and time series analysis methods are introduced. A hierarchical adaptive information filter is proposed to separate and estimate the system noise parameters. Combining simulation experiments of USBL/DVL navigation and localization in environments with unknown ocean currents with actual measurement experiments, the proposed modified adaptive filtering method was analyzed and validated to be effective.

In Chapter 6, fault detection and identification methods for underwater integrated navigation are studied, and the SINS/USBL/DVL/PG sensor refinement model is developed based on Bayesian filtering theory and observed features of underwater navigation sensors. Based on the interactive multi-model filtering principle, we propose an adaptive federated interactive filtering design scheme for deep-sea towing systems.

Chapter 7 presents the principles and methods of collaborative navigation filtering for underwater multi-vehicle applications, including decentralized and centralized modes. Based on the Bayesian filtering principle, the delay value is estimated using the maximum A-posteriori. Motivated by the existence of bidirectional ranging or mutual localization observations in multi-carrier formation networks, and considering the possibility of anomalous pilots, we propose a centralized filtering algorithm for underwater multi-carrier formation based on a weight-selective filtering model. Simulation experiments are designed to validate the results.

The summary and outlook sections mainly summarize the main research content of this paper, point out the limitations of the current research, plan the next research work, and give an outlook for future research work.

Key words: underwater vehicle, Bayesian filter, integrated navigation, nonlinear filtering, colored noise, fault tolerant filter, collaborative navigation