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Ground and Marine Resilient Integration Technology of Multi-Source Sensors for Navigation and Positioning

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ABSTRACT

Integration of multi-source sensor is the main development direction of modern technology to meet the growing demand for the high-accuracy, high-reliability and high-stability Positioning, Navigation and Timing (PNT) information in multiple scenes. With the establishment of Global Navigation Satellite System (GNSS), the benchmark of spatial-temporal information service has been guaranteed, which further promotes the research on the resilient integration technology for multi-source PNT sensors. In the PNT information service, GNSS can provide users with a unified spatio-temporal datum and full-time, accurate navigation and positioning information, but it is easy to be obstructed and interfered by the surroundings or equipment. Thanks to the good independence and anti-interference ability, Inertial Navigation System (INS) has the ability to navigate without external information, but it needs external information to calibrate and suppress error accumulation from time to time. Long Baseline sonar (LBL) system fills the blank of underwater PNT services for GNSS, but its positioning accuracy and stability, especially for the elevation, is limited by the observation geometry. The Conductivity/Temperature/Depth profile (CTD) can provide additional elevation information for LBL positioning, and salinity to determine the overwater and underwater scene of the rover. The resilient integration of multi-source sensor can address the limitations and dependencies of the single sensor on the application scenes, and achieve the cooperative work and complementarity among each sensor. This capacity will provide users with continuous, stable and reliable PNT information.

The present thesis focuses on the resilient technological integration for ground and marine navigation and positioning based on GNSS, INS, LBL and CTD. The conclusions of the research are:

1. In multi-GNSS kinematic Precise Point Positioning (PPP), three stochastic models, white noise, random walk and constant, as well as the Single-Differenced (SD) are studied for Inter-System Biases (ISBs). The equivalence between the white noise model and the SD model is theoretically demonstrated. The urban kinematic and permanent station pseudo-kinematic results show that the constant ISB model performs better in the positioning accuracy and convergency time.

2. The robust estimation based Helmert Variance Component Estimation (HVCE) algorithm is proposed to post-fit the stochastic models for pseudorange and carrier phase observations in multi-GNSS relative positioning. Experimental results show that HVCE can effectively improve the positioning performance. Furthermore, the variances of unit weight for multi-GNSS observations are stable, whose monthly averages are effective in improving the positioning accuracy of next month data and reducing the processing time.

3. A resilient functional model has been proposed based on the stationarity detection algorithm for GNSS/INS integration in vehicles, to inhibit the divergency of the INS error during GNSS outages. According to the frequency features of the idling engine, a stationarity detection method based on Fast Fourier Transform (FFT) sliding window is proposed, which achieves a correction rate of 99.7% in vehicular tests. This thesis also proposes the yaw constraint considering the effect of Earth rotation. The results of the vehicular tests demonstrate the effectiveness of the proposed method.

4. For maritime navigation, the robust estimation based LBL/CTD Tightly Coupled (TC) integration has been proposed. The marine test results show that, with the constraint of CTD depth, the Dilution of Precision (DOP) and positioning accuracy of LBL are evidently optimized. The robust estimation algorithm can effectively improve the positioning performance by adjusting the stochastic model of the integrated observations.

5. The LBL observation model considering the INS velocity error in the INS/LBL integration is proposed, based on the stability of the INS velocity error during the propagation time of the LBL signal. The marine test results show that the proposed model can effectively improve the positioning accuracy and robustness of INS/LBL/CTD TC integration.

6. A rigorous GNSS/INS semi-tightly coupled (STC) integration model is proposed based on full position information. The proposed STC model performs equally well as LC and TC models in good GNSS conditions. In the INS faulted test and the urban occluded test, the proposed STC model based GNSS/INS integration is more robust than LC and TC model.

7. Based on the integrated observations of GNSS, INS, LBL and CTD, this thesis proposes a recognition algorithm for the overwater and underwater scene. The proposed algorithm achieves scene recognition through analyzing the GNSS observable satellite number and DOP, the depth and salinity measured by the CTD, and LBL observable signal number. The proposed algorithm achieves second-level fast recognition in the practical experiment.

8. Combining all the achievements mentioned above, the overwater and underwater seamless navigation and positioning based on resilient integration of GNSS/INS/LBL/CTD is achieved. The experimental results show that the proposed resilient integration technology improves the positioning performance in all the scenes from overwater to underwater. One multi-source sensor resilient integrated navigation and positioning software has been developed with C++ programming language, on the basis of above-mentioned studies and researches.

Key words: GNSS; INS; LBL; PNT; Ground and Marine Navigation and Positioning; Resilient Multi-source Integration; Multi-source Integration Model; Seamless Positioning