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Research on Algorithms of High Precision Acoustic Positioning for Seafloor Geodetic Networks

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ABSTRACT

As an important national marine spatial information infrastructure, seafloor geodetic network (SGN) is the vital support for the construction of marine positioning, navigation and timing service system. High-precision positioning is a prerequisite for the construction and maintenance of SGN. The dynamic change of marine environment and the multi-source and complex observation errors bring severe challenges to the data processing of SGN, which seriously restricts the positioning accuracy and reliability. Aiming at realizing the high-precision positioning of SGN, according to the research main line from "single point station layout" to "multi-point network", systematic theoretical research, algorithm improvement and experimental analysis have been carried out in view of the shortcomings existing in the construction of mathematical model of seafloor geodetic point (SGP) positioning and sound velocity error processing, optimal design and network adjustment of SGN. The research content mainly includes:

1. The underwater positioning function model (UPFM) based on the round-trip acoustic path was constructed and the unified expression of UPFM was derived. Due to the continuous sailing of the surveying vessel on the sea, the position of the transducer corresponding to the signal transmission and reception time changes. Combined with active sonar working mode and the actual propagation path of acoustic signal, the coordinate parameters of shipborne transducer at the time of acoustic signal reception and transmission were taken into account, and the round-trip acoustic path UPFM is established to effectively suppress the coordinates' deviation of transducer. The new model was compared with the existing non-difference, difference or constrained function models. The transformation relationship between the design matrices of different model was given, and the unified expression of underwater acoustic positioning function model was derived.
2. Based on the analysis of the stochastic characteristics of underwater acoustic observations, a series of refinement methods for the underwater positioning stochastic model (UPSM) are proposed. Considering the relationship between the incident angle of acoustic ray and ranging error, the empirical stochastic model related to the incident angles (IASM) was constructed; However, in view of the limitation of the IASM under the observation conditions such as circular sailing, a real-time stochastic model (RTSM) based on the on-line estimation of a posteriori residual was constructed from the adjustment residual sequence; Aiming at the heteroscedasticity and time correlation of acoustic differential observations, the minimum norm quadratic unbiased estimation (MINQUE) variance-covariance component estimation method was proposed. The decorrelated differential observations were obtained by constructing the equivalent transformation matrix. Based on the MINQUE method, the iterative refinement of UPSM is realized. The experimental results showed that the refined stochastic model had advantages in positioning accuracy.
3. Aiming at suppressing the influence of time-varying error and horizontal gradient of sound speed structure (SSS), a precise positioning method of SGP based on sound speed time domain variation fitting using B-spline is proposed. The time-domain and spatial variation

characteristics of SSS and the influence of time delay difference were analyzed. The time-domain variation of sound velocity is fitted and corrected based on cubic B-spline function, and a high-precision positioning method of SGPs was proposed. Through the iterative inversion of position information and sound velocity information, the coordinates of the SGP and the disturbed sound velocity were corrected gradually; According to the characteristics of vertical stratification and horizontal heterogeneity of SSS, the parameters of nadir timing delay, and gradient factors were compensated. The random walk method and adaptive filter were introduced to estimate the parameters. The testing results showed that the precision positioning method of SSS error estimation weakens the influence of space-time representative error of SSS and effectively improves the positioning accuracy.

4. Based on the derivation of key parameters such as effective range of submarine beacon, sound field modeling and simulation analysis, the optimal configuration of SGN was designed. The optimization design basis of submarine geodetic control network, including basic design requirements, design types and quality standards was summed. And the key parameters such as effective operating distance of submarine beacon are deduced based on the acoustic ray-tracing principle. Bellhop sound field model is used to model and simulate the sound field of seafloor near / far field, medium / high frequency seafloor beacon sound signal effective range, eigen sound line trajectory, propagation loss distribution, etc; Two types of submarine geodetic control network, five array element and six array element, were designed, and the encryption and expansion strategy of submarine geodetic control network were given. Based on the positioning dilution of precision (PDOP), the positioning accuracy of four typical network types was compared and analyzed.
5. Aiming at overcoming the shortcomings of the traditional stepwise adjustment method of SGN, a joint adjustment (JA) method of SGN is proposed. Considering the positioning error of control points on the sea surface, coordinates of these points are regarded as the parameters to be estimated. Combined with the prior information of these points' positions, the virtual observation equation is added to eliminate the rank defect, the JA model of SGN is established. And the block elimination adjustment is referenced, the method of equivalent parameter elimination is used to solve the problem of low calculation efficiency due to high-order design matrix. The experimental results show that the JA method of SGN can weaken the transmission of uncertain information of sea surface position to seabed array, and improve the adjustment accuracy of SGN.

Key words: seafloor geodetic network (SGN), underwater positioning, functional model, stochastic model, sound velocity error, joint adjustment.