Development of a kinematic GNSS-A positioning method using the extended Kalman-filter to detect precise vertical displacement

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1. Background

GNSS-Acoustic (GNSS-A) seafloor geodetic observations have provided many observation results from campaign surveys using a research vessel (e.g., Tomita et al., 2017), and continuous surveys using a moored buoy has been tried recently (e.g., Kido et al., 2018). The classic GNSS-A positioning methods (e.g., Spiess et al., 1998; Kido et al., 2006) can provide a position for each ping simultaneously transmitted to all seafloor transponders; therefore, it is possible to perform real-time positioning. However, the classic method has been developed to detect horizontal motions, and it has not been well investigated to detect precise vertical motions. Meanwhile, Tomita et al. (2018) developed a kinematic GNSS-A positioning method using the extended Kalman-filter (EKF-based GNSS-A positioning method), and they demonstrated that vertical solutions could be improved. However, they has not been well investigated its improvement.

2. Numerical tests

We applied the EKF-based GNSS-A positioning method (Tomita et al., 2018) to simulation data. Here, we created simulation data based on three types of synthetic seafloor transponder arrangements, and we then investigated difference of precision of vertical solutions due to the transponder arrangements. As a result, for the transponder arrangements having diversity of shot angles from center of the array (multi-angled transponder arrangement), vertical positions can be solved even by the classic positioning method. Furthermore, the positioning precision can be improved by applying EKF.

3. Application to actual observation data

We applied the EKF-based positioning method to the actual observation data obtained by campaign surveys at sites with the multi-angled transponder arrangement in the off-Tohoku region (Tomita et al., 2017). Although vertical positions should not be changed with time during each campaign, the results showed long-term variation (~10 cm of standard deviation) by both the classic and the EKF-based GNSS-A positioning method. Since such long-term variations were similar to errors of the onboard kinematic GNSS positioning estimated by the means of Fujita & Yabuki (2003), it is expected that the GNSS-A positioning for the vertical component would be improved by improvement of the kinematic GNSS positioning. Meanwhile, we found that short-term temporal variation was improved by EKF. We calculated differential time-series of the solutions to remove the long-term errors, and we then calculated standard deviations of the differential solutions: ~10 cm and ~5 cm for the classic and the EKF-based positioning methods, respectively. Although we still have uncertainty in the long-term variation of the vertical solutions, precision for each acoustic ping can be greatly improved by EKF.

4. Investigation for real-time positioning

In order to implement EKF, we have to provide the appropriate process noise value. As we investigated the optimal process noise based on likelihood using the actual observation data of various campaigns, their values were similar each other; therefore, the appropriate process noise value can be fixed. The computation cost of the EKF-based positioning method is relatively low when the process noise value if

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fixed. Such low computation cost is plausible for the continuous survey using a moored buoy. Meanwhile, for the continuous survey, sampling frequency of the acoustic ranging is limited to save electricity of systems on the moored buoy and battery of the seafloor transponders. Then, we investigated effects of the sampling interval to the precision by re-sampling the observation data, and we found that difference of the precision between the classic and the EKF-based positioning methods was small for the sampling intervals longer than 30 minutes. Thus, to take advantage of the EKF-based positioning method, the sampling interval should be shorter than 30 minutes at least although much shorter sampling interval is plausible for precise positioning.

Keywords: Seafloor geodetic observation, Kalman-filter, Real-time positioning

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