Monitoring of moored buoy attitude by single GPS antenna and rate-gyro

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Tohoku University, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and Japan Aerospace Exploration Agency (JAXA) has developed real-time observation system for tsunami and crustal movement using a moored buoy in the SIP (Cross-Ministerial Strategic Innovation Promotion Program) “Reinforcement of resilient function for preventing and mitigating disasters”. The Tohoku University team is in charge of the GPS/Acoustic seafloor positioning. The current buoy system is equipped with four GPS antennas formed into a 1 m ×1 m square on the top, which compose a GPS gyro system and provide buoy attitude as well as position of the main antenna. The four GPS antenna system has much less power consumption (~6 W) compared with fiber optic gyro or ring laser gyro, but further power saving system is desirable for observation of long duration. We propose a method to monitor buoy attitude using one GPS antenna and a MEMS 3-axis gyroscope/accelerometer (<1 W power consumption). We analyzed data collected during a sea trial to examine accuracy of attitude obtained from the single-antenna system.

There are two observation equation describing (1) the relationship between 3-axis angular rate and the rate of change of attitude angles (yaw, pitch, and roll), and (2) that amount of change of GPS antenna velocity equals to the sum of integral value of acceleration and amount of change of velocity by rotation. The time variation of yaw, pitch, and roll was each expanded in cubic B-spline basis functions, and the expansion coefficients were calculated using the method of nonlinear least squares. We utilized angular rate and acceleration data (10 Hz) measured by a MEMS gyro (Xsens, MTi-G) and time differential values of GPS antenna position data (1 Hz) obtained by kinematic PPP analysis for antenna velocity. During a sea trial conducted off Kii Peninsula in 2014, observations ~20 minutes long were repeated once a week for four months, and we chose data of 8 observations 19 minutes long without missing data. Besides, we performed the estimation of true buoy attitude variation using GPS gyro data (JAVAD, Sigma-Q) for the comparison with the results from the single-antenna system. Instead of interpolating GPS gyro data, attitude variations were estimated considering errors in GPS gyro data by using together rate data provided by MEMS gyro. The error of GPS gyro data was estimated as 0.2 °, almost equivalent to the nominal accuracy, and that of MEMS rate data as 0.6 °/s, twice the nominal accuracy.

Errors of attitude angles obtained from our method were 0.5 °, 1.3 °, and 1.0 °for yaw, pitch, and roll, respectively. These amounts correspond to the horizontal and vertical position errors of transducer of 9 and 3 cm, respectively. Although the accuracy is not enough at present, it was shown that a small rotation of the axes of MEMS gyro relative to those of GPS gyro, which results in bias errors, caused considerable part of the errors. Errors actually have common bias among all observations, and amount of the rotation was estimated as −0.1 °, −1.3 °, and −1.0 °for yaw, pitch, and roll, respectively. Errors still remaining after correction for the rotation arise from the limited ability of the method including accuracy of data. The errors were 0.5 °for yaw and 0.4 °for pitch and roll. It was confirmed by trail measurements on board a research vessel that errors in pitch and roll could be reduced to as small as 0.03 °when using a high-performance MEMS gyro with higher accuracy (Xsens, MTi-G700). Considering that error of yaw angle less affects final result of acoustic ranging than that of pitch and roll, yaw with 0.5 °error is practically sufficient. Therefore, we conclude that the single-antenna system can provide attitude with enough accuracy. However, rotation of the MEMS gyro coordinates relative to the buoy coordinates directly results in

attitude errors. The task is to establish technique to fix the rotation angles.

Keywords: GPS/Acoustic seafloor positioning, MEMS gyroscope/accelerometer

