Improvements in GNSS-Acoustic analysis for the enhancement of positioning accuracy: application of phase-only correlation to travel time determination and positioning analysis considering the effect of earth tide

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GNSS-Acoustic technique is a geodetic method for ocean areas, which combines GNSS positioning of a sea-surface platform and acoustic ranging of seafloor stations. Its positioning accuracy is typically several and ten to twenty centimeters for the horizontal and vertical positions, respectively. For further accuracy enhancement, we first examined errors in travel time, the most fundamental data in acoustic ranging, by substituting phase-only correlation (POC) for conventional cross-correlation to detect the main peak more robustly. Second, we performed a positioning analysis considering earth tide which mainly affects the vertical position.

Two-way travel times are determined to an accuracy of a few micro seconds by calculating cross-correlation between a reference waveform generated by the onboard transducer and a signal returned from the seafloor transponder. The reference waveform we use is a series of sinusoidal waves modulated by binary phase shift keying with a maximal length sequence, whose auto-correlation has a clear main peak at zero lag. Cross-correlation between actual returned signal and the reference signal is, however, often accompanied by many large side lobes and looks very different from the synthetic auto-correlation. Possible causes for the distortion of the cross-correlation are the distortion of transmitted signal due to the frequency characteristics of the transducer, the distortion of returned signal brought by frequency dependent absorption, reflected waves from the surface of a glass sphere of the seafloor transponder or from the ship bottom. In practice, the main peak is empirically selected from several comparable peaks in the cross correlation, which would likely lead to systematic errors in travel time. We tried to substitute phase-only correlation (POC) for cross-correlation and found that side lobes were significantly reduced in POC. POC is widely used as a high-accuracy image matching technique, which gives more weight to short-wavelength variation compared with conventional cross-correlation. It is considered that simpler and clearer correlation can be obtained by focusing on the timing of phase changes in our acoustic signal, where short-wavelength components stand out. In addition, it turned out that similar POC waveforms were generally resulted from acoustic signals obtained using different kind of transducers and vessels, or at various water depths, although the waveform of conventional cross-correlation strongly depends on these observation conditions. It is a great advantage that the main peak can be uniquely identified among campaigns, because we cannot always use the same observation system. On the other hand, POC has common characteristics as conventional cross-correlation that the waveform primarily depends on the incident angle of acoustic wave. Therefore, we created templates for each band of the incident angle to consistently identify the main peak when analyzing actual signals with various incident angles.

The surface displacement due to earth tide is several and ten to twenty centimeters in the horizontal and

vertical directions, respectively. Because its main component has relatively long periods (~12 hours and longer), it can affect GNSS-A positioning depending on the duration or style of observation. In many cases of our observation, the vertical array position is determined from data collected during moving survey which is usually carried out for several hours, and therefore, significant bias in the vertical position can be left by earth tide. We applied a revised positioning analysis method considering the effect of earth tide to our GNSS-A data and confirmed that ignoring the effect could cause errors in the vertical position as much as several to ten centimeters.

Kaiyo Denshi Co., Ltd. is currently applying for a patent on the application of POC to acoustic ranging.

Keywords: GNSS-Acoustic, Phase-only correlation, Earth tide

