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For Advance of Acoustic Ranging for Observing Ocean Crustal Deformation

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Magnitude 8 class interplate earthquakes have occurred in the Suruga-Nankai Trough with the recurrence intervals of about 100-150 years. To reveal process and estimate occurrence of offshore interplate earthquakes, repeated observation of ocean floor crustal deformation is performed there using the observation system using Kinematic GPS positioning and precise acoustic ranging.

There are next two problems for acoustic ranging caused by the delayed signal that is considered the measure signal reflected at the sea surface : 1) cross-correlation coefficient on the true arrival time relatively drops, and the number of observation data decreases, and 2) the delayed signal causes cross-correlation coefficient on the true arrival time to be smaller than that on the lag time, and true arrival time is estimated wrongly. We must develop a method to perform cross-correlation computation automatically in order to determine true arrival time and to use data containing delayed signal. In this study, we performed numerical experiment of composing multiple waves to verify variation of cross-correlation coefficient depended on amplitude rate and delay time of direct and delayed signal.

We made the theoretical reference wave of the fifth-order M-sequence wave with six cycle carrier waves per unit digit same as measure signal. Considering composed two waves assuming reflection once at the sea surface, we combined the reference wave with delayed wave with delay time, DT. Performing cross-correlation procedure with the combined wave and reference wave, we got cross-correlation coefficient CC1 at the arrival time of direct wave and CC2 at the arrival time of reflected wave. Varying the amplitude ratio of reflected wave relative to the direct wave from 0 to 1, we verified the variation of two cross-correlation coefficients. In the same way, considering composed four waves assuming reflection twice at the sea surface, we the verified variation of three cross-correlation coefficients. Delay time of third reference wave supposed as reflected twice signal is 2DT, and cross-correlation coefficient at the arrival time of twice reflected wave is CC3. DT was varied from 1 to 3 because delay lag of observed wave is this variation.

Combining two waves assuming once reflected wave suggested that delayed wave drop cross-correlation coefficient at the true arrival time relatively to decrease useful data. Numerical experiment proved that CC1 changed from 0.7 to 0.75 when we combined direct wave with reflected wave with the ratio of 1 to 1. We can expect increase of data with cross-correlation coefficients less than the threshold 0.7 because CC1 easily drops less than 0.7 due to some noise. Therefore cross-correlation coefficient of retuned signal containing delayed signal decreases caused by measure wave oneself reflected at the sea surface.

For the case of four waves assuming twice reflected wave, CC1 could be less than CC2, and arrival time was read wrongly. CC1 equals CC2 in the only case of combining direct wave with reflected wave with the ratio of 1 to1. Actually, CC1 is larger than CC2 because the theoretical reflectance the sea surface is less than 1.0. CC1 was less than CC2 and CC2 was larger than CC3 in every DT on experiment of combining four waves when the ratio of direct wave, once reflected wave and twice reflected wave was 1 to 2 to 1, respectively. CC1 was sometimes less than CC3. Therefore DT on which it is showed CC1<CC3<CC2 existed, and we demonstrated numerically that CC1 could be minimum. For the actual data of observed returned signal, second peak of cross-correlation coefficient was found in time DT=2.5ms. This fact is consistent in the result of numerical experiment. In consequence, it is caused by measure signal oneself reflected twice at the sea surface that cross-correlation coefficient at the true arrival time was not maximum so that arrival time was read wrongly.

Keywords: Ocean Crustal Deformation, Acoustic Ranging, Advance of Precision, Reflected Signal at the Sea Surface, Cross-corrrelation Procedure, Numerical Experiment