1P6-4

Study on depth and range estimation of sound source in deep water with a bottom mounted single hydrophone off Hatsushima Island in Sagami Bay
相模湾初島沖深海底設置単一ハイドロフォンによる音源深度と水平距離の推定

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1. Introduction

For the research of vocalizing whales in the ocean, passive acoustic monitoring is a fundamental method. In Japanese waters, the detection of vocalizing signal of large whales at the seafloor cabled observatories off east Japan Pacific Ocean has been reported recently[1)]. The localization of sound source was implemented by analyzing waveform data of both hydrophone and seismometer, or of seismometer only[2)]. Since most of those observatories aim at the observation of earthquake and tsunami whose dominant frequency ranges are less than 50 Hz, the sampling rate of attached apparatus, i.e., seismometer and hydrophone, is usually less than 100 Hz. Consequently, the detected signals at those observatories are fin whale calls, one of the baleen whales, whose frequency range is 17–25 Hz.

Meanwhile, the vocalizing signal of sperm whales, a kind of large toothed whales, whose dominant frequency is around 10 kHz, has been detected at the multidisciplinary cabled observatory off Hatsushima Island in Sagami Bay[3)] (hereafter "off Hatsushima Island observatory", **Fig. 1**), which is comprised of several kinds of sensors including a single hydrophone (ITC-1010A) and video cameras in addition to a seismometer. Unlike the other observatories, the underwater acoustic signal observed with the hydrophone has been recorded on the soundtrack of videotapes as audible sound, i.e. ranging over several kHz in frequency with video images of seafloor obtained with the video cameras.

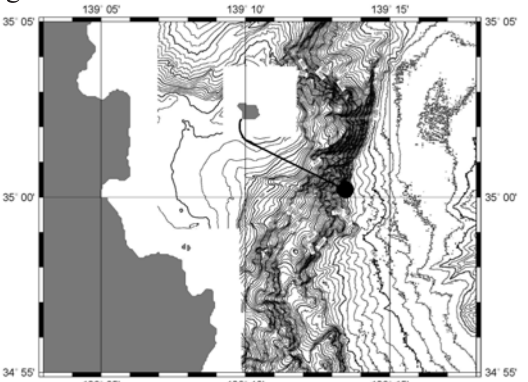

Fig. 1 Location of off Hatsushima Island observatory.

However, the sperm whale vocalization has not been localized at the off Hatsushima Island observatory while the fin whale vocalization at the other observatory has localized. It is because only a single hydrophone is attached to the observatory while conventionally the sound source is localized by using time of arrival (TOA) or time difference of arrival (TDOA) of the received signals with more than three hydrophones[4)], and is also because the frequency of the sperm whale vocalization is too high to be detected with the seismometer. There are previous studies of localization with a single hydrophone by using modal dispersion of acoustic signal in Ref. 5 and so forth, however, the mothods in those studies are applicable to relatively low frequency and broadband sound source in shallow water and are not applicable to the sperm whale vocalization in deep water of this study. There are another previous studies of localization with a single hydrophone by using time difference of multi-path arrivals (TDOMA) of the phonating dolphins in shallow water in Ref. 6 and so forth. In those studies, the depth and range of the dolphins were estimated by using TDOMA of received signals at the observatory denoted by A, B and C in **Fig. 2**. They are direct, 1st order surface reflection, and 1st order bottom reflection. Although this method is not always applicable in this study because the target area of this study belongs to deep water and it is not the case that those multi-path signals are observable, some artificial sound sources with multi-path signals, whose locations in water are known, were found in the archived hydrophone data this time. In this paper, by using these artificial sound sources, the above and the proposed method of estimating depth and range with a single hydrophone are examined.

2. Depth and range estimation of artificial sound

The artificial acoustic signals with known source locations used in this study are pulse signals emitted from remotely operated vehicle (ROV) "Dolphin 3K". Those pulse signals were emitted in

10 s interval from the ROV for the localization made by mother vessel. A part of the pulse signals emitted in the dives of the ROV carried out on June 10th in 1999 were found in the archived sound data, which had been digitized from more than 7 thousand videotapes obtained through more than 20 year observation and had been stored in hard disks as an archiving process[7] until very recently. A paste-up waveforms of dive #425 is shown in **Fig. 3**. The notations A, B and C correspond with those in Fig. 2, respectively.

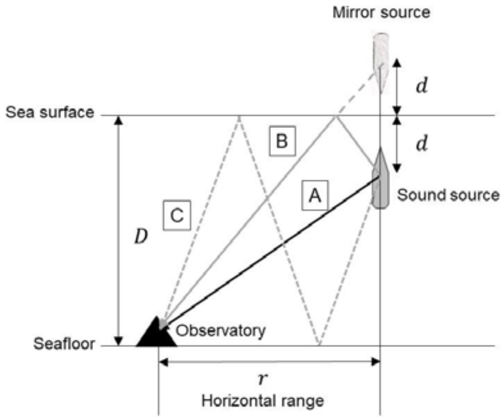

Fig. 2 Schematic of direct and multi-path signals.

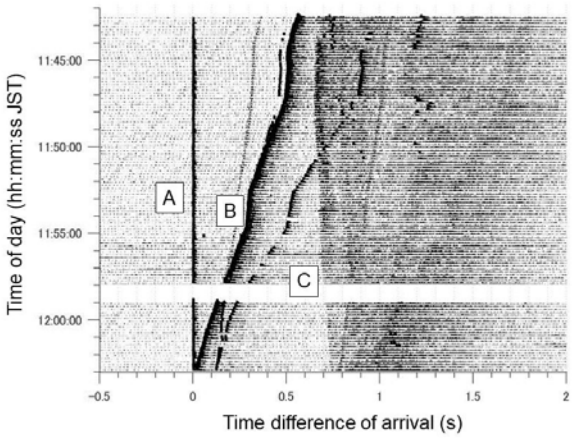

Fig. 3 Paste-up waveform of pulse signal from ROV.

Assuming water depth between the observatory and the sound source (D) and sound velocity (V) are constant, TDOMA of 1st order surface reflection (ΔT_{1s}), and 1st order bottom reflection (ΔT_{1b}) are related to depth (d) and range (r) of the sound source by the following equations.

$$\Delta T_{1s} = \frac{\sqrt{(D+d)^2+r^2}-\sqrt{(D-d)^2+r^2}}{V} \quad (1)$$

$$\Delta T_{1b} = \frac{\sqrt{(3D-d)^2+r^2}-\sqrt{(D-d)^2+r^2}}{v} \quad (2)$$

Estimated depth and range of the ROV for the case of Fig. 3 by solving these equations are shown by white circles in **Fig. 4** with the original value (black squares) that were localized by mother ship. D and V are assumed to be 1175 m and 1485.8 m/s, respectively. The difference between the estimated and original value are rather large. This difference is mainly caused by the deviation of the assumed water depth D from the actual water depth, that can be recognized with the topography in Fig. 1.

An alternative estimating method is proposed this time. Under the assamption that the target moves vertically in constant velocity (v) when it ascends and descends, the depth and range are estimated by searching best fit values of equation (1) for the dataset of ΔT_{1s} and corresponding time. The assamption would be proper for the diving behavior of sperm whales according to Ref. 8. The result of the estimated depth and range are shown by white triangles in Fig. 4. Although prior knowledge of v is necessary, the result is not affected by the deviation of water depth (D) and is closer to the original value. The proposed method would be applicable to the sperm whale vocalization whose 1st order bottom reflection has not been found in the archived data to date.

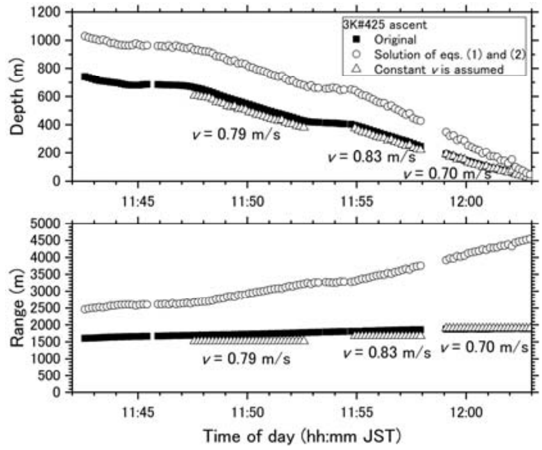

Fig. 4 Estimated and original depths and ranges of ROV.

3. Concluding Remarks

The existing and proposed method of estimating depth and range with a single hydrophone are examined by using artificial sound source with known location. Proposed method would be applicable to the vocalizing sperm whale.

References

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