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Acoustic theory application in ultra short baseline system for tracking AUV

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Abstract. The effective tracking area of ultra short baseline (USBL) systems strongly relates to the safety of autonomous underwater vehicles (AUVs). This problem has not been studied previously. A method for determining the effective tracking area using acoustic theory is proposed. Ray acoustic equations are used to draw rays which ascertain the effective space. The sonar equation is established in order to discover the available range of the USBL system and the background noise level using sonar characteristics. The available range defines a hemisphere like enclosure. The overlap of the effective space with the hemisphere is the effective area for USBL systems tracking AUVs. Lake and sea trials show the proposed method's validity.

Keywords: ultra short baseline system; track; AUV; ray equations; sonar equations

1. Introduction

The ultra short baseline (USBL) acoustic positioning system plays a very important role in the location of autonomous underwater vehicles (AUVs) (Xing *et al*. 2002, Xing *et al.* 2003, Batista *et al*. 2009, Hegrenaes and Hallingstad 2011). The safety of AUVs is an important problem in sea or lake trials. To obtain information on location, USBL systems have been used to track long range AUVs in both lake and sea trials. The main technical specifications of the USBL system is given in Table 1. USBL systems include two important acoustic instruments as shown in Fig. 1. One is a transceiver which is deployed on the ship, and the other is a beacon fixed in the AUV. The ship and AUV move over a certain distance, and then the USBL system locates and tracks the AUV using acoustic communication between transceiver and beacon. An effective tracking area exists where the acoustic communication is normal and the AUV can be easily located. Acoustic communication is subjected to both of these factors. One is the space that sound rays can go through. The other is the range that the rays can reach. This problem has never been annalistically solved. In this paper, a method for determining the effective space and range is given using acoustic theory.

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Table1 Main technique parameter of USBL

Frequency(kHz)	Depth(m)	Range(m)	accuracy(%)
18-36	1000	3000	0.1

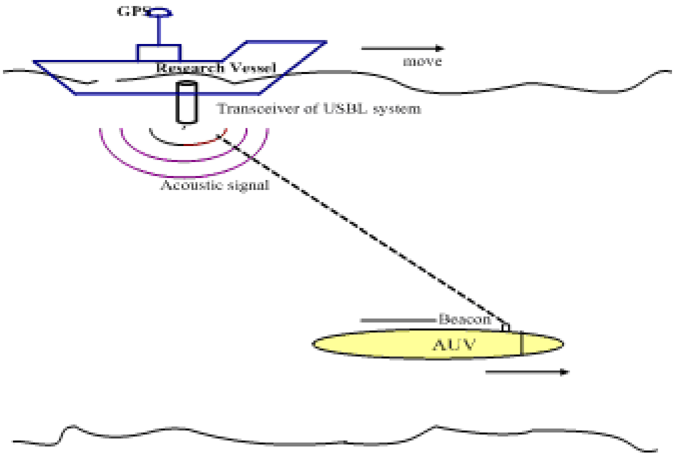

Fig. 1 Sketch for USBL tracking AUV

2. Methods and principles

Acoustic ray theory is applied to determine the effective space. The sound ray path is dependent on the variation of the speed of sound which is a function of depth, saltiness and temperature. The horizontal sound speed gradient of can be neglected when the distance that sound travels is not too long. An ordinary differential equation (ODE) algorithm is adopted to draw the sound rays (Ziomek and Polnicky 1993). Ji presents a ray theory method in a long baseline (LBL) system (Ji and Liu 2010). The presented method for the determination of the effective space is summarised below. Firstly, the sound speed profile (SSP) of water is obtained by conductivity, temperature and depth (CTD) sampling. Secondly, the ODE algorithm is used to draw sound rays. And the gracing angle is from zero to ninety degrees. Finally, the effective space is defined in terms of sound rays. A general sketch of the space is shown in Fig. 2. Usually, there are two parts in the effective space if there is a thermal layer in the water. The shadow area from which sound rays cannot arrive is beyond the effective space. In order to keep acoustic communication normal, AUVs should sail within the effective space.

The available range of acoustic signal propagation can be acquired from the sonar equation (Waite 2002) given below

$$PL = SL - (N + \log B - DI) - DT \tag{1}$$

where PL is the propagation loss, SL is the source level, DI is the detection index, N is the noise level, B is the bandwidth of the USBL system and DT is the detection threshold.

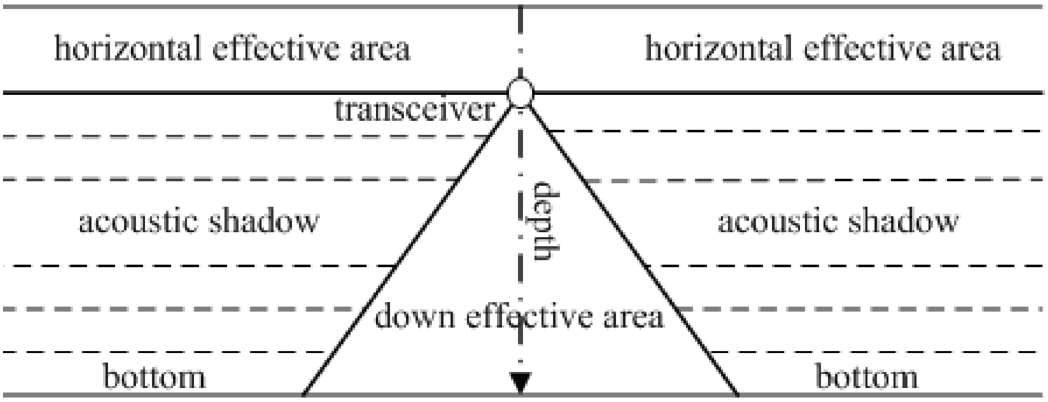

Fig. 2 Sketch graph of determination for spread boundary using ray acoustics

This range is mainly dependent on parameters PL and N in Eq. (1) since the other factors can be obtained from the USBL system. Assuming that N is known, PL should satisfy both of the following equations. The first is the propagation loss equation from transceiver to AUV

$$PL_{TB} = SL_T - (N + \log B - DI_T) - DT_B \tag{2}$$

The second is the propagation loss equation from AUV to transceiver

$$PL_{BT} = SL_B - (N + \log B - DI_B) - DT_T \tag{3}$$

where T denotes the transceiver and B denotes the beacon fixed in the AUV.

Based on Eqs. (2) and (3), the allowable PL can be obtained from the following equation.

$$PL_{\min} = \min(PL_{TB}, PL_{BT}) \tag{4}$$

In general, the propagation loss is considered to be the sum of the spherical spreading loss and absorption loss (Waite 2002).

$$PL = 20\log r + \alpha \cdot r \times 10^{-3} \tag{5}$$

where r denotes range (km) and α denotes the absorption coefficient (dB/km) which is dependent on the working frequency of the USBL system. The available range r between transceiver and AUV can be acquired from Eq. (5) if the noise level N is known. The enclosure defined by the available range is shown in Fig. 3 and has the form

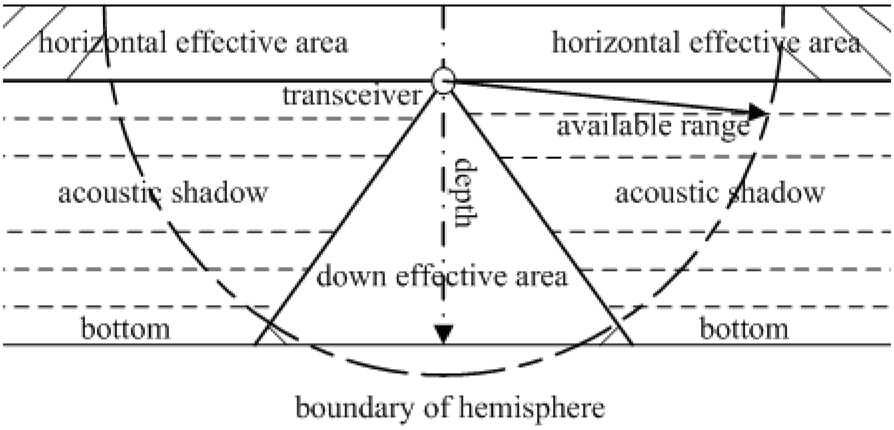

Fig. 3 More determination for boundary using sonar equations

of a hemisphere. It is obvious that the overlap of the effective space and the hemisphere is just the effective area for the USBL system tracking the AUV. It means that the USBL system may track the AUV well only if the AUV goes into the effective area.

The presented method for the determination of the effective area is summarised below as an example algorithm.

Require: sonar characteristics of the USBL system.

1. Acquire SSP by CTD.
2. Draw rays pinging from 0° to 90° using ray theory.
3. Fix the effective area used.
4. Start tracking.
5. Acquire the noise level.
6. Calculate the allowable PL.
7. Obtain the hemisphere for which the radius is in its available range.
8. Determine the overlap between the effective space and the hemisphere.
9. Adjust the movement of the ship to allow the AUV to go into the overlap.

3. Experiments and results

A Sonardyne USBL system was used to track our AUVs in both the lake and the sea trial. Sonar characteristics of the USBL system are listed in Tables 2 and 3. The bandwidth B of the working frequency

Table2 Sonar characteristics of transceiver

SL(dB)	DI(dB)	DT(dB)
195	10	14

Table3 Sonar characteristics of beacon

SL(dB)	DI(dB)	DT(dB)
187	10	15

is 400 Hz. A very useful feature is that the noise level can be given by the USBL system. Therefore, the available propagation range can be obtained from Eq. (5). We have calculated each available range according to different noise levels. This is shown in Table 4

Table4 Available ranges according to different noise level

Noise level(dB)	60	70	80	90	100
Range(m)	4000	2500	1945	800	600

The SSP was obtained by CTD in the lake trial as shown in Fig. 4. The UBSL system's transceiver was deployed at a depth of 5 m. The depth of the lake was 56 m. Fig. 5 shows sound rays starting at the transceiver. The gracing angle is between 0° and 90° with 0.1° intervals. It is obvious that there exists an acoustic shadow below a depth of 23 m and beyond 1200 m. Very few rays can penetrate the shadow area. The noise level was measured at 65 dB by the USBL system. According to table 4, the available range was approximately 3400 m. The AUV was set to sail at a depth of 10 m. The USBL system tracked the AUV well at that depth, but badly below 20 m if the horizontal range was further than 1100 m. This fact is consistent with the above discussion. The longest range recorded during the trial was 3250 m at a depth of 10 m.

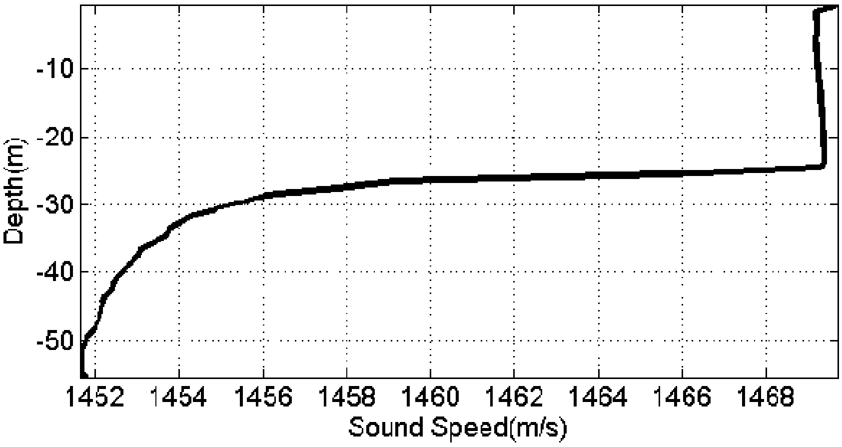

Fig. 4 Sound speed profile n trial lake

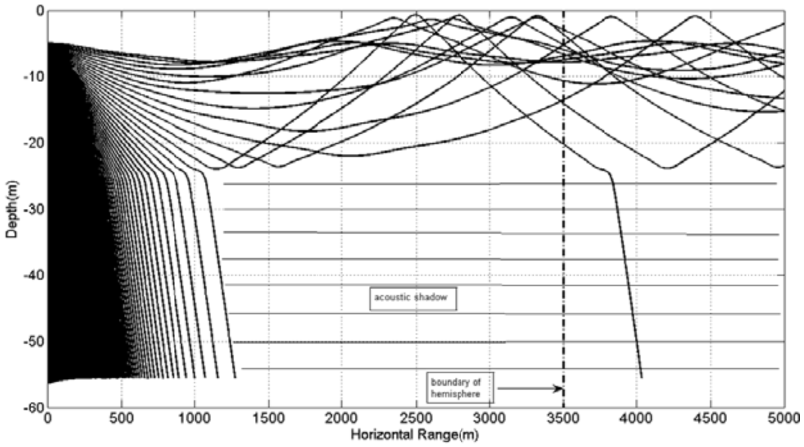

Fig. 5 Spread track of sound rays in trial lake

The SSP is shown in Fig. 6 for the sea trial where there are some dramatic thermal layers. Fig. 7 shows sound rays pinging from 0° to 90° with a 0.1° interval. An acoustic shadow was present here. The ship and the AUV moved at the same time, and the transceiver was installed below the ship at a depth of 6 m. The noise level was measured to be approximately 90 dB by the USBL system. The available horizontal range was about 600 m according to table 4, and the USBL system tracked the AUV well at a depth of 50 m with a range of less than 600 m. This fact is also consistent with the above discussion. The AUV would need to sail at a lower depth if a longer range were needed.

Fig. 6 Sound speed profile of trial sea area

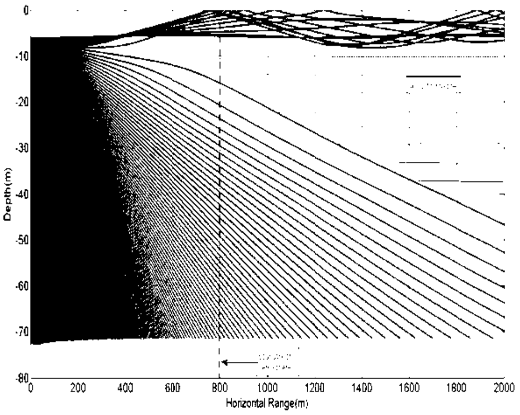

Fig. 7 spread track of sound rays

4. Conclusions

A method based on acoustic theory for the determination of the effective tracking area of USBL systems was studied. Ray acoustic equations were used to draw rays to ascertain the effective space. The sonar equation was established in order to calculate the available range of the USBL system and background noise levels using sonar characteristics. The available range defined a hemisphere like enclosure. The overlap between the effective space and the hemisphere is simply the effective area for the USBL system tracking the AUV. The user should adjust the movement of the ship to allow the AUV to go into the effective tracking area. This method can improve the tracking performance of a moving USBL system. The lake and sea trials show that the method is valid and reliable. Thus it could become a guide to USBL system users for tracking AUVs.

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