PASSIVE AUV TRACKING USING SOUND PRODUCED BY SHRIMPS

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ABSTRACT

An autonomous Underwater Vehicle (AUV) is a self driven vehicle travelling underwater and used for variety of purposes. Sometimes, for proper operation of AUVs, it is important to know where the AUVs are, particularly the depth. Usually depth of AUV is measured using an active technique where a known signal is transmitted and ocean ambient noise (OAN) generated in the ocean is considered as noise. However, the technique described in this paper makes use of this OAN rather than transmitting anything. Theoretical and experimental analyses show that if AUVs are travelling in the shrimp dominated area then the depth of the AUVs can be estimated using a passive technique.

***Index Terms*—** Autonomous Underwater Vehicle (AUV), Passive depth estimation, Shrimps, Ocean Ambient Noise (OAN), Cross-correlation

1. INTRODUCTION

Autonomous Underwater Vehicle (AUV) is of great interest to researcher and industry since 1994 which can be used to communicate with submarines and other underwater devices [1, 2, 3], detect the submarines of the enemy [4], map seafloor [5], monitor the ocean environment, collect data [6] and so on. [4]. Navigation and position estimation of AUV are important requirements of many of these applications, in particular, in autonomous inspection applications [7]. Inspection of pipes, water or oil, bridges, oil platforms, boats are some of these application which require the relative position of the AUV with respect to the object to be inspected [7].

Usually, GPS devices are not effective to localise underwater devices due to large attenuation of electromagnetic signals. Therefore, underwater localisation are mainly based on measurement of time of flight of acoustic signal from emitter and receiver [8]. Both active and passive techniques are used in the positioning of AUV [9]. Position of AUV can be estimated using the motion data available on-board with the information on the range between AUV and transponder. An approach of relative positioning of two AUVs using velocity and depth sensors are described in [8]. In [2], position of the AUV can be estimated from moving acoustic beacons by applying Kalman filter. Another Kalman filter based navigation is proposed in [10]. However, all of these positioning techniques require active transmission of acoustic signals.

Sometimes, active navigations can not be applied in particular areas of ocean due to environmental restrictions. This is because the transmitted active signal may interfere with the other signals and marine species in the area. Marine animals produce and listen a wide range of sounds from about 10 Hz to more than 200 kHz for the purpose of their daily life communication, navigation and detection of prey [11]. When a sound from this range is transmitted from an active sonar, some marine animals can hear the transmitted signal, which masks their ability to perform these tasks effectively [12]. This is where passive techniques find their place in underwater acoustic applications.

One of the passive AUV navigations is described in [13] where terrain matching technology is applied and topographic features are used in navigation. Another passive AUV localisation technique is demonstrated in [9] which actually requires a sonar transmission. In this paper, an alternative approach of estimating depth of AUV is proposed which makes use of the ocean ambient noise produced by the shrimps. Shrimps are a little creature that lie on the sea bed and produce very loud sound. By listening the sound produced by shrimps and cross-correlating them, depth of the AUVs can be estimated in the shrimp dominated shallow areas.

Rest of the paper is organised as follows. Section two describes theoretical analysis of passive depth estimation of the AUV. Section three shows experimental results and section four concludes the paper.

2. THEORETICAL ANALYSIS OF AUV DEPTH ESTIMATION

2.1. Broadband Shrimp sounds

A wide variety of sounds are produced by marine life in the ocean, with biological sounds observed in frequency ranges from as low as 10 Hz to ultrasonic frequencies [14, 15, 16, 11]. Generally, although the sound produced by an individual

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creature is of short duration and distinct, frequently repeated sounds of different types over a period are a good approximation of Ocean Ambient Noise (OAN).

The sound produced by snapping shrimps is the best-known source of biological noise in the ocean and is found in shallow warm waters around the world [15]. It has been shown that this sound is actually generated by the collapse of cavitation bubbles produced by the shrimps' snapping claws [17] whereas it was previously believed that it was due to the actual noise of the snaps [18]. In Australia's shallow waters, a large number of shrimps is always evident and their snapping sounds form a continuous crackling background noise. The length of an individual snap is about 10 s and the spectrum of shrimp noise is spread over a large frequency band from about 1 kHz to beyond 200 kHz [11, 16, 19]. The monitoring of shrimps in different parts of Australia suggests that the contribution of their sounds to OAN depends on their habits and habitats [11]. They are generally dominant in rocky bottom areas of the ocean rather than on its sandy bottom and at depths of less than 60 m [11]. Shrimps in Australian waters also make sounds in a group which creates a chorus. The chorus of shrimps is observed throughout the day with small diurnal variations.

A time series of the sounds produced by shrimps is shown in Figure 1.

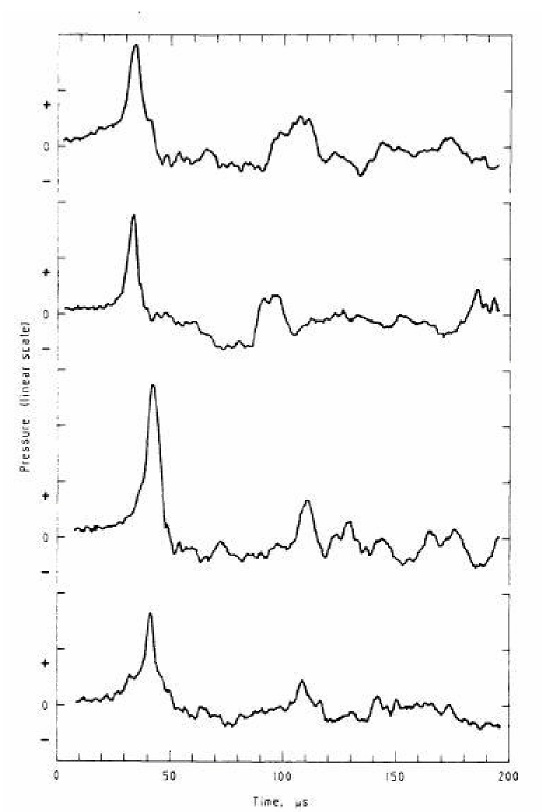


Fig. 1. Time series of clicks produced by shrimp [11]

Figure 1 shows a time series of the pulses from the snaps of four individual shrimps in Sydney Harbour at Pyrmont[11].

2.2. Procedure

Two vertically separated hydrophones could be attached to the AUV to record the ocean ambient noise (OAN) all around the AUV. When the AUV travels in the shrimp dominated area, the clicks of shrimps coming from underneath the AUV are dominant in the recorded OAN. The cross-correlation between the direct signal at one hydrophone and its surface reflected version at the other hydrophone gives the estimation of the delay difference between them. Thus the depth of the AUV can be estimated using the sound clicks generated by the bottom shrimps. The shrimps located just under the AUV produces the farthest correlation peak from correlation centre due to the cross-correlation between the direct and the surface reflected signals. However, the shrimp sounds are not only coming from underneath the AUV, but also from distant places. These distant sounds produce correlation peaks in between the correlation peak representing AUV depth and correlation centre. Therefore, these peaks do not interfere with the correlation peak representing the depth of the AUV. Better AUV tracking should be observed in shallow water and in the rocky bottom because of the dominance of the shrimps compared to the deep and sandy bottom.

2.3. Theory

It is considered that a shrimp noise source A is positioned at the ocean bottom. The geometry of the passive estimation of the depth of the AUV using sound produced by the shrimp is shown in figure 2.

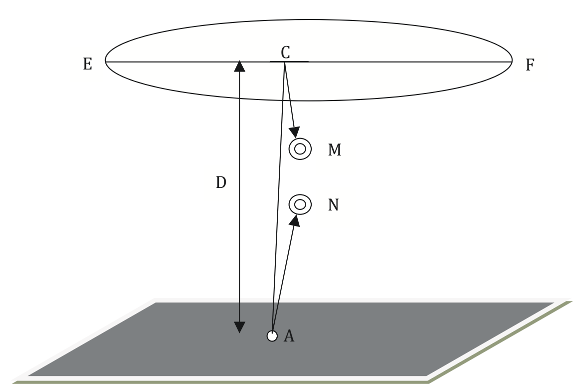


Fig. 2. Geometry of AUV depth estimation

In figure 2, a direct signal from A comes to the hydrophone N following AN path and a surface reflected path of the same signal comes to hydrophone M following ACM path. The cross-correlation between these two signals gives the delay difference between them, $\Delta\tau_{MN}$, which gives an estimation of the depth of the hydrophones, which in turns gives estimation of the depth of the AUV. From figure 2, depth of top hydrophone M, d_t can be estimated as.

$$2d_t + d_s = \Delta\tau_{MN} * c \quad (1)$$

where $d_s = MN$ is the spacing between hydrophones and c is the speed of sound. Speed of sound c can be calculated using equation 2

$$\begin{aligned} c = 1449.05 + 45.7(\frac{T_c}{10}) - 5.21(\frac{T_c}{10})^2 + 0.23(\frac{T_c}{10})^3 \\ + (1.333 - 0.126(\frac{T_c}{10}) + 0.009(\frac{T_c}{10})^2)(S_c - 35) \\ + 16.3Z_c + 0.18Z_c^2 \end{aligned} \quad (2)$$

where c, T_c, S_c and Z_c are the speed of sound, water temperature in ^oC, salinity and depth in km respectively.

3. EXPERIMENTAL RESULTS

Two vertically separated hydrophones are placed underwater where the depth of the seabed is about 15 m and the type of seabed is rocky. The experiment is conducted near Jervis Bay, NSW, Australia on 27^{th} of October 2012. The top hydrophone is about 5.2 m depth and the separation between the hydrophones is 0.5 m. The shrimp dominated OAN field is recorded at two hydrophones at sampling rate of 192 ksps for 50 seconds. A temperature sensor is also deployed at the same depth of the hydrophones to measure water temperature at that place which so as to calculate the speed of sound. The speed of sound is calculated using equation 2 where the temperature at the location of the experiment is 20^oC measured by temperature sensor, the salinity of the water is 35.30 PSU [20] and the depth of the measurement is 5m. Using these parameters, speed of sound is calculated as 1521.9 m/s.

Cross-correlation between the equalised noise fields of the frequency band 2 to 20 kHz received at two hydrophones is shown in Figure 3.

A correlation peak is observed at about 7 ms away from the correlation centre in figure 3. Two other peaks in figure 3 are produced at about 5.67 and 4 ms away from the correlation centre. Two shrimp clicks responsible for correlation peaks at about 7 ms and 4 ms is shown in figure 4.

The delay difference between the direct and the surface reflected signal of figure 4(a) is about 7 ms. The shrimp sound of figure 4(a) contributes to the correlation peak at 7 ms in figure 3. In the same way, the delay difference between the direct and the surface reflected signal of figure 4(b) is about 5 ms which contributes to the correlation in between the correlation peaks at 4 ms and 5.67 ms.

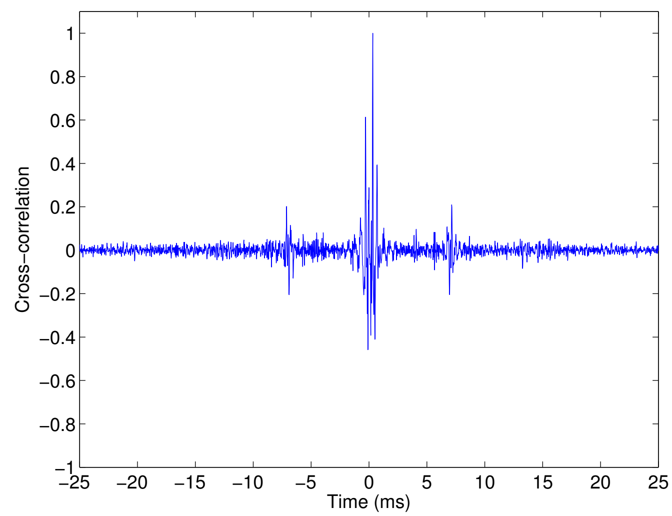
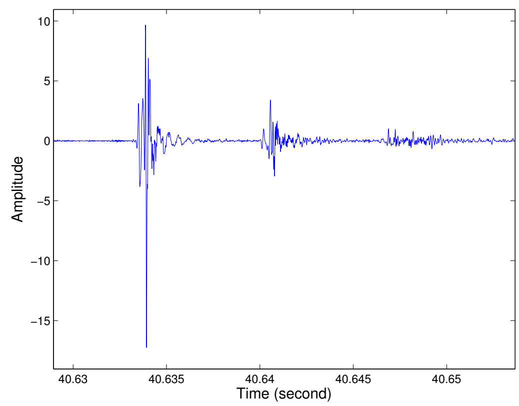


Fig. 3. Cross-correlation of shrimp dominated noise fields (2-20kHz) received at two vertical hydrophones

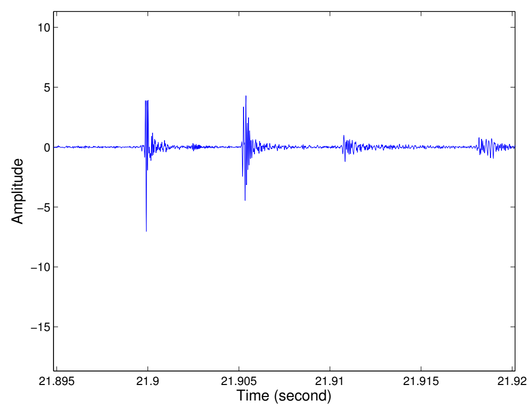
Therefore, the correlation peak at 7 ms is generated due to the cross-correlation between the direct and the surface reflected signal coming from near the bottom end-fire region. Also other two peaks at about 5.67 and 4 ms are generated because of the shrimps located away from the end-fire region. Since the farthest correlation peak due to the cross-correlation between direct and the surface reflected signal is at about 7 ms, this gives the estimate of the depth of the hydrophones. The distance corresponding to 7 ms is 10.65 m considering the speed of sound in water in experimental place as 1521.9 m/s, which is used to measure the depth of the hydrophones. If the hydrophones are attached to the AUV, then the depth of the hydrophones also represents the depth of the AUV. Now, the depth of the top hydrophone, d_t can be calculated using equation 1:

$$2d_t + 0.5 = 10.65$$

Therefore, the value of d_t is estimated as 5.08 m where in the experiment setup it was 5.2 m. The possible reasons of the variation of the depth are the fluctuation of the surface and also shrimps not located exactly in the end-fire region. If no shrimp is located in the end-fire region or close to the end-fire, the farthest correlation peak at about 7 ms moves towards the centre of the correlation which results inaccuracy in the depth estimation of the AUV. A directional array of hydrophones could be used to emphasise the shrimp noise coming from the end-fire region which gives the accurate and the improved estimation of the depth of the AUV.



(a) shrimp click from end-fire region



(b) shrimp click from a distant place

Fig. 4. Two shrimp clicks coming from the bottom end-fire region and away from the end-fire region

4. CONCLUSIONS

In this paper, it is shown that the cross-correlation between the direct and the surface reflected noise fields dominated by the sound of the shrimps and received at two vertical hydrophones can be used in the passive estimation of the depth of the hydrophones. This helps in the passive estimation of the depth of AUV when two vertical hydrophones are attached to the AUV and it moves in the shrimp dominated shallow water. This potential passive technique of AUV positioning can be a great alternative of active positioning technique in the areas where active transmission is prohibited due to environmental restriction. Performance of this passive depth estimation can be improved if an array of vertical hydrophone is used instead of only two hydrophones and it is left as future work. At this stage we are just able to estimate the depth of the AUV, however, using an array of hydrophone and making use of the shrimp sounds coming from directions other than bottom end-fire region, we would be able estimate the 3D position of AUV and it will be investigated in future.

5. REFERENCES

[1] E.R.B. Marques, J. Pinto, S. Kragelund, P.S. Dias, L. Madureira, A. Sousa, M. Correia, H. Ferreira, R. Goncalves, R. Martins, D.P. Horner, A.J. Healey, G.M. Goncalves, and J.B. Sousa. Auv control and communication using underwater acoustic networks. In *OCEANS 2007 - Europe*, 2007.

[2] N. Matos, A.and Cruz. Auv navigation and guidance in a moving acoustic network. In *Oceans 2005-Europe*, 2005.

[3] E. M. Sozer, M. Stojanovic, and J. G. Proakis. Underwater acoustic networks. *IEEE Journal of Oceanic Engineering*, 25(1):72–83, 2000.

[4] O.A. Yakimenko, D.P. Horner, and D.G. Pratt. Auv rendezvous trajectories generation for underwater recovery. In *Control and Automation, 2008 16th Mediterranean Conference on*, pages 1192 –1197, june 2008.

[5] R. Henthorn, D.W. Caress, H. Thomas, R. McEwen, W.J. Kirkwood, C.K. Paull, and R. Keaten. High-resolution multibeam and subbottom surveys of submarine canyons, deep-sea fan channels, and gas seeps using the mbari mapping auv. In *OCEANS 2006*, pages 1 –6, sept. 2006.

[6] I. Vasilescu, K. Kotay, D. Rus, M. Dunbabin, and P. Corke. Data collection, storage, and retrieval with an underwater sensor network. In *SenSys05*, 2005.

[7] E. Campos, J. Torres, S. Mondie, and R. Lozano. Depth control using artifitial vision with time-delay of an auv. In *Electrical Engineering, Computing Science and Automatic Control (CCE), 2012 9th International Conference on*, pages 1–6, 2012.

[8] F. Arrichiello, G. Antonelli, A.P. Aguiar, and A. Pascoal. Observability metric for the relative localization of auvs based on range and depth measurements: Theory and experiments. In *Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on*, pages 3166–3171, 2011.

[9] Zhiguo Yang, Wen Xu, Zhuan Xiao, and Xiang Pan. Passive localization of an autonomous underwater vehicle with periodic sonar signaling. In *OCEANS 2010 IEEE - Sydney*, pages 1–4, 2010.

[10] A.S. Gadre and D.J. Stilwell. A complete solution to underwater navigation in the presence of unknown currents based on range measurements from a single location. In *Intelligent Robots and Systems, 2005. (IROS*

2005). 2005 IEEE/RSJ International Conference on, pages 1420–1425, 2005.

[11] D.H. Cato and M.J. Bell. Ultrasonic ambient noise in australian shallow water at frequencies up to 200khz. Technical report, DSTO Materials Research Laboratory, 1992.

[12] W. J. Richardson, C. R. Greene, Jr., C. I. Malme, and D. H. Thomson. *Marine Mammals and Noise*. Academic Press. NY, 1995.

[13] Zhang Feizhou, Geng Jiazhou, and Cheng Peng. Design of underwater passive navigation simulation system based on information fusion. In Gary Lee, editor, *Advances in Computational Environment Science*, volume 142 of *Advances in Intelligent and Soft Computing*, pages 229–238. Springer Berlin Heidelberg, 2012.

[14] V. O. Knudsen, R. S. Alford, and J. W. Emling. Survey of underwater sound, report no. 3, ambient noise. *Office of Scientific Research and development , National Defence Research Committee, Washinton, DC. Rept. 4333*, 1944.

[15] V. O. Knudsen, R. S. Alford, and J. W. Emling. Underwater ambient noise. *Journal of Marine Research*, 7:410–429, 1948.

[16] G. M. Wenz. Acoustic ambient noise in the ocean: Spectra and sources. *J. Acoust. Soc. Am.*, 34:1936–1956, 1962.

[17] M. Versluis, B. Schmitz, A. von der Heydt, and D. Lohse. How snapping shrimp snap: Through cavitating bubbles. *Science*, 289(5487):2114–2117, 2000.

[18] G. B. Goode. The voices of crustacea. In *Proc. United States National Museum*, 1878.

[19] D. H. Cato and R. D. McCauley. Australian research in ambient sea noise. *Acoustics Australia*, 30, 2002.

[20] P. E. Holloway, G. Symonds, and R. N. Vaz. *Temperature and Salinity measurements in the Jervis Bay Region*. Department of Geography and Oceanography, Univeristy College, The University of New South Wales, Australian Defence Force Academy, 1992.