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PASSIVE ACOUSTIC LOCALIZATION AND TRACKING OF VESSELS USING A COMPACT ARRAY OF HYDROPHONES

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Пассивное акустическое оценивание местоположения кораблей с использованием компактной решетки гидрофонов

Рассматривается задача оценивания местоположения и направления движения объекта за счет использования пеленгов, измеряемых с помощью стационарной компактной пассивной решетки гидрофонов. Наблюдаемость оценок достигается за счет использования априорной информации о скорости объекта. Точность предлагаемого алгоритма максимального правдоподобия оценивается по результатам измерения местоположения кораблей с известными GPS координатами.

Passive acoustic vessel localization and tracking plays an important role in port security applications and, more generally, for monitoring coastal and offshore vessel activities. The approach can provide vessel presence and distribution information at locations where automatic identification systems (AIS) cannot be deployed or do not work well. Passive acoustic monitoring (PAM) approaches can be used, for example, to monitor vessel activities in marine protected areas and conservation areas. The basic requirements of vessel tracking systems are the ability to identify vessels within a surveillance area, and to estimate their headings, speeds and positions.

Time difference of arrival (TDOA) methods can be applied to acoustic measurements obtained from compact arrays of hydrophones. Recent advances in undersea digital networks allow real-time streaming of high-bandwidth acoustic data from compact arrays. The TDOA-based techniques can be applied to these data to implement practical localization and tracking solutions [1]-[3].

The problem of estimating positions and heading angles of sources from bearing measurements is known as bearing-only target motion analysis (BO-TMA) [4]–[5]. The main difficulty in implementing BO-TMA techniques is that they require a moving observer, which is not possible for most long term PAM applications.

In this work the problem of estimating the positions and heading angles of vessels, using bearing-only measurements from a stationary compact array, is considered. We assume that bearing errors are represented as a correlated Gaussian random process with known or estimated statistical characteristics. We also assume that the speed of sources is approximately known. Thus, position estimates are obtained by combining bearing measurements with speed assumptions. The goal of this work is to evaluate the influence of various factors on accuracy of the position and heading estimates. The influencing factors include duration of correlation interval, variance of bearing errors, duration of the source observation interval, and variance of speed errors.

We assumed that locating and tracking sources is to be performed within an area specified in 2D Cartesian (*x*,*y*) coordinates. At time *t* the position of the source is described by the vector

$$\boldsymbol{r}(t) = \boldsymbol{r}(t_0) + v_0\boldsymbol{e}(\gamma_0)(t - t_0) = \begin{bmatrix} x(t) \\ y(t) \end{bmatrix} \in R^2, \quad (1)$$

where v_0 is the source's speed, γ_0 is its heading angle, and the vector $\boldsymbol{e}(\gamma_0) = [\sin\gamma_0, \cos\gamma_0]^T$ indicates its travel direction in Cartesian coordinates, and $\boldsymbol{r}(t_0) = [x_0, y_0]^T$ is its initial position. We assumed that the parameters x_0, y_0, γ_0 were unknown, such that the vector of parameters to be estimated is defined as

$$\boldsymbol{\theta}_0 = [x_0, y_0, \gamma_0]^T \in R^3, \quad (2)$$

where symbol "T" denotes transpose. The bearing estimates provided by the array are

$$\hat{\alpha}(t) = \alpha(t, \boldsymbol{\theta}_0) + \varepsilon(t), \quad (3)$$

where $\alpha(t, \boldsymbol{\theta}_0) = tan^{-1}\frac{x(t)}{y(t)}$ is the true bearing and $\varepsilon(t)$ is the bearing estimation error.

To overcome the observability problem, we assumed that the unknown speed of a source can be described probabilistically by a mean value and variance. When the mean speed is used, the vector (2) becomes observable from (3) in the sense that the unambiguous estimate of the parameters (2) exists.

The logarithmic likelihood function of the vector of bearing estimates (3) is

$$lnW(\hat{\boldsymbol{\alpha}}|\boldsymbol{\theta}) = -\frac{1}{2}\left(\hat{\boldsymbol{\alpha}} - \boldsymbol{\alpha}(\boldsymbol{\theta})\right)^T \boldsymbol{C}^{-1}\left(\hat{\boldsymbol{\alpha}} - \boldsymbol{\alpha}(\boldsymbol{\theta})\right). \quad (4)$$

From (4), the maximum likelihood (ML) estimates of vector $\boldsymbol{\theta}$ obtained for the speed v are

$$\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\theta}}(v) = \{\hat{x}_0(v), \hat{y}_0(v), \hat{\gamma}_0\} = arg\max_{x,y,\gamma} lnW(\hat{\boldsymbol{\alpha}}|\boldsymbol{\theta}). \quad (5)$$

In practice, the estimates (5) can be calculated using a grid search algorithm that maximizes (4) in 3D space over the parameters $x, y,$ and γ.

The performance of the ML estimator (5) was evaluated experimentally using a stationary compact tetrahedral array of hydrophones monitored by an Autonomous Multichannel Acoustic Recorder (AMAR, JASCO Applied Sciences) [2]. The array was deployed on the Victoria Experimental Network Under the Sea

(VENUS) cabled ocean observatory operated by Ocean Networks Canada (ONC) in the Salish Sea, BC, Canada. The array was deployed on the seabed at 168 m depth; the hydrophones of the array were approximately 1.84 m apart. The position and orientation of the array was measured during the deployment and calibrated using surface vessels with known GPS coordinates. Although tetrahedral array used in our tests could measure both azimuth and elevation angles, only azimuths were used to compute the parameter estimates (5).

Root mean square errors (RMSE) of range and heading estimates were obtained at the closest point of approach (CPA) of 171 vessels, and were used to evaluate the performance of the ML estimator (5). Test results (see Fig. 1) demonstrated that in the case of Gaussian bearing errors, and in the absence of speed errors, the RMSE of the range and heading ML estimates (5) are close to the Cramér-Rao bounds.

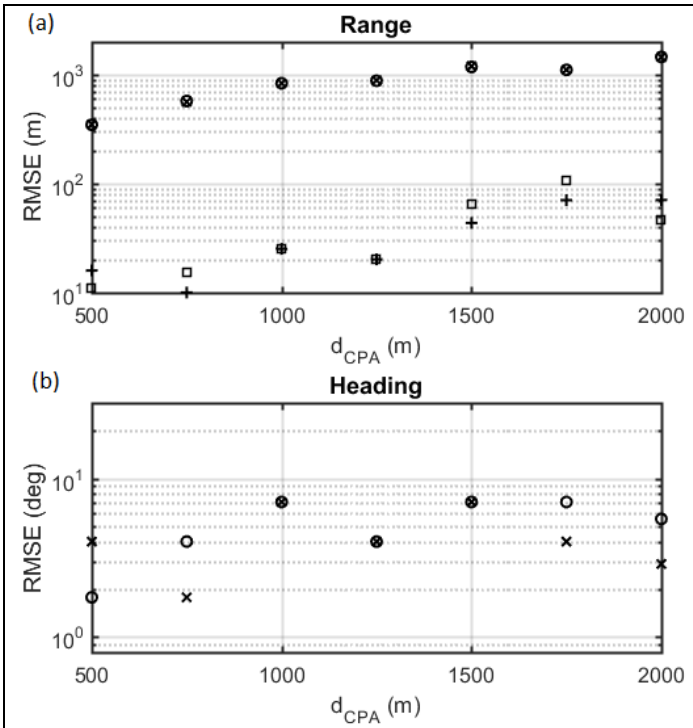

Fig. 1. RMSE of (a) range estimates and (b) heading estimates as functions of CPA distance obtained from *in situ* tests. Parameter estimates were obtained using the mean vessel speed of 7.3 m/s (Scenario 1) using a diagonal covariance matrix (symbol "×") and a non-diagonal covariance matrix (symbol "○"). Parameter estimates obtained with the actual speed of vessels (Scenario 2) are shown by the symbols "+" (diagonal covariance matrix) and "□" (non-diagonal covariance matrix).

References

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