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## INFORMATION CRITERIA FOR A SOUND SOURCE LOCALIZATION BY HUMAN

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**RÉSUMÉ** - Une mesure informatique est proposée pour l'analyse de l'efficacité de localisation de la source sonore par l'homme. En partant de cette mesure on examine l'influence sur l'efficacité du rapport signal/bruit, de la durée de l'observation et de la largeur de la bande de l'analyse fréquentielle, ainsi que l'influence d'une source locale de perturbations.

**ABSTRACT** - Some information measure is suggested for analysis of sound source localization efficiency by human. Using this measure the influence of signal-noise ratio, observation time and frequency analysis bandwidth was studied, as well as presence of local source of interference.

## 1. INTRODUCTION

The human auditory system (HAS) allows to analyze acoustic medium, to localize and to identify sound source. Due to the presence of ambient acoustic noise and of nervous spontaneous activity (internal noise) the problems to be solved by the HAS are statistical in nature and its analysis should be fulfilled using signal processing theory approach. As a rule, an accurate calculation of the efficiency of estimation algorithms simulating the work of the HAS is impossible. In order to approximate its calculation the authors have used recently [1] some modification of the generalized ambiguity function. One of the basic drawbacks of this estimation characteristic statistic lies in the fact that it does not allow to analyze simultaneously the influence on the efficiency of such important factors as the signal processing time  $T$ , the frequency analysis band  $\Delta f$  and the signal/noise ratio (SNR). In this paper we suggest some information measure (IM) which does not possess the above mentioned drawbacks and, moreover, characterize both local and global features of the estimation statistic. The last property determines its resolution capacity in the space of the parameters to be estimated.

This IM is used for the analysis of localization problem by HAS.

## 2. INFORMATION MEASURE

The well known information measures like Chernoff's, Bhattacharyya's and Kullback's measures are widely used in the signal process-

ing theory for analysis of the estimation efficiency (see, for example [2]). However their application to the analysis of signal processing by HAS requires its generalization. We suggest a new information measure (IM), which had already been applied in [3].

Let the sound pressure field  $p_n$  ( usually  $n=T\Delta f$  ) have the probability density  $f(p_n/\theta)$ , where  $\theta \in \Theta$  is an unknown parameter to be estimated by means of  $p_n$ . Let us construct the estimate  $\hat{\theta}_v$  of  $\theta$  by an estimation statistic  $V(p_n; \theta)$  as follows:  $\hat{\theta}_v = \operatorname{argmax}_{\theta \in \Theta} V(p_n; \theta)$ . We imply that estimation methods used by human are similar to this. Exhaustive characteristic of  $\hat{\theta}_v$  is the probability distribution density  $f(\hat{\theta}/\theta)$ . However the calculation of  $f(\hat{\theta}/\theta)$  is hardly possible. Therefore different approximation and appropriate bounds of corresponding errors are commonly used.

The probability of estimate  $\hat{\theta}_v$  being beyond some domain around  $\tau_\theta$  (here  $\tau_\theta = \operatorname{argmax}_{\tau \in \Theta} M_\theta V(p_n; \tau)$  and at  $n \gg 1$   $M_\theta \hat{\theta}_v \cong \tau_\theta$ ), including the true value of unknown parameter  $\theta$  as well, determines the resolution power of statistic  $V(p_n; \theta)$ . It can be shown that the upper bound is determined for discrete parametric space  $\Theta$  by the information measure

$$\rho_v(\tau, \theta) = \inf_{\alpha > 0} \rho_v(\tau, \theta; \alpha)$$

$$\rho_v(\tau, \theta; \alpha) = M_\theta \exp\{\alpha [V(p_n; \tau) - V(p_n; \theta)]\} \quad (1)$$

This bound can be made more tight but it requires more complicated calculation. Note that if  $V(p_n; \theta) = \ln f(p_n/\theta)$ , i.e.  $\hat{\theta}$  is a maximum likelihood estimate, then  $\rho_v(\tau, \theta; \alpha)$  is Chernoff's measure and if moreover  $\alpha = 1/2$  then it becomes Bhattacharyya's measure  $\rho_B(\tau, \theta) = \int (f(p_n/\theta) f(p_n/\tau))^{1/2} d\mu$ , which is widely used in the estimation theory.

The typical curve of  $\rho_v(\tau; \theta)$  for scalar parameter  $\theta$  is presented in Fig. 1. The width of the curve in vicinity of the point  $\tau_\theta$  is attributed to the local feature of  $\hat{\theta}_v$ , the difference  $\tau_\theta - \theta$  approximately determines the bias of  $\hat{\theta}_v$  and the level of  $\rho_v(\tau; \theta)$  beyond some domain, say  $(a, b)$ , determines the  $V(p_n; \theta)$  resolving power. When this level is large the resolution power is low.

The expression for the IM was obtained in 3D case for different models of source signal and environment noise, including anisotropic noise, and for the model HAS, which takes into account the directivity pattern of each ear and the interior noise. The estimation statistic is based on the calculation of some quadratic form for each frequency filter and subsequent summation of its outputs over frequency analysis band.

In the following two examples illustrating our approach, we investigated for simplicity the case when internal noise is zero-mean gaussian noise with spectral density  $g(f)$  and omnidirectional directivity pattern of each ear. The source signal is also zero-mean gaussian noise with spectral density  $g_s(f)$ ,  $f \in (f_1, f_2)$ . The localizati-

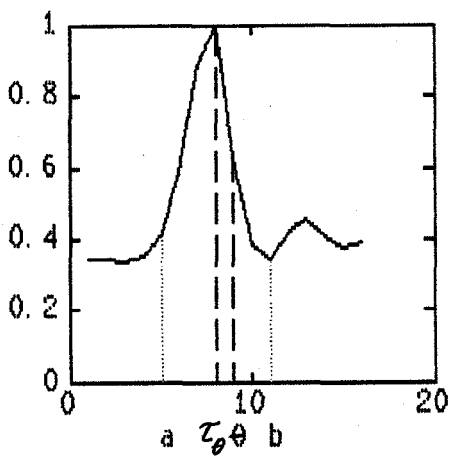


Fig. 1

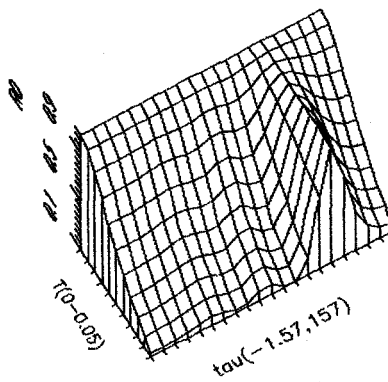


Fig.2

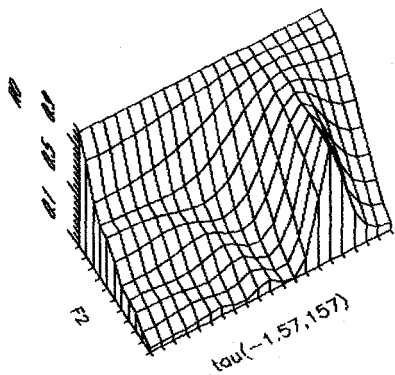


Fig.3

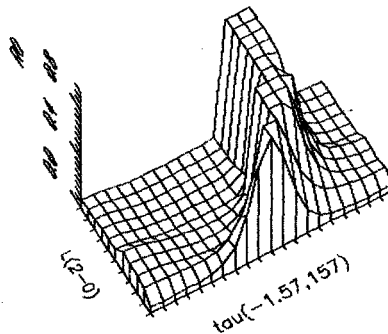


Fig.4

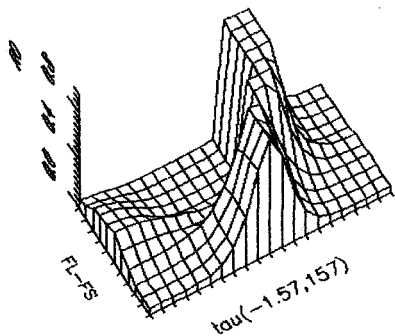


Fig.5

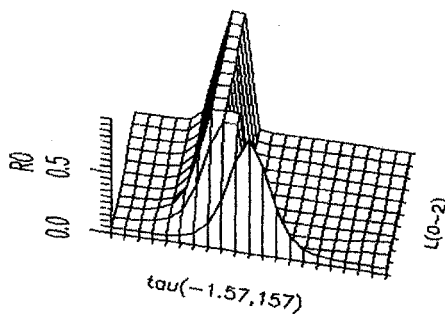


Fig.6

on problem is considered for horizontal plane only.

### 3. SNR, T and $\Delta f$ influence on the efficiency.

For the simplest model of HAS the IM(1) is defined as

$$\rho(\tau, \theta) = \exp\left\{-T \int_{f_1}^{f_2} \ln\left[1 + \frac{\rho_s^2(f)}{1 + 2\rho_s(f)} \sin^2 \pi f \frac{d}{c} (\sin \tau - \sin \theta)\right] df\right\} \quad (2)$$

where  $\rho_s(f) = g_s(f)/g(f)$  is the out put SNR,  $d$  is the interaural base and  $c$  is the sound speed. The graphs in Fig.2 and Fig.3 indicate the evolution of  $\rho(\tau, \theta)$ ,  $\tau \in [-\pi/2; \pi/2]$  due to the change of  $T$  and  $f_2$  in (2) respectively when correct value of azimuth  $\theta = \pi/4$ ,  $\rho_s(f) = 0.5$  and  $f_1 = 100\text{Hz}$ . In the first case  $T$  is changed from 0 to 50 ms at  $f_2 = 3000\text{ Hz}$  but in the second case  $f_2$  is changed from 100Hz till 3000Hz at  $T = 10\text{ ms}$ .

### 4. Localization efficiency in presence of interfering local source of noise.

The two problems are investigated here: influence of distinction between signal and noise spectrum densities; analysis of possible rejection of local noise source by spatial processing in the HAS when these densities coincide.

For convenience of numerical calculation we suggested that  $g_s(f) = S \exp\{-O_s^2(f - f_s)^2\}$  and  $g_1(f) = L \exp\{-O_1^2(f - f_1)^2\}$ , where  $S$  and  $L$  are intensities of the signal and noise sources. The calculation is fulfilled at  $f_1 = 100\text{Hz}$ ,  $f_2 = 3000\text{Hz}$ ,  $T = 25\text{ms}$ ,  $S = 1.0$ ,  $f_s = 1000\text{Hz}$ ,  $O_s = O_1 = 300\text{Hz}$ ,  $\theta = 0$  and  $\theta_1 = \pi/6$ , where  $\theta_1$  is the azimuthal angle corresponding to the local noise source.

In Fig.4 the dependence of  $\rho(\tau, \theta)$  upon  $L$  is presented when  $g_s(f) = g_1(f)$  and  $L$  is changed from 2 to 0. Fig.5 illustrates the evolution of  $\rho(\tau, \theta)$  when difference of  $g_s(f)$  and  $g_1(f)$  is increased by change of  $f_1$  from 100Hz to 2000Hz. It is seen for  $f_1 = 2000\text{Hz}$  that the interfering source ( $L = 2$ ) has no influence on the localization efficiency for the given condition. The dependence of  $\rho(\tau, \theta)$  upon  $L$  when rejection of noise source is used and  $g_s(f) = g_1(f)$  is illustrated in Fig.6. The value  $L$  is changed from 2 to 0.

### 5. Conclusion

The suggested information measure can be used for working out the models of human auditory system especially in solving the problem of sound source detection and localization at different acoustic conditions. We should note also that considered examples were concerned with the investigation of stationary cases by using Fourier transformation. However, our approach allows to study also nonstationary case using for example Wigner's or Gabor's transformation.

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