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SOME CONSIDERATIONS ABOUT UNDERWATER ACOUSTIC NOISES

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Résumé - On présente brièvement un survol de caractéristiques et de problèmes rencontrés en modélisation des bruits d'acoustique sous-marine, dans le contexte du sonar passif.

Abstract - We present briefly a survey of characteristics and problems met in the modelling of underwater acoustic noises, in the frame of passive sonar.

1- INTRODUCTION

This survey paper briefly presents an outline about underwater noise modelling. Several questions arise about this subject: why to do it? What is generally done? How to improve it? Complexity and diversity of the approaches imply that this overview can only be incomplete and covers only some aspects; it sums up materials developed in [1,2,3].

In fact, the knowledge of underwater noise is searched for different purposes. We can distinguish three relevant sectors, each with a privileged attitude: OCEANOGRAPHY interested in the description of the noises generated by the medium, SHIP SILENCING dealing with the modelling of the generation of noises generated by a ship (knowledge modelling), DESIGN OF UNDERWATER COMMUNICATION SYSTEMS concerned with the modelling of the noises received by the systems (representation modelling). And we can distinguish four steps of noises study: measure of quantities bound to the noises, understanding of the physical generation phenomena, modelling, palliative processing. Elsewhere, underwater sounds are usually studied in frequency ranges considered as useful processing ranges for systems to be designed or used; there is a large diversity of working frequencies of underwater acoustics systems.

Restricting to the step of modelling for processing purposes in the frame of passive sonar, we present description and modelling characteristics of the underwater noises and some consequences for signal processing.

An analysis in terms of "communication systems" shows some general characteristics of the underwater noise: it is a superposition of noises with various origins, properties and consequences; the noises are generated by the transmitter, the channel or the receiver; the noises are depending on the reception system type (active - passive, hull - towed - buoys); it is difficult to have access to each elementary noise and to part the set sounds - propagation - receiver.

For example, the passive sonar is submitted to a noise disturbing the reception of the desired signal. This signal is a sound (a noise) radiated by a target. The disturbing noise is obtained by superposition of different components which can be ambient noise, platform self noise, jamming-luring-masking noises, and, for a towed array, platform radiated noise.

2- TYPES OF MODELS

Those caracteristics, with the space-time aspect of the phenomena, explain that we can found a large variety of models. The required quality and therefore the used type of modelling are, in practice, depending on the need of the user. In this way, the models can be divided in two types, each schematically attached to a special need:

- A first need corresponds to the level "using of the system" (external design and adjusting of external parameters of the system). There, schematically, we search for the knowing of the mean power of the noise, we use a rough parametrization to fit the model to the reality, we work in the frame of the sonar equation concept. We use a descriptive type of modelling: the noise is a sum of sounds and each compounding noise is modelled with measured physical parametrization.
a second need corresponds to the level "system design" (internal design and accurate evaluation of the system). There, schematically, we search for the knowing of the space-time second order of the noise, we use a fine parametrization to fit the model to the reality, we work in the frame of the decision theory concept. We use a global type of modelling: the noise is modelled as a whole with identified out of sense parametrization.

The two aspects of parametrization associated with the two types of models are obtained:
- the first with measurable physical parameters: their value is inferred from conditions of the moment (state of the sea, season, geographical zone, speed, ...);
- the second with non physical meaning parameters: their value is estimated from a realization at the using moment.

A third type of modelling can be thought of, the descriptive-global type, which corresponds to the global identification of a linear combination of descriptive models.

The models provide different quantities according to the case, the needs, the possibilities of the model, the used simplifying hypotheses. We can see that they are generally limited to a second order description, with some simplifying hypothesis.

An ideal general model is a random function

\[ \mathbf{X}(t, \mathbf{M}; \mathbf{\Theta}) = \mathbf{X}(t, \mathbf{M}; \mathbf{\Theta}) \]

(t : time; \( \mathbf{M} \) : space point \( \mathbf{M}(x,y,z) \) or vector \( \mathbf{OM} \); \( \mathbf{\Theta} \) : parameters). A gaussian statistical law (asking knowledge of the second order) can only be supposed if it is not contradictory with experience or with generating mechanism, or if the corresponding error can be tolerated by the need. So, in practice, we confront three problems:
- obtaining a second order without too much simplifying hypothesis;
- taking into account of the non-stationnarity;
- not using a Gaussian hypothesis.

Consequently, usually, the modelling restricts to incomplete stationary models of the second order, fitted to reality by parametrization and using some simplifying hypotheses among the following ones (they are scarcely true in real noises):

- STRICT OR SECOND ORDER STATIONARITY (invariance by translation; depending on time, on space or on both (global)).
- (SPATIAL) ISOTROPY (invariance of the properties by rotation; spherical or cylindrical).
- ERGODISM (bound to the corresponding stationnarity; equality of statistical and time means; depending on time, on space or on both).
- WHITENESS (in discrete case, the stochastic process is constituted with uncorrelated random variables; depending on time, on space or on both (global)).
- STRICT OR SECOND ORDER SPACE-TIME SEPARABILITY (factoring of the covariance (or correlation) in space and time; property transmitted to the spectral density).

A complete second order representation with space-time stationarity is the knowing of one of the six quantities:

- SPACE-TIME CORRELATION FUNCTION: \( \Gamma(t, \mathbf{M}; \mathbf{\Theta}) = \mathbf{E}[ \mathbf{X}(t, \mathbf{M}; \mathbf{\Theta}) \mathbf{X}(t-\mathbf{M}; \mathbf{\Theta}) ] \);
- TEMPORAL SPECTRAL DENSITY (or spatial correlation function at frequency \( f \)): \( \gamma'(f, \mathbf{z}; \mathbf{\Theta}) \);
- SPATIAL SPECTRAL DENSITY (or temporal correlation function at spatial frequencies \( k \)): \( \gamma''(t, k; \mathbf{\Theta}) \);
- SPACE-TIME SPECTRAL DENSITY: \( P(f, k; \mathbf{\Theta}) \) or \( \gamma(f, k; \mathbf{\Theta}) \);
- DIRECTIVITY: in the spatial case:

\[ Q(f, \theta, s; \mathbf{\Theta}) = \frac{1}{\lambda^2} \cos s P(f, \frac{1}{\lambda} \cos \theta \cos s, \frac{1}{\lambda} \sin \theta \sin s, \frac{1}{\lambda} \sin s; \mathbf{\Theta}). \]

in the plane case:

\[ Q(f, \theta; \mathbf{\Theta}) = \frac{1}{\lambda^2} P(f, \frac{1}{\lambda} \cos \theta, \frac{1}{\lambda} \sin \theta; \mathbf{\Theta}). \]
Those considerations are illustrated by some selected underwater noise models.

The ambient noise is induced by the medium, still existing in absence of the system and its platform. It has numerous origins: traffic (preponderant from about ten Hertz to a few hundred Hertz), surface agitation (preponderant above one thousand Hertz), rain (from a few hundred Hertz to a few thousand Hertz), biological activity (from one Hertz to one hundred thousand Hertz), ocean turbulence (from one Hertz to ten Hertz), seismic phenomena (from one Hertz to ten Hertz), industrial activities. It depends on several factors: water height, receiver immersion, listening direction, geographical area, weather conditions and state, season (sound velocity profile), presence of an ice layer... It is not an isotropic noise: in horizontal directions there is no general rule; in vertical directions there is a maximum about the horizontal in low frequencies, and the vertical in high frequencies.

For ambient noise we have different experimental models, such as, for example, with local parametrization:

- (isotropic) punctual temporal spectral density $\gamma'(f,0;\theta)$ with the part of traffic and sea state;
- vertical or horizontal directivity $Q(f,0,s;\theta)$ and $Q(f,0,0;\theta)$, at a given frequency $f$;
- wind effect on noise level (punctual temporal spectral density $\gamma'(f,0;\theta)$).

Always for ambient noise we have theoretic models:

- elementary isotropic models and special isotropic models, giving a temporal spectral density (or spatial correlation function at given frequency) $\gamma'(f,0;\theta)$;
- traffic noise models, giving the mean power $\Gamma(0,0;\theta)$ from traffic data and propagation models (we must remember that, for example, in a rail, there are a lot of different transmitters, giving, with propagation, various contributions).

The self and radiated noises are generated, the first, by the communication system carrier (it is the near-field aspect of the noise generated by a platform), the second, by a ship interesting the communication system (it is the far-field aspect of the noise generated by a platform). They are noises with the same general origins but with different characteristics; they can be submitted to a physical analysis by identification of sources, resonators, and paths. Their principal sources are of hydrodynamic, propellers, and mechanical origins, with preponderance depending on speed, immersion, working state, and frequency; in fact, are rather preponderant the hydrodynamic part at high speed, and the mechanical part at low speed. Those two noises are not isotropic and their punctual temporal spectral densities $\gamma'(f,0;\theta)$ contain:

- a continuous part in $o(1/f )$, of power increasing with speed (hydrodynamic),
- a set of spectral lines in low frequency (mechanical, propellers),
- especially in self noise, a non stationary "impulsive" part (multi-origin).

For self and radiated noises, even if theoretic models may be considered (about propeller cavitation, hydrodynamic or mechanical noises), we have essentially different experimental models, such as, for example, with special parametrization:

- punctual temporal spectral density with speed parametrization;
- low frequency punctual temporal spectral density and lofargram.

4. CONSEQUENCES IN SIGNAL PROCESSING

Those models show the existence of temporal and spatial correlations in the noise field and the array processing must take into account the (global) space-time correlation even if a separability hypothesis must be used.

The array processing is the input step of a "communication system" as a passive sonar. Its aim is the separation of the two input contributions: signal (point sources, spatially coherent) and noise (spatially incoherent). For this purpose the array perform the estimation of the space-time spectral density $P(f,k)$ (or of the directivity $Q(f,\theta,s)$), generally via the space-time correlation function $F(t,r)$ or the temporal spectral density (that is the spatial correlation function at given frequency) $\gamma'(f,\theta)$. 

$t =$ duration, $r =$ distances vector, $k =$ wave number (or spatial frequencies) vector, $\theta =$ bearing angle, $s =$ site angle, $\Theta =$ parameters).
We can distinguish the three following types of array processing: classical beamforming, Capon optimum array, high resolution array (let's say MUSIC or goniometer). As for the noise spatial correlation, the first type assumes no hypothesis, the second one is adaptive, and the third one uses classically an hypothesis of spatial white noise.

A method to modify this fact for the first and third systems consists to take into account the noise spatial correlation by introducing a global model of the noise. Then, having an observation, created by unknown noise and sources, the method introduce three points and three questions, which are approached in /1/ to /5/:
- the choice of a noise model: what is the effect of the array and of the array processing on the properties of the model?
- the identification of the noise model parameters (from the observation at the using instant): what identification method is to use, knowing that sources may be present?
- the introduction of the estimated parameter values in the array processing: what is the performance increase? In high resolution methods, what is the effect on spurious peaks, on bias in bearing estimation, and on detection of weak sources?

One important fact is that a useful model is, very classically, a spatial AR(MA) model; a special isotropic model, linear combination of elementary isotropic models does not seem a very relevant one.

5- CONCLUSION

As a brief conclusion, we can give an answer to the questions of the introduction in connection with underwater noise modelling.
- Why to do it? Because the modelling of the underwater acoustic noises appears as an essential component of the design of sonar and related systems.
- What is generally done? Two types of models, descriptive with inferred value of parameters and global with identified value of parameters.
- How to improve it? In matching the noise models to the processing of the received signals.

REFERENCES