Using multivariate methods (PCA) for the online prediction of underwater radiated sound

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Introduction

The acoustical signature is one of the crucial criteria for the detection and classification of vessels. For the estimation of the underwater radiated sound of marine vessels based on actual measurements of structure-borne sound, a procedure was developed and implemented into an operational monitoring system. It is used to calculate a realtime prediction of the radiated underwater sound in the far field. A combination with propagation models is possible.

The prediction method is based on a signal analytic approach, which makes use of the Principal Component Analysis (PCA) based on cross spectra. From the derived components transfer functions to the water borne sound can be calculated. This approach has similarities to the (operational) transfer path analysis (TPA) and the cross talk cancellation (CTC).

Also the necessary parallel measurements of structure and waterborne sound to derive and calibrate the model are described here. The possibilities of the integration into an acoustical monitoring system and into a general signature management are illustrated.

Concept

The determination of the acoustical signature is in general time-consuming and only possible at special acoustic test ranges with hydrophone installation, tracking system etc. Acoustical monitoring has the aim to inform the crew about the acoustic signature of the vessel and the radiated underwater sound continuously. One is interested to describe the acoustic condition by quantities, which can be obtained easily by onboard measurements. Such quantities are e.g. vibration levels of relevant machinery and the vibration measured at the hull, from which the sound is radiated into the water. The goal of the monitoring system is to estimate the radiated underwater sound into the water and, subsequently, the detection range based on structure-borne sound measurements.

To realize such a predicition method, a signal analytic approach was chosen. The model parameters are determined from simultanous measurements of structure-borne and waterborne sound ("calibration"). In operation the waterborne sound is predicted by actual strucure borne sound measurements and the calibrated model.

The approach used here consists of a description of the measurements as a stochastic process. It is based on an orthogonalization of the spectral cross power matrix $\mathbf{R_{xx}}$ of the structure-borne measurement channels. The measurement signals are the elements of the vector $\mathbf{x}$.

$$\mathbf{R_{xx}} = E\left\{\mathbf{x(k)} \cdot \mathbf{x^T(k)}\right\} = \mathbf{V \Lambda V^T} \qquad (1)$$

Where $\mathbf{V}$ is the eigenvector matrix and Λ is the diagonal matrix of the eigenvalues of $\mathbf{R_{xx}}$. The matrix is decomposed into components, for which transfer functions from the structure-borne sound to the waterborne sound are derived, using the cross correlation to the waterborne sound from the calibation measurement. The components then are calculated using the eigenvectors and eigenvalues from above (Karhunen-Loève transformation, e. g. [1, 2]).

$$\mathbf{y} = \mathbf{V^T} \cdot \mathbf{x} \qquad (2)$$

All calculations are based on operational data. With the cross correlation from the calibration the waterborne noise can be calculated in operation by using only the structure-borne sound measurements. The procedure has similarities to the operational transfer path analysis (TPA, see e. g. [3]) and it is also possible to make the predicted farfield noise hearable.

The result of the calculations can be subsumed into a model network. All input channels (acceleration signals) are processed by filters. Different channels can be grouped (e.g. machines, platforms and hull). Noise contributions can be identified according to their origin and transfer path. The sum of all channels is the prediction of the underwater radiated sound (Figure 1).

Application

Measurements

The quality of the prediction depends on the position of the sensors on board. The positions of sensors have to be selected carefully in order to consider relevant noise sources and radiating structural dynamic modes of the ship structure.

During the calibration measurement, structure-borne and waterborne noise is measured simultaneously with two different measurement systems aboard and on the test range. These calibration measurements can be conducted stationary while the vessel is fixed at a buoy

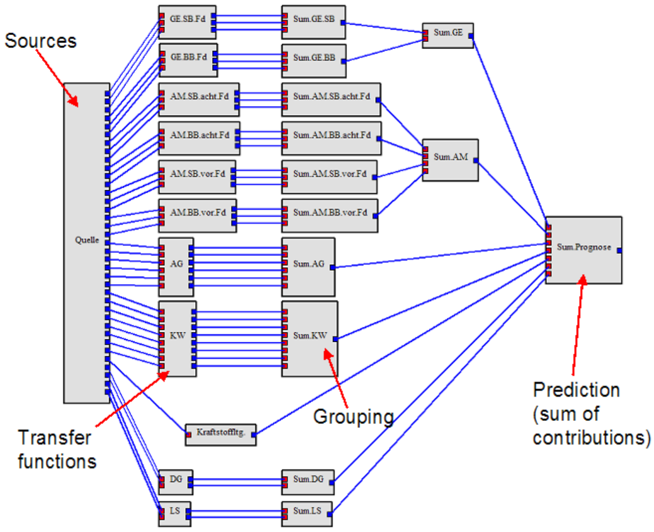

Figure 1: TPA Network

and dynamically while the vessel passes the test range. The situation at the test range is illustrated in Figure 2.

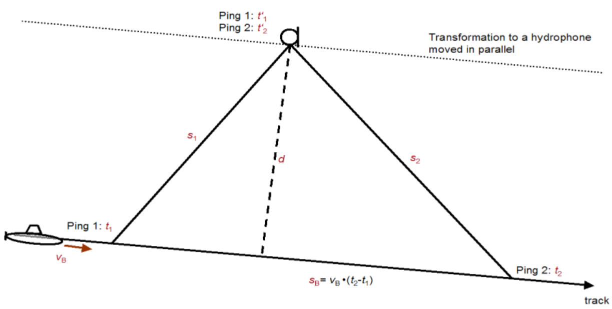

Figure 2: Dynamic calibration of the model

To build an appropriate model for the prediction of underwater sound, a synchronisation of the two data sets is required. Synchronisation is possible via two highly accurate clocks for both measurement systems or via synchronisation signals. A transformation of the waterborne sound signal of the dynamic measurements is performed to a virtual hydrophone, moving parallel to the track of the vessel. This transformation is necessary to provide stationary transfer conditions between the vessel and the hydrophone. Also a Doppler correction is necessary as otherwise the Doppler effect has a negative effect on the frequency and on the phase relation.

Results

The predicted waterborne sound shows good correlation to the measured waterborne sound. Signature lines from on board machinery (e.g. rotating machinery) can be predicted very well. In between the lines the predicted noise is below the measured as the environmetal noise is not correlated with the vessel.

Monitoring System

An application is the implementation of an Operational Monitoring System for the use onboard of submarines (Figure 3). Besides classical monitoring, a similar algorithm as described above was implemented for the real-time estimation of the acoustic signature. The monitoring functions include, among others, visualization of spectral information, detections of transient signals, recording time or spectral data, logging operational data and a headset connection. Further integration into the ship automation and ship signature management is intended.

Figure 3: Operational Monitoring System

Conclusion

In this paper we introduced a concept to determine the waterborne noise from vessels in operation using only structure-borne sound measurements onboard. With the principal components calculated from the cross correlation function and the component transfer function to the waterborne sound from the calibration measurement it is possible to calculate the waterborne noise in operation. The algorithm is implemented in monitoring systems operating on several vessels and shows good results.

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