MECHANICS
Vol. 28 No. 3 2009

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A NEW APPROACH TO ACOUSTIC DISTRIBUTED FIELD SHAPING

SUMMARY

In the paper a new approach to acoustic distributed field shaping is proposed. In the proposed approach the problem of acoustic distributed field shaping is decomposed into a set of the corresponding autonomous acoustic local field adaptive synthesis and generation problems that are coordinated. These acoustic local fields are synthesized and generated using a recursive synthesis and simulation of power spectral density defined multisine random time-series with the multisine transformation that is additionally aided by an active noise control system.

***Keywords**: active noise control systems, adaptive signal processing, field control, field synthesis, multisine random processes, system identification*

NOWE PODEJŚCIE DO KSZTAŁTOWANIA ROZPROSZONEGO POLA AKUSTYCZNEGO

W pracy przedstawiono nowe podejście do problemu kształtowania rozproszonego pola akustycznego. Polega ono na zastąpieniu problemu kształtowania rozproszonego pola akustycznego pewnym zbiorem autonomicznych problemów adaptacyjnej syntezy i generacji lokalnych pól akustycznych, które są koordynowane przez nadrzędną strategię. Do syntezy i generacji lokalnych pól akustycznych używana jest bazująca na transformacji wielosinusoidalnej rekurencyjna synteza i symulacja wielosinuoidalnych procesów losowych o własnościach widmowych zadanych poprzez funkcję gęstości widmowej mocy, wspomagana dodatkowo układem aktywnej redukcji hałasu.

***Słowa kluczowe**: aktywne systemy sterowania dźwiękiem, sterowanie polem, synteza pola, wielosinuoidalne procesy losowe, identyfikacja systemów*

1. INTRODUCTION

Acoustic, distributed in a space fields with specified time- or frequency-domain properties are important in many areas of acoustic techniques applications, including for example medicine, telecommunication, and sonar technologies. In this paper, a new approach to acoustic, distributed in 3-dimensional space field shaping understood as an adaptive synthesis and generation of piece-wise wide-sense stationary random acoustic distributed field (Figwer 2008a) with properties similar to given ones is presented. Properties of the piece-wise wide-sense stationary random acoustic distributed field to be synthesized and generated are given by a time- or frequency-domain pattern being a piece-wise deterministic function of time.

In the proposed approach the problem of adaptive synthesis and generation of piece-wise wide sense stationary random acoustic distributed field is decomposed into a set of the corresponding autonomous acoustic local field adaptive synthesis and generation problems (Figwer 2008a, 2008b, 2009) that are coordinated. These acoustic local fields are synthesized and generated on the bases of a recursive synthesis and simulation of power spectral density defined multisine random time-series (Figwer 1999) with the multisine transformation (Figwer 2004, 2007) aided by a control system. This control system is a classical single-channel active noise control system with an additional piece of software for piece-wise wide-sense stationary random acoustic local field synthesis and generation. In the presented discussion an influence of environment is also taken into account. It should be emphasized that in the proposed approach there is no necessity of solving partial differential equations describing the acoustic distributed field and environment.

2. PROBLEM STATEMENT

Acoustic, distributed in 3-dimensional space field is in general a multidimensional random process that properties may be defined by its multidimensional autocorrelation or power spectral density function (Figwer 2000). Such description is difficult to interpret and from real world application point of view it is easier to describe such field by the corresponding, equivalent by means of the multidimensional Fourier transform, a 3-dimensional space distribution of power spectral density function (Fig. 1). In this case acoustic distributed field shaping is understood as an adaptive synthesis and generation of the piece-wise wide-sense stationary random acoustic distributed field (Figwer 2008a) with properties similar to the given pattern being space distribution of power spectral density function – the resulting 3-dimensional space distribution of power spectral density function should be similar (e.g. proportional) to the given one with a scale of similarity.

Let S be a subspace of the space R^3 with a closed boundary defined by the function $g(x, y, z)$ ($(x, y, z) \in R^3$ is a 3-tuple describing space coordinates). Consider that a piece-wise wide-sense stationary random acoustic distributed field to be synthesised and generated inside the subspace S is a band-limited continuous-time random process $s_{xyz}(x, y, z, t)$ (t denotes time) that is defined by the

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corresponding power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ (ω denotes frequency) being a piece-wise deterministic function of the time t. It is assumed that the power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ is changing only at the given time instants t_r ($r = 1, 2, ...$) and

$$\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t) < \infty \tag{1}$$

for $0 \le \omega < \infty$, all $(x, y, z) \in S$ and $t \ge 0$. The corresponding autocorrelation function $R_{s_{xyz}s_{xyz}}(x, y, z, \iota, t)$ satisfies for $(x, y, z) \in S$ the following condition:

$$\lim_{\iota \to \infty} R_{s_{xyz}s_{xyz}}(x, y, z, \iota, t) = 0 \tag{2}$$

Sampling of the power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ in 3-dimensional space implies that the adaptive synthesis and generation of the piece-wise wide-sense stationary random acoustic distributed field may be decomposed into a set of the corresponding adaptive synthesis and generation of piece-wise wide-sense stationary random acoustic local fields (Figwer 2008a, 2008b, 2009) that are defined by local patterns – the power spectral densities $\Phi_{s_{n_xn_yn_z}s_{n_xn_yn_z}}(\omega, t)$. It means that the power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ is approximated by the following set of power spectral densities

$$\{\Phi_{s_{n_xn_yn_z}s_{n_xn_yn_z}}(\omega, t) : n_x = 0,1,\ldots N_x - 1; n_y = 0,1,\ldots N_y - 1; n_z = 0,1,\ldots N_z - 1\} \tag{3}$$

being a piece-wise deterministic functions of the time t. It is assumed that the numbers n_x, n_y, n_z are indexes of the 3-dimensional space coordinates $(x_{n_x}, y_{n_y}, z_{n_z})$ belonging to the subspace S.

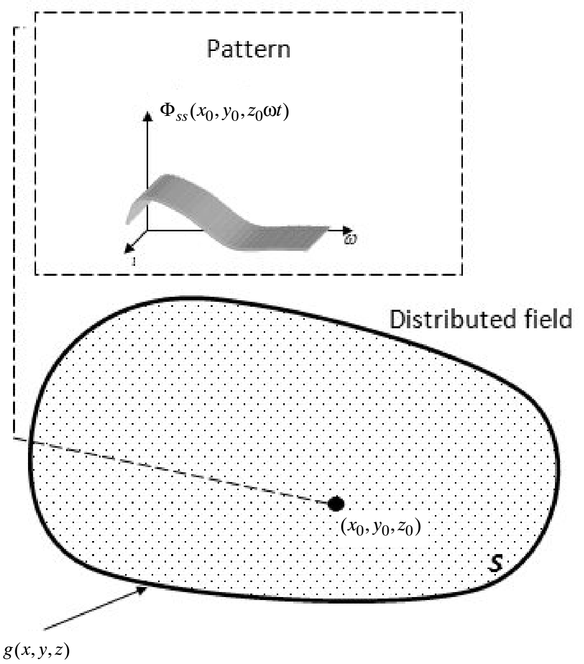

Fig. 1. Acoustic distributed field pattern definition

Choice of all 3-dimensional space coordinates so that the sampling theorem is satisfied allows to reconstruct the power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ based on elements of the set (3). Having this set the problem of piece-wise wide-sense stationary random acoustic distributed field synthesis and generation may be decomposed into a distributed in subspace S the corresponding $N_xN_yN_z$ autonomous adaptive piece-wise wide-sense stationary random acoustic local field synthesis and generation problems. It means from the technical point of view that at each 3-dimensional space coordinates $(x_{n_x}, y_{n_y}, z_{n_z})$ ($n_x = 0, 1, ... N_x - 1$, $n_y = 0, 1, ... N_y - 1$, $n_z = 0, 1, ... N_z - 1$,) an error sensor (e.g. microphone) is placed and around this error sensor the corresponding piece-wise wide-sense stationary random acoustic local field with properties defined by the power spectral density $\Phi_{s_{n_xn_yn_z}s_{n_xn_yn_z}}(\omega, t)$ is synthesised and generated using for example a loudspeaker. It should also be taken into account that that these synthesised and generated acoustic local fields may mutually affect each other. Additionally, these acoustic local fields are affected by properties of the environment. It implies that the corresponding autonomous adaptive synthesis and generation of piece-wise wide-sense stationary random acoustic local fields should be coordinated by higher level strategy. In Figure 2 idea of an acoustic distributed field shaping system is presented.

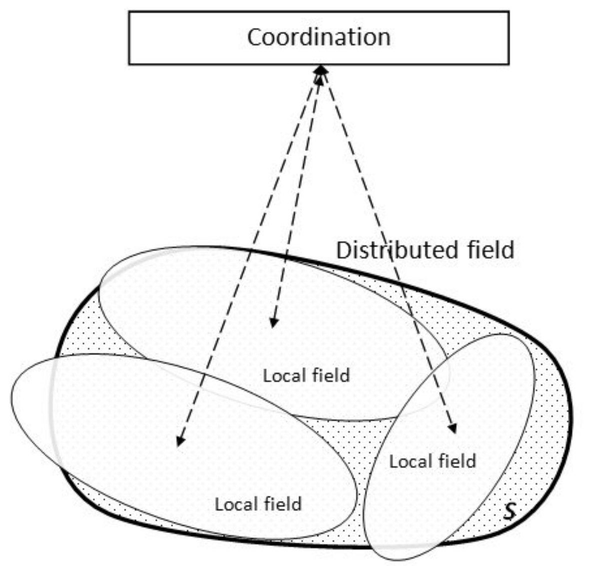

Fig. 2. Idea of acoustic distributed field shaping system

3. ADAPTIVE SYNTHESIS AND GENERATION OF ACOUSTIC LOCAL FIELD

It follows from the above decomposition of the acoustic distributed field shaping problem that each acoustic local field is a one dimensional piece-wise wide-sense stationary continuous-time random process $s_{n_xn_yn_z}(t)$. Its adaptive synthesis and generation is based on a synthesis and simulation of power spectral density defined multisine random time-series with the multisine transformation (Figwer 2008a, 2008b, 2009). For the each time interval $[t_{r-1}, t_r]$ ($r = 1, 2, ...$) the power spectral density $\Phi_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega, t)$ of acoustic local field to be synthesised and generated is used to synthesise and simulate the corresponding N-sample power spectral density defined multisine random time-series realisation $u^r(iT)$ (T is a chosen sampling interval for the time-domain). It is based on an approximation of $\Phi_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega, t)$ by the power spectral density $\Phi_{uu}(\omega T)$ of a discrete-time random process $u(iT)$. The corresponding continuous-time band-limited random process realisation $u^r(t)$ may be obtained from $u^r(iT)$ in different ways, e.g. using analogue filtration (Figwer 1999, 2008a). To generate the synthesised piece-wise wide sense stationary random acoustic local field the obtained realisation $u^r(t)$ of the band-limited continuous-time random process $s_{n_x n_y n_z}(t)$ excites the loudspeaker. The generated acoustic wave propagates in the 3-dimensional space reaching the given point with coordinates $(x_{n_x}, y_{n_y}, z_{n_z})$ around which the piece-wise wide-sense stationary random acoustic local field is generated. It implies that the acoustic wave propagation path and dynamics of the loud-speaker channel should also be taken into account – the power spectral density $\Phi_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega, t)$ used to synthesise and simulate power spectral density defined multisine random time-series realisation $u^r(iT)$ should be corrected to compensate the influence of the mentioned dynamics (Figwer 2008b). This correction is based on *off*- and *on-line* acoustic wave propagation path model identification. Signal from the microphone placed at the point with coordinates $(x_{n_x}, y_{n_y}, z_{n_z})$ may be applied:

- to reduce a noise coming from the environment using ideas of active noise control system (Hansen and Snyder 1997; Kuo and Morgan 1996; Nelson and Eliot 1992), and
- to compensate an influence of the residual noise on properties of the obtained acoustic local field.

This compensation is simply a change of the power spectral density $\Phi_{uu}(\omega T)$ during synthesis and simulation of the realisation $u^r(iT)$. It is based on a comparison of the assumed power spectral density $\Phi_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega, t)$ at the microphone and identified *on*-line power spectral density $\hat{\Phi}_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega T, iT)$ using signal from the microphone. If for all frequencies $\omega T \in [0, \pi)$ and $iT \cong t_r$ the following condition:

$$\Phi_{uu}(\omega T) \geq \hat{\Phi}_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega T, iT) \tag{4}$$

is not satisfied then there is no possibility to synthesise and generate acoustic local field with the required power spectral density $\Phi_{s_{n_x n_y n_z} s_{n_x n_y n_z}}(\omega, t)$. In this case coordination strategy receives the corresponding information. In Figure 3 the block diagram of an exemplary acoustic local field adaptive synthesis and generation system is presented.

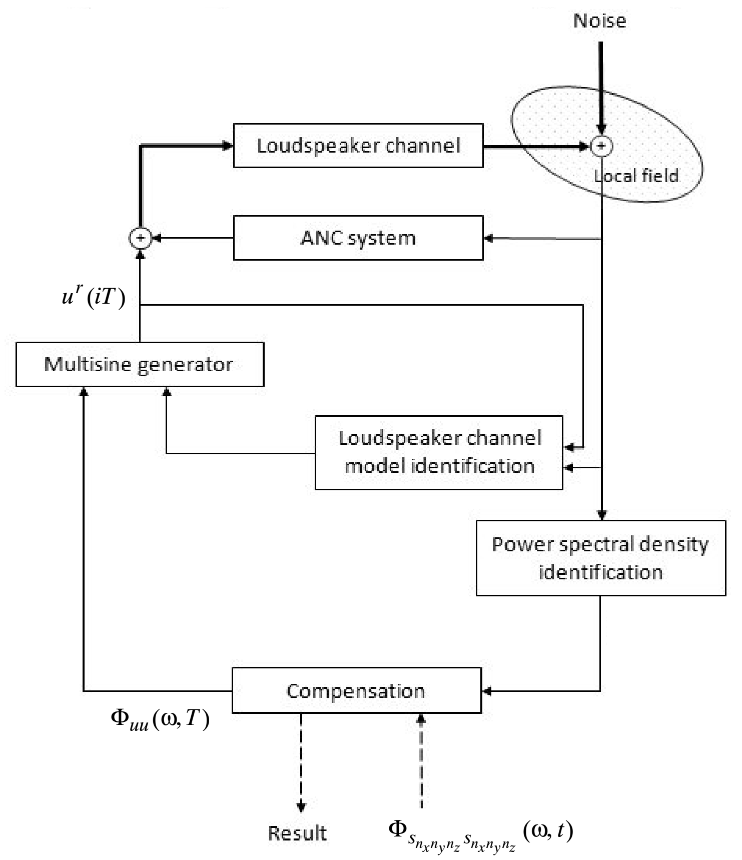

Fig. 3. Block diagram of an acoustic local field adaptive synthesis and generation system

It follows from the above discussion that the acoustic local field adaptive synthesis and generation system is a single-channel active noise control system with additional piece of software for piece-wise wide-sense stationary random acoustic local field synthesis and generation.

4. ACOUSTIC DISTRIBUTED FIELD SHAPING SYSTEM COORDINATION

Acoustic distributed field shaping is coordinated by a higher level strategy. The basic engineering rule of this coordination strategy is the following:

If there exists autonomous acoustic local field adaptive synthesis and generation system that returns the following result "there is no possibility to synthesise and generate an acoustic local field with the given properties" than the power spectral density $\Phi_{s_{xyz}s_{xyz}}(x, y, z, \omega, t)$ *is transformed by a transformation with the chosen scale of similarity and new local patterns are sent to the corresponding local field adaptive synthesis and generation systems.*

It must be emphasised that the mentioned above transformation influences convergence of the acoustic distributed field shaping system and its choice is an open research problem. It also defines coordination level hardware requirements. For example, in the case of the transformation being a proportional scaling only new single number should be sent to all local systems and coordination of the acoustic distributed field shaping system may be performed without any dedicated hardware.

The coordination strategy may be also extended by additional rules based, for example on sampling theorems with deterministic or random interval, and constrained programming methods (Frühwirth and Abdennadher 2003; Szczygieł 2002) solving a packing problem with gaps or overlaps of the corresponding acoustic local fields in the subspace S. It increases numerical complexity of the corresponding coordination strategy algorithm and implies application of a dedicated hardware. Additional rules may also add new feature to the acoustic distributed field shaping system – a system structure self organisation.

It must also be emphasized that in the proposed approach to acoustic distributed field shaping the number $N_xN_yN_z$ of autonomous adaptive acoustic local field synthesis and generation systems may be easy changed *on-line*. New autonomous adaptive acoustic local field synthesis and generation system can be added to the set of existing ones and activated. Activation of the acoustic local field synthesis and generation system means obtaining from the coordination strategy only the corresponding local pattern.

5. CONCLUSIONS

In this paper, a new approach to acoustic, distributed in 3-dimensional space field shaping taking into account influence of the environment is presented. The approach is a merge of the adaptive synthesis and generation of piecewise wide sense stationary random acoustic local field technique with active noise control ideas. The problem of acoustic distributed field shaping is decomposed into a set of the corresponding autonomous acoustic local field adaptive synthesis and generation problems that are coordinated by a higher level strategy.

Acknowledgement

Partial financial support of this research by Polish Ministry of Science and Higher Education is gratefully acknowledged.

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