Progress In Electromagnetics Research, PIER 34, 285–298, 2001

A TRIAL ON HIERARCHICAL EXTRACTION OF HIGHER ORDER CORRELATION BETWEEN ELECTROMAGNETIC AND SOUND WAVES AROUND A VDT ENVIRONMENT — PRACTICAL USE OF BACKGROUND NOISE AND PROBABILITY PREDICTION

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Abstract—In this paper, a trial of probabilistic signal processing which is possible to give methodological suggestion to some quantitative measurement method of compound and/or ac-cumulation effect in electromagnetic (abbr. EM) environment is discussed. In order to extract various types of latent interrelation characteristics between many of waved environmental factors (EM and sound waves) leaked from VDT in a real working situation, some extended regression system model reflecting hierarchically not only linear correlation information of the lower order but also nonlinear correlation information of the higher order is firstly introduced. Especially, differing from the previous study, all regression parameters of this model are identified by positively utilizing information of a background EM noise instead of eliminating it. Then, some evaluation method for predicting a whole fluctuation distribution form from sound to EM is newly proposed. Finally, the validity and effectiveness of this proposed method are partly confirmed through some principle experiment too by applying it to the actually observed data leaked by a VDT playing some television games in the room of an actual working environment.

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1. INTRODUCTION

It is well-known that usually EM and sound waves are precisely measured in a frequency domain under the standardized measuring situation in a reverberation room, anechoic room and radio-frequency anechoic chamber. Surely, these standard methods in a frequency domain are useful especially for the purpose of analyzing (from a bottom-up way viewpoint) the mechanism of individual phenomena, but they seem to be insufficient for evaluating (from a top-down way viewpoint) total images of fluctuation on the compound and/or mutual relationship between EM and sound waves in a complicated living circumstances (e.g., thunder, electrostatic discharge, earthquakes, some kinds of energy between Eastern mind-body theory, microwave hearing [1], magnetophosphen [2] and so on). Not to say, studies on mutual relationship between EM and sound waves, even a study on only EM wave itself leaked by electronic equipment in the actual working environment are becoming more important year by year, according to very rapid increase of various types of information and communication equipment like personal computers and portable radio transmitters [3, 4]. For instance, concerning their individual and/or compound effects on a living body, it is well-known that even now there are many unsolved questions on VDT symptoms for study [5]. To cite several concrete examples, as we have already touched upon, our brain nerve seems mostly influenced around the frequency of 15–20 Hz at sound and EM waves including light wave. This is recognized even in an amplitude modulation of the high frequency domain as well [6]. Also, the generating order, the interval and each duration of flashes and sound noises along a time axis produce some problems for the relationships to physiological processes. Otherwise, there are more other similar problems, such as a predominant effect of sight (Hearing seems to be dragged to sight having higher warning ability.), a promotion effect among different kind of senses [7], participation to VDT symptom groups (e.g., complain of general malaise) as well as multiplication effect with stress, relationships between daily rhythm of human life and the effects to a pineal body by EM field [8], some changes of brain waves by stimulus of light and sound, and so on. For these modern EM environmental problems, mutual compound correlation and/or accumulation effects seem unable to be originally denied.

In these studies, it is generally pointed out that the first important topic is to find some new help to measurement and evaluation methods even in a quantitative approximation [9, 10].

In general, in the actual phenomena affected in a complex manner by the natural, social and human factors, it is necessary even in approximation to abstract various type latent correlation information of not only the ordinary lower orders, but also of the higher orders to quantitatively investigate and evaluate the mutual relationship among them [11, 12]. In this paper, a stochastic methodology to grasp quantitatively the mutual relationship between EM and sound waves leaked by a VDT in an actual working environment is discussed as a trial, especially by employing a system model based on an extended regression analysis [13] reflecting not only the linear but also the nonlinear correlation information. More specifically, in order to identify each regression parameter of this system model under the existence of a background EM noise, we have proposed a parameter identification method on the above regression model based on a positive utilization of the statistics of the steady background EM noise in an actual situation which is capable of giving some methodological suggestion to some quantitative measurement technology of compound and/or accumulation effects in the EM environment. Such a treatment remains at an early stage of study. So, the validity and effectiveness of our proposed method are partly confirmed through some principle experiment by an application to the observation data leaked by a VDT playing some television games in the room of an actual working environment.

2. GENERAL THEORY

2.1. Regression Relationships between Two-Wave Environmental Factors

In order to evaluate quantitatively and hierarchically the complicated relationship between the two-wave environmental factors (e.g., sound and EM waves) leaked from electronic information equipment, first, let us introduce a generalized regression analysis method [13] employing not only the linear correlation but also the nonlinear correlation information among many stochastic variables. Especially, in the case with a prediction variable x and a criterion variable y, it must be noticed that all information on mutual correlation between x and y is included in the conditional probability distribution $P(y|x)$.

In the stream of our present description, first, let us summarize only an essence of previously reported general theory [14, 15]. Generally, the joint probability distribution $P(x, y)$ can be expanded into an orthonormal polynomial series on the basis of the fundamental probability distributions $P_0(x)$ and $P_0(y)$, which can be artificially chosen as the probability functions describing approximately the dominant parts of the actual fluctuation pattern, as follows:

$$P(x, y) = P_0(x)P_0(y) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} \varphi_m^{(1)}(x) \varphi_n^{(2)}(y), \tag{1}$$

$$A_{mn} \equiv \left\langle \varphi_m^{(1)}(x) \varphi_n^{(2)}(y) \right\rangle, \tag{2}$$

where $\langle \cdot \rangle$ denotes an averaging operation with respect to the random variables. Here, $\varphi_m^{(1)}(x)$ and $\varphi_n^{(2)}(y)$ are two kinds of orthonormal polynomial with respective weighting functions $P_0(x)$ and $P_0(y)$. Thus, the information on the various types of linear and nonlinear correlations between x and y is reflected hierarchically in each expansion coefficient A_{mn}. Based on Eq. (1), the conditional probability distribution function can be derived, as follows:

$$P(y|x) = \frac{P(x, y)}{P(x)} = \frac{P_0(y) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} \varphi_m^{(1)}(x) \varphi_n^{(2)}(y)}{\sum_{m=0}^{\infty} A_{m0} \varphi_m^{(1)}(x)}. \tag{3}$$

After employing an orthogonal series expansion expression of y by $\varphi_n^{(2)}(y)$ and the orthonormal condition of $\varphi_n^{(2)}(y)$, the regression function as a typical regression relationship between x and y (especially from x to y) can be explicitly given, as follows:

$$\begin{aligned} \hat{y}(x) &= \langle y|x\rangle \\ &= \frac{\sum_{m=0}^{\infty}\sum_{n=0}^{1} C_{1n}A_{mn}\varphi_m^{(1)}(x)}{\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x)}. \end{aligned} \tag{4}$$

Thus, after estimating the expansion coefficient A_{mn} defined by Eq. (2) on the basis of the observed data on x and y, the regression function between x and y can be evaluated in a concrete form.

2.2. Prediction of Specific Probability Distribution Based on Regression Information

A specific probability distribution $P_s(y)$ of y based on an arbitrary type random fluctuation of regressively related stochastic variable x can be predicted by using several types of mutual correlation information. It seems to be rather rational to predict the response distribution by the following averaging operation based on Eq. (3) than by ordinary method of data transformation directly using the regression function Eq. (4) (based on the original definition of regression curve), because the conditional probability distribution Eq. (3) has all of the correlation information of lower and higher orders from x to y. So, the specific probability distribution of y should be predicted, as follows:

$$\begin{aligned} P_s(y) &= \int P(y|x)P(x)dx \\ &= \langle P(y|x)\rangle_x \\ &= P_0(y)\sum_{n=0}^{\infty} B_n\varphi_n^{(2)}(y), \end{aligned} \tag{5}$$

$$B_n = \left\langle \frac{\sum_{m=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)}{\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x)} \right\rangle_x . \tag{6}$$

Also, in predicting a specific probability distribution $P_s(x)$ of x based on an arbitrary type random fluctuation of regressively related stochastic variable y, it seems natural to utilize the same method for evaluating $\langle P(x|y)\rangle_y$.

2.3. Extraction of Mutual Correlation Information Based on a Positive Utilization of the Statistics of a Background EM Noise

Now, let us pay our attention to the case in which the estimation purpose A_{mn} cannot be directly calculated from Eq. (2) under an actual working environment contaminated by the background EM noise v. And it is assumed that each random variables: x, y and v are the non-negativity variables on a power scale and so the positive utilization of well-known Gamma probability distribution and related to the Laguerre orthonormal polynomial originally defined only over the non-negative region is reasonable, respectively. If Eq. (4) can be explained in the finite term M, based on the well-known additive law of energy, the observed data z can be firstly formulated, as follows:

$$\begin{aligned} z &= \langle y|x\rangle + v \\ &= \frac{\sum_{m=0}^{M}\sum_{n=0}^{1} C_{1n}A_{mn}\varphi_m^{(1)}(x)}{\sum_{m=0}^{M} A_{m0}\varphi_m^{(1)}(x)} + v \\ &\equiv \hat{y}(x, \mathbf{A}_{m0}, \mathbf{A}_{m1}) + v, \end{aligned} \tag{7}$$

where, $\mathbf{A}_{m0}$ and $\mathbf{A}_{m1}$ denote parameter vectors defined as follows, respectively:

$$\begin{cases} \mathbf{A}_{m0} \equiv [A_{00}, A_{10}, \ldots, A_{M0}]^{\mathrm{T}}, \\ \mathbf{A}_{m1} \equiv [A_{01}, A_{11}, \ldots, A_{M1}]^{\mathrm{T}}. \end{cases} \tag{8}$$

By adopting the well-known Schmidt's orthogonalization method [16], with taking the observation distribution $P_R(v)$ of only the stationary background EM noise v as the first term, the general expression on the theoretical distribution $P(v)$ of arbitrarily fluctuating EM noise v can be expressed by the orthogonal expansion in advance, as follows:

$$P(v) = P_R(v)\left\{1 + \sum_{j=1}^{\infty} D_j\theta_j(v)\right\}. \tag{9}$$

Therefore, the following equation must be satisfied in Eq. (9) so that theoretical distribution curve may agree with experimentally observed probability distribution curve in all values of v:

$$\sum_{j=1}^{\infty} D_j\theta_j(v) = 0. \tag{10}$$

Thus, the condition of $D_j = 0$ is required for the every expansion term j. By multiplying $\theta_j(v)$ on the both sides of Eq. (9) and integrating the equation, each expansion coefficient D_j can be expressed, as follows:

$$\begin{aligned} D_j &= \int P(v)\theta_j(v)dv \\ &= \langle \theta_j(v) \rangle \\ &= 0. \end{aligned} \tag{11}$$

Therefore, when the background EM noise v is dominant, based on the calculated value by Eq. (11) and Eq. (7) of v $(= z - \hat{y}(x, \mathbf{A}_{m0}, \mathbf{A}_{m1}))$, each expansion coefficient vector $\mathbf{A}_{m1}$ can be successively and concretely identified by using the Robbins-Monro's stochastic approximation method [17], as follows:

$$\hat{\mathbf{A}}_{m1}(k+1) = \hat{\mathbf{A}}_{m1}(k) - \Gamma_k \begin{bmatrix} \theta_1\left(z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))\right) \\ \theta_2\left(z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))\right) \\ \vdots \\ \theta_{M+1}\left(z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))\right) \end{bmatrix}, \tag{12}$$

where, $\Gamma_k \equiv diag\left\{\gamma_k^{(1)}, \gamma_k^{(2)}, \ldots, \gamma_k^{(M+1)}\right\}$, $\gamma_k^{(i)} \equiv G_i/k$ $(G_i > 0,\ i = 1, 2, \ldots, M+1)$ and k denotes a recurrent time stage. It must be noticed that the expansion coefficient vector $\mathbf{A}_{m0}$ is given in advance, since it can be calculated from only an input x.

By applying each expansion coefficients $\hat{\mathbf{A}}_{i1}$ $(i = 0, 1, \ldots, M)$ estimated by the Eq. (12) to Eqs. (1) and (4), under the contamination of the background EM noise v, it is possible to estimate and evaluate the fluctuation probability distribution of output data y itself for known input data x under the ideal environment without background EM noise. Also, based on this identified system model, it is possible to theoretically predict and evaluate the fluctuation probability distribution of output data z with the existence of the background EM noise v for unknown input data x by use of the Eq. (7).

3. CONCRETIZATION OF THEORY

In order to realize the above theory in a concrete form, let us pay our attention to the property that each random variables: x, y and z

fluctuate only within the non-negative region, respectively. As stated above, then, the expansion expression form of the statistical Laguerre orthonormal series type [14] can be first adopted to the each observed distribution from the problem-oriented viewpoint. Consequently, the observation model of Eq. (7) is concretized in the following form:

$$\begin{aligned} z &= m_y S_y - \sqrt{m_y} S_y \frac{\sum_{m=0}^{M} A_{m1} \sqrt{\frac{m!\Gamma(m_x)}{\Gamma(m_x+m)}} L_m^{(m_x-1)}\left(\frac{x}{S_x}\right)}{\sum_{m=0}^{M} A_{m0} \sqrt{\frac{m!\Gamma(m_x)}{\Gamma(m_x+m)}} L_m^{(m_x-1)}\left(\frac{x}{S_x}\right)} + v \\ &\equiv \hat{y}(x, \mathbf{A}_{m0}, \mathbf{A}_{m1}) + v, \end{aligned} \tag{13}$$

where, m_x, S_x, m_y and S_y denote the parameters of the Gamma distribution defined by the well-known method of moment as follows:

$$m_x = \frac{\mu_x^2}{\sigma_x^2}, \tag{14}$$

$$S_x = \frac{\mu_x}{m_x}, \tag{15}$$

$$m_y = \frac{\mu_y^2}{\sigma_y^2}, \tag{16}$$

$$S_y = \frac{\mu_y}{m_y}, \tag{17}$$

$$\mu_x = \langle x \rangle, \tag{18}$$

$$\sigma_x^2 = \left\langle (x-\mu_x)^2 \right\rangle, \tag{19}$$

$$\mu_y = \langle y \rangle, \tag{20}$$

$$\sigma_y^2 = \left\langle (y-\mu_y)^2 \right\rangle. \tag{21}$$

In Eqs. (20) and (21), by use of the known statistics of a background EM noise: mean μ_v and variance σ_v^2, μ_y and σ_y^2 can be calculated in advance since y and v are statistically independent of each other, as follows:

$$\mu_y \equiv \hat{\mu}_y = \mu_z - \mu_v, \tag{22}$$

$$\sigma_y^2 \equiv \hat{\sigma}_y^2 = \sigma_z^2 - \sigma_v^2. \tag{23}$$

Also, the successive estimation algorithm of the each expansion coefficient $\mathbf{A}_{m1}$ in Eq. (12) is realized in the following explicit form:

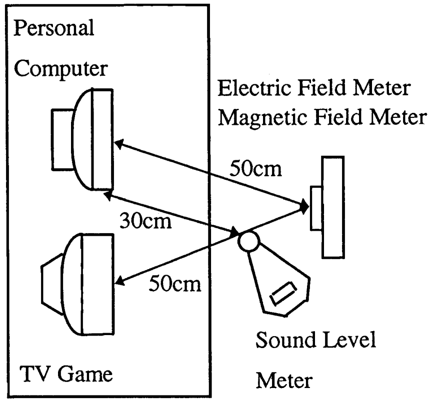

Figure 1. A schematic drawing of the experiment.

$$\hat{\mathbf{A}}_{m1}(k+1) = \hat{\mathbf{A}}_{m1}(k) - \Gamma_k \begin{bmatrix} \sum_{i=0}^{1} \lambda_{1\,i} L_i^{(m_v-1)} \left(\frac{z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))}{S_v} \right) \\ \sum_{i=0}^{2} \lambda_{2\,i} L_i^{(m_v-1)} \left(\frac{z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))}{S_v} \right) \\ \vdots \\ \sum_{i=0}^{M+1} \lambda_{M+1\,i} L_i^{(m_v-1)} \left(\frac{z_k - \hat{y}(x_k, \mathbf{A}_{m0}, \hat{\mathbf{A}}_{m1}(k))}{S_v} \right) \end{bmatrix}, \quad (24)$$

where, λ_{ji} denote the coefficients given by the Schmidt's orthogonalization method.

4. EXPERIMENT

The proposed method is applied to the actually measured data leaked by a VDT while playing television games in the actual working environment. Figure 1 shows a schematic drawing of the experiment. The r.m.s values of the electric field [V/m], magnetic field [mA/m] leaked from a VDT and the sound level [dB] emitted from a speaker of the personal computer are simultaneously measured. The data of electric field strength, magnetic field strength and sound level are measured by using the HI-3603 type EM field survey meter of Holaday Industries Inc., the 8532 type precision gauss meter of Loral Co. and the 22331 type sound level meter of Brüel & Kjær Co., respectively.

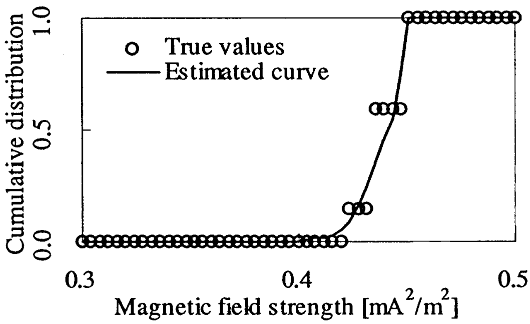

Figure 2. A comparison between theoretically estimated curve and true values for a specific probability distribution (from sound to magnetic field).

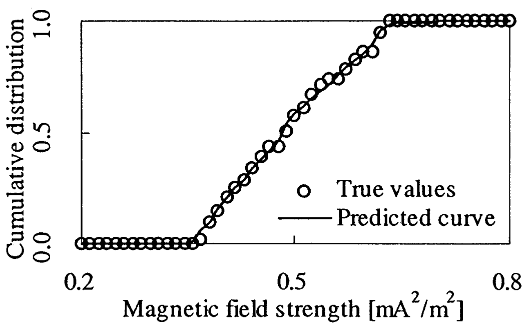

Figure 3. A comparison between theoretically predicted curve and true values for a specific probability distribution (from sound to magnetic field).

The experiment has been carried out especially with existence of a background EM noise. The slowly fluctuating 720 data of non-stationary type for each stochastic variable are sampled with a sampling interval of 5 second. Based on the former 500 data points, the regression parameter: $\mathbf{A}_{m1}$ is firstly identified by use of Eq. (24). Next, Based on the latter 220 sampled data of non-stationary type, the specific probability distribution is estimated and predicted in order to confirm the effectiveness of our proposed theoretical method based on the proposed parameter identification algorithm. Figures 2 and 3 show the experimental results for the estimation and prediction of the specific probability distribution of magnetic field based on sound data, respectively. Also, Figures 4 and 5 show the experimental results for

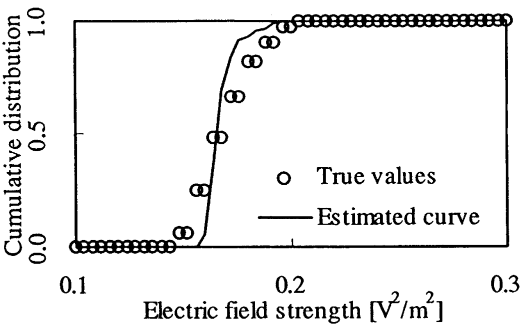

Figure 4. A comparison between theoretically estimated curve and true values for a specific probability distribution (from sound to electric field).

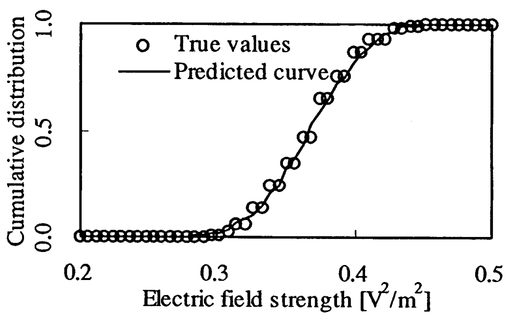

Figure 5. A comparison between theoretically predicted curve and true values for a specific probability distribution (from sound to electric field).

the estimation and prediction of the specific probability distribution of electric field based on sound data, respectively. From these figures, it can be found that the theoretical curves show a fairly good agreement with experimentally sampled points. So, the effects of a background EM noise are theoretically removed.

5. CONCLUSIONS

In this paper, first, a trial of finding some new stochastic methodology has been discussed in close connection with the mutual relationship among sound and EM waves leaked by a VDT in an actual working environment, especially by employing a system model of extended regression type reflecting not only the linear but also the nonlinear correlation information. More specifically, in order to identify regression parameters $\mathbf{A}_{m1}$ of the system model, we have proposed a parameter identification method based on a positive utilization of the statistics on only a steady background EM noise in an actual situation with the existence of a background which is capable of giving some methodological suggestion to the quantitative measurement technology of compound and/or accumulation effects in the EM environment. Finally, since the proposed method remains at an early stage of study, the validity and effectiveness of our proposed method have been confirmed through some principle experiment by applying it to the observation data leaked by a VDT playing a television game in the room of an actual working environment.

As mentioned at the beginning, there still remains many unsolved problems even in the methodological research in quantitative measurements and evaluations which give any suggestion to compound and/or accumulation effect in the EM environmental problems in an actual working environment. From now on, it seems to become important to find out more accurate correlation evaluation method and/or accurate measurement technique in a time domain rather than an analytic technique in frequency domain, needless to say to make clear quantitatively more and more the biological effect of EM noise.

ACKNOWLEDGMENT

We would like to express our cordial thanks to Prof. Y. Fujita, Prof. A. Ikuta, Prof. Y. Mitani, Mr. S. Kodani, Mr. K. Mukai, Mr. D. Morie, Mr. N. Shinohara and Mr. M. Shigemi for their helpful assistance and discussion.

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