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MUTUAL CORRELATION CHARACTERISTICS BETWEEN SOUND LEVEL AND ELECTRIC FIELD INTENSITY FLUCTUATION IN CONNECTION WITH ELECTROMAGNETIC ENVIRONMENTAL PROBLEM OF VDT GAMES

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ABSTRACT

In this paper, some generalized regression analysis method considering not only linear correlation but also higher order nonlinear correlation informations is especially proposed in order to find mutual relationship minutely between sound and electromagnetic waves leaked from an electronic information equipment. Concretely, a hierarchical extended regression analysis method reflecting various type correlation informations is theoretically derived by introducing an expression of multi-variate probability distribution in an orthonormal expansion series form. The effectiveness of the proposed theory is experimentally confirmed too by applying it to the observed data leaked from VDT in the actual working environment.

1. INTRODUCTION

Some studies on mutual relationship among light, sound and electromagnetic waves leaked from an electronic equipment in the room of actual working environment have become gradually important according to the increase of daily use of various information and communication systems like a personal computer and portable radio transmitters [1][2]. Especially, concerning to their individual and/or compound effects on a living body, it is well-known that there are too many unsolved modern questions on VDT symptom group to study, such as the complain of general malaise, the effect to a pineal body, the allergic or stress reaction, any relationship to cataract or leukemia and so on. In these researches, it is generally pointed out as the first important problem to find any new trial of quantitative measurement and evaluation even in the approximation. In the actual phenomena affected complexly by the natural, social and human factors, it is necessary to consider various types of latent correlation information of not only the lower order but also the higher orders in order to investigate and evaluate minutely the mutual relationship among them.

Especially, the above sound and electromagnetic waves are often measured mainly in a frequency domain under the standardized measuring situation, e.g., in a reverberation room, anechoic room and radiofrequency anechoic chamber. Though 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 phenomenon, these seem to be inadequate for evaluating as they are (from a top-down way viewpoint) the total effects on the compound or mutual relationship between sound and electromagnetic waves in the complicated circumstances such as actually working room. In order to evaluate universally these mutual correlation characteristics in the actual complex working environment, it is necessary to find some minute methods of signal processing especially in a time domain [3]-[6].

From the above viewpoints, in this paper, a generalized regression analysis method reflecting the linear and nonlinear correlation informations with lower and higher orders is proposed in order to grasp minutely and universally the mutual relationship between sound and electromagnetic waves leaked from an electronic information equipment. More specifically, an extended regression analysis method is theoretically derived by introducing a joint probability function in an expansion series type. First, based on the observation data of sound and electromagnetic waves leaked from an electronic information equipment, a new trial to evaluate the latent regression relationship among the data is theoretically derived. Next, by use of this regression relationship, a prediction method of the probability distribution only for a specific stochastic variable (e.g., electromagnetic wave) based on the observation data for another kind of stochastic variable (i.e., sound) is theoretically derived.

Finally, by applying the proposed methodology to the measurement data in an actually working environment, the effectiveness of theory is partly confirmed experimentally, too.

2. THEORETICAL CONSIDERATIONS

2.1 Regression Relationship between Sound and Electromagnetic Waves

In order to evaluate quantitatively and hierarchically the complicated relationship between sound and electromagnetic waves leaked from an electronic information equipment, let us introduce a generalized regression analysis method [7] considering not only the linear correlation but also the nonlinear correlation informations among these stochastic variables. In order to derive a mathematical expression in a general form, two kinds of variables (i.e., sound and electromagnetic waves), x and y, are first considered. In the case when paying our attention to a prediction variable x and a criterion variable y, all of the information on mutual correlations between x and y is included in the conditional probability distribution $P(y|x)$.

First, 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:

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

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

where $\langle\cdot\rangle$ denotes the averaging operation with respect to the random variables. Here, $\varphi_m^{(1)}(x)$ and $\varphi_n^{(2)}(y)$ are orthonormal polynomials with two weighting functions $P_0(x)$ and $P_0(y)$, and must satisfy respectively the following orthonormal relationships:

$$\int \varphi_m^{(1)}(x)\varphi_{m'}^{(1)}(x)P_0(x)dx = \delta_{mm'}, \tag{3}$$

$$\int \varphi_n^{(2)}(y)\varphi_{n'}^{(2)}(y)P_0(y)dy = \delta_{nn'}. \tag{4}$$

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}.

Next, from Eq. (1), the following expression can be obtained.

$$\begin{aligned} P(x) &= \int P(x,y)dy \\ &= P_0(x)\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x). \end{aligned} \tag{5}$$

Thus, by using Eqs. (1) and (5), the conditional probability distribution function containing a whole information on the regression relationship can be derived under the employment of the well-known Bayes' theorem, as follows:

$$\begin{aligned} P(y|x) &= \frac{P(x,y)}{P(x)} \\ &= \frac{P_0(y)\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)\varphi_n^{(2)}(y)}{\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x)}. \end{aligned} \tag{6}$$

Therefore, the regression function as a typical regression relationship between x and y is given by

$$\begin{aligned} \hat{y}(x) &= \langle y|x\rangle \\ &= \frac{\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)}{\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x)} \cdot \int y\varphi_n^{(2)}(y)P_0(y)dy. \end{aligned} \tag{7}$$

Here, y can be expressed in advance in a series expansion form by use of $\left\{\varphi_j^{(2)}(y)\right\}$:

$$y=\sum_{j=0}^{1} C_j\varphi_j^{(2)}(y), \tag{8}$$

where C_j's $(j=0,1)$ are appropriate constants in the orthonormal expansion of y. Therefore, by considering the orthonormal condition in Eq. (4), the regression relationship of Eq. (7) can be explicitly given in a series form, as follows:

$$\hat{y}(x)=\frac{\sum_{m=0}^{\infty}\sum_{n=0}^{1} A_{mn}C_n\varphi_m^{(1)}(x)}{\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x)}. \tag{9}$$

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 by use of Eq. (9).

Concretely, for example, let us assume that x and y are two stochastic variables denote a sound level on dB scale and an electric field intensity on power scale, respectively. As the fundamental probability functions $P_0(x)$ and $P_0(y)$, the well-known Gaussian distribution and Gamma distribution can be chosen, respectively:

$$P_0(x)=N\left(x;\mu_x,\sigma_x^2\right)\equiv\frac{1}{\sqrt{2\pi}\sigma_x}e^{-\frac{(x-\mu_x)^2}{2\sigma_x^2}}, \tag{10}$$

$$P_0(x)=P_\Gamma\left(y;m_y,S_y\right)\equiv\frac{1}{\Gamma(m_y)S_y}e^{-\frac{y}{S_y}}\left(\frac{y}{S_y}\right)^{m_y-1} \tag{11}$$

with

$$\mu_x=\langle x\rangle,\sigma_x^2=\left\langle(x-\mu_x)^2\right\rangle, \tag{12}$$

$$\mu_y=\langle y\rangle,\sigma_y^2=\left\langle(y-\mu_y)^2\right\rangle,m_y=\frac{\mu_y^2}{\sigma_y^2},S_y=\frac{\mu_y}{m_y}. \tag{13}$$

Thus, from Eqs. (3) and (4), the orthonormal functions can be determined as

$$\varphi_m^{(1)}(x)=\frac{1}{\sqrt{m!}}\mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right), \tag{14}$$

$$\varphi_n^{(2)}(y)=\sqrt{\frac{n!\Gamma(m_y)}{\Gamma(m_y+n)}}\mathrm{L}_n^{(m_y-1)}\left(\frac{y}{S_y}\right), \tag{15}$$

where $\mathrm{H}_m(\cdot)$ and $\mathrm{L}_n^{(\cdot)}(\cdot)$ are Hermite polynomial of the m-th order type and Laguerre polynomial of the n-th order type, respectively. By substituting Eqs. (10)-(15) into Eqs. (2) and (9), the objective regression function $\hat{y}(x)$ can be obtained in the concrete form as follows:

$$\hat{y}(x) = m_y S_y - \sqrt{m_y} S_y \frac{\sum_{m=0}^{\infty} A_{m1} \frac{1}{\sqrt{m!}} \mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right)}{\sum_{m=0}^{\infty} A_{m0} \frac{1}{\sqrt{m!}} \mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right)}, \tag{16}$$

$$A_{mn} \equiv \left\langle \frac{1}{\sqrt{m!}} \mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right) \cdot \sqrt{\frac{n!\Gamma(m_y)}{\Gamma(m_y+n)}} \mathrm{L}_n^{(m_y-1)}\left(\frac{y}{S_y}\right) \right\rangle. \tag{17}$$

2.2 Prediction of Specific Probability Distribution from Related Fluctuation Factors

Based on the conditional probability distribution $P(y|x)$, the specific probability distribution $P_s(y)$ of y based on the arbitrary type random fluctuation of related stochastic variable x can be predicted, as follows:

$$P_s(y) = \langle P(y|x) \rangle_x . \tag{18}$$

Thus, by use of Eq. (6), $P_s(y)$ can be expressed, as follows:

$$P_s(y) = P_0(y) \sum_{n=0}^{\infty} B_n \varphi_n^{(2)}(y) \quad \textit{with} \quad B_n = \left\langle \frac{\sum_{m=0}^{\infty} A_{mn} \varphi_m^{(1)}(x)}{\sum_{m=0}^{\infty} A_{m0} \varphi_m^{(1)}(x)} \right\rangle_x . \tag{19}$$

Furthermore, introducing the same assumption as in section 2.1, after substituting Eqs. (10)-(15) into Eqs. (19), the above specific probability distribution $P_s(y)$ can be also obtained in the concrete form as follows:

$$P_s(y) = \frac{1}{\Gamma(m_y) S_y} e^{-\frac{y}{S_y}} \left(\frac{y}{S_y}\right)^{m_y-1} \cdot \sum_{n=0}^{\infty} B_n \sqrt{\frac{n!\Gamma(m_y)}{\Gamma(m_y+n)}} \mathrm{L}_n^{(m_y-1)}\left(\frac{y}{S_y}\right) \quad \textit{with}$$

$$B_n = \left\langle \frac{\sum_{m=0}^{\infty} A_{mn} \frac{1}{\sqrt{m!}} \mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right)}{\sum_{m=0}^{\infty} A_{m0} \frac{1}{\sqrt{m!}} \mathrm{H}_m\left(\frac{x-\mu_x}{\sigma_x}\right)} \right\rangle_x . \tag{20}$$

3. EXPERIMENTAL CONSIDERATIONS

3.1 Mutual Relationship Between Sound and Electromagnetic Waves Leaked from VDT in the Room of Actual Working Environment

By adopting some television games in the room of actual working environment as a specific information equipment, the proposed method is applied to investigate the mutual relationship between sound and electromagnetic waves leaked from VDT under the situation playing television games. The experiment has been carried out in our laboratory. Figure 1 shows a schematic drawing of the experiment. The r.m.s value [V/m] of the electric field radiated from VDT and the sound level [dB] emitted from a speaker of the personal computer are simultaneously measured. The data of electric field strength and sound level are measured by use of HI-3603 type electromagnetic field survey meter of Holaday Industries Inc. and a sound level meter of Brüel&Kjær Co., respectively. The slowly fluctuating 720 data of nonstationary type for each stochastic variable are sampled with a sampling interval of 10 second. Figure 2 shows the plots of sampled data. Based on the 500 data points, the regression relationships $\hat{y}(x)$ is first evaluated by use of Eq. (16). Next, Based on the latter 220 sampled data which is nonstationary different, the specific probability distribution $P_S(y)$ is predicted in order to confirm the effectiveness of our proposed theory.

The experimental results for the regression characteristics from a sound level to an electric field strength are shown in Figure 3. Also, Figure 4 shows the experimental results for the regression characteristics, but from an electric field strength to a sound level. From these figures, it can be found that the theoretical curves coincide precisely with the experimental values. The experimental results for the prediction of the specific probability distribution from a sound level to an electric field strength are shown in Figure 5. Also, Figure 6 shows the experimental results for the prediction of the specific probability distribution, but from an electric field strength to a sound level. From these figures, it can be found that the theoretical curves shows good agreement with experimentally sampled points. From these experimental results, the effectiveness of the proposed method seems to be partly confirmed.

4. CONCLUSION

In this paper, in order to grasp minutely and universally the mutual relationship between sound and electromagnetic waves leaked from an electronic information equipment, a new trial toward estimating the mutual regression characteristics especially in a time domain has been proposed. Our proposed method has utilized not only the linear correlation of lower order but also the nonlinear correlation informations of higher order among stochastic variables. The validity and effectiveness of the proposed method have been confirmed experimentally by applying it to the observation data radiated from a television games in the room of actual working environment.

The proposed approach is obviously quite different from the ordinary approach of standard type, and it is still at an early stage of study. Thus, there is a number of problems to be continued in future, building on the basic study in this paper. Some of the problems are shown in the following.

(i) In order to estimate more accurately the regression relationship, it is essential to estimate more accurately the conditional probability distribution $P(y|x)$ given by the expansion expression in Eq. (6). From the theoretical viewpoint, the proposed regression relationship can be expressed with higher precision, by employing many of expansion coefficients A_{mn} of higher order. From the practical viewpoint, however, the reliability of the proposed regression analysis tends to be lacked especially for the higher-order correlation information because only a finite number of data can be observed in practice. It is thus a problem that how the optimal number of terms in the above expansion expression should be determined according to the statistical property of the phenomenon and the available number of data.

(ii) The proposed method should be applied to many actual problems in the other kinds of electromagnetic environment engineering, and then the practical usefulness should be verified.

(iii) The proposed theory should be further improved to fit to the actual problem, so that it can be applied to the situation in the presence of the external and internal noises.

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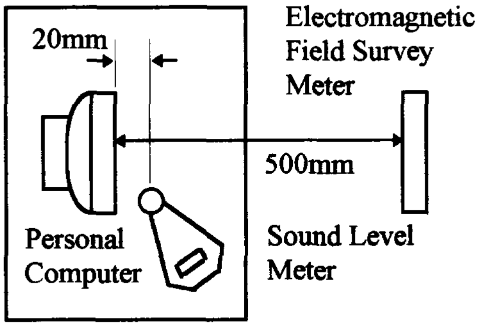

Fig. 1 a schematic drawing of the experiment

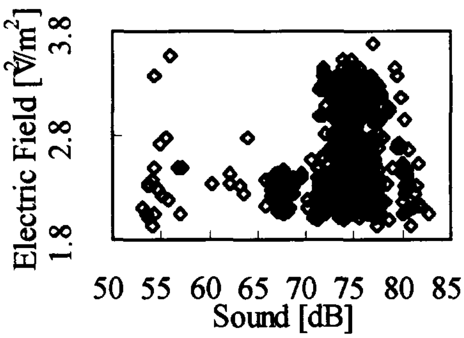

Fig.2 the plots of sampled data

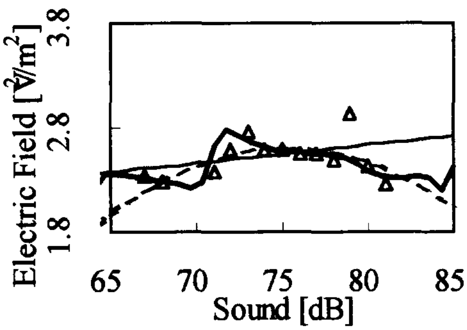

Fig. 3 A comparison between theoretical curves (——: 1st. approximation, -----: 2nd. approximation, ——— : 10th. Approximation) and experimentally sampled points (△) for the regression characteristics (from a sound level to an electric field strength).

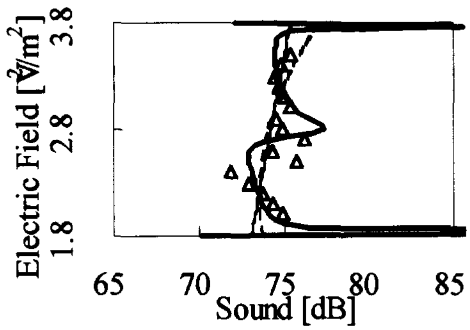

Fig. 4 A comparison between theoretical curves (——: 1st. approximation, -----: 2nd. approximation, ——— : 9th. Approximation) and experimentally sampled points (△) for the regression characteristics (from an electric field strength to a sound level).

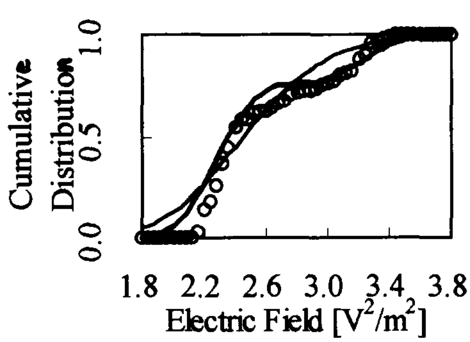

Fig. 5 A comparison between theoretically predicted curves (—— : 1st. approximation, ——— : 10-9th. Approximation) and experimentally sampled points (○) for the specific probability distribution (from a sound level to an electric field strength).

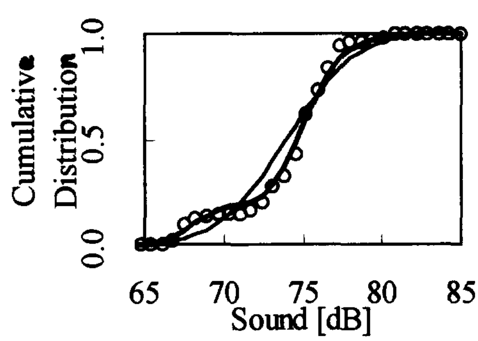

Fig. 6 A comparison between theoretically predicted curves (—— : 1st. approximation, ——— : 9-10th. Approximation) and experimentally sampled points (○) for the specific probability distribution (from an electric field strength to a sound level).