

Estimation of Higher Order Correlation between Electromagnetic and Sound Waves Leaked from VDT Environment Based on Fuzzy Probability and the Prediction of Probability Distribution

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Abstract—In this paper, a signal processing method considering not only linear correlation but also the higher order nonlinear correlation information is proposed on the basis of fuzzy observation data, in order to find the mutual relationship between sound and electromagnetic waves leaked from electronic information equipment. More specifically, by applying the well-known fuzzy probability to an expression on the multi-dimensional probability distribution in an orthogonal expansion series form reflecting systematically various types of correlation information, a method to estimate precisely the correlation information between the variables from the conditional moment statistics of fuzzy variables is proposed. The effectiveness of the proposed theory is experimentally confirmed by applying it to the observation data leaked from VDT in the actual work environment.

1. Introduction

Some studies on the mutual relationship between sound and electromagnetic waves leaked from electronic equipment in the actual working environment have become important recently because of the increased use of various information and communication systems like the personal computer and portable radio transmitters [1, 2], especially concerning their individual and/or compound effects on a living body. Sound and electromagnetic waves, especially, are often measured in a frequency domain under the standardized measuring situation in a reverberation room, anechoic room and radiofrequency anechoic chamber. Though these standard methods in a frequency domain are useful for the purpose of analyzing the mechanism of individual phenomena, they seem to be inadequate for evaluating total effects on the compound or the mutual relationship between sound and electromagnetic waves in complicated circumstances, such as the actual working environment. In order to evaluate universally the mutual correlation characteristics and its total image in the actual complex working environment, it is necessary to introduce some signal processing methods, especially in a time domain.

On the other hand, the actual observed data often contain fuzziness due to confidence limitations in sensing devices, permissible errors in the experimental data, and quantizing errors in digital observations. Therefore, in order to evaluate precisely the objective sound and electromagnetic environments, it is desirable to estimate the mutual relationship between sound and electromagnetic waves based on the fuzzy observations.

In this study, a signal processing method considering not only linear correlation but also the higher order nonlinear correlation information is proposed on the basis of fuzzy observation data, in order to find the mutual relationship between sound and electromagnetic waves leaked from electronic information equipment. More specifically, a conditional probability expression for fuzzy variables is first derived by applying the fuzzy probability [3] to a multi-dimensional joint probability function in a series type expression reflecting information on various correlation relationships between the variables. Next, by use of the derived probability expression, a method for estimating precisely the correlation information from various conditional moment statistics based on the observed fuzzy data is theoretically proposed. On the basis of the estimated correlation information, the probability distribution for a specific variable (e. g., electromagnetic wave) based on the observed fuzzy data of the other variable (e. g., sound) can be predicted. Finally by applying the proposed methodology to the measurement fuzzy data in an actual working environment, the effectiveness of theory is confirmed experimentally.

2. Prediction of Specific Probability Distribution from Arbitrary Fuzzy Fluctuation Factor

The observed data in the actual sound and electromagnetic environments often contain fuzziness due to several factors such as limitations in the measuring instruments, permissible error tolerances in the measurement, and quantization errors in digitizing the observed data.

In order to evaluate quantitatively the complicated relationship between sound and electromagnetic waves leaked from an identical electronic information equipment, let two kinds of variables (i. e., sound and electromagnetic waves) be x and y , and the observed data based on fuzzy observations be X and Y respectively. There

exist the mutual relationships between x and y , and also between X and Y . Therefore, by finding the relations between x and X , and also between y and Y , based on the fuzzy probability [3], it is possible to predict the true value y (or x) from the observed fuzzy data X (or Y). For example, for the prediction of the pdf (probability density function) $P_s(y)$ of y from X , averaging the conditional pdf $P(y|X)$ on the basis of the observed fuzzy data X , $P_s(y)$ can be obtained as: $P_s(y) = \langle P(y|X) \rangle_X$. The conditional pdf $P(y|X)$ can be expressed under the employment of the well-known Bayes' theorem:

$$P(y|X) = \frac{P(X, y)}{P(X)}. \quad (1)$$

The joint probability distribution $P(X, y)$ is expanded into an orthonormal polynomial series on the basis of the fundamental probability distribution $P_0(X)$ and $P_0(y)$, which can be artificially chosen as the probability function describing approximately the dominant parts of the actual fluctuation pattern, as follows:

$$P(X, y) = P_0(X)P_0(y) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} \psi_m(X) \phi_n(y),$$

$$A_{mn} = \langle \psi_m(X) \phi_n(y) \rangle. \quad (2)$$

The information on the various types of linear and nonlinear correlations between X and y is reflected in each expansion coefficient A_{MN} . When X is a fuzzy number expressing an approximated value, it can be treated as a discrete variable with a certain level difference. Therefore, as the fundamental probability function $P_0(X)$, the generalized binomial distribution with a level difference interval h_X can be chosen:

$$P_0(X) = \frac{\left(\frac{N_X - M_X}{h_X}\right)!}{\left(\frac{X - M_X}{h_X}\right)! \left(\frac{N_X - X}{h_X}\right)!} p_X^{\frac{X - M_X}{h_X}} (1 - p_X)^{\frac{N_X - X}{h_X}},$$

$$p_X = \frac{\mu_X - M_X}{N_X - M_X}, \quad \mu_X = \langle X \rangle, \quad (3)$$

where M_X and N_X are the maximum and minimum values of X . Furthermore, as the fundamental pdf $P_0(y)$ of y , the standard Gaussian distribution is adopted:

$$P_0(y) = \frac{1}{\sqrt{2\pi\sigma_y^2}} \exp\left\{-\frac{(y - \mu)^2}{2\sigma_y^2}\right\},$$

$$\mu_y = \langle y \rangle, \quad \sigma_y^2 = \langle (y - \mu_y)^2 \rangle. \quad (4)$$

The orthonormal polynomials $\psi_m(X)$ and $\phi_n(y)$ with the weighting functions $P_0(X)$ and $P_0(y)$ can be determined as [4]

$$\psi_m(X) = \left\{ \left(\frac{N_X - M_X}{h_X} \right)^{(m)} m! \right\}^{-\frac{1}{2}} \left(\frac{1 - p_X}{p_X} \right)^{\frac{m}{2}} \frac{1}{h_X^m} \cdot \sum_{j=0}^m \frac{m!}{(m-j)! j!} (-1)^{m-j} \left(\frac{p_X}{1 - p_X} \right)^{m-j} (N_X - X)^{(m-j)} (X - M_X)^{(j)},$$

$$(X^{(n)} = X(X - h_X) \cdots (X - (n-1)h_X), \quad X^{(0)} = 1), \quad (5)$$

$$\phi_n(y) = \frac{1}{\sqrt{n!}} H_n\left(\frac{y - \mu_y}{\sigma_y}\right); \text{ Hermite polynomial} \quad (6)$$

Thus, the predicted pdf $P_s(y)$ can be expressed in an expansion series form:

$$P_s(y) = P_0(y) \sum_{n=0}^{\infty} \left\langle \frac{\sum_{m=0}^{\infty} A_{mn} \psi_m(X)}{\sum_{n=0}^{\infty} A_{m0} \psi_m(X)} \right\rangle_X \phi_n(y). \quad (7)$$

3. Estimation of Correlation Information Based on Fuzzy Observation Data

The expansion coefficient A_{mn} in (2) has to be estimated on the basis of the fuzzy observation data X and Y , when the true value y is unknown. Let the joint probability distribution of X and Y be $P(X, Y)$, and the joint pdf of x and y be $P(x, y)$. By applying fuzzy probability [3] to $P(X, y)$, $P(X, Y)$ can be expressed as:

$$P(X, Y) = \frac{1}{K} \int \mu_Y(y) P(X, y) dy, \quad (8)$$

(K : a constant satisfying the normalized condition : $\sum_X \sum_Y P(X, Y) = 1$).

The fuzziness of Y can be characterized by the membership function $\mu_Y(y) (= \exp\{-\alpha(y-Y)^2\})$, α ; a parameter). Substituting (2) in (8), the following relationship is derived.

$$P(X, Y) = \frac{1}{K} P_0(X) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} a_n \psi_m(X),$$

$$a_n = \int \exp\{-\alpha(y-Y)^2\} P_0(y) \psi_n(y) dy. \quad (9)$$

The conditional N th order moment of the fuzzy variable X is given from (9) as

$$\begin{aligned} \langle X^N | Y \rangle &= \sum_X X^N P(X|Y) = \sum_X X^N P(X, Y) / P(Y) \\ &= \sum_X X^N P_0(X) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} a_n \psi_m(X) / \sum_{n=0}^{\infty} A_{0n} a_n. \end{aligned} \quad (10)$$

After expanding X^N in an orthogonal series expression, by considering the orthonormal relationship of $\psi_m(X)$, (10) is expressed explicitly as

$$\begin{aligned} \langle X^N | Y \rangle &= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} d_m^N A_{mn} a_n / \sum_{n=0}^{\infty} A_{0n} a_n, \\ (X^N &= \sum_{m=0}^N d_m^N \psi_m(X), d_m^N; \text{appropriate constant}). \end{aligned} \quad (11)$$

The right side of the above equation can be evaluated numerically from the fuzzy observation data. Accordingly, by regarding the expansion coefficients A_{mn} as unknown parameters, a set of simultaneous equations in the same form as in (11) can be obtained by selecting a set of N and/or Y values equal to the number of unknown parameters. By solving the simultaneous equations, the expansion coefficients A_{mn} can be estimated. Furthermore, using these estimates, the pdf $P_s(y)$ can be predicted from (7).

4. Mutual Relationship between Sound and Electric Field from a VDT in Actual Working Environment

By adopting a personal computer in the actual working environment as specific information equipment, the proposed method is applied to investigate the mutual relationship between sound and electromagnetic waves leaked from a VDT under the situation of playing a computer game. In order to eliminate the effects of sound from outside, a personal computer is located in an anechoic room (cf. Fig. 1). The RMS value (V/m) of the electric field radiated from the VDT and the sound intensity level (dB) emitted from a speaker of the personal computer are simultaneously measured. The data of electric field strength and sound intensity level are measured by use of a electromagnetic field survey meter and a sound level meter respectively. The slowly changing nonstationary 600 data for each variable are sampled with a sampling interval of 1 [s]. Two kinds of fuzzy data with the quantized level widths of 0.1 [v/m] for electric field strength and 5.0 [dB] for sound intensity level are obtained. Based on the 400 data points, the expansion coefficients A_{mn} are first estimated by use of (11). Next, the 200 sampled data within the different time interval which are nonstationally different from data used for the estimation of the expansion coefficients are adopted for predicting the probability distributions of

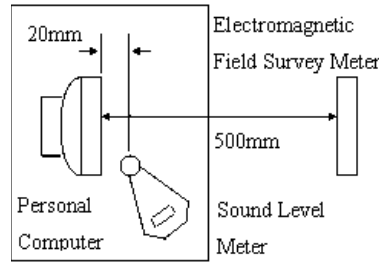


Figure 1: A schematic drawing of the experiment.

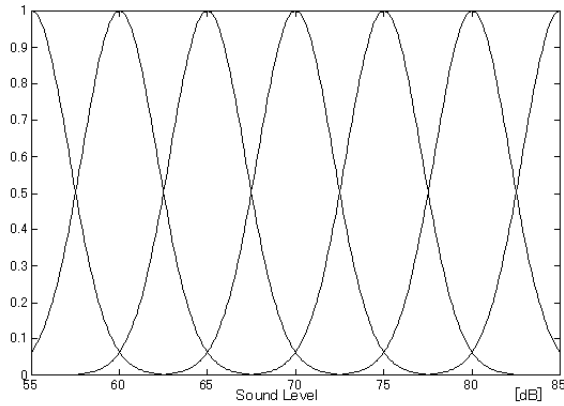


Figure 2: Membership function of sound level.

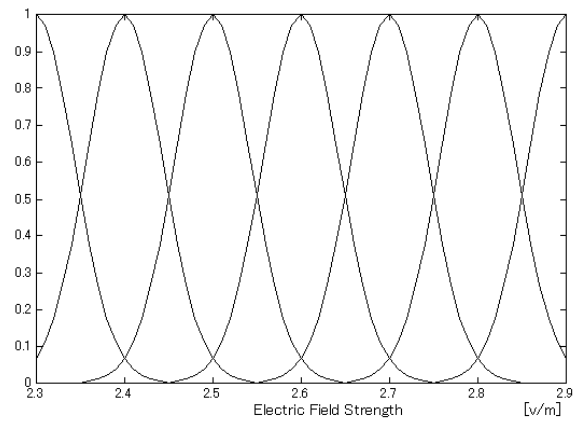


Figure 3: Membership function of electric field.

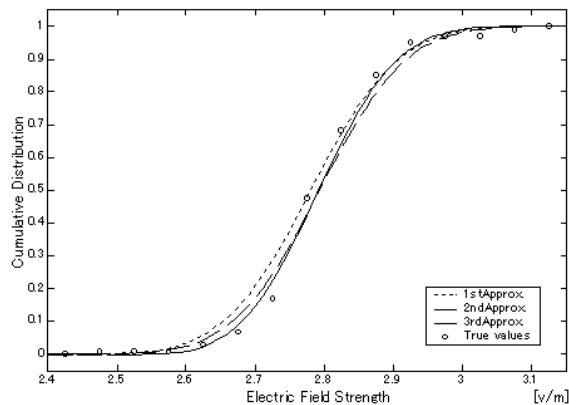


Figure 4: Prediction of the cumulative distribution for the electric field strength based on the fuzzy observation of sound.

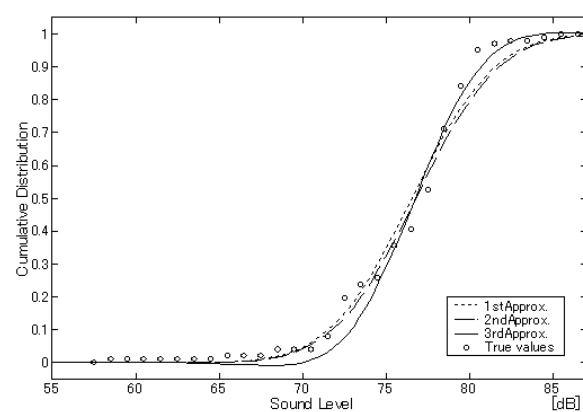


Figure 5: Prediction of the cumulative distribution for the sound level based on the fuzzy observation of electric field.

(i) the electric field based on sound and (ii) the sound based on electric field. Membership functions of the sound level and electric field are shown in Figs. 2 and 3. The parameter α is decided so as to express the distribution of data as precisely as possible.

The experimental results for the prediction of electric field strength and sound level are shown in Figs. 4 and 5 respectively in a form of cumulative distribution. From these figures, it can be found that the theoretically predicted curves show good agreements with experimental sample points by considering the expansion coefficients with several higher orders.

For comparison, the generalized regression analysis method [4] previously reported is applied to fuzzy observation data as a trial. After paying our attention to the probability distribution without considering any membership function, the probability distribution Y can be predicted on the basis of fuzzy observation data X . The predicted results for electric field strength and sound level are shown in Figs. 6 and 7 respectively.

The theoretical curves show large prediction error to the true values as compared with the prediction results in Figs. 4 and 5. These results clearly show the effectiveness of the proposed method for application to the fuzzy observation data.

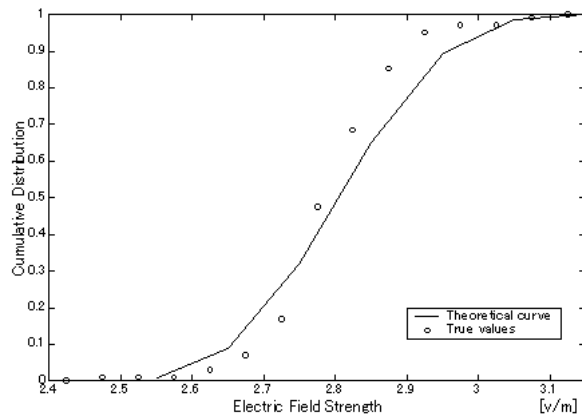


Figure 6: Prediction of the cumulative distribution for the electric field strength by use of the extended regression analysis method.

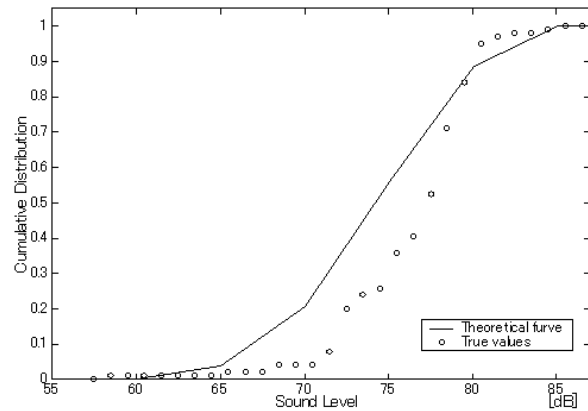


Figure 7: Prediction of the cumulative distribution for the sound level by use of the extended regression analysis method.

5. Conclusion

In this paper, a signal processing method has been proposed in order to grasp minutely and universally the mutual relationship between sound and electromagnetic waves leaked from electronic information equipment. More specifically, based on the fuzzy observation data on the sound and electromagnetic waves, a method to estimate not only the linear correlation of lower order but also the nonlinear correlation information of higher order between both variables has been derived by introducing the fuzzy probability. The validity and effectiveness of the proposed method have been confirmed experimentally by applying it to the observation data radiated from a personal computer in an actual working environment playing a computer game.

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