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Inter-subjective relationship of higher-order among spatial-temporal wavy environmental factors – a methodological trial based on a standpoint of "Relationism-First"

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In this paper, first, partly is noted the suggestions by well-known philosophical emphasis of Herakleitos, Hegel etc. (i.e., several of famous other philosophers) based on their original standpoint that the truth exists not in fragmentarily individual things but only in their relational fact or process (i.e., event) itself through some concrete self-exercise of existing contradiction. That is, it is stated that a central core and/or primary existence is not in only mutual intermediation of time series type among past, present and future, but also mutual intermediation and/or relationship among different environmental factors in especially dynamic styles (more explicitly, some temporal) harmony and/or objectively latent (severe or hierarchical) contradiction. It seems true even if apparently it has no connection according to only our individual professional sense. After all, such a viewpoint of "Relationism(us)-First" seems to be exceedingly important to all things including our human being evolving after the beginning of only material nature with Big Bang. Two kinds of actual example of the above (hierarchical type) mutual correlation in the time series and mutual correlation distributed in the space among different environmental factors are considered. More concretely, the proposed method is applied especially to the acoustic environment in the actual indoor living surroundings. Then, the mutual intermediation among sound and light waves (served for utility) and leaked EM waves (served for risk) around personal computer under playing a game is investigated through some principle experiment. As the result, some effectiveness of the proposed methodology is experimentally confirmed by taking the mutual intermediation among only physical environmental factors as an example.

1. INTRODUCTION

Recently, due to the spread of the modern technology, (especially with wide use of IT instruments) the closed interior space in the room and car, as if smog, have been filled with miscellaneous waves such as electro-magnetic (including light) [1–6], sound waves [7–10] and so on. This problem seems to be related even to our environment (or information) ethics [11, 12], too. This is gradually facing to the problem in every relationship of the world

composed of our life and cultural environment, which have some inter-independence property with our will (see Appendix I).

In this study, we positively take the standing point that the primary property – "Relationism-First" on everything should be found in principle first (see Appendix II) and after then, based on it, every type of inter-independence properties should be individually studied as the secondary property. That is, every linear and non-linear type multi-correlation analyses should be considered at the first stage of a study (i.e., for a search of truth). Only after then, by decomposing the compound effect into each factor according to our study purpose, the measurement and evaluation only for our specific interesting factor should be considered (i.e., a search of effectiveness) individually.

More concretely, for the compound and accumulation effects, at once, as a new principle trial we have proposed some evaluation method of wavy environment in the actual indoor living style, especially by limiting our study to the correlation problem between past and present states (in time region) or only two different kinds of factors (in space region) on environmental wave motion. Furthermore, by paying our attention to only natural scientific environmental factors except the cultural environmental factors from which we cannot remove some active-subjectivity even in each element, and based on the mutual intermediation among only natural scientific environmental factors as the first step of study, we have done theoretically (see Appendix III) and experimentally on trial some principle measurements and evaluations on acoustics and/or electromagnetic (abbr. EM) environment in the electrified modern living environment of closed room type.

2. MUTUAL CORRELATION IN TIME REGION (EX. SOUND FIELD)

2.1. General theory: time series regression model of orthonormal expansion type representation

Consider a stochastic process $x(t)$. Let its instantaneous values at a discrete time k be x_k. All sort of linear and nonlinear correlation information between x_k and p-variable past value $\mathbf{x}_{k-1}$ ($\underline{\underline{\Delta}}(x_{k-1},x_{k-2},\ldots,x_{k-p})$) are contained in the conditional probability density function (abbr. pdf) $P(x_k \mid \mathbf{x}_{k-1})$ of x_k for given $\mathbf{x}_{k-1}$. Especially, when x_k is to be predicted from $\mathbf{x}_{k-1}$, the expectation of x_k for given $\mathbf{x}_{k-1}$ and its prediction error ε_k can be directly expressed by its definition as

$$\hat{x}_k \underline{\underline{\Delta}} \langle x_k \mid \mathbf{x}_{k-1} \rangle = \int x_k P\left(x_k \mid \mathbf{x}_{k-1}\right) dx_k, \; \varepsilon_k \underline{\underline{\Delta}} x_k - \hat{x}_k, \qquad (1), (2)$$

(i.e., the usual regression function).

If all sort of relation between x_k and $\mathbf{x}_{k-1}$ can completely well be presented by Eq. (1), ε_k becomes an accidental error and can be represented by a white noise model with mean 0. For this purpose, the conditional pdf $P(x_k|\mathbf{x}_{k-1})$ of Eq. (1) must be constructed as precisely as possible, reflecting the effective substantial information such as non-Gaussian and nonlinear properties originally contained in the stochastic process.

First, the joint pdf $P(x_k,\mathbf{x}_{k-1})$ for the time series x_k and $\mathbf{x}_{k-1}$ is expanded as follows. The standard distribution representations $P_0(x_k)$ and $P_0(\mathbf{x}_{k-1})$ are considered that they can approximate the essential configurations of the whole fluctuations of x_k and $\mathbf{x}_{k-1}$, respectively. Using those distributions, the joint pdf is expanded in the orthonormal form only as its mathematical frame as follows:

$$P\left(x_k, \mathbf{x}_{k-1}\right) = P_0\left(x_k\right) P_0\left(\mathbf{x}_{k-1}\right) \sum_{m=0}^{\infty} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{mn} \psi_m^{(1)}\left(x_k\right) \psi_{\mathbf{n}}^{(2)}\left(\mathbf{x}_{k-1}\right),$$

$$A_{m\mathbf{n}} = \left\langle \psi_m^{(1)}\left(x_k\right) \psi_{\mathbf{n}}^{(2)}\left(\mathbf{x}_{k-1}\right) \right\rangle = \iint \cdots \int \psi_m^{(1)}\left(x_k\right) \psi_n^{(2)}\left(\mathbf{x}_{k-1}\right) P\left(x_k, \mathbf{x}_{k-1}\right) dx_k d\mathbf{x}_{k-1}, \qquad (3)$$

where $\mathbf{n} \triangleq (n_1, n_2, \cdots, n_p)$, $\sum_{\mathbf{n}=\mathbf{0}}^{\infty} \triangleq \sum_{n_1=0}^{\infty} \sum_{n_2=0}^{\infty} \cdots \sum_{n_p=0}^{\infty}$.

Now, two function $\psi_m^{(1)}(x_k)$ and $\psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1})$ are orthonormal polynomials satisfying the following orthonormality conditions:

$$\int \psi_m^{(1)}(x_k)\psi_n^{(1)}(x_k)P_0(x_k)dx_k = \delta_{mn} , \tag{4}$$

$$\iint \cdots \int \psi_{\mathbf{m}}^{(2)}(\mathbf{x}_{k-1})\psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1})P_0(\mathbf{x}_{k-1})d\mathbf{x}_{k-1} = \prod_{i=1}^{p} \delta_{m_i n_i} \quad \left(\mathbf{m} \triangleq (m_1, m_2, \cdots, m_p)\right). \tag{5}$$

All sort of linear and nonlinear correlation information concerned with the regression between x_k and $\mathbf{x}_{k-1}$ are reflected hierarchically on each expansion coefficients $A_{m\mathbf{n}}$.

Forming the marginal pdf of Eq. (3), the pdf $P(\mathbf{x}_{k-1})$ for $\mathbf{x}_{k-1}$ is given easily as

$$P(\mathbf{x}_{k-1}) = \int P(x_k, \mathbf{x}_{k-1})dx_k = P_0(\mathbf{x}_{k-1}) \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}). \tag{6}$$

Using the well-known Bayes' theorem [13] (see Appendix III), the conditional pdf $P(x_k|\mathbf{x}_{k-1})$, which is essential in extracting various types of linear and nonlinear correlation information, is given as follows in the expanded form using Eq. (3) and (6):

$$\begin{aligned} P(x_k|\mathbf{x}_{k-1}) &= P(x_k, \mathbf{x}_{k-1}) / P(\mathbf{x}_{k-1}) \\ &= P_0(x_k) \sum_{m=0}^{\infty} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{m\mathbf{n}} \psi_m^{(1)}(x_k) \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) \Big/ \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}). \end{aligned} \tag{7}$$

Then, the desired regression relation $\hat{x}_k$ is given by Eq.(1) and its coefficient c_m is constant in the expansion expression using the j-th orthogonal polynomial $\psi_{\mathrm{n}}^{(1)}(x_k)$ of x_k (satisfying the orthonormal condition (4)), as follows:

$$\hat{x}_k = \sum_{m=0}^{1} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{m\mathbf{n}} c_m \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) \Big/ \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}), \; x_k = \sum_{j=0}^{\infty} c_j \psi_j^{(1)}(x_k) . \tag{8),(9}$$

By Eqs. (2) and (8), the new autoregression model for the stochastic process x_k can be easily given as follows:

$$x_k = \left[\sum_{m=0}^{1} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{m\mathbf{n}} c_m \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) \Big/ \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) \right] + \varepsilon_k \quad . \tag{10}$$

Here, ε_k is the white noise diagnosis input to the forementioned autoregression model (white noise with mean 0). Viewed from the standpoint of applying the constructed model, it is easy to show that it is the same as the prediction error defined by Eq. (2). The reasoning is similar to the analysis of the ordinary well-known AR model.

2.2. Development of autoregression model using one-variate Hermite expansion type distribution

Gaussian distribution, which is one of the most typically standard type probability distributions, is used as the reference distribution $P_0(x_k)$ and $P_0(x_{k-1})$ (employed as only the 1st expansion term). Then,

$$P_0(x_k) = N(x_k; \mu, \sigma^2), \; P_0(\mathbf{x}_{k-1}) = \prod_{i=1}^{p} N(x_{k-i}; \mu, \sigma^2), \tag{11), (12}$$

$$\text{where } N(x; \mu, \sigma^2) \triangleq \exp\left\{-(x-\mu)^2 / 2\sigma^2\right\} \Big/ \sqrt{2\pi}\sigma \tag{13}$$

with $\mu \triangleq \langle x_{k-i} \rangle$, $\sigma^2 \triangleq \left\langle (x_{k-i} - \mu)^2 \right\rangle$; stationarity ($i$=0,1,2,...,$p$).

The orthonormal polynomials satisfying Eqs. (4) and (5) are the well-known Hermite Polynomials:

$$\psi_m^{(1)}(x_k) = \frac{1}{\sqrt{m!}} H_m\left((x_k - \mu)/\sigma\right), \psi_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) = \prod_{i=1}^{p} \frac{1}{\sqrt{n_i!}} H_{n_i}\left((x_{k-i} - \mu)/\sigma\right). \quad (14), (15)$$

The pdf of x_k and $\mathbf{x}_{k\text{-}1}$ are represented by statistical Hermite expansions, which can handle any non-Gaussian distribution [12]. Eq. (9) is written as

$$x_k = \sum_{j=0}^{1} c_j \frac{1}{\sqrt{j!}} H_j\left((x_k - \mu)/\sigma\right) \ (c_0 = \mu, c_1 = \sigma). \quad (16)$$

By substituting Eqs. (11) to (16) into Eq. (10), the objective time series regression model is developed as follows:

$$x_k = \mu + \left[\sigma \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{1\mathbf{n}} \prod_{i=1}^{p} \frac{1}{\sqrt{n_i}} H_{n_i}\left((x_{k-i} - \mu)/\sigma\right) \Big/ \sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} \prod_{i=1}^{p} \frac{1}{\sqrt{n_i}} H_{n_i}\left((x_{k-i} - \mu)/\sigma\right) \right] + \varepsilon_k \quad (17)$$

with

$$A_{m\mathbf{n}} = \left\langle \left[H_m\left((x_k - \mu)/\sigma\right)/\sqrt{m!} \right] \prod_{i=1}^{p} \left[H_{n_i}\left((x_{k-i} - \mu)/\sigma\right)/\sqrt{n_i!} \right] \right\rangle$$

$$= \iint \cdots \int \left[H_m\left((x_k - \mu)/\sigma\right)/\sqrt{m!} \right] \prod_{i=1}^{p} \left[H_{n_i}\left((x_{k-i} - \mu)/\sigma\right)/\sqrt{n_i!} \right]$$

$$\cdot P\left(x_k, x_{k-1}, \cdots, x_{k-p}\right) dx_k dx_{k-1} \cdots dx_{k-p}. \quad (18)$$

Next, consider the relation of the foregoing expression to the well-known AR model. Consider in particular, the case of p=1 and assume that x_k follows the Gaussian stochastic process. Then, Eq. (18) is written as

$$A_{mn} = \left(\gamma_1/\sigma^2\right)^m \delta_{mn}, \gamma_1 \triangleq \left\langle \left(x_k - \mu\right)\left(x_{k-1} - \mu\right) \right\rangle. \quad (19)$$

Considering A_{00}=1, Eq. (17) is modified as follows:

$$x_k - \mu = r_1\left(x_{k-1} - \mu\right)/\sigma^2 + \varepsilon_k. \quad (20)$$

Letting μ=0 in the foregoing expression, the result is the same as the well-known one-variate AR model for p=1.

In the ordinary multidimensional AR model, the linear correlation information among variables $x_{k\text{-}i}$ (i=1,2,…,p) are reflected on the parameters a_i. To establish a non-Gaussian nonlinear time series regression model generalizing the forementioned model including the model in the first expansion term, the first term of $P_0(x_{k\text{-}1})$ of the expansion should be analyzed at the start for the multidimensional correlation information of Gaussian distribution, reflecting the linear correlation information among multivariables. The derivation analysis is shown in subsection 2.3.

In this case, the product of independent Gaussian distribution is used as $P_0(\mathbf{x}_{k\text{-}1})$ as shown in Eq. (12) and the linear correlation information among the variables is not reflected at all in the first term of the expansion. Consequently, when $\mathbf{x}_{k\text{-}1}$ is of multidimension ($p \geqq 2$), the model cannot be generalized by an expansion with finite number of expansion terms including the well-known AR model in the first expansion term. In this sense, the match to the AR model is shown only for the one-variable case (p=1), where the correlation information among variables need not be considered at all.

2.3. Development of autoregression model using multivariate Hermite expansion type distribution [10]

The purpose of the development is that as much statistical information as possible should be reflected on the reference pdf $P_0(\mathbf{x}_{k\text{-}1})$, which is placed at the first term of the expansion in the series expansion distribution representation to aim a rapid convergency of expansion too. The following (correlative) multidimensional Gaussian distribution is used instead of Eq. (12):

$$\left.\begin{aligned}
&P_0\left(\mathbf{x}_{k-1}\right)=N\left(\mathbf{x}_{k-1};\mu,\mathbf{R}\right)\underline{\underline{\Delta}}\frac{1}{\left(2\pi\right)^{p/2}\left|\mathbf{R}\right|^{1/2}}\exp\left\{-\frac{1}{2}\left(\mathbf{x}_{k-1}-\mu\right)^T\mathbf{R}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right\}\\
&\text{with}\\
&\mu\underline{\underline{\Delta}}\left(\mu,\mu,\cdots,\mu\right)^T,\\
&\mathbf{R}\underline{\underline{\Delta}}\left\langle\left(\mathbf{x}_{k-1}-\mu\right)\left(\mathbf{x}_{k-1}-\mu\right)^T\right\rangle=\begin{bmatrix} r_0 & r_1 & r_2 & \cdots & r_{p-1}\\ r_1 & r_0 & r_1 & \cdots & r_{p-2}\\ r_2 & r_1 & r_0 & \cdots & r_{p-3}\\ \vdots & \vdots & \vdots & & \vdots\\ r_{p-1} & r_{p-2} & r_{p-3} & \cdots & r_0\end{bmatrix},\\
&r_i\underline{\underline{\Delta}}\left\langle\left(x_k-\mu\right)\left(x_{k-i}-\mu\right)\right\rangle\quad\left(r_0=\sigma^2\right).
\end{aligned}\right\}\tag{21}$$

Then, the pdf of $\mathbf{x}_{k\text{-}1}$ is given by the well-known distribution representation by the multidimensional Hermite expansion

$$P\left(\mathbf{x}_{k-1}\right)=N\left(\mathbf{x}_{k-1};\mu,\mathbf{R}\right)\sum_{\mathbf{n=0}}^{\infty}\frac{b_{n_1n_2\cdots n_p}}{n_1!n_2!\cdots n_p!}H_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}\left(\mathbf{x}_{k-1}-\mu\right)\right),\tag{22}$$

where $\tilde{\mathbf{R}}$ is the upper triangular matrix satisfying the following relation (this decomposition is possible since $\mathbf{R}$ is a positive-definite matrix):

$$\mathbf{R}=\tilde{\mathbf{R}}\tilde{\mathbf{R}}^T.\tag{23}$$

Thus, $H_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right)$ and $b_{n_1n_2\cdots n_p}$ are the multidimensional Hermite polynomial and quasi-moment function [14], respectively, which are defined by

$$\begin{aligned}
&H_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right)\underline{\underline{\Delta}}\left(-1\right)^{n_1+n_2+\cdots+n_p}\\
&\cdot\exp\left\{-\frac{1}{2}\left(\mathbf{x}_{k-1}-\mu\right)^T\mathbf{R}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right\}\frac{\partial^{n_1+n_2+\cdots+n_p}}{\partial x_{k-1}^{n_1}\partial x_{k-2}^{n_2}\cdots\partial x_{k-p}^{n_p}}\exp\left\{-\frac{1}{2}\left(\mathbf{x}_{k-1}-\mu\right)^T\mathbf{R}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right\},
\end{aligned}\tag{24}$$

where

$$\left.\begin{aligned}
&b_{n_1n_2\cdots n_p}\underline{\underline{\Delta}}\iint\cdots\int G_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right)P\left(\mathbf{x}_{k-1}\right)d\mathbf{x}_{k-1},\\
&G_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)\right)\underline{\underline{\Delta}}\left.G^*_{n_1n_2\cdots n_p}\left(\tilde{\mathbf{R}}^T\mathbf{Z}\right)\right|_{\mathbf{Z}\to\mathbf{R}^{-1}\left(\mathbf{x}_{k-1}-\mu\right)},\\
&G^*_{n_1n_2\cdots n_p}\left(\mathbf{R}^T\mathbf{Z}\right)\underline{\underline{\Delta}}\left(-1\right)^{n_1+n_2+\cdots+n_p}e^{\frac{1}{2}\mathbf{Z}^T\mathbf{R}\mathbf{Z}}\frac{\partial^{n_1+n_2+\cdots+n_p}}{\partial Z_1^{n_1}\partial Z_2^{n_2}\cdots\partial Z_p^{n_p}}\exp\left\{-\mathbf{Z}^T\mathbf{R}\mathbf{Z}/2\right\}.
\end{aligned}\right\}\tag{25}$$

Then, the time-series regression model for the scalar stochastic variable x_k in Eq. (10) is developed as follows:

$$x_k = \mu + \sigma \frac{\sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{1\mathbf{n}} H_{n_1 n_2 \cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right) \prod_{i=1}^{p} 1/\sqrt{n_i!}}{\sum_{\mathbf{n}=\mathbf{0}}^{\infty} A_{0\mathbf{n}} H_{n_1 n_2 \cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right) \prod_{i=1}^{p} 1/\sqrt{n_i!}} + \varepsilon_n \tag{26}$$

with

$$A_{m\mathbf{n}} = \left\langle \frac{1}{m!} H_m\left(\frac{x_k - \mu}{\sigma}\right) \frac{1}{\sqrt{n_1! n_2! \cdots n_p!}} G_{n_1 n_2 \cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_k - \mu\right)\right) \right\rangle$$

$$= \iint \cdots \int \frac{1}{m!} H_m\left(\frac{x_k - \mu}{\sigma}\right) \frac{1}{\sqrt{n_1! n_2! \cdots n_p!}} G_{n_1 n_2 \cdots n_p}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_k - \mu\right)\right) P\left(x_k, \mathbf{x}_{k-1}\right) dx_k d\mathbf{x}_{k-1}. \tag{27}$$

Especially when x_k is the Gaussian process, the expansion coefficients in Eq. (26) are given as follows:

$$A_{0\mathbf{n}} = \begin{cases} 1 & \left(\text{if } n_1 = n_2 = \cdots = n_p = 0\right) \\ 0 & \left(\text{otherwise}\right) \end{cases} \tag{28}$$

and

$$A_{1\mathbf{n}} = \begin{cases} r_i/\sigma & \left(\text{if } n_i = 1 \text{ and } n_j = 0\left(i \neq j\right) \text{ for any } i\right) \\ 0 & \left(\text{otherwise}\right) \end{cases}. \tag{29}$$

By definition, the lower-order multidimensional Hermite polynomials are given as follows:

$$H_{00\cdots 0}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right) = 1, \tag{30}$$

$$\mathbf{H}_1\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right) \triangleq \left[H_{10\cdots 0}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right), H_{01\cdots 0}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right), \cdots, H_{00\cdots 1}\left(\tilde{\mathbf{R}}^{-1}\left(\mathbf{x}_{k-1} - \mu\right)\right)\right]^T$$
$$= \mathbf{R}^{-1}\left(\mathbf{x}_{k-1} - \mu\right). \tag{31}$$

Substituting Eqs. (28) to (31) into Eq. (26), we directly have

$$x_k - \mu = \left[r_1, r_2, \cdots, r_p\right] \mathbf{R}^{-1}\left(\mathbf{x}_{k-1} - \mu\right) + \varepsilon_k = -\sum_{i=1}^{p} a_i\left(x_{k-i} - \mu\right) + \varepsilon_k. \tag{32}$$

Letting μ=0, the foregoing expression coincides with the AR model. In other words, when the stochastic process is Gaussian, Eqs. (26) and (27) agree with the well-known AR model. In other words, the autoregression model proposed in this paper includes the well-known multi-variates AR model as a special case. Theoretically, this suggests partly the validity of the proposed model.

2.4. Another autoregression model based on marginal distribution

2.4.1. General theory

As the reference distribution $P_0(x_k)$ and $P_0(\mathbf{x}_{k-1})$ in subsection 2.1, the marginal distribution for x_k and $\mathbf{x}_{k-1}$ are employed intentionally in the following. In other words, based on the product of $P_0(x_k)$ and $P_0(\mathbf{x}_{k-1})$, the joint pdf $P(x_k,\mathbf{x}_{k-1})$ can be represented in expanded form as follows:

$$P\left(x_k, \mathbf{x}_{k-1}\right) = P\left(x_k\right) P\left(\mathbf{x}_{k-1}\right) \sum_{m=0}^{\infty} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} B_{m\mathbf{n}} \theta_m^{(1)}\left(x_k\right) \theta_{\mathbf{n}}^{(2)}\left(\mathbf{x}_{k-1}\right) \tag{33}$$

with

$$B_{m\mathbf{n}} = \left\langle \theta_m^{(1)}\left(x_k\right) \theta_{\mathbf{n}}^{(2)}\left(\mathbf{x}_{k-1}\right) \right\rangle,$$

where $\theta_m^{(1)}(x_k)$ and $\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1})$ are orthonogonal polynomials satisfying the following relations:

$$\int \theta_m^{(1)}(x_k)\theta_n^{(1)}(x_k)P(x_k)dx_k = \delta_{mn}\ , \tag{34}$$

$$\iint\cdots\int \theta_{\mathbf{m}}^{(2)}(\mathbf{x}_{k-1})\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1})P(\mathbf{x}_{k-1})d\mathbf{x}_{k-1} = \prod_{i=1}^{p}\delta_{m_i n_i}\ . \tag{35}$$

Then, the conditional pdf $P(x_k|\mathbf{x}_{k-1})$ is given by

$$P(x_k|\mathbf{x}_{k-1}) = P(x_k)\sum_{m=0}^{\infty}\sum_{\mathbf{n}=\mathbf{0}}^{\infty}B_{m\mathbf{n}}\theta_m^{(1)}(x_k)\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}). \tag{36}$$

Using the foregoing expression and by the same derivation as in subsection 2.2, the regressive relation for x_k and $\mathbf{x}_{k-1}$ is given as follows:

$$x_k = \sum_{m=0}^{1}\sum_{\mathbf{n}=\mathbf{0}}^{\infty}B_{m\mathbf{n}}d_m\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}), \tag{37}$$

where d_m is the expansion coefficient in the expansion representation:

$$x_k = \sum_{j=0}^{1}d_j\theta_j^{(1)}(x_k), \tag{38}$$

which corresponds to Eq. (9). Thus, the following another autoregression model can be derived from Eqs. (2) and (37):

$$x_k = \sum_{m=0}^{1}\sum_{\mathbf{n}=\mathbf{0}}^{\infty}B_{m\mathbf{n}}d_m\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) + \varepsilon_k\ , \tag{39}$$

where ε_k is the white noise with mean 0.

2.4.2. Development of autoregression model (development by statistical Hermite expansion distribution representation)

The pdf for x_k and $\mathbf{x}_{k-1}$ are represented as follows, in the general representation form which can handle any type of non-Gaussian distribution:

$$P(x_k) = N(x_k;\mu,\sigma^2)\sum_{m=0}^{\infty}\alpha_m^{(1)}H_m\left((x_k-\mu)/\sigma\right),\ \alpha_m^{(1)} \triangleq \left\langle H_m\left((x_k-\mu)/\sigma\right)/\sqrt{m!}\right\rangle, \tag{40}$$

and

$$P(\mathbf{x}_{k-1}) = \prod_{i=1}^{p}N(x_{k-1};\mu,\sigma^2)\sum_{\mathbf{n}=\mathbf{0}}^{\infty}\alpha_{\mathbf{n}}^{(2)}\prod_{i=1}^{p}H_{n_i}\left((x_{k-i}-\mu)/\sigma\right)/\sqrt{n_i!} \tag{41}$$

with

$$\alpha_{\mathbf{n}}^{(2)} \triangleq \left\langle \prod_{i=1}^{p}H_{n_i}\left((x_{k-i}-\mu)/\sigma\right)/\sqrt{n_i!}\right\rangle. \tag{42}$$

As to the linearly independent series of polynomials to compose the orthonormal polynomials satisfying Eqs. (34) and (35), the following Hermite polynomials are employed, since Gaussian distribution is placed in the first term of expansion representations (40) and (42) ($\mathbf{l} \triangleq (l_1, l_2, \cdots, l_p)$):

$$\theta_m^{(1)}(x_k) = \sum_{j=0}^{m}\lambda_{mj}^{(1)}H_j\left((x_k-\mu)/\sigma\right)/\sqrt{j!}\ , \tag{43}$$

$$\theta_{\mathbf{n}}^{(2)}(\mathbf{x}_{k-1}) = \sum_{\mathbf{l}=\mathbf{0}}^{\mathbf{n}}\lambda_{\mathbf{nl}}^{(2)}\prod_{i=1}^{p}H_{l_i}\left((x_{k-i}-\mu)/\sigma\right)/\sqrt{l_i}\ . \tag{44}$$

The coefficients $\lambda_{mj}^{(1)}$ and $\lambda_{\mathbf{nl}}^{(2)}$ are calculated beforehand by a well-known Schmidt's orthogonalization.

Then, Eq. (38) is given by

$$x_k = \sum_{j=0}^{1} \sum_{i=0}^{j} d_j \lambda_{ji}^{(1)} H_i\left(\left(x_k - \mu\right)/\sigma\right)/\sqrt{i!},\ \left(d_0 = \mu/\lambda_{00} - \sigma\lambda_{10}/\lambda_{00}\lambda_{11},\ d_1 = \sigma/\lambda_{11}\right). \tag{45}$$

The time series regression model (39) for x_k can be explicitly developed as follows:

$$x_k = \left[\sum_{m=0}^{1} \sum_{\mathbf{n}=\mathbf{0}}^{\infty} \sum_{\mathbf{l}=\mathbf{0}}^{\mathbf{n}} B_{m\mathbf{n}} d_m \lambda_{\mathbf{nl}}^{(2)} \prod_{i=1}^{p} H_{l_i}\left(\left(x_{k-i} - \mu\right)/\sigma\right)/\sqrt{l_i}\right] + \varepsilon_k \tag{46}$$

with

$$B_{m\mathbf{n}} = \left\langle \sum_{j=0}^{m} \sum_{\mathbf{l}=\mathbf{0}}^{\mathbf{n}} \left[\lambda_{mj}^{(1)} \lambda_{\mathbf{nl}}^{(2)} H_j\left(\left(x_k - \mu\right)/\sigma\right)/\sqrt{j!}\right] \prod_{i=1}^{p} \left[H_{l_i}\left(\left(x_{k-i} - \mu\right)/\sigma\right)/\sqrt{l_i!}\right] \right\rangle. \tag{47}$$

2.5. Application to sound environmental field [8–10]

To examine in principle the practical usefulness of the time series regression model proposed in this paper, the method is applied to the sound environment data, which is an example of the non-Gaussian stochastic process. The content of the experiment is as follows. The following data are used.

1) Sound data recorded in a sound experiment laborlatory (called data 1),
2) Sound data recorded from home-use washer (called data 2).

Using the autoregression model of Eqs. (17) and (18) as well as Eqs. (26) and (27), the sequential prediction of the time-series data is attempted. The real situation of our experiment and related evaluation of prediction error are given in more detail in Appendix IV.

Figure 1 shows an example of sequential prediction of the time series. The results are compared to those of the well-known AR model; M is the number of terms in the expansion. It can be seen from the result of experiment that a better prediction result is obtained by the proposed model than the traditional AR model. It should be noted that the prediction error in the proposed method is completely equal to that of the traditional AR model when M=2, which obviously indicates that the prediction error decreases gradually by considering a larger number of expansion coefficients.

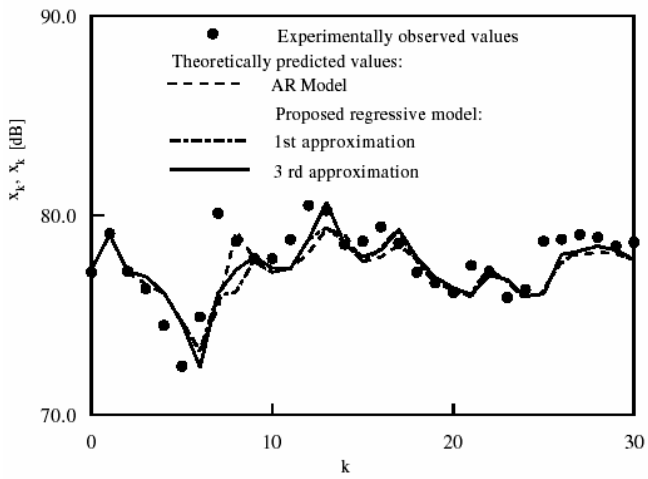

Figure 1.

A comparison between the theoretically predicted values and the experimentally observed values for the actual time series

2.6. Probability distribution prediction once after correlation analysis based on idea of "Relationism-First"

It can be obviously seen from Figure 2 that data 2 are strongly non-Gaussian, and a considerable error is produced if only the Gaussian distribution of the first expansion term is used. That is, it seems to be necessary to apply the proposed method, which considers the higher-order statistical information and the nonlinear correlation information. Accordingly, some effectiveness of the background idea: "Relationism-First" (to Individualism-2nd) has been partly proved through this principle experiment in time region analysis.

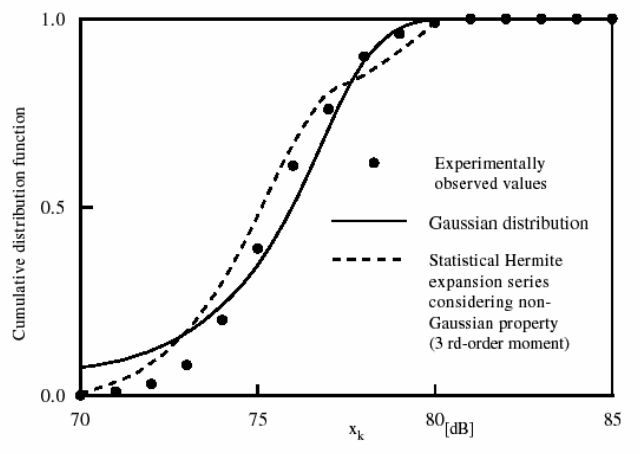

Figure 2.

Cumulative distribution function of data 2

3. MUTUAL CORRELATION IN SPACE REGION (EX. LIGHT, SOUND AND EM FIELDS)

From the methodological viewpoint, it is desirable that our analytical method can be easily extended to the problems with arbitrary number of environmental indexes and environmental factors not only in the fields of the same kind but also in the fields of the different kind including the humanities. To cope with actual problems, this must be necessary in principle. However, in this paper, as a trial at an early stage of our study, the proposed method is limited to the analysis of the correlation between only two environmental physic factors.

3.1. General theory: spatial regression model of orthonormally expanded regression type

Let us consider the electrified modern living environment of closed room type especially under the exposure of electromagnetic (abbr. EM), sound and light waves leaked from VDT under playing the game on a personal computer [11, 12] (notice that light wave is discriminated from EM wave only technically in the international law of EMC, differing from a pure scientific field).

For the evaluation of such an environment under exposure of EM, sound and light fields, it is necessary to know the mutual correlation information between environmental factors as minutely as hierarchically as possible based on the idea of "Relationism-First". Since originally these environmental factors fluctuate in a non-Gaussian distribution form, it is difficult to find this correlation minutely only by employing the usual standard type correlation analysis based on the idea of "Artificial Operation Facility First" in contrast to the above "Relationism-First", in terms of only linear type regression function. So, in this paper, let us introduce a general correlation analysis hierarchically including all sort of correlation) based on the idea of "Relationism-First", by limiting in trial the problem between two special random variables. In general, the correlation between two random variables x and y can be

determined completely in terms of the conditional pdf, $P(y|x)$, of y conditioned by x or $P(x|y)$, of x conditioned by y:

$$P(y|x) = P(x,y)/P(x),\ P(x|y) = P(x,y)/P(y), \tag{48}$$

where $P(x,y)$ and $P(x)$ or $P(y)$ denote the joint pdf of x and y, and the pdf of x or y, respectively. In order to get the hierarchical expansion type general expression for this conditional pdf, let us expand it into orthonormal series expansion form in the same way as in subsection 2.1:

$$P(x,y) = P_0(x)P_0(y)\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)\varphi_n^{(2)}(y),\ A_{mn} = \left\langle \varphi_m^{(1)}(x)\varphi_n^{(2)}(y)\right\rangle, \tag{49), (50}$$

where <> denotes the expectation operation with respect to x and y, and $\varphi_m^{(1)}(x)$ and $\varphi_n^{(2)}(y)$ denote two orthonormal functions $P_0(x)$ and $P_0(y)$, respectively, satisfying the orthonormal relationship:

$$\int_{-\infty}^{\infty}\varphi_m^{(1)}(x)\varphi_n^{(1)}(x)P_0(x) = \delta_{mn},\ \int_{-\infty}^{\infty}\varphi_m^{(2)}(y)\varphi_n^{(2)}(y)P_0(y)dy = \delta_{mn}. \tag{51), (52}$$

Here, δ_{mn} denotes Kronecker's delta. When x and y fluctuate dominantly in a Gaussian distribution form, $\varphi_m^{(1)}(x)$ and $\varphi_n^{(2)}(y)$ are given as follows:

$$\varphi_m^{(1)}(x) = H_m\left((x-\mu_x)/\sigma_x\right)/\sqrt{m!},\ \varphi_n^{(2)}(y) = H_n\left((y-\mu_y)/\sigma_y\right)/\sqrt{n!}, \tag{53), (54}$$

where $H_m()$ denotes the m-th order Hermite polynomial, and μ_x, μ_y are means of x and y, respectively. Also, σ_x and σ_y are standard deviations of x and y, respectively. From Eq. (49), the marginal pdf $P(x)$ of x is expressed as follows:

$$P(x) = \sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}(x). \tag{55}$$

Upon substituting Eqs. (49) and (55) into Eq. (48), we can obtain

$$P(y(x) = P_0(y)\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)\varphi_n^{(2)}(y)\Big/\sum_{m-0}^{\infty} A_{m0}\varphi_m^{(1)}(x). \tag{56}$$

This determines all sort of correlation of y to x. To determine the mutual correlation between x and y, moreover, the conditional pdf $P(x|y)$ is needed. In the similar way, the conditional pdf $P(x|y)$ of x conditioned by y can be obtained such as

$$P(x|y) = P_0(x)\sum_{m-0}^{\infty}\sum_{n=0}^{\infty} A_{mn}\varphi_m^{(1)}(x)\varphi_n^{(2)}(y)\Big/\sum_{n=0}^{\infty} A_{0n}\varphi_n^{(2)}(y). \tag{57}$$

3.2. Various type regression function

Now, let us derive concretely various type of regression function. The average tendency in some sense between x and y can be grasped by these. In order to derive the regression function y^k(k=1,2,…) with respect to x in advance, let us expand y^k such as

$$y^k = \sum_{i=0}^{k} C_{ki}\varphi_i^{(2)}(y). \tag{58}$$

To obtain the regression function, we can calculate the conditional expectation $\left\langle y^k \middle| x\right\rangle$. Upon employing Eqs. (51), (52) and (58), we obtain the objective expression:

$$\left\langle y^k \middle| x\right\rangle = \sum_{m=0}^{\infty}\sum_{n=0}^{k} C_{kn}A_{mn}\varphi_m^{(1)}\Big/\sum_{m=0}^{\infty} A_{m0}\varphi_m^{(1)}. \tag{59}$$

In the similar way, upon expanding x^l such as

$$x^l = \sum_{j=0}^{l} D_{ij} \varphi_j^{(1)}(x), \tag{60}$$

we can obtain the inverse regression function:

$$\langle x^l | y \rangle = -\sum_{n=0}^{\infty} \sum_{m=0}^{l} D_{lm} A_{mn} \varphi_n^{(2)}(y) \Big/ \sum_{n=0}^{\infty} A_{0n} \varphi_n^{(2)}(y). \tag{61}$$

Especially, when two Gaussian distribution forms are chosen as $P_0(x)$ and $P_0(y)$ as stated in subsection 2.2, Eqs. (59) and (61) reduce to the following concrete forms, respectively:

$$\langle y | x \rangle = \mu_y + \left\{ \sigma_y \sum_{m=0}^{\infty} \left[A_{m1} H_m\left((x-\mu_x)/\sigma_x \right) / \sqrt{m!} \right] \Big/ \sum_{m=0}^{\infty} \left[A_{m0} H_m\left((x-\mu_x)/\sigma_x \right) / \sqrt{m!} \right] \right\} \tag{62}$$

and

$$\langle x | y \rangle = \mu_x + \left\{ \sigma_x \sum_{n=0}^{\infty} \left[A_{1n} H_n\left((y-\mu_y)/\sigma_y \right) / \sqrt{n!} \right] \Big/ \sum_{n=0}^{\infty} \left[A_{0n} H_n\left((y-\mu_y)/\sigma_y \right) / \sqrt{n!} \right] \right\}. \tag{63}$$

3.3. Objective probability prediction once after correlation analysis based on idea of "Relationism-First"

Once after employing mutual correlation information in the above, the whole probability distribution of only one variable can be obtain in an individual form. First, let us estimate the probability distribution of y from the fluctuation of x. Upon integrating Eq. (56) with respect to x, it can be expressed as follows:

$$P_s(y) = P_0(y) \sum_{i=0}^{\infty} E_i \varphi_i^{(2)}(y) \tag{64}$$

with

$$E_i = \left\langle \sum_{m=0}^{\infty} A_{mi} \varphi_m^{(1)}(x) \Big/ \sum_{m=0}^{\infty} A_{m0} \varphi_m^{(1)}(x) \right\rangle_x, \tag{65}$$

where $P_s(y)$ denotes the estimated pdf of y and $< >_x$ denotes an expectation operation with respect to x. In the similar way, the estimated pdf $P_s(x)$ can be obtained as follows:

$$P_s(x) = P_0(x) \sum_{j=0}^{\infty} F_j \varphi_j^{(1)}(x) \tag{66}$$

with

$$F_j = \left\langle \sum_{n=0}^{\infty} A_{jn} \varphi_n^{(2)}(y) \Big/ \sum_{n=0}^{\infty} A_{0n} \varphi_n^{(2)}(y) \right\rangle_y, \tag{67}$$

where $< >_y$ denotes an expectation operation with respect to y. When two Gaussian distribution forms are especially chosen as $P_0(x)$ and P_0(y), Eqs. (64) and (66) reduce to the following forms, respectively:

$$P_s(y) = \left[1 \Big/ \left(\sqrt{2\pi}\sigma_y \right) \right] \exp\left\{ -\left(y-\mu_y \right)^2 \Big/ \sigma_y^2 \right\} \left\{ 1 + \sum_{i=1}^{\infty} E_j H_j\left((y-\mu_y)/\sigma_y \right) / \sqrt{i!} \right\} \tag{68}$$

with

$$E_i = \left\langle \left[\sum_{m=0}^{\infty} A_{mi} H_m\left((y-\mu_y)/\sigma_y \right) / \sqrt{m!} \right] \Big/ \left[\sum_{m=0}^{\infty} A_{m0} H_m\left(y-\mu_y/\sigma_y \right) / \sqrt{m!} \right] \right\rangle, \tag{69}$$

and

$$P_s(x) = 1\Big/\left(\sqrt{2\pi}\sigma_x\right)\exp\left\{-(x-\mu_x)^2\Big/\sigma_x^2\right\}\left\{1+\sum_{j=1}^{\infty}F_j\,H_j\left((x-\mu_x)/\sigma_x\right)\Big/\sqrt{j!}\right\} \tag{70}$$

with

$$F_j = \left\langle\left[\sum_{n=0}^{\infty}A_{jn}H_n\left((x-\mu_x)/\sigma_x\right)\Big/\sqrt{n!}\right]\Big/\left[\sum_{n=0}^{\infty}A_{0n}H_n\left((x-\mu_x)/\sigma_x\right)\Big/\sqrt{n!}\right]\right\rangle. \tag{71}$$

3.4. Application to electromagnetic, sound and light waves leaked from VDT

We have applied the proposed method to the environment under the exposure of electromagnetic, sound and light waves leaked from VDT under playing the game on a personal computer (sometimes by expecting faintly that this method may be some future help of the explanation of VDT syndrome). We have experimented in a usual laboratory. We have measured either when only one personal computer has been operated or when two personal computers have been operated. In each case, the rms-value of electric field, the sound pressure level and illuminance of light have been sampled at every 10 second, and 500 sets of data have been obtained. We have employed HI-3603 VDT/VLF Radiation Survey Meter (Holaday Industries, Inc.) for the measurement of the electric field strength [11, 12].

By applying Eqs. (62) and (63) to the first 400 sets of data, we have obtained the regression curves of electric field strength to the sound pressure level, sound pressure level to electric field strength, electric field strength to illuminance of light and illuminance of light to electric field strength. These theoretical curves have been compared to experimental conditional expectations. The results when only one computer has been operated are shown in Figures 3, 4, 5 and 6.

These theoretical regression curves in each figure have been calculated by truncating the series expansion form in the denominator up to the 8-th order polynomial and taking the first expansion term, from the first expansion term to the 2-nd expansion term, from the first expansion term to the 3-rd expansion term and from the first expansion term to the 4-th expansion term in the series form in Eqs. (62) and (63) and they are called ad the 1-st approximation, the 2-nd approximation, the 3-rd approximation and the 4-th approximation.

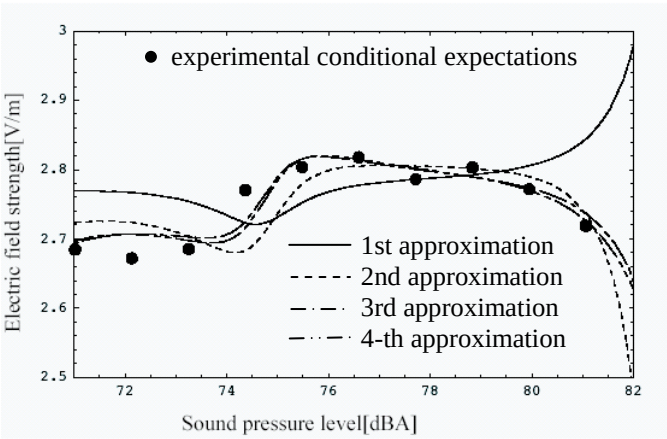

Figure 3.

A comparison between theoretical regression function of electric field strength to sound pressure level

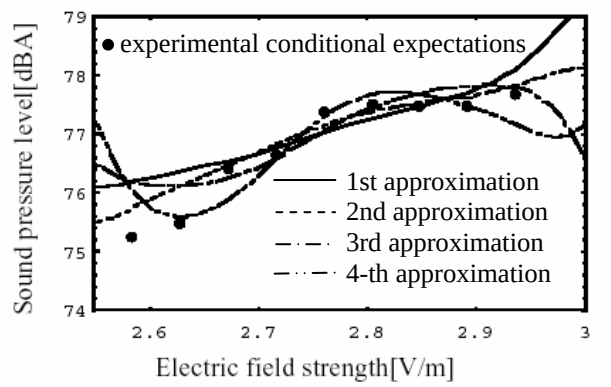

Figure 4.

A comparison between theoretical regression function of sound pressure level to electric field strength

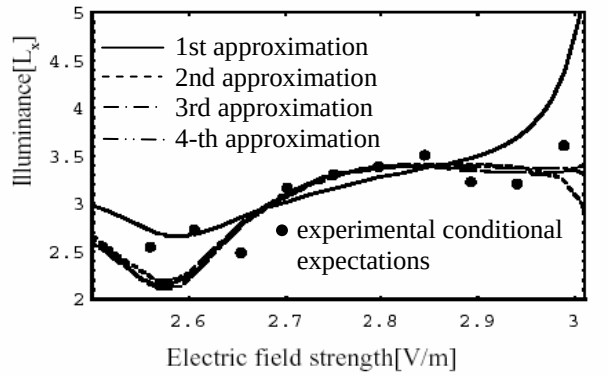

Figure 5.

A comparison between theoretical regression function of illuminance to electric field strength

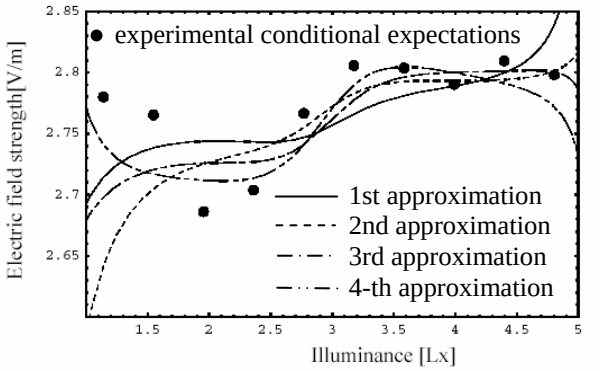

Figure 6.

A comparison between theoretical regression function of electric field strength to illuminance

Next, by applying Eqs. (64) and (66) to the first 400 sets of data, we have estimated the probability distribution of the electric field strength based on sound pressure level fluctuation and the one of sound pressure level based on electric field strength. Here, we have employed the lower and higher order mutual correlation information A_{mn}. The results when only one computer has been operated are shown in Figure 7.

The theoretically estimated pdf has been calculated by replacing the series of right hand side in Eqs. (68) and (70) with no expansion term, from the first expansion term to the 3rd expansion term and from the first expansion tern to the 6-th expansion term (they are called as the 1st approximation, 4-th approximation and 7-th approximation). Then, E_i and F_j have been calculated by truncating the series of the denominator up to the 8-th polynomial and the series of numerator up to the 6-th polynomial in Eqs. (69) and (71).

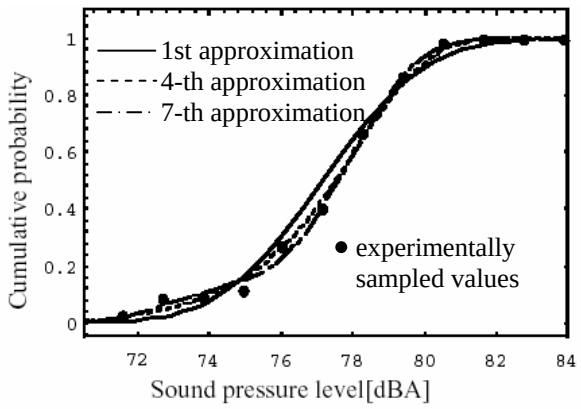

Figure 7.

A comparison between the theoretically estimated cumulative probability distribution curves of sound pressure level based on the electric field strength fluctuation

In this experiment, although environmental factors have fluctuated in non-Gaussian distribution form and the linear correlation quantity has been rather small, as expected usually only in each individual (professional) sense, by using hierarchically many of the higher order mutual correlations following to the proposed method, the whole probability distribution form could be well estimated individually. That is, it has been shown that the proposed method is useful for the correlation analysis of the environment under EM, sound and light field exposure. Accordingly, some effectiveness of the background idea: “Relationism-First” to Individualism-2nd” has been partly proved through this principle experiment in space region analysis.

4. CONCLUSIONS

In this paper, partly suggested by the well-known philosophical emphasis of Herakleitos and Hegel and etc. (i.e., several of famous other philosophers) [15] based on their original standpoint that the truth exists not in fragmentarily individual things but only in their relational fact or process (i.e., event) itself with some concrete self-exercise of existing contradiction, we have stated that a central core and/or primary existence is not only mutual intermediation of time series type between past and present, but also mutual intermediation (i.e. relationship) in space region among different environmental factors(even if apparently it seems to have no connection according to only individual professional sense). That is, such a viewpoint of “Relationism-First” seems to be exceedingly important to all things including our human being evolving after the beginning of only material nature with Big Bang. Originally, all sorts of phenomena that are not intermediated by some identity are merely disjointed individual alien existences. Inversely, any identity that is not intermediated by a whole image of phenomena (sometime) with latent contradiction (mainly from the idea: “Relationism-First”) can produce no new anything whatever.

Concretely, from the above viewpoint, we have selected some types of modern high-technology pollution as an example of study. That is, we have showed in trial some hierarchical type quantitative methodology among different type environmental fields such as light, sound and electromagnetic waves. In our analysis, first, their mutual intermediation including linear and/or nonlinear type higher order correlations has been investigated along to the aspect of “Relationism-First”. Next, based on this correlation analysis, we have studied selectively the fluctuation form of individual behavior of only each of waves(light, sound or electromagnetic waves) in the probability distribution form. After all, through such a study of “Relationism-First” (i.e., onotological relationship), we can expect that the viewpoint of first grasping every type of mutual intermediation among environmental factors in different fields (observed not only in a time series analysis but also in a space analysis) will become an essential key for solving not only the high-technology pollution but also many difficult problems including many of our cultural field too (if possible, in the form of (temporal) harmony between utility and risk or product and control) in the present day.

More concretely, in the present paper, as two kinds of actual example of the above hierarchical type correlation in the time series and (in contrast with this) the similar type correlation distributed in the space among different environmental factors, we have applied the proposed method especially to the acoustic environment and the mutual intermediation among sound and light waves (served for utility) and leaked EM waves (served for risk) around personal computer under playing a game through some principle experiment. As the result, we have partly confirmed in principle its effectiveness of the proposed methodology by taking only the mutual intermediation among only physical environmental factors as an example.

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