Proceedings of the 12th
KACC, October 1997

ANALYSIS OF HUMAN DECISION MAKING PROCESS BASED ON CONDITIONAL PROBABILITY

°Masatoshi NAKAMURA and Satoru GOTO

Department of Electrical and Electronic Engineering, Saga University, Honjomachi, Saga 840, Japan
Tel: +81-952-28-8644; Fax: +81-952-28-8651: e-mail: nakamura@cntl.ee.saga-u.ac.jp

Abstracts Automatic realization of on–off human decision making was derived based on a conditional probability. Following the proposed procedure, problems of insulator washing timing in power substations and spike detection on EEG (electroencephalogram) records were appropriately solved.

Keywords On–off human decision making, Conditional probability, Insulator washing timing, Spike detection

1. INTRODUCTION

We have been encountered many on-off human decision making problems in our daily life, industries and medical fields so on. Examples of the problem can be found in a judgment of medical doctors for the disease of subjects. Visual inspection of spikes on EEG record for a subject of epilepsy is one of the problems. Medical doctors inspect the EEG time series and try to find out specific waves which represent significant features of the spike on the EEG record[2]. Similar problems can be found in industries. Experts in a power substation must make decision for washing out polluted deposits from insulators to prevent flash over due to the deterioration of insulation[1]. Another example is that a technical manager makes maintenance scheduling of equipments in the factory to circumvent failures. Many researchers and technicians have been engaged in automatization of these human decision making. Although much efforts have been done for automatization, final automatized techniques were something like ad hoc ones. Then, logical and reasonable automatic realization of on-off human decision procedure is required to develop.

This paper investigates an analysis of on-off human decision making process based on conditional probability and proposes a reasonable procedure for automatization of on–off human decision making as seen in Fig.1.

2. AUTOMATIC REALIZATION OF ON–OFF HUMAN DECISION MAKING

2.1. *Problem Statement*

Acquired data set $\{y\}$ is classified into two groups of human decision x (1: Go, 0: Nogo). The measurement y may be a vector variable. The numbers of decision making for Go are M and those for Nogo are N, respectively. The problem of automatic realization of on–off human decision making is to obtain the probability Go $P(1|y)$ based on the measurement y.

2.2. *Automatic On–Off Decision Making*

(a). *Frequency and histogram.* Based on data $M+N$ set of $\{x, y\}$, frequencies of Go and Nogo and the histograms of y for Go and Nogo are calculated as follows.

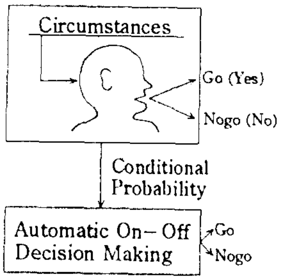

Fig. 1. Automatic realization of on–off human decision making.

The probability of Go $P(1)$ and that of Nogo $P(0)$ are defined as the relative frequencies for the discrete events Go and Nogo as follows:

$$P(1) = M/(M+N), \quad P(0) = N/(M+N). \qquad (1)$$

The normalized histogram of the measurement data y for Go and that for Nogo are denoted by $h(y|1)$ and $h(y|0)$ as seen in Fig. 2-I. The histograms have the following property of the normalization as

$$\int h(y|1)dy = 1, \quad \int h(y|0)dy = 1. \qquad (2)$$

(b). *Probability density function.* To obtain the probability of Go $P(1|y)$ based on the measurement data y, we use Bayesian rule[7] which requires the probability density function $f(x)$ for x and that of $f(y|x)$ conditioned on x.

The probability density function of $f(x)$ for discrete event x is derived by use of the probability $P(0)$ and $P(1)$ and Dirac delta function $\delta(x)$ as

$$f(x) = P(0)\delta(x) + P(1)\delta(x-1). \qquad (3)$$

The probability density functions of $f(y|1)$ and $f(y|0)$ are obtained by approximating $h(y|1)$ and $h(y|0)$ under the restriction of the probability density function as

$$\int f(y|1)dy = 1, \quad \int f(y|0)dy = 1. \qquad (4)$$

Fig.2-II illustrates the probability density functions for discrete event x and that for continuous event y.

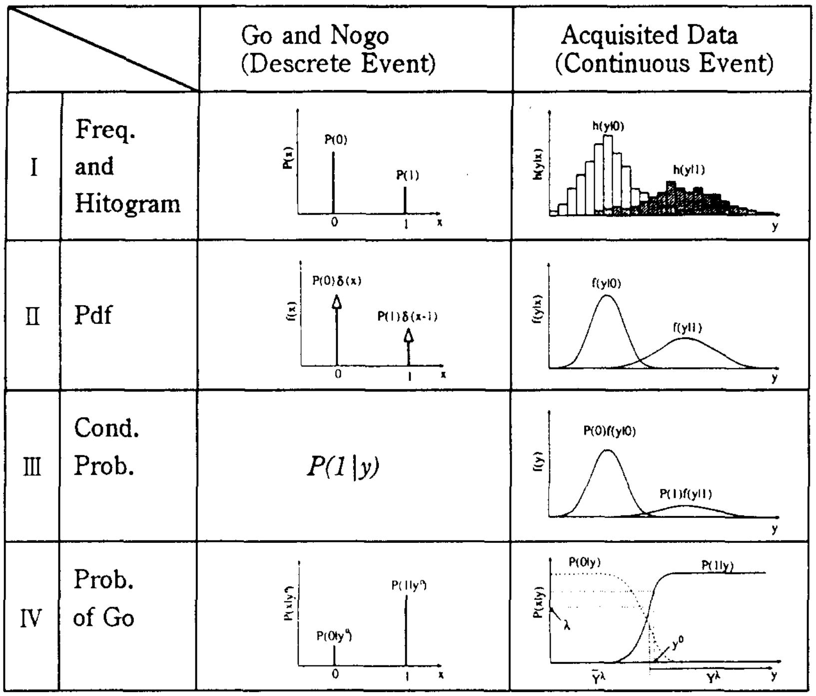

Fig. 2. Procedure of automatic realization of on-off decision making based on a conditional probability.

(c). *Bayesian rule.* By use of Bayesian rule and (3), we obtain $f(x|\boldsymbol{y})$ as

$$f(x|\boldsymbol{y}) = \frac{f(x,\boldsymbol{y})}{f(\boldsymbol{y})} = \frac{f(x)f(\boldsymbol{y}|x)}{\int f(x)f(\boldsymbol{y}|x)d\boldsymbol{y}} \quad (5)$$
$$= \frac{P(0)f(\boldsymbol{y}|x)\delta(x) + P(1)f(\boldsymbol{y}|x)\delta(x-1)}{P(0)P(\boldsymbol{y}|0) + P(1)f(\boldsymbol{y}|1)}.$$

In the derivation of the denominator of (5), integral properties of the generalized function[6] of Dirac delta function are adopted as

$$\int P(0)f(\boldsymbol{y}|x)\delta(x)dx = P(0)f(\boldsymbol{y}|0),$$
$$\int P(1)f(\boldsymbol{y}|x)\delta(x-1)dx = P(1)f(\boldsymbol{y}|1). \quad (6)$$

(d). *Conditional probability.* Conditional probability for Go $P(1|y)$ can be calculated by taking the integral of the impulsive conditional probability density function (5) around the neighborhood of 1(Go) as follows:

$$P(1|\boldsymbol{y}) = \int_{1\epsilon} f(x|\boldsymbol{y})dx$$
$$= \frac{P(1)f(\boldsymbol{y}|1)}{P(0)f(\boldsymbol{y}|0) + P(1)f(\boldsymbol{y}|1)}. \quad (7)$$

Fig.2-III shows the each term in (7) and the summation of the two terms shows the probability density function of the data $\boldsymbol{y}$ as

$$f(\boldsymbol{y}) = P(0)f(\boldsymbol{y}|0) + P(1)f(\boldsymbol{y}|1). \quad (8)$$

Fig.2-IV illustrates the conditional probability $P(1|\boldsymbol{y})$ based on the data $\boldsymbol{y}$. The conditional probability of Nogo $P(0|\boldsymbol{y})$ can be obtained by taking a similar procedure for the calculation of $P(1|\boldsymbol{y})$. In this case, the integral of $f(x|\boldsymbol{y})$ is taken around the neighborhood of 0 (Nogo) as

$$P(0|\boldsymbol{y}) = \int_{0\epsilon} f(x|\boldsymbol{y})dx$$
$$= \frac{P(0)f(\boldsymbol{y}|0)}{P(0)f(\boldsymbol{y}|0) + P(1)f(\boldsymbol{y}|1)}. \quad (9)$$

(e). *On-off decision making.* Automatic decision making of Go is done if the conditional probability $P(1|\boldsymbol{y}^0)$ for a given measurement data $\boldsymbol{y}^0$ is greater than or equal to a given threshold value λ as

$$P(1|\boldsymbol{y}^0) \geq \lambda \to \text{Go}. \quad (10)$$

Equation (10) shows the automatic decision making rule for a given value of λ.

(f). *Properties of the automatic on-off decision making.* Accuracy of the decision making of Go, rate of the false negative, and rate of the false positive are calculated by $\int_{Y^\lambda} f(\boldsymbol{y}|1)d\boldsymbol{y}, \int_{\bar{Y}^\lambda} f(\boldsymbol{y}|1)d\boldsymbol{y}, \int_{Y^\lambda} P(0)f(\boldsymbol{y}|0)d\boldsymbol{y} / \int_{Y^\lambda} f(\boldsymbol{y})d\boldsymbol{y}$, respectively, where Y^λ is the region defined by $\{\boldsymbol{y} \in Y^\lambda | P(1|\boldsymbol{y}) \geq \lambda\}$ and $\bar{Y}^\lambda$ is the counter set of Y^λ.

By appropriate selection of λ, the characteristic of the automatic decision making can be regulated. In order to increase the accuracy (consistency) of the automatic decision making, appropriate selection of the measurement variable $\boldsymbol{y}$ which affects to human decision making is crucial.

Appropriate selection of the measurement variable $\boldsymbol{y}$ will be done in order to reduce the area of intersection

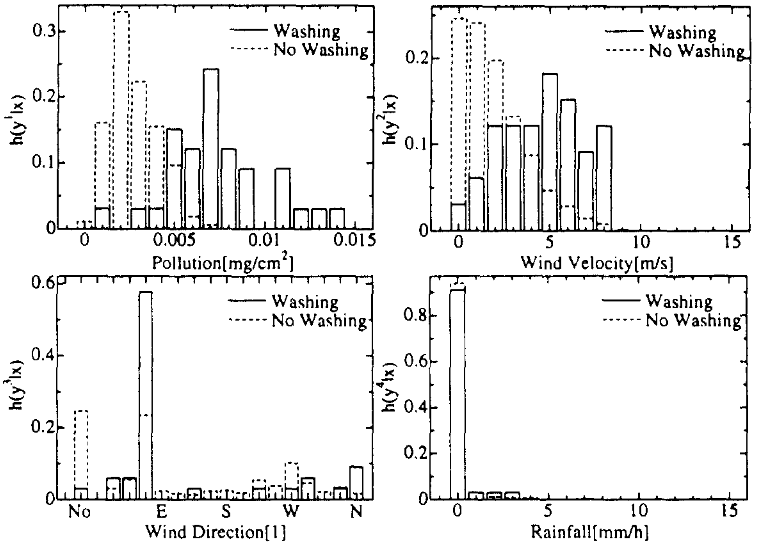

Fig. 3. Normalized histograms of pollution deposit, wind velocity, wind direction and rain fall for Go(washing) and Nogo(no washing) during the period of April, September and October 1994 at Karatsu substation in Japan.

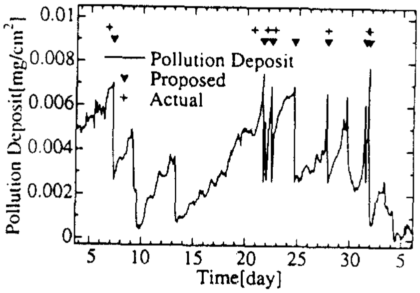

Fig. 4. Result of automatic decision making by use of the processed data of Karatsu substation during the period of 3rd September to 5th October 1996.

of $f(\boldsymbol{y}|0)$ and $f(\boldsymbol{y}|1)$ as seen in Fig.2-II. If the intersection of two functions is zero by appropriate selection of $\boldsymbol{y}$, the automatic decision always coincides with the human decision making.

3. EXAMPLES OF ON–OFF DECISION MAKING

3.1. *Insulator Washing Timing*

(a). *Objective of insulator washing.* Strong wind from seashore often causes rapid pollution of insulators. The rapid pollution of insulators caused by strong wind is very dangerous, specially for coastal substations. The analysis of the actual data reveals that it takes only two or three hours to reach the hazardous levels of pollution when typhoons attack substations. The insulators are washed with much amount of pure water before the pollution deposits increase to a critical level. In actual practice, based on the decision making by human experts, the polluted insulators are washed[3].

(b). *Automatic decision making of insulator washing timing.* Automatic decision making of insulator washing timing was derived based on the procedure of automatic realization of on–off human decision making procedure. By use of the raw data of weather conditions and insulator pollution acquired from Karatu substation in Japan during the period of April, September and October 1994.

The non conditional probability for Go (washing) and that for Nogo (no washing) were

$$P(1) = 33/(923+33), \quad P(0) = 923/(923+33) \quad (11)$$

and the normalized histograms for pollution deposits y^1, wind velocity y^2, wind direction y^3 and rainfall y^4 are illustrated in Fig.3. By use of the equations from (3) to (10), we calculated the automatic decision making of insulator washing timing.

(c). *Evaluation of the decision making of insulator washing timing.* The proposed decision making method was verified by using the actual collected data. In the actual data, the pilot insulator for the measurement of the pollution deposits, was also washed as same as the actual insulators. The modified data, which neglected the effect of the actual insulator washing, were constructed from the actual data for the validation of the proposed decision making method. The modified pollution deposits $d_m(t)$ were calculated by following procedure.

1. The actual pollution deposit difference $\Delta d(t)$ was added to the current modified pollution deposits $d_m(t)$ for the pollution deposits in the next step if the insulator was not washed.
2. Drop of the pollution deposits due to manual insulator washing was neglected in the modified pollution deposits $d_m(t)$.
3. When the proposed method decided the insulator washing, the modified pollution deposits $d_m(t)$ were set to the mean value of the pollution deposits, just after manual washings.
4. If the pollution deposits became less than zero, as a result of the combined effect of the modified washing and the natural washing, the modified pollution deposits $d_m(t)$ were set to zero.

The results of the proposed decision making method in case of λ being 0.5 is shown in Fig. 4. The total number of insulator washings using the proposed method were 7 which was the same numbers as that of the actual washing.

3.2. *Spike Detection*

(a). *Necessity of automatic spike detection.* Spike detected on EEG records give important information for clinical diagnosis, especially that of epileptic disorders. Usually the spikes are detected by EEGer (electroen-

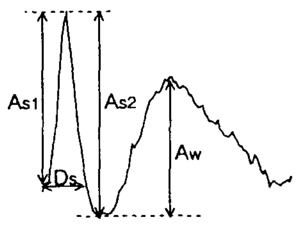

Fig. 5. Parameters for detection the spikes on EEG record.

cephalographer) with much laborious task. The automatization of the spike detection will be a powerful aid for EEGers.

(b). *Automatic spike detection.* Typical features of the spike on EEG records are illustrated in Fig.5. The parameters A_{S1}, A_{S2}, D_S, A_W can be the measurement data $\boldsymbol{y}$ which characterize the spike and are used for discrimination of the background EEG and artifacts such as eye blinks and EMG (electromyogram).

Based on the procedure of automatic realization of on–off human decision making, the automatic spike detection method was developed. This automatic spike detection method was incooperated with a method for renovation of the template for the spike waveform according to the detected spike[9], because the shape of the spike changes depending on the subjects and the topographical portion of the scalp.

(c). *Evaluation of the automatic spike detection.* The automatic spike detection method was applied 71 segments (1 segment = 5 sec) of EEG recorded from 9 subjects. Figure 6 illustrates a part of the results of the automatic spike detection. The upper arrows indicate the spikes detected by EEGer and the lower ones show the spikes detected by the automatic detection method. Concerning these waves, the spikes were correctly detected by the automatic method. An accuracy of 88.5% (54/61) was obtained as the result of the automatic detection, which was in good agreement with the EEGer's visual inspection.

4. CONCLUSION

A schematic procedure for automatic realization of on–off human decision making was derived based on conditional probability by use of acquired actual data. The proposed method was successfully applied to the problems of insulator washing timing and the spike detection on EEG record. The proposed method based on the conditional probability of mixture of discrete and continuous events is closely related to likelihood test method[5], fuzzy logic[10], mutual entropy[8] and voice decision[4], and is understood as an extended concepts of those related topics.

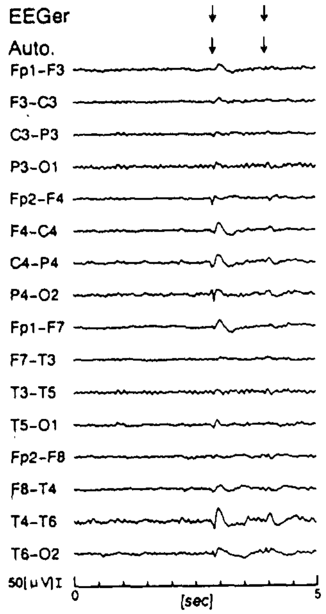

Fig. 6. Result of the automatic spike detection.

REFERENCES

[1] Electric Joint Research, vol. 35, no. 3, 1979 (in Japanese).

[2] J. Gotman, "Practical Use of Computer-Assisted EEG Interpretation in Epilepsy", J. clin. Neurophysiol., vol. 2, pp. 251-265, 1985.

[3] S. Goto, M. Nakamura, N. Nanayakkara and T. Taniguchi, "Reliable Automatic Decision Making for Washing the Polluted Insulators in Coastal Substations", Conference on Electrical Insulation and Dielectric Phenomena, pp. 408-411, 1995.

[4] H. Kobatake, "Optimization of Voice/Unvoiced Decisions in Nonstationary Noise Environments", IEEE Trans. Acoustics, Speech, and Signal Processing, vol. 35, no. 1, pp. 9-18, 1987.

[5] S. Kullback, "*Information Theory and Statistics*", Peter Smith, USA, 1978.

[6] M. J. Lighthill, "*An Introduction to Fourier Analysis and Generalized Function*", Cambridge University Press, New York, 1959.

[7] A. Popoulis, "*Probability, Random Variables and Stochastic Processes*", McGraw-Hill Kogakusha, Tokyo, 1965.

[8] C. E. Shannon, "*The Mathematical Theory of Communication*", The University of Illinois Press, 1949.

[9] T. Sugi, M. Nakamura, A. Ikeda and H. Shibasaki, "Automatic EEG Spike Detection by Use of Adaptive Decision Criteria to Individual EEG Records", 11th IFAC Symposium on System Identification (SYSID'97), CS20-4, pp. 1313-1318, 1997.

[10] L. A. Zadeh, "Outline of a New Approach to the Analysis of Complex Systems and Decision Process", IEEE Trans. Sys. Man & Cybern., vol. 3, no. 1, pp. 28-44, 1973.