Multi-Valued Decision Making for Transitional Stochastic Event: Determination of Sleep Stages through EEG Record

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ABSTRACT

Multi-valued decision making for transitional stochastic events was newly derived based on conditional probability of database. The two values (on-off) decision making method without transition had been proposed by one of the author in a previous work for a purpose of realizing human on-off decision making. The current method is an extension of the previous on-off decision making. By combining the conditional probability and the transitional probability, the closed form of the algorithm for the multi-valued transitional decision making was derived. The proposed multi-valued decision making was successfully applied to the determination of the five levels of the vigilance of a subject during the EEG recording; awake stage, drowsy stage and sleeping stages (stage 1, stage 2/3, REM (rapid eye movement)). The method for determining the vigilance level can be directly usable for the two purposes: selection of awake EEG segments for automatic EEG interpretation, and determination of sleep stages through sleep EEG. The proposed multi-valued decision making with a mathematical background of the probability can be applicable widely, in industries and in medical fields for purposes of the multi-valued decision making.

1. INTRODUCTION

Automatic realization of human decision making is required in many fields for a purpose of reducing and assisting human mental works. On-off decision making based on conditional probability of database was proposed by some of the authors [1] at KACC'97 and was successfully applied to the problems of insulator washing timing in subpower stations and an another problem of spike detection on EEG records. The method, however, was restricted to the on-off (two valued) decision making for static events. A restriction of the number of values is required to be released for wide application of the method.

This paper proposed a method of multi-valued decision making for transitional stochastic event based on conditional probability of database. The current method is an extension of the previous on-off decision making. Automatic determination of sleep stages of a subject through EEG record was successfully implimented by the use of the proposed method.

2. MULTI-VALUED DECISION MAKING

2.1 Problem Statement

The n-valued scalar variable at the step (time, k) is denoted by $x_k = \{\xi^1, \xi^2, \cdots, \xi^n\}$. The purpose of the multi-valued decision making for the transitional stochastic event x_k is to estimate the current stage ξ^* out of n stages ξ^i based on a conditional probability of the current measurement y_k (m-dimensional vector) and database of the past measurements Y_{k-1}. The method is derived by using the Baysian rule and the transitional probability in the following sections.

2.2 Automatic Decision Making

(a) *Conditional probability* The probability density function (pdf) of x_k based on $Y_k = \{Y_0, y_1, y_2, \cdots, y_k\} = \{Y_{k-1}, y_k\}$ is derived by the use of Baysian rule as

$$
\begin{aligned}
f(x_k|Y_k) &= \frac{f(x_k, Y_k)}{f(Y_k)} \\
&= \frac{f(x_k, y_k, Y_{k-1})}{f(y_k, Y_{k-1})} \\
&= \frac{f(y_k, x_k, Y_{k-1})}{f(x_k, Y_{k-1})} \frac{f(x_k, Y_{k-1})}{f(Y_{k-1})} \frac{f(Y_{k-1})}{f(y_k, Y_{k-1})} \\
&= \frac{f(y_k|x_k)f(x_k|Y_{k-1})}{f(y_k|Y_{k-1})} \\
&= \frac{f(y_k|x_k)f(x_k|Y_{k-1})}{f(y_k|x_k)f(x_k|Y_{k-1})dx_k}
\end{aligned}
\tag{1}
$$

The discrete pdf $f(x_k|Y_{k-1})$ in the right hand side of equation (1), as seen in Fig. 1-1. is described by the