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AUTOMATIC INTERPRETATION OF AWAKE EEG: ARTIFICIAL REALIZATION OF HUMAN SKILL

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Abstract: A full automatic interpretation of awake electroencephalogram (EEG) had been developed by the authors and presented at the past KACCs in series. The automatic EEG interpretation consists of four main parts: quantitative EEG interpretation, EEG report making, preprocessing of EEG data and adaptable EEG interpretation. The automatic EEG interpretation reveals essentially the same findings as the electroencephalographer's (EEG's), and then would be applicable in clinical use as an assistant tool for EEGer. The method had been developed through collaboration works between the engineering field (Saga University) and the medical field (Kyoto University). This work can be understood as an artificial relization of human expert skill. The procedure for the artificial realization was summarized in a methodology for artificial realization of human skill which will be applicable in other fields of systems control.

Keywords: automatic EEG interpretation, awake EEG, artificial realization of human skill, neural network

1. INTRODUCTION

The electroencephalogram (EEG) is a summation of electrical activities generated by nerve cells in the cerebral cortex and recorded from the scalp. As the EEG reflects at least a part of the functional status of the subject's brain, the EEG interpreted by electroencephalographers (EEGers) is used as a diagnostic aid in diseases affecting the brain. Automatic analyses of the EEG have been attempted by many investigators. Among various kinds of automatic EEG interpretations previously reported, spike detections in either the scalp-recorded or depth-recorded EEG in epileptic patients has drawn particular attention (Frost 1985, Gotman 1985). Automatic

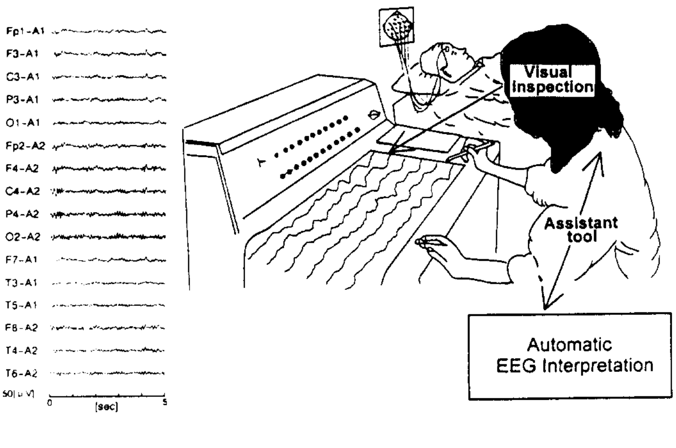
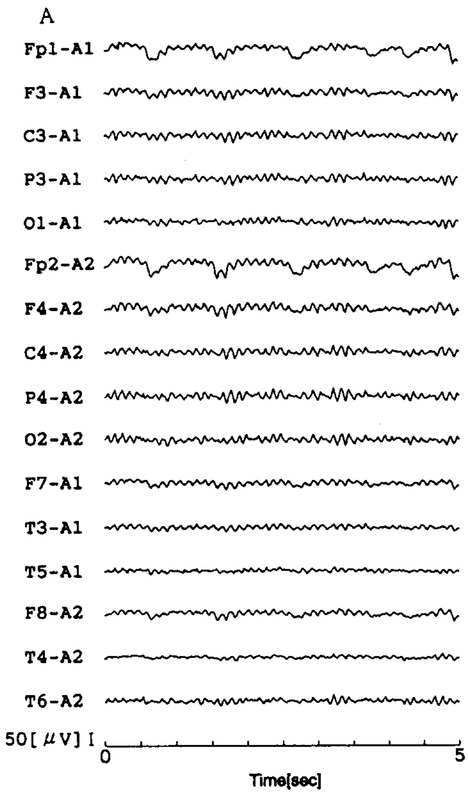


Fig. 1 EEG recording and its interpretation by an EEGer. Automatic EEG interpretation will be an assistant tool for the EEGer.

analyses of sleep stages by using EEG data have also been implemented, and a high accuracy in the recognition was achieved. Automatic diagnosis of awake EEGs has been investigated by Kowada et al. (1971) and others. Although, an awake background EEG is a basis of the subject's EEGs, most previous studies of automatic diagnosis for awake background EEG were restricted to a certain aspect of EEG characteristics such as the dominant rhythm or slow waves. A full automatic integrative interpretation of an EEG record had not been accomplished, mainly because a large number of complex items are involved in the interpretation of the awake background EEG. The automatic integrative interpretation of awake background EEG has been developed through an intimate collaborations between the engineering site and the medical site of the authors. and presented at the KACCs in series: quantitative EEG interpretation(KACC'90), EEG report making(KACC'92), preprocessing of EEG data for clinical use(KACC'94) and adaptable EEG interpretation to individual EEGer using an artificial neural network(KACC'95)

This paper describes the whole story of the automatic interpretation method of awake background EEG, and shows how the methods have been developed through the collaboration work between the both fields. Finally, the way of developing of the automatic EEG interpretation is extended in general, and summarized as a methodology of artificial realization of human expert skill, which will be adopted to a wide range of fields for systems control, such as power systems, plant systems and mechatronic systems.



B 1 B 2

Items		EEGer Estimate	EEGer Score	Automatic Estimate	Automatic Score
Dominant rhythm					
1	Existence	Yes	0	Yes	0
2	Organization	Mild. ab.	1	0.9	1
3	Asymmetry[1]	0	0	0.2	0
4	Frequency[Hz]	9.5	0	9.2	0
5	Asymmetry[Hz]	0	0	0.1	0
6	Amplitude[μV]	40	0	31.7	0
7	Asymmetry[%]	0	0	20.0	0
8	Extension[μV]	Fp. AT	2	8.3	0
Beta rhythm					
9	Amplitude[μV]	5	0	10.3	0
10	Asymmetry[%]	0	0	20.2	0
Theta rhythm					
11	Duration [%]	4	1	3.6	1
12	Electrodes	indefinite		$F_{p1,2}$, $F_{3,4,7,8}$, C_3, P_4, O_2	
Delta rhythm					
13	Duration [%]	0	0	0.0	0
14	Electrodes	---		---	
Non-dominant alpha rhythm					
15	Duration [%]	0	0	21.1	1
16	Electrodes	---		F_3, $C_{3,4}$, $P_{3,4}$, $O_{1,2}$, T_{56}	

C 1 EEGer's report

Mildly abnormal record

because of

(1)poorly organized background activity.
(2)too anteriorly extended α rhythm.
(3)occasional θ waves diffusely.

C 2 Automatic EEG report

Mildly abnormal waking record

because of

(1)poorly organized background activity.
(2)occasional θ waves bianteriorly, and
(3)occasional waves of α frequency posteriorly.

[Artifact detection]
Blink artifacts were present in the following segments(1.2.3.4.5.6.7.8.9.10), and were taken into account in the interpretation.

[Vigilance level]
Waking record

Fig. 2 EEG record and its EEG interpretation. (a) Time series of 5 sec. long out of 50 sec record. (b) the quantitative interpretation for 16 items. (c) the corresponding EEG report in a written form. The remarks on artifact and vigilance level in the automatic EEG report (c) were correct by described using the preprocessing with the artifact detection and the vigilance level detection procedures. (cited from KACC'94)

2. EEG RECORDING AND INSPECTION

2.1 EEG recording

All EEGs were recorded in a quiet, dimly lit room where a subject was placed in a supine position in a bed with the eyes closed (see Fig. 1). Exploring cup electrodes were fixed to the scalp at points Fp_1, F_3, C_3, P_3, O_1, Fp_2, F_4, C_4, P_4, O_2, F_7, T_3, T_5, F_8, T_4 and T_6 of the international $10-20$ system, and all electrodes were referenced to the ipsilateral ear electrode (A_1 or A_2). The 16-channel EEGs were recorded by an electroencephalograph with the time constant of 0.3 sec and a high frequency cut-off at 120 Hz(−3dB) at a paper speed of 3cm/sec and a sensitivity of 0.5cm/50μV.

2.2 *Visual inspection of EEGs by a qualified EEGer*

The procedure of visual inspection of EEGs was sequentially categorized into 16 items and was arranged in order of interpretation for the purpose of developing an automatic EEG interpretation (Fig. 2). The 50 sec long EEG record of each subject was inspected quantitatively according to the following standard criteria, without any prior knowledge of the clinical picture of each subject. First of all, the dominant rhythm was defined as a dominant EEG activity that consisted of waves with an approximately constant period and with the maximum amplitude at the occipital or parieto-occipital regions (O_1, O_2, P_1, P_2) of the head. As the first step, the dominant rhythm was checked as to whether it was recognizable or absent. If the dominant rhythm was identified, it was then analyzed with respect to its organization, frequency and amplitude. Differences of these 3 quantities of the dominant rhythm between the corresponding sites of the two hemispheres were defined as 'asymmetry'. Extension of the dominant rhythm to anterior regions of the head was also taken into account. For beta rhythm, the amplitude and asymmetry in its amount within the band(13Hz<) at each electrode were taken into account. As regards the waves of theta(4-8 Hz) and delta(<4 Hz) frequency and the activity of alpha frequency (8-13Hz) other than the dominant rhythm, which was defined as 'non-dominant alpha rhythm,' the proportional duration of the respective rhythm at each electrode was estimated and expressed as a percentage, and the electrodes active for each component were listed. Every item of EEG was graded into 4 scores: normal (0), mildly abnormal (1), moderately abnormal (2) and markedly abnormal (3). The criteria (threshold value) for each score were quantitatively specified for each item (KACC'90).

2.3 Computation of periodogram parameters

The EEG records that were interpreted by the EEGer as described above were divided into 10 segments of 5 sec duration each. The digital data of the EEG time series were then transformed into the Fourier components by the FFT method (Cooley and Tukey 1965), and the periodogram of each segment was obtained for each of the 16 channels as the squares of the Fourier components for each frequency of 0.2Hz. Features of the periodogram for each 5sec EEG segment for each individual channel were expressed by the periodogram parameters for each of the 5 frequency : the dominant rhythm (d), and beta (β), theta (θ), delta (δ) and non-dominant alpha (α) bands. The periodogram consisted of 11 parameters : the amount of the periodogram within the respective bands (S_d, S_β, S_θ, S_δ and S_α), the peak frequency (f_d, f_β, f_θ, f_δ and f_α), and the standard deviation for alpha band(σ_α). Thus, the time and spatial features of the 16 channel EEG record of 50 sec duration for each subject were condensed into 1760 periodogram parameters (11 parameters $\times$ 16 channel $\times$ 10 segments). Based on the periodogram parameters, we developed an automatic EEG interpretation which was equivalent to the EEG interpretation done by the EEGer.

3. AUTOMATIC EEG INTERPRETATION

3.1 Quantitative EEG interpretation

By using the periodogram parameters thus obtained, EEG parameters were constructed so that could closely conform to the procedures of visual EEG interpretation by the EEGer (KACC'90).

EEG parameters were computed for each segment data for each subject by using the periodogram parameters and the formulae as mentioned above, and the final estimates of the EEG parameters were obtained by averaging the EEG parameters of all 10 segments. Then the scores for each item were calculated based on the criteria (threshold values) which were employed for the visual inspection of each item (KACC'90) and were compared with the results obtained by the EEGer's visual inspection for each subject (Fig. 2(b)). The automatic interpretation revealed essentially the same findings as the EEGer's.

3.2 EEG report making

Although the automatic quantitative EEG interpretation was found to be in good agreement with the visual interpretation by the EEGer, the style for expressing the results of the quantitative EEG interpretation was different from that of EEG reports which was usually written by EEGers (Fig. 2(c1)), and therefore was not easily understandable to other medical doctors.

For the development of an automatic report making, the necessary terminology for the EEG report and the rules for the EEG report making were established (KACC'92) by analyzing the relationship between the EEG reports and the quantitative EEG interpretation done by the EEGer. Thus the automatic EEG report was obtained by using the defined terminology and the EEG report making rule based on the results of the automatic quantitative EEG interpretation. The integrative grade of EEG (first line of the EEG report (Fig. 2(c2)) was determined by taking into account the grading scores of each item for the integrative EEG interpretation. The appropriate term for the integrative grading of EEG was selected from the terminologies described by summing up the corresponding weights for each item for quantitative EEG interpretation. The weights for each item (KACC'92) were determined so as to attain the conformity between the results of automatic interpretation and those by the qualified EEGer for all subjects. Fig. 2(c) shows quantitative EEG interpretation for each item and EEG report, comparing the EEGer's reports. Although a slight difference of expression between the EEGer's report and the automatic report was found, total meaning of the automatic EEG reports was equivalent to that of the EEGer's report.

3.3 Pre-processing of EEG interpretation

While applying the automatic EEG interpretation method to clinical use, we have encountered two problems: contamination of various artifacts such as eye blinks, EMG (electromyogram) artifacts and electrode artifacts in the EEG record, and change in the vigilance level of the subjects during the recording. If the EEG records were automatically interpreted without paying any attention to the artifacts, misinterpretation of the EEG records is expected to occur not infrequently. Moreover, as EEG records during drowsy state are clearly different from those during wakefulness, the detection of the change in the vigilance level is an important task for EEGers for correctly interpreting awake EEGs. Therefore, the automatic detection of these artifacts and the reduced vigilance level were required as the pre-processing for the automatic EEG interpretation. The equations for detecting artifacts and reduced vigilance level were determined such that they would conform to the procedures that the EEGer actually adopts for the visual inspection of the EEG record (KACC'94).

The quality of the automatic EEG interpretation was shown to be improved by the newly developed preprocessing method even in the record contaminated with artifacts or obtained during the drowsy state of the subjects (KACC'94), and thus the present method will be effective for clinical use.

3.4 Adaptation of EEG interpretation

In view of the fact that the visual EEG interpretation could be a subjective task and may vary among the EEGers, an automatic EEG interpretation system which is adaptable to each electroencephalographer (EEGer) was required. The adaptable automatic EEG interpretation was accomplished by using a constructive neural network with forgetting factor (combination of Ash's algorithm, 1989 and Ishikawa's algorithm, 1990). The artificial neural network (ANN) was constructed so as to give the integrative interpretation of the EEG based on the intermediate judgment of 13 items. The ANN consists of 3 layers as shown in Fig. 3, initially fully connected: input, hidden and output layer. The input layer contains 13 units that represents the items considered in the quantitative interpretation. The hidden layer, initially, is formed by a variable number of units. The output layer consists of one unit that represents the final judgment that is scored again from 0 to 3 (normal(0), mildly abnormal(1), moderately abnormal(2) and markedly abnormal (3)) for the input pattern introduced. The final judgment made by the EEGer was used as the teaching signal for the ANN. The judgment emitted by the ANN was considered to be correct if the absolute value of the difference between the teaching signal and the output of the ANN was less than 0.5. The training of the ANN was performed such that the output of the neural network produced values similar to those of the final judgment made by the EEGer.

The testing consisted in verifying the generalization capability of the ANN or its ability to return appropriate results with data which were not used to train it. The testing of this ANN gave 100 % of accuracy for the data interpreted by EEGer-A. However, the generalization performance of the ANN, using the data of EEGer-B only produced 55% of accuracy, indicating that ANN-A was not good at interpreting records for EGGer-B. Since ANN-A could not well generalize for the data interpreted by EEGer-B, the adaptation process was performed. To adapt the ANN, the network was trained again by using both data interpreted by EEGer A and B. The parts that changed by the adaptation process were the amount of linking connections and the magnitude of the weights.

The adapted network (ANN-B) was able to interpret data either from EEGer A or B. When the generalization performance was verified, an improvement was obtained

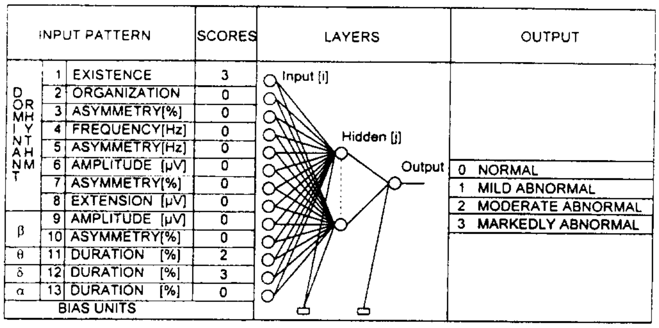


Fig. 3 Structure of the artificial neural network (ANN) which gives a final judgement of the EEG based on the results of the quantitive interpretation of 13 items.

with 96.5% of accuracy over the training and testing data (KACC'95). The automatic EEG interpretation of adapted one would be applicable in the clinical use as an assistant tool for EEGer and physician. As all the procedures were programmed in a personal computer equipped with AD (analogue to digital) converter, the automatic EEG interpretation was implemented in almost real time if the adaptation process was completed.

4. ARTIFICIAL REALIZATION OF HUMAN SKILL

4.1 Methodology

The automatic EEG interpretation was developed through a long term collaboration work between the engineering site and the medical site. This work can be understand as an artificial realization of the human expert's skill. Through the collaboration works with the researchers in different field, not only medical but also power systems, plant systems and mechatronic systems, the authors have theoretically solved many problems which had been encountered in the actual fields. Those experiences can be summerized in a methodology for artificial realization of the human skill of the experts. Experts in an individual field are engaged in a job for a long time. Their tasks are skillful based on the know-how of the specific field. Their skills are mainly gained through long term experience and intuitive manner (see Fig. 4). Only the final technique of human skill is visible and recognizable to others but not the procedure behind the development. In order to realize the human skill artificially by use of the mathematical tools, clarifi-

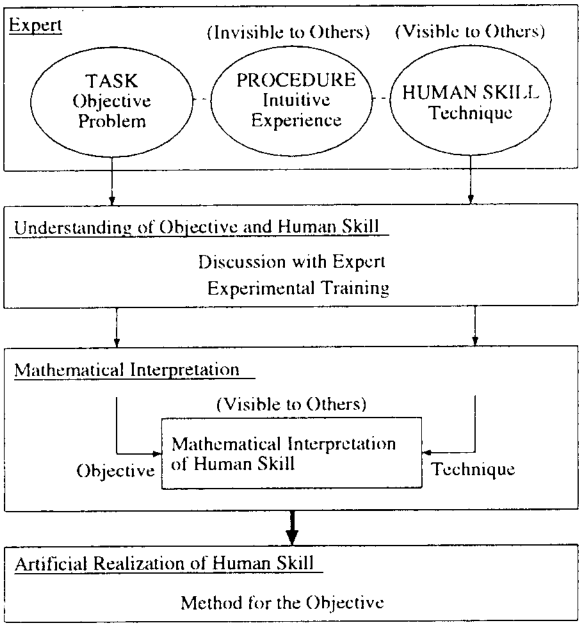


Fig. 4 Methodology for artificial realization of human skill: expert, understanding of objective and human skill, mathematical interpretation and artificial realization of human skill.

cation of the procedure of the human skill is crucial. The procedure for the artificial realization of human skill is summarized as follows:

1. *Understanding of objective and visible human skill* It is required for the designer to understand the objective of the problem and the causes of the existing problems clearly as the same level as the expert through the intimate discussion with the experts or by the experimental tests as to work out the problem. The designer should also learn the human skill through the experts.
2. *Mathematical interpretation* The procedure of the human skill is clarified through the understanding of the objective and human skill. Thus kind of task can be understood as an identification problem of the invisible procedure of the human skill and can be referred to the mathematical interpretation of human skill.
3. *Artificial realization of the human skill* If the procedure for solving the problem is clarified logically or mathematically, the realization of the human skill by use of mathematical tools is rather straightforward through the selection and the development of the mathematical tool box, such as signal processing, system identification, control theory and so on. The artificial realization of the human skill thus obtained should be discriminated from a mere imitation of the human skill.

4.2 Remarks

In order to realize the methodology the designers are required to keep the following points in mind: 1) exact understanding of the objective and the human skill, 2) long and intimate discussion with collaborators, 3) good human relationship between collaborators.

5. CONCLUSION

The automatic interpretation of awake background EEG, which had been presented at KACCs in series, was summerized and was explained how the method have been developed through a colloboration works between the engineering field and medical field. This work can be understand as an artificial realization of human expert skill. The procedure for the artificial realization was summerized in a methodology for artificial realization of the human skill. The methodology will hopefully be adopted to a wide range of different fields of systems control.

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