博　士　学　位　論　文

Doctoral Thesis

内容の要旨

及び

審査結果の要旨

Thesis Abstracts

and

Summaries of the Thesis Review Results

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はしがき

博士の学位を授与したので、学位規則（昭和28年4月1日文部省令第9号）第8条の規定に基づき、その論文の内容の要旨及び論文審査の結果の要旨をここに公表する。

学位記番号に付した「甲」は学位規則第4条第1項（いわゆる課程博士）によるものであることを示す。

Preface

On granting the Doctoral Degree to the individuals mentioned below, abstracts of their theses and the theses review results are herewith publicly announced, in according to the provisions provided for in Article 8 of the Ruling of Degrees (Ministry Of Education Ordinance No.9, enacted on April 1, 1953)

The Chinese character, “甲”, at the beginning of the diploma number represents that an individual has been granted the degree in accordance with the provisions provided for in Paragraph 4-1 of the Ruling Of Degrees (what in called “Katei Hakase,” or the Doctoral Degree granted by the University at which the grantee was enrolled.)

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The Date of Conferment 学位授与日	September 18, 2009 平成 21 年 9 月 18 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of “University Regulation on University Degrees” 会津大学学位規程　第5条該当
Thesis Title 論文題目	Signal Processing for Brain-Computer Interfaces Based on Electroencephalogram and Electrocardiogram 脳波と心電図に基づくブレインコンピュータインターフェイスの信号処理
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Signal Processing for Brain-Computer Interfaces Based on Electroencephalography and Electrocardiography

Thesis Abstract

Brain-Computer Interfaces (BCI) are interfaces connecting human brain with computers and are applied for quadriplegic patients, as this technique enables to control some electrical devises or computers. Recently, the electroencephalogram (EEG)-based BCI is mainstream in this field, which I also studied.

In this thesis, I introduce basic signal processing techniques for the EEG-based BCI. My works are broadly divided into two parts. One part is a signal processing technique for P300-based BCI, whose goal is to detect and to eliminate the electro-oculogram (EOG) artifact. Feature extraction of P300 is often prevented from EOG, so EOG must be detected and eliminated from EEG signal. I applied continuous wavelet transformation (CWT) to detect EOG and used normalized averaging method to eliminate EOG artifacts. Another part contains three basic signal processing techniques for a stress assessment of BCI, whose aim is to obtain the EEG and electrocardiographic (ECG) signals with one measurement. Some previous researches revealed that user's stress made a controlling the EEG-based BCI system difficult. Actually, it is reported that the EEG signal is sensitive to subject's stress or loss of concentration. Thus, the stress assessment can be important for the BCI system; I consider the ECG signal is usable. However, although an the ECG-based stress assessments are effective for the EEG measurement, some ECG electrodes are not required by the BCI system itself, so it is desirable if EEG and ECG signal are obtained without additional ECG electrode.

My study enables us to measure EEG and ECG signal with EEG electrode. The ECG component occasionally mixes in the EEG signal with balanced non-cephalic referential electrode (BNE) or mixes if a subject is auxocardia, adiposity or so on. In addition, the ECG component can be measured intentionally in the EEG recording with a noncephalic reference (NCR) electrode. My aim is to detect and separate the ECG component from above-described EEG recordings. In this thesis, a stationarization-based method is proposed for R wave detection in EEG recording with ear referential electrode or BNE. To separate EEG-ECG combined signal with NCR electrode, the wavelet shrinkage and window function-based method and the wavelet shrinkage and signal averaging ECG-base method are applied.

In this thesis, I introduce above-described research as following chapters.

Chapter 1 Introduction
In this chapter, I explain the goal and the motivation of this research. These have already been described above. Moreover I introduce fundamental knowledge of EEG, ECG, and BCI.

Chapter 2 Elimination of EOG components for P300 detection

In this chapter, I proposed a wavelet transformation and normalized averaging-based method to eliminate EOG artifact for an effective P300 detection. Proposed method was verified using EEG collected from 6 healthy male students. The result showed that it was possible to estimate P300 from recovered EEG data which was contaminated by EOG in each trial. It suggested the effectiveness and possibility of applying the P300 derived from EEG data, even when it was contaminated by EOG during trials.

Chapter 3 R wave detection in EEG signal by the stationarization-based method

I proposed to separate EEG and ECG in order to use separated EEG and ECG in chapters 3, 4, and 5. In this chapter, I applied a stationarization method to detect R wave in the EEG signal, and the signal averaging ECG (SAECG) is subtracted from raw EEG signal, and then resultant EEG signal is obtained. This method requires no ECG electrode. As a result of simulations, R wave can be detected to a certain degree even if the SBRr (the spike-to-background signal energy ratio) was low.

Chapter 4 Separation of EEG and ECG by wavelet shrinkage and window function-based method

In this chapter, EEG measurement using non-cephalic reference (NCR) electrode was proposed and I introduced method to separate EEG and ECG. I have confirmed that by applying NCR electrode in the EEG recording, it is possible to obtain ECG signals available for signal processing. I also improved the wavelet shrinkage algorithm by performing window operations in approximation level five of wavelet components to successfully separate the EEG components from the ECG signal. My results showed that the improved normalized power spectrum (INPS) were accurate in all frequency bands (alpha, theta and delta) for the EEG components, while sensitivities and specificities surpassed approximately 90%.

Chapter 5 Separation of EEG and ECG by wavelet shrinkage and signal averaging ECG-based method

I proposed the wavelet shrinkage algorithm and SAECG-based method to successfully separate the EEG components from the ECG signal in EEG measurement with the NCR electrode. In evaluation using simulation data sets, my results showed that INPS were accurate in all frequency bands for the EEG components. In evaluation of actual signal of eight subjects with NCR electrode, it was confirmed that the energy of ECG component which affect the frequency analysis of EEG was removed as same level as that of background EEG.

Chapter 6 Discussion and conclusions

In this chapter, I compared proposed methods and discussed the basic signal processing techniques for a stress assessment of BCI. It was concluded that the stationarization-based method was feasible to detect R waves in the EEG signal and the wavelet shrinkage and SAECG-based method is easier-to-use and more accurate than wavelet shrinkage-based one if a stable SAECG can be absolutely obtained, but the condition to use the wavelet shrinkage and window function-based method is less keen than that of wavelet shrinkage and SAECG-based method. Proposed methods

had advantages and disadvantages, although which were feasible to assess user's stress based on the ECG signal in BCI operation without additional ECG electrode.

Summaries of the Thesis Review Results

The application's research is focused on signal processing methods in brain computer interface (BCI) including:

- A method to eliminate EOG components for P300 detection
- An R wave detection method in measured EEG signals using cephalic reference electrode, and R wave detection in the EEG signals by stationarization
- A method to separate the EEG and ECG components in measurement with non-cephalic reference electrode using wavelet shrinkage and window function-based algorithm
- A method to separate the EEG and ECG components in measurement with non-cephalic reference electrode using wavelet shrinkage and signal averaging -based method.

Mr. Sakai has published three conference papers in the IEEE and other well-known international conferences. He has recently published a full paper (the first author) in a journal listed in the Major Journals. So his achievement is good enough to be approved to get a Ph.D. degree.

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Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of “University Regulation on University Degrees” 会津大学学位規程　第5条該当
Thesis Title 論文題目	User-Perceived Reliability of Fault-Tolerant Systems with Shared Backup Units 予備ユニット共用型耐障害システムにおける利用者観点の信頼性
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User-Perceived Reliability of Fault-Tolerant Systems with Shared Backup Units

Thesis Abstract

The reliability of computer networks is an important issue because the Internet has become a part of social infrastructure. The fault-tolerant systems with shared backup units are effective to improve the reliability in a cost-, space-, and energy-saving manner.

In this thesis, we investigate the reliability of fault-tolerant systems with shared backup units from the end user's viewpoint. We focus on the redundant systems composed of (M+N) units. M spare units are shared by mutually independent users of N units. We call this type of system a fault-tolerant system with shared backup units in general, or M-for-N shared protection system more specifically. (We use these two terms interchangeably in this thesis.) We assume that any failed unit is instantly replaced by one of the M units (if available). We describe the effectiveness of such a protection system in a quantitative manner.

After reviewing some related works that treat fault-tolerant systems, we introduce the concept of "user-perceived reliability". As a first contribution of this thesis, we establish and analyze basic Markovian models of fault-tolerant systems with shared backup units. In the models, we assume that the time between failures and the time for repair are subject to exponential distributions. We also assume that FCFS (first come first served) protection switching and FCFS unit re-housing are adopted. We derive the closed-form solutions of user-perceived availability and recurrence computation methods of the user-perceived MTTFF (Mean Time to First Failure) and MTTF (Mean Time to Failure) from our above assumptions. Numerical examples for telecommunication network devices are shown and analyzed. We also investigate the effect related to the number of repairers. The results can be applied to make the exact prediction of the reliability and optimal design of fault-tolerant systems with shared backup units.

As a second contribution, we analyze an advanced Markovian model of M-for-N shared protection systems. In the model, the time for repair is assumed to follow the Erlang type-k distribution that is useful to express many empirical distributions. We investigate the effect of the shape parameter of these distributions. The results can be applied to the optimal design of repair systems.

As a third contribution, we analyze the priority-controlled systems in which a priority is given to each end user. We show the computation method of user-perceived availability in such systems. We investigate the effect of prioritized protection switching and prioritized unit re-housing individually. After that, we investigate the combined effect of the two operations. The result can be applied to an optimal design of the device that provides end users prioritized services that are subject to the SLA (Service Level Agreement) involving reliability measures.

As a fourth contribution, we analyze unrepairable systems that can be applied to integrated circuits, submarine cables that accommodate multiple optical fibers etc. We derive the reliability function and MTTF of such systems from the viewpoint of a user of the unit. The results can be applied to the prediction of MTTF improvement when the preventive replacement of the whole of the system is adopted.

As a fifth contribution, we derive approximations of user-perceived reliability by ignoring irrelevant (low probability) states of the systems. We show simple the closed-form of the user-perceived availability, MTTF of one-for-*N* and two-for-*N* systems and an approximation of TTF distribution of *M*-for-*N* systems by an exponential function.

Summaries of the Thesis Review Results

Chapter 1 presents the background and the objectives of the research.

Chapter 2 describes the former research on the reliability of fault-tolerant systems including dual-unit, k-out-of-n, shared backup system, etc.

Chapter 3 introduces the concept of "user-perceived reliability" in fault-tolerant systems with shared backup units and points out the importance. The limitation/scope of this research is also described.

Chapter 4 establishes and analyzes basic Markovian models of fault-tolerant systems with shared backup units. In the models, it is assumed that the time between failures and the time for repair are subject to exponential distributions. Also, FCFS (first come first served) protection switching rule and FCFS unit re-housing rule are assumed. The closed-form solutions of user-perceived availability and recurrence computation methods of the user-perceived MTTFF (Mean Time to First Failure) and MTTF (Mean Time to Failure) are derived. The numerical examples for real-life telecommunication network devices are shown and analyzed. The effect of the number of repairers is also investigated.

Chapter 5 analyzes an advanced Markovian model of M-for N shared protection systems. In the model, the time for repair is assumed to be subject to the Erlang type-k distribution that is useful to express many empirical distributions. The effect of the shape parameter of these distributions is investigated. The results can be applies to the design of optimal repair systems.

Chapter 6 analyzes priority-controlled systems. In the Systems a priority is given to each end user. The computation method of the user-perceived availability in such systems is presented. The effect of prioritized protection switching and prioritized unit re-housing are investigated individually. After that, the combined effect of the two operations is analyzed. The result can be applied to the optimal design of the devices that provide end users the prioritized services that are subject to SLA (Service Level Agreement) involving reliability measures.

Chapter 7 analyzes unrepairable systems that can be applied to for example integrated circuits, submarine cables that accommodate multiple optical fibers etc. The reliability function and MTTF of such systems from the viewpoint of the user of a unit are derived. The results can be applied to the prediction of MTTF improvement when the preventive replacement of the whole of the system is adopted.

Chapter 8 discusses the approximations of the user-perceived reliability by ignoring irrelevant (low probability) states of the systems. The simple closed-form of the user-perceived availability, MTTF of one-for-N and two-for-N systems are presented. The approximation of TTF distribution of M-for-N systems by an exponential function is also presented.
Chapter 9 describes conclusions.

The committee members unanimously agreed that as a result of the thesis review, the applicant has been recognized as qualified for conferment for an academic degree.

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