J. Biomed. Eng. Res : 280-286, 2007

Implementation of the Wearable Sensor Glove Using EDA Sensor and Conducting Fabric

Youngbum Lee, Byungwoo Lee, Youngmin Choo, Jinkwon Kim, Wanjin Jung, Daehoon Kang, Myoungho Lee

Department of Electrical and Electronic Engineering
College of Engineering, Yonsei University
(Received June 21, 2006. Accepted March 7, 2007)

Abstract

The wearable sensor glove was developed using EDA sensors and conducting fabric. EDA(Electro-dermal Activity) signal is an electric response of human skin. There are SIL(Skin Impedance Level) and SIR(Skin Impedance Response) in EDA. SIL consists mostly of a DC component while SIR consists of an AC component. The relationship between drowsiness and the EDA signal is utilized. EDA sensors were made using a conducting fabric instead of AgCl electrodes, for a more suitable, more wearable device. The EDA signal acquisition module was made by connecting the EDA sensor gloves through conductive fabric lines. Also, the EDA signal acquisition module can be connected to a PC that shows the results of the EDA signal processing analysis and gives proper feedback to the user. This system can be used in various applications to detect drowsiness and prevent accidents from drowsiness for automobile drivers.

Key words : wearable sensor glove, EDA, conducting fabric

I. INTRODUCTION

The characteristics of the EDA signal and the correlation between this signal and drowsiness were studied. Preliminary research consisted of making an EDA signal measurement system and conducting experiments to detect arousal and prevent drowsiness by using such things as an alarm signal or music. Next, the characteristics of conducting fabric were researched in order to solve the discomfort associated with the AgCl electrode. In this paper, the characteristics of the EDA signal is reviewed, and the outline of the wearable sensor glove is explained. Finally, the properties of conducting fabric were demonstrated by experimenting with the design concept of the wearable sensor glove.

II. CHARACTERISTICS OF EDA SIGNAL

Skin impedance is one type of electro-dermal activity (EDA). Skin impedance signal is a change of electrical impedance caused by electric currents on the skin layer. SIR (Skin Impedance Response) signals are an AC component of skin impedance and SIL(Skin Impedance Level) is the total skin impedance change. According to related research, the correlation between SIR and SIL can be used to determine drowsiness accurately[1].

This work is supported in part by MIC &IITA through IT Leading R&D Support Project (Project No. 2005-S-093)
Corresponding Author : Myoungho Lee
Department of Electrical and Electronic Engineering,
College of Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea
Tel : +82-02-2123-4947 / Fax : +82-02-312-2770
E-mail : mhlee@yonsei.ac.kr

The correlation between SIR and SIL is below.

1. When aroused, SIL is low and IRI(Inter SIR Interval) is short.
2. When drowsy, IRI and SIL increase.
3. When sleeping, SIL is fixed in a high state and there is no SIR signal.

SIL signal is in the 0 ~ 5 Hz frequency band and SIR signal is in the 0.03 ~ 5 Hz frequency band[1]. The SIL and SIR signals are obtained from the skin when a 2 ~ 30 Hz constant current signal is introduced on the skin. SIL is filtered by LPF (Low Pass Filter), which has a cutoff frequency of 3.5 Hz, and SIR is filtered by HPF(High Pass Filter), which has a cutoff frequency of 0.3 Hz.

III. OUTLINE OF THE WEARABLE SENSOR GLOVE

The total system is consisted of EDA sensor gloves, an EDA measurement system, and a PC. In the EDA sensor gloves, we located EDA sensors using conducting fabric for properly measuring EDA signals. There are two electrodes for measuring EDA signals. The EDA sensor gloves are connected to the EDA measurement system through the conducting

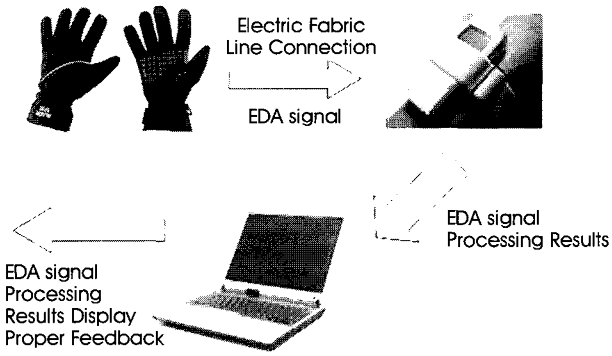


Fig. 1. Outline of the Wearable Sensor Glove

fabric lines. The EDA sensors were made using a conducting fabric instead of an AgCl electrode for a more suitable, more wearable device. The EDA signal acquisition module was connected to the EDA sensor gloves through conducting fabric lines. Also, the EDA signal acquisition module can be connected to a PC that shows the results of EDA signal processing analysis and gives proper feedback to the user. The EDA measurement system was configured as an arm band because that is more comfortable for the user. The system is analog circuit hardware that measures and filters EDA signals to make the SIR and SIL signals. That system makes the AD conversion of the SIR and SIL signals, and then the converted signals can be transmitted to the PC for signal processing for the SIR and SIL signals. In the PC, the user interface software shows the EDA signal processing results to the user, and makes feedback responses, such as a drowsiness alert.

IV. HARDWARE DESIGN AND IMPLEMENTATION

Fig. 2 is total block diagram of the EDA signal measurement system. The hardware consists of a constant current source, an instrumental amplifier , and an ADC circuit.

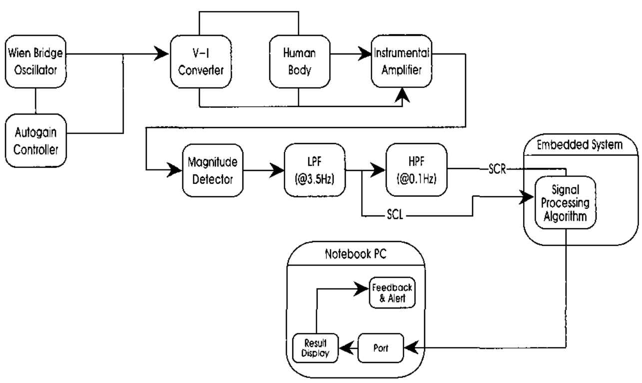


Fig. 2. EDA Measurement System Block Diagram

The first part is constant current source. This component utilizes a WBO(Wien Bridge Oscillator) and an AC(Autogain Controller) to oscillate AC voltage and a V-I Converter to generate a constant current that is delivered to the skin. The second part is instrumental amplifier. The instrumental amplifier is used to obtain a response signal, and the lock-in amplifier is used to watch the real-time waveform. The Lock-in amplifier makes it easy to determine the change of signals. The last part is an ADC circuit that allows for signal processing in the PC.

V. EDA SENSOR GLOVE DESIGN

A. Conducting Fabric Analysis

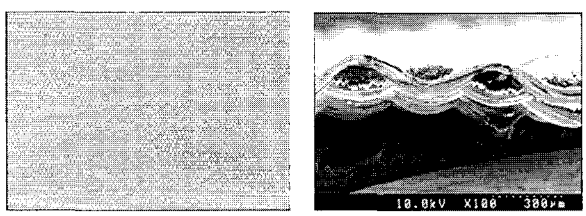
The AgCl electrode is typically used for measuring biopotential. However, this electrode can only be used when the user remains motionless because the electrode must have constant contact with the skin. Because of this, a new electrode type is necessary for tasks which require movement while wearing an electrode. Thus, conducting fabric was selected as an alternative to the AgCL electrode. This way, the sensor can be built into a user's clothes.

This conducting fabric is made by "the metex."

The conducting fabric consists of a copper coating on polyester, making the fabric conductive. However, cond-

Table 1. Textile specifications of the wearable sensor

□		Value	Magnitude
Material	Base	Polyester	–
	Metal	Copper	–
Thickness		0.09	mm
Weight		24	g/m^2
Surface Impedance		0.15~0.20	Ω/sq. inch
EMI effectiveness		48~55	dB



(a) (b)

Fig. 3. Surface and cross-section of the wearable textile sensor

Table 2. Measurement conditions

No.	Temperature	dry/wet condition
1	25 ℃	dry (normal condition)
2	25 ℃	wet
3	37 ℃	dry
4	37 ℃	wet

uctivity does not ensure efficiency as an electrode. Therefore, an experiment was conducted to test the fabric's performance as an electrode.

The devices and materials used in this experiment are the HP precision impedance analyzer 4294a(40Hz~100MHz), a drying oven(do-32), metex elective fabric, an AgCl electrode and saline solution. With the impedance analyzer, we measured impedance and phase in the elective fabric. Measurements were taken in four different conditions, in order to reflect the different conditions users of the wearable sensor glove may encounter.

A 'wet' condition was intended to mimic sweat, so saline solution was used in lieu of real human sweat. Graphs separating impedance and phase were drawn using Matlab.

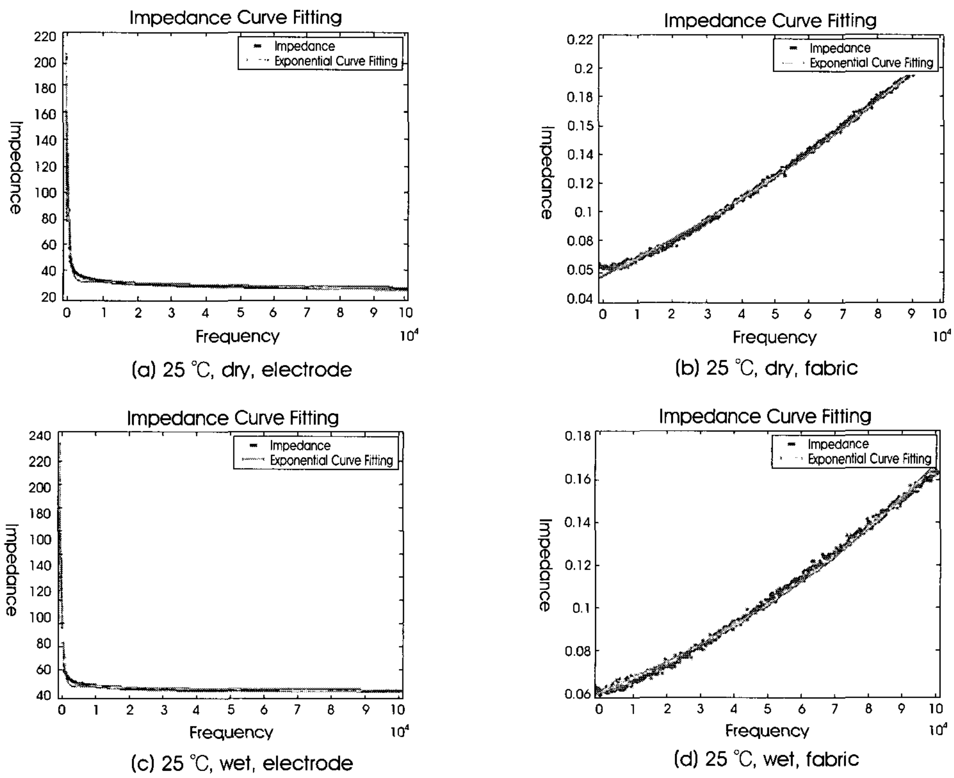
First of all, variables(size of fabric, temperature, and wet or dry) almost never influence phase and impedance value.

Figures 4 and 5 show the frequency response of impedance characteristics and that range of electrode impedance is 30~100 ohm and fabric impedance is 0.05~0.25 ohm. A cursory inspection of these two graphs reveals their dramatic difference in shape. The electrode graph is almost constant, but the graph for fabric shows a steady increase. Despite this, these two graphs are not significantly different because the impedance value is so small. The electrical conductivity increases as impedance decreases. Fabric impedance has very small value relative to electrode impedance, meaning that fabric impedance is the more sensitive of the two.

Specifically, this means that the signal detection rate is sensitive and it is highly sensitive to noise, interference, and movement. Therefore, more effort is need when conductive fabric is used instead of the AgCl electrode.

Next, Figures 6 and 7 show the frequency response of phase characteristics. When the graph is linear, phase holds the same time delay at all frequencies. And when the graph is not linear, phase overlaps at some frequencies. Exact measurements are possible when the graph is linear. As a result, it can be concluded that the size of the fabric, temperature, and wet/dry conditions almost never influence phase and impedance value.

Impedance



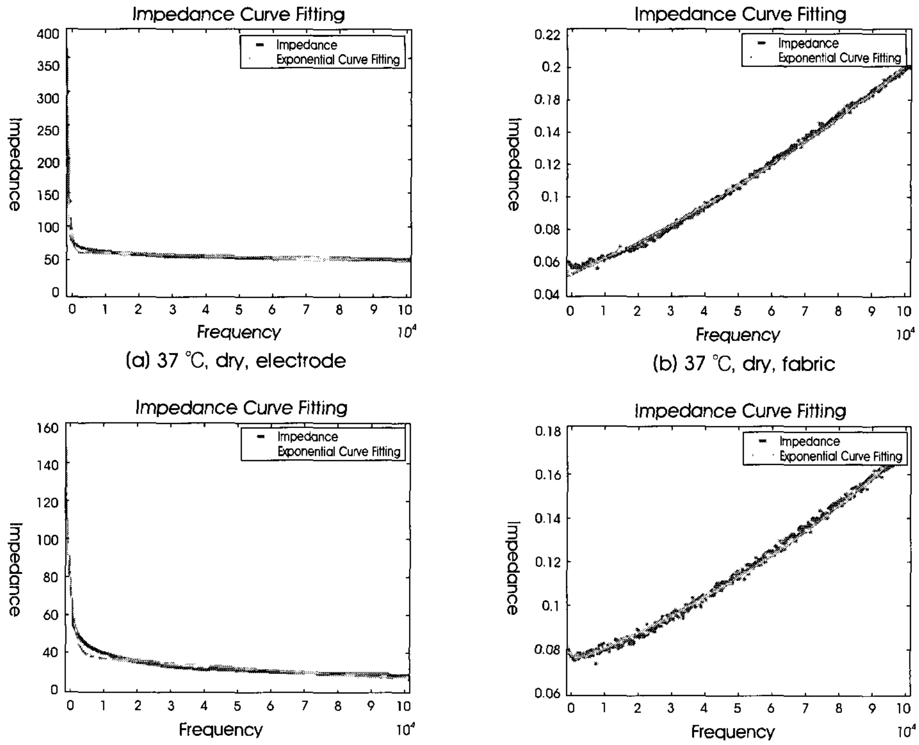
(a) 25 ℃, dry, electrode

(b) 25 ℃, dry, fabric

(c) 25 ℃, wet, electrode

(d) 25 ℃, wet, fabric

Fig 4. Frequency response of impedance characteristics for conditions 1 and 2

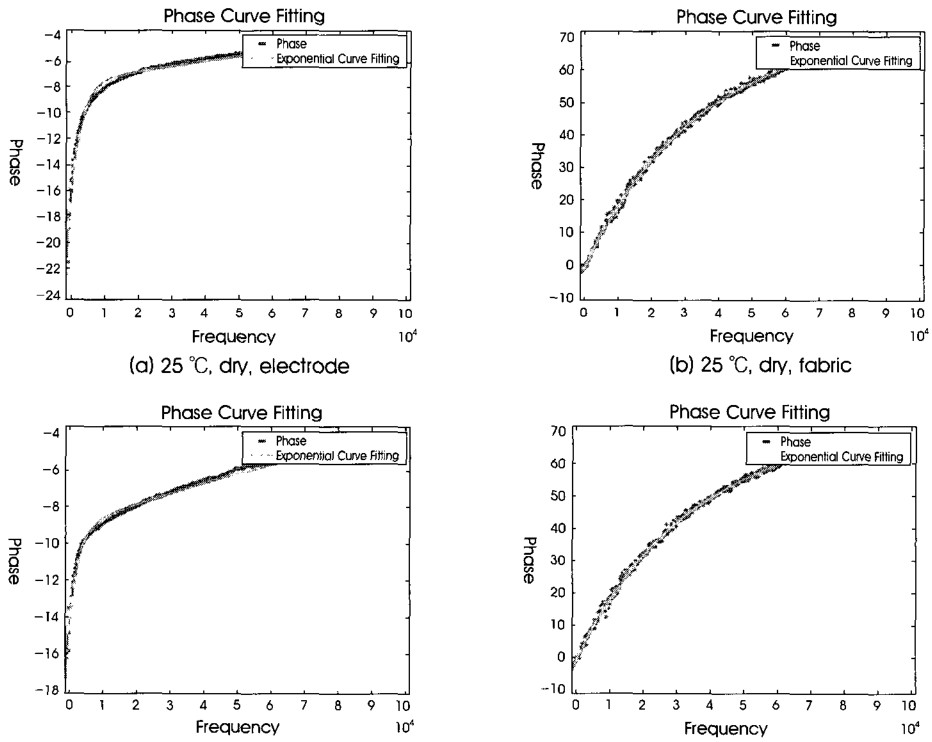


(a) 37 ℃, dry, electrode (b) 37 ℃, dry, fabric

(c) 37 ℃, wet, electrode (d) 37 ℃, wet, fabric

Fig. 5. Frequency response of impedance characteristics for conditions 3 and 4

Phase



(a) 25 ℃, dry, electrode (b) 25 ℃, dry, fabric

(c) 25 ℃, wet, electrode (d) 25 ℃, wet, fabric

Fig. 6. Frequency response of phase characteristics for conditions 1and 2

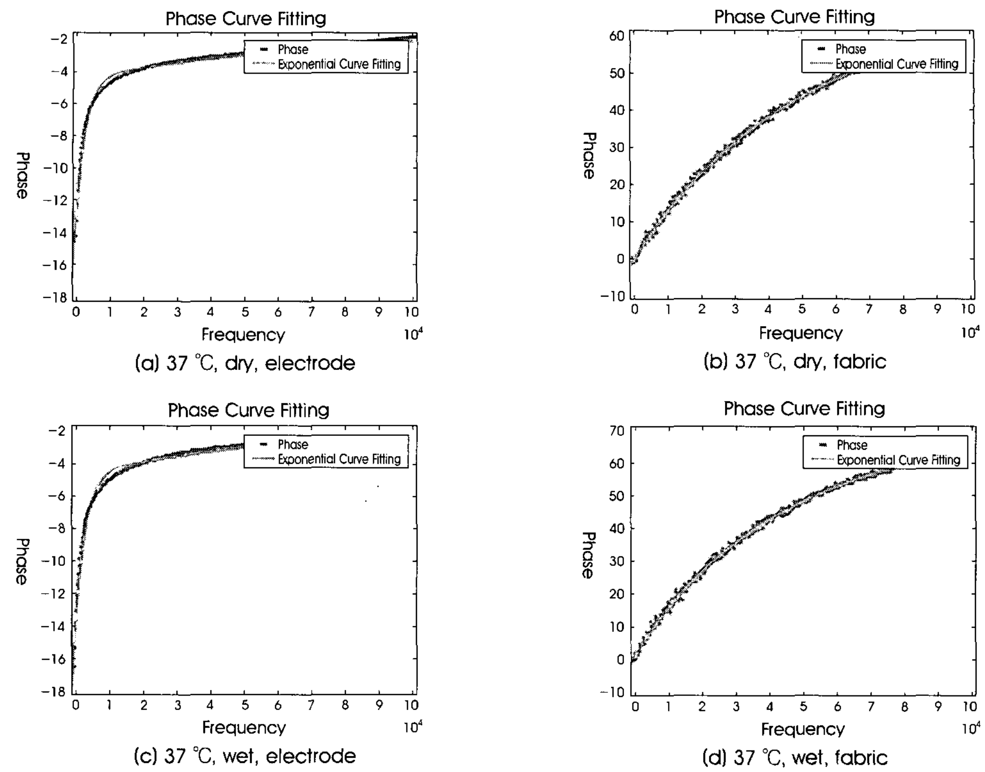


Fig. 7. Frequency response of phase characteristics for conditions 3 and 4

Fig. 8 is the design abstract of the EDA sensor glove. A golf glove was used because of its high quality texture, comfort, and good ventilation. The EDA sensors using conducting fabric were fitted to the fingers. The glove's practical and artistic features were carefully considered especially in the conducting fabric line and arm-banded pocket that contains the embedded board. Figure 9 is a picture of the EDA sensor glove.

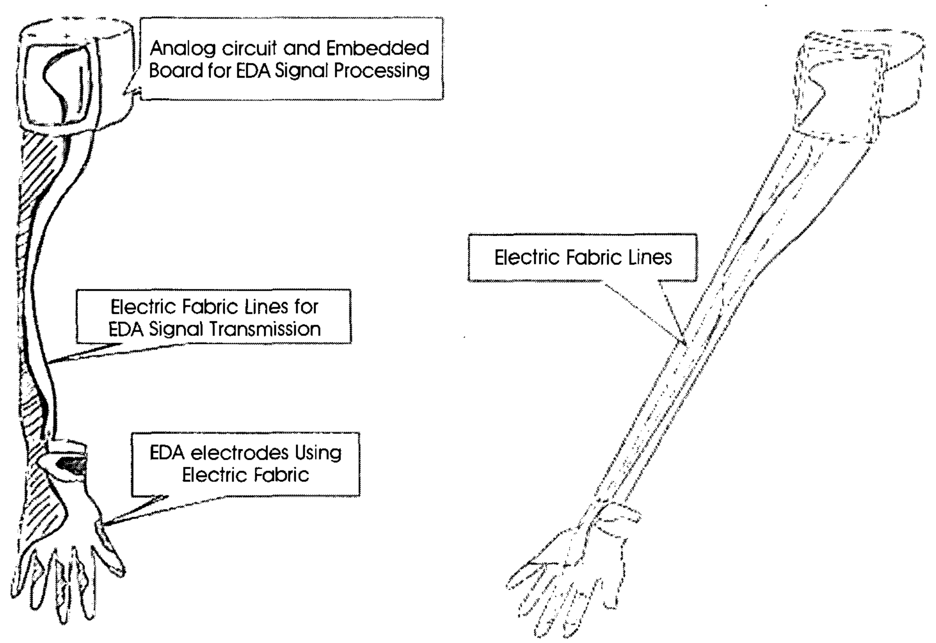
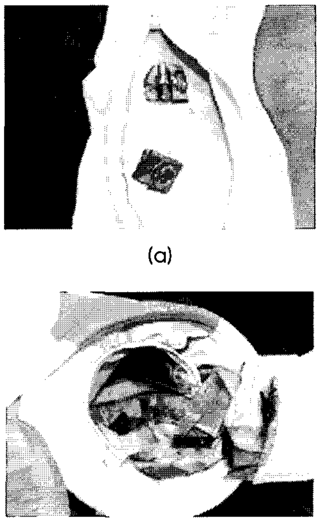


Fig. 8. EDA sensor glove design

Fig. 9. EDA sensor glove



(a)

(b)

Fig.10. Inner appearance of wearable sensor gloves

Since the mid-1990s, wearable device design focused on being human-friendly. This was facilitated with the creation of smaller and lighter computing devices. The development of smart texture was another important step that combined sensor technology and texture manufacturing technology. All of these factors helped make wearable devices comfortable and easy to use. Now, wearable devices are nearly the same as normal wear.

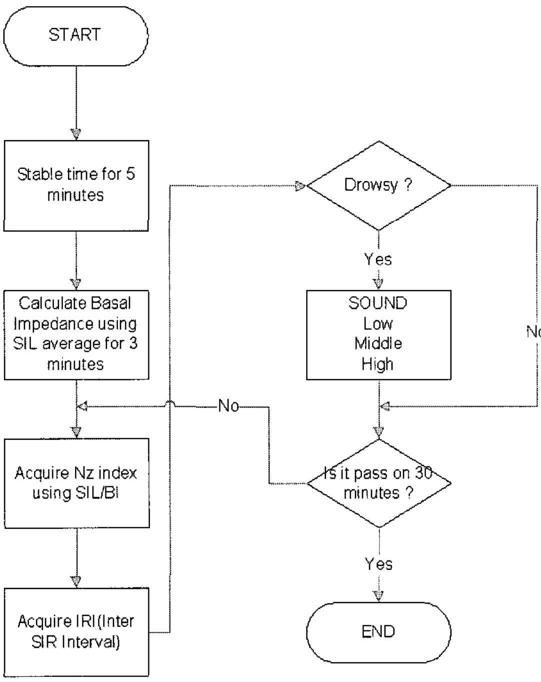


Fig. 11. Experimental protocol [2]

Because this design focused on the user's utility and comfort, not only was the problem of uncomfortable electric wires solved, but also the issue of wash-ability became resolved as well. Since the wearable device uses conducting fabric wire, the sensor glove can be washed. In addition, the conducting fabric line does not interrupt the movement of arm. Also, the user can control the size of glove using Velcro strap at the wrist.

Lastly, the pocket for glove and wire were designed. This can be used as an auxillary storage space by the user. Since it is essential to separate the board from the glove when washing, the glove was designed with button type boards.

VI. EXPERIMENT AND DISCUSSION

The purpose of this experiment was to investigate the correlation between skin impedance and drowsiness. Figure 11 shows the experimental protocol. The total time of the experiment was 30 minutes and drowsiness was measured in 3 steps: an aroused condition(small), being drowsy(medium) and sleeping(large). Table 3 shows the decision table for drowsiness.

In experiment, we have stable time for 5 minutes and calculate Basal Impedance(BI) using SIL average for 3 minutes.

Table 3. Decision table for drowsiness [2]

□		Nz(SIL/BI) 1.2<Nz<1.5	1.5<Nz<2.0	2.0<Nz
IRI (sec)	IRI<60	Small	Small	Medium
	60≤IRI≤90	Small	Medium	Large
	90<IRI	Medium	Large	Large

BI : Basal Impedance, IRI : Inter SIR Interval, Nz : SIL/BI

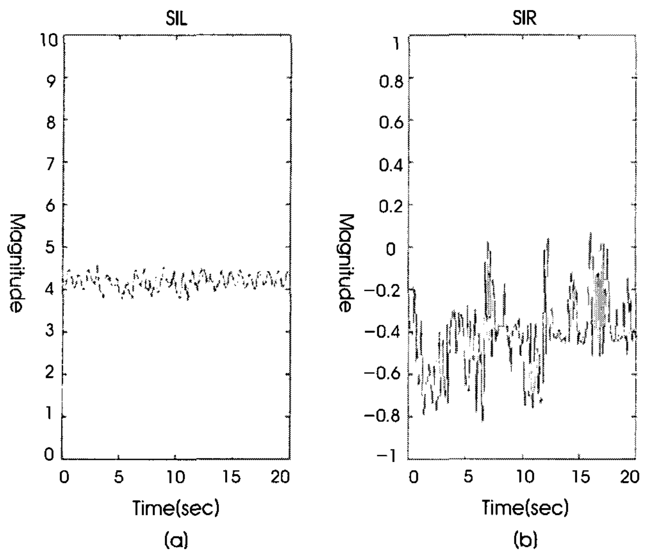


Fig. 12. SIL and SIR signal in an aroused state

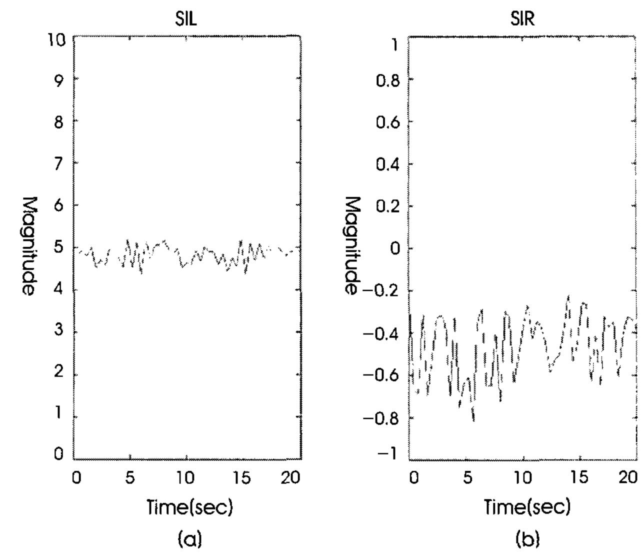


Fig.13. SIL and SIR signal while sleeping

BI means reference value for the variation of arousal status. And we acquire Nz index using SIL/BI that means SIL assessment indicator. And we acquire IRI(Inter SIR Interval) that means SIR revelation interval.

At first, the subject was aroused, but he became drowsy and finally fell asleep. The SIL signal was expected to increase and the FPS (Frequency of Peak in SIR signal) was expected to decrease. Figure 12 shows SIL and SIR signals in an aroused state. The SIL signal is on the left and the SIR signal is on the right. Figure 13 shows SIL and SIR signals while sleeping. The two figures show an SIL increase and a FPS decrease.

The DC component of the SIL signal is larger during arousal than sleep, while the AC component of SIR signal, that is, FPS, is smaller. As FPS decreases, the IRI becomes larger. This EDA signals the transition from arousal to sleep. This correlation between skin impedance and drowsiness was verified through the experiment. In Figure 12, Nz was calculated at approximately 1.3 and IRI was calculated at 50, reflecting the subject's lack of drowsiness in an aroused state. In Figure 13, Nz is approximately 2.2 and IRI is 100, indicating a high magnitude of drowsiness, or sleep.

VII. CONCLUSION

This EDA signal measurement system obtains a skin impedance signal and monitors the SIL and SIR signals by filtering it. The EDA sensor was made using conducting fabric, and connected to an embedded EDA measurement system providing for many possible applications such as EDA signal processing, algorithm implementation, and wearable device upgrading. The design of the EDA sensor glove is centered on user comfort and functionality. Future work on this project will involve the completion of the EDA signal processing algorithm implementation. Through the use of a wireless communication module, this system could send EDA signal processing results to an outside display system, giving proper feedback to user.

REFERENCES

[1] H.W. Ko, W.G. Lee and G.K. Lee, "Arousal monitoring system using the change of skin impedance (1) ," in *Proc. KOSOMBE Spring Conference*, 1995, vol.17, no.1.

[2] H.W. Ko and Y.H. Kim, "Relationship between skin impedance signal, reaction time, and eye blink depending on arousal level," *Journal of KOSOMBE*, vol.18, no.4, 1997.

[3] Jennifer Healey and Rosalind Picard, "Smart car: detecting driver stress," in *Proc. ICPR'00*, Barcelona, Spain, 2000.

[4] F. Axisa, C. Gehin, G. Delhomme, C. Collet, O. Robin and A Dittmar, "Wrist ambulatory monitoring system and smart glove for real time emotional, sensorial and physiological analysis," in *Proc. the 26th Annual International Conference of the IEEE EMBS*, San Francisco, CA, USA, September, 2004, pp.1-5.

[5] Y.B. Lee, J.Y. Kim, C.K. Lee and M.H. Lee, "Automobile system for drowsiness accident prevention using EDA signal analysis," in *Proc. KOSOMBE Spring Conference*, 2005.