Journal of the Korea Fashion &
Costume Design Association
Vol. 12 No. 2 (2010) pp.119~129

A Design of Jacquard Woven Textile Electrode to Monitor the Electrical Activity of the Heart for Smart Clothing

Ha-Young Song[+] · Joo-Hyeon Lee[*]
Adjunct Prof., Dept. of Fashion Design & Merchandising, Kongju University[+]
Prof., Dept. of Clothing and Textiles, Yonsei University[*]

스마트 의류의 전기적인 심장 활동을 모니터링 할 수 있는 자카드 텍스타일 전극 디자인

송 하 영[+] · 이 주 현[*]
공주대학교 의류상품학과 겸임교수[+]
연세대학교 의류환경학과 교수[*]
(2010. 4. 5. 접수; 2010. 5. 3. 수정; 2010. 5. 7. 채택)

요 약

오늘날 인간의 수명이 연장되고, 웰빙과 건강에 대한 관심이 증가됨에 따라서 언제 어디서나 건강을 모니터링 할 수 있는 건강 스마트 의류 시스템이 개발되고 있다. 이를 위하여 최근에는 생체신호의 모니터링이 가능하도록 디자인된 의류에 통합된 형태의 직물 전극이 개발되고 있다. 혁신적으로 의류 시스템에 통합되어 착용 가능한 니트, 우븐, 자수방식의 텍스타일 전극에 대한 다양한 연구가 개발 제시되고 있으며, 이의 일부는 상용화되어 있다. 이에 본 연구는 경위사의 일정한 직조제어 자동화 시스템이 가능한 컴퓨터 자카드 직기의 캐드(CAD) 직조디자인 방식을 통하여 생체신호 센싱 기능이 향상된 새로운 텍스타일 전극디자인을 연구하고자 하였다.

이를 위하여 본 연구에서는 기존 생체신호 센싱 전극의 개발 및 연구 동향, 비직물/전극 타입에 대한 단점과 장점에 대한 비교 분석을 이론적으로 살펴보고, 자카드 직조 직물 기반으로 심전도 센싱용 텍스타일 전극을 디자인하여 실험 연구하였다. 자카드 직조 방식의 심전도 센싱용 직물 전극은 전극 인터페이스 디자인 방식, 이중직물형 직조 디자인 방식, 사가공 등의 요인들을 고려하여 개발하였다. 본 연구에서 도출된 최종 자카드 직조 직물 기반의 텍스타일 전극은 스마트 의류에 통합시킨 텍스타일 전극 모듈로서 적용되어 향후 상용화 방안을 모색할 수 있다.

키워드: 텍스타일 전극(Textile electrode), 자카드 직물(Jacquard woven fabric), 이중직 직물 구조(Double weave structure), ECG 생체신호(ECG signal), 전도사(Conductive yarn), 통합형 직물 전극(Integrated fabric electrode)

Corresponding author ; Ha-Young Song
Tel. +82-2-3413-1612, Fax. +82-2-3413-1613
E-mail : fabricsong@hanmail.net

I. Introduction

In the last few years, the innovative application of textile technology has been developed for the wearable monitoring system, which is far distant from conventional textiles. The smart textiles with fabric-based sensors to monitor gesture or to detect biosignals have become more prevalent, leading to developments in new wearable sensing systems. Smart clothing with the innovative textile sensors or electrodes has been able to acquire vital signals from the human body and transmit them to a third device.[1)] These smart textile sensing systems can measure and monitor the physiological conditions of the wearer so that they can be applied in U-healthcare systems.[2)]

Biosignal monitoring clothing with conductive textiles for healthcare applications has recently become one of the most interesting upcoming research topics. The necessity of using smart textiles in healthcare monitoring is due to the consideration of a growing world population, greater longevity, and raising the interest level for sustained well-being.[3)] Smart textiles in health care, which textiles with integrated electronics and microsystems that can be in clothes and in technical textiles, have been developed for the protection of the individuals in hostile environments and for the necessity for communication and monitoring health.[4)] The integration of textile-based sensors into clothes for the purpose of monitoring health would aid the daily acquisition and processing of multiparametric health data, providing an early detection of pathological signs without interfering with daily life.[5)] Smart wearable systems, which are comprised of smart textiles in light weight, comfort, durability, energy management and wireless communication, are applied for personalized services, especially for monitoring purposes.

The monitoring of electrocardiogram or ECG by the wearable integrated textile sensing system can usually be accepted and used for detecting aberrations in healthcare; this creates a “natural” environment without any discomfort for the users and without interfering with their daily activities.[6)] The integrated textile electrodes enable detection of the signals used in respiration, motion, cardiogram, and temperature.7)

Loriga *et al.* (2005) developed the knitted integrated sensors for cardiopulmonary signs.[8)] These textile electrodes were knitted with the stainless steel strings with cotton yarn, using a tubular intarsia technique to get a double face. Scilingo *et al.* (2005) also developed the ECG and EMG textile electrodes that were knitted with stainless steel strings with viscose yarn, using the tubular intarsia technique, as well.[9)] The textile electrode in ‘WEALTHY’ systems[10)] was developed for monitoring physiological signals of electrocardiogram; the textile electrodes were knitted with stainless steel strings with viscose yarn and embedded in the knitted garment of tubular intarsia technique. Jamg (2007) developed the embroidered textile electrodes with stainless steel threads for monitoring ECG in men’s sleeveless clothing.[11)] Koo (2008) also made the embroidered textile electrodes with silver yarn to evaluate the effects of body movements and the ECG sensing capability in static and dynamic states.[12)]

These textile electrodes perform long-term measurement without irritating the skin. In addition, they are resistant to abrasion, absorb moisture, dry quickly, lightweight, ductile, and washable.[13)] To design a textile electrode, the textile electrode needs to fulfill all requirements of the conventional electrode such as conductivity, low impedance, and simultaneously have reasonable textile qualities, such as comfort and washability. The structure of textile electrodes can be configurated by knitting, weaving, or embroidering. Knit fabric has good strain properties but it stretches and lacks returning to the original shape after repeated use, and has some noise problems for monitoring the biosignals. However, in case of woven fabric, which consists of cloth woven in both the warp and weft directions, has fewer strain properties than knit fabric. Woven fabrics provide more dimensional stability, and have more suitable properties for interlacing the warp and weft yarn in a certain continuity of the weaving machine.

Therefore in this study, textile electrodes woven with conductive yarn are developed for a more stable sensing data in computerized jacquard weave system, designed the integrated fabric electrode for monitoring the electrical activity of the heart, and studied the biosignal of the ECG measurement. To develop the jacquard woven fabric-based textile electrode (*i.e.,* JWFTE), the multilateral effective factors are determined from the electrode design, weave structure, yarn processing of conductive yarn, and so on.

II. Theoretical Background

1. Smart Clothing for the Biosignal Monitoring

In the health and safety industry, a number of research groups have been more challengingly or discreetly applied to sense physical bodily or positioning data and relay them to a communication center. The innovation in terms of textile is related to the use of functional yarns integrated in the fabric for sensing and acquisition of vital signs.[14] Textiles are ubiquitous in our society, and provide the ideal base or support for wearable monitoring electronics. Because textile garments or accessories can be worn close to the skin, integrating electronics within the textiles gives benefits unrivalled by other systems. Measurements of data requiring close contact with the skin are possible, with minimal effects on the comfort of the wearer, and with minimal disruption to his/her day-to-day activities.[15] In fact, a new type of the interfaces should be invented to go with 'natural' environment without interfering with daily activity.

A number of smart garments have incorporated existing, adapted or developed sensors for the measurement of biometric factors such as body temperature, heart rate, respiration rate, skin conductivity, etc.[16)-20] Applications for such types of garments or accessories cover the healthcare, clinical, military, rescue or sports sectors, where the monitoring of vital signs is essential.[21] The sensing interface should be minimally invasive, conformable to human body and easy to wear, to allow their use during rehabilitation from cardio-pulmonary diseases or in the prevention of acute crises. Finally by providing direct feedback to the users, they can act on the level of awareness and allow better control of their own condition. In this respect, smart monitoring clothing is powerful a new tool to drive people towards healthier life styles.[22]

2. Recent Developments in the Biosignal Electrode

There is an emerging need for renovation in our health managing system; people need to be more and more conscious of their health status, and more interactive with the social assistance services. Remote health monitoring can be accepted and used only if the monitoring device is based on a comfortable sensing interface, easy to customize; the new interface must allow continuous remote control, in a "natural" environment without any discomfort for the users and without interfering with their daily activities.[23]

The methods for the clinical monitoring of physiological parameters using textile structures have taken the form of a shirt (SmartShirt System), vest(LifeShirt™), and a loose fitting bodysuit (Hokie). A number of organizations actively explore the use of garment based health monitoring including: MIT, Georgia Tech, Philips, Infineon Technologies (now InteractiveWear), Frauhoffer Institute, ETH Wearable Computing Laboratory, MyHeart, and so on. In the 'WEALTHY' system,[24] conductive and piezoresistive yarns are used to manufacture a

<Figure 1> Textile Electrodes for the Biosignal Monitoring

knitted garment possessing distributed functional regions. Conductive and piezoresistive yarns are integrated and used as sensors, connections, and electrodes in <Figure 1>.

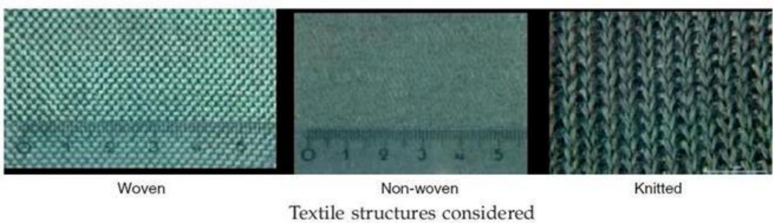
Actually, a key component for smart clothing systems for monitoring applications is the sensor, which gathers data from the wearer and relays the information to a processing unit. Recent works in monitoring vests and garments have integrated multiple sensors that provide physiological data such as body temperature, heart rate, skin conductivity, etc., and location data, using satellite facilities.[25] The type, position and number of sensors used naturally depend on the application end-use of the smart clothing.

3. Textile Electrodes

Regarding as electrocardiogram(*i.e.,* ECG) recordings with textile electrode of E-textiles, measured potential is not only dependent on heartbeat but also on neuron reactions (activity) in the body, instantaneous conductivity of the skin, humidity and oxygen concentration of the surrounding air, humidity of the skin in contact with the surface, therefore many parameters can possibly interfere with the measure signal. The limited reproducibility of intelligent textile monitoring systems is caused to the noise problems on contact of human body surface.[26] Textile materials are insulators, but in the textile electrodes conductive yarn is attached to the fabric during their manufacturing process.

These electrodes do not need to gel to achieve connection to the skin. The textile electrodes can be made by weaving, knitting or embroidering conductive yarn to the structure in <Figure 2>. The textile electrode materials are typically synthetic, for example polyester or polyamide.[27] The advantages of these textile electrodes are that they perform long-term measurement without irritating the skin, are abrasion-resistant, absorb moisture, dry quickly, lightweight, ductile, and washable. Compared to the 10 KΩ/cm^2 impedance of the disposable Ag-AgCl electrodes, the textile electrodes have 1~5 MΩ/cm^2 impedance.[28][29] Due to the wearable and comfortable properties, bio-monitor applications are also popular based on the fabric-based sensors.[30]

Knitted stretchy sensors are made up of conductive fibers by knitting techniques and are applied for posture detection. Structurally, both knitted and woven fabrics have been used for wearable



<Figure 2> Textile Structure: Woven, Non-woven, Knitted[31]

electronic clothing for monitoring applications. The main advantage with textiles is their flexibility, which relates to some extent to wearing comfort. Knitted fabrics have the advantage of being stretchable and deformable to some extent, and have been used where the fabrics need to be close to the body, or close fitting, such as for leotards or other sportswear. Comparatively, woven fabrics provide more dimensional stability, and are more suitable where large movements of the body are not an essential factor to consider.

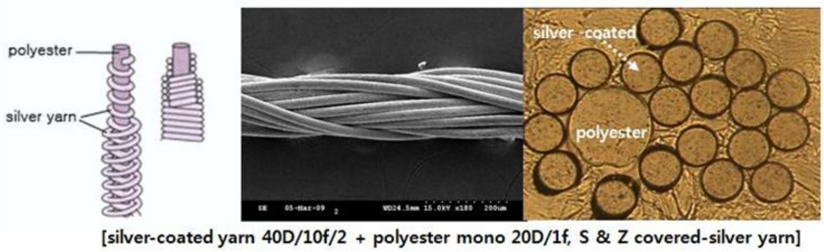
III. Contents and Method of Research

1. Fabric Specification for Jacquard Textile Electrode

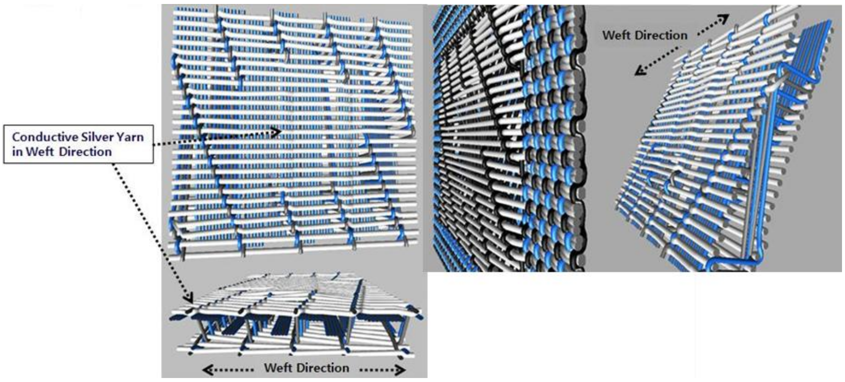
Jacquard fabrics were woven by jacquard loom, which can be produced the various woven patterns and weaving fabrics uniformly in a large scale. The specification of textile electrode in this study, which was called jacquard woven fabric-based textile electrode (*i.e.,* JWFTE) in Jacquard Loom, as shown in <Table 1>. The silver yarn was chosen to monitor the biosignals for a fine conductivity and the safety to the body. JWFTE was made with the polyester filament of a warp (75 D/48f), and the conductive silver yarn of a weft (100D/21f covering yarn) in <Figure 3>. The covered silver yarn (*i.e.,* 100D/21f) was made by a silver yarn of 40 denier (*i.e.,* 40D/10f), which twisted in the S and Z directions around a standard continuous mono polyester yarn of 20 denier (20D/1f). The fabric electrodes of the two layering system were woven by a Stabuli-JC5 (C.Illies & Co., Germany) jacquard loom with 168 EPI (ends per inch) of polyester warp yarn, 120 PPI (picks per inch) of polyester yarn in the ground layer, and 150 PPI (picks per inch) of silver covering yarn in the effective layer in <Figure 4>. Therefore, JWFTE can be more uniformly and more compactly woven with a conductive yarn on a large scale to ensure consistent properties.

<Table 1> Fabric Specification in Jacquard Loom

Yarn name	Type	Denier	Material	Colors	Scale	YarnSample
	Warp	75 den	polyester	HLS(67.76 0.93 0.04)	100.0	Polyester 600 T/M
Yarn name	**Type**	**Denier**	**Material**	**Colors**	**Scale**	**YarnSample**
	Weft-ground	150 den	polyester	HLS(49.41 0.49 0.38)	100.0	Polyester 600 T/M
	Weft-ground	150 den	polyester	HLS(100.24 0.26 0.38)	100.0	Polyester 600 T/M
	Weft-Effect	100 or 80 den	Nylon/ Silver	HLS(0.00 0.94 0.04)	100.0	Silver Coating Yarn
	Weft-Effect	100 or 80 den	Nylon/ Silver	HLS(0.00 0.94 0.04)	100.0	Silver Coating Yarn



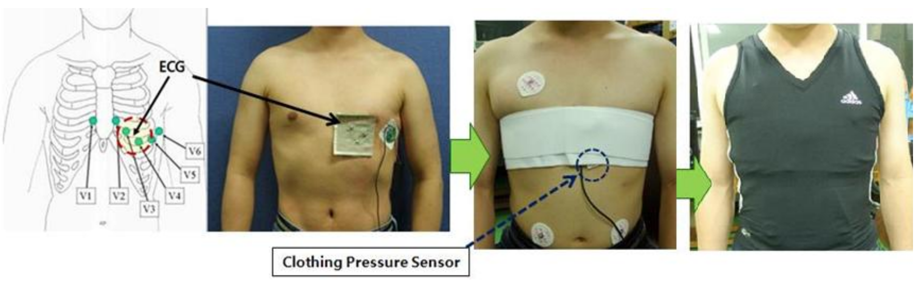
<Figure 3> SEM photo of the Covered Silver Yarn



<Figure 4> 3-Dimensional Look of Double Cloth Weave

2. Position of the Electrode for ECG Measurement

In this study, it is impossible to measure ECG signals using the electrode developed with standard lead because of the short distance between electrodes, so the test position of the chest lead configuration was chosen to be between V3 and V4 in <Figure 5>. At this position, the signals are more influenced by the cardiac ventricle, but were able to approximate a clinical ECG in terms of the point-to-point signal level in chest lead. The SNR (i.e., Signal to Noise Ratio) of the ECG signal was measured by using the RMS (Root Mean Square) of the iso-electric region. Then, the ECG was measured by using an MP 150 (Biopac System Inc., CA, USA) instrument device. All ECG measurements in this study were obtained under the clothing pressure of 40 grams-force/cm^2.



<Figure 5> The position for the ECG measurement

<Table 2> Subjects for ECG Experiment

Subject	Gender	Age (yr)	Height (cm)	Weight(kg)	Bust (cm)	BMI (kg/m^2)	Skin
1	male	24	173	63	90	21	less hairy
2	male	25	163	68	96	25.5	less hairy
3	male	25	170	58	90	20	less hairy

* BMI: Body Mass Index, kg/m^2: weight(kg)/Height(m^2)

3. Subjects for ECG Experiment

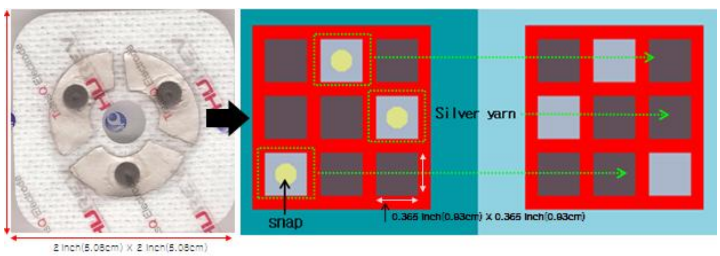
For the ECG Experiment, Korean males in their twenties were selected as the subjects, as shown in <Table 2>. All subjects within standard somatotypes (i.e., in height and weight, less hairy skin) were purposively recruited. Three subjects were recruited for ECG experiments in resting conditions.

IV. Results & Discussions

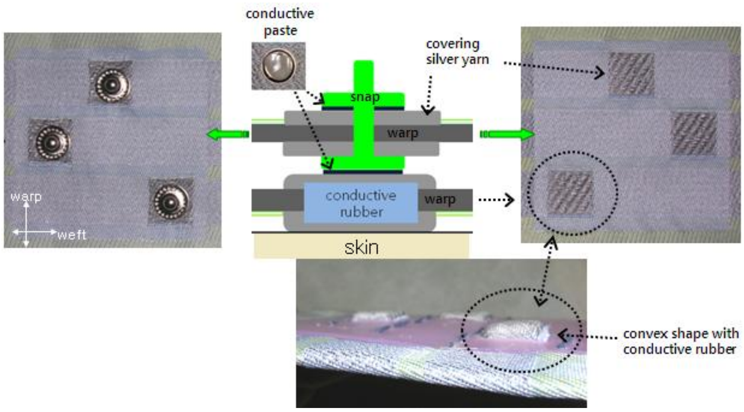
1. Electrodes Interface Design of JWFTE

The interface design of JWFTE was devised as the basis for the conventional electrode, which is the three electrode points of Silver/Silver chloride (AgCl) electrode, as shown in <Figure 6>. The basic idea for JWFTE design was originated in the structure of medical Silver/Silver chloride(AgCl) electrode, which consisted of three electrode points and devised for the small size electrode with low-noise. Size and position of the textile electrodes and distance between them were mimetically followed those in the medical Ag/AgCl electrode. The size of JWFTE is 50 X 50 mm^2 that consists of each three electrode points of 10 X 10 mm^2. An interface design of three points on front and back electrode were devised to minimize a noise for sensing biosignals efficiently within the shot distance with a low impedance.

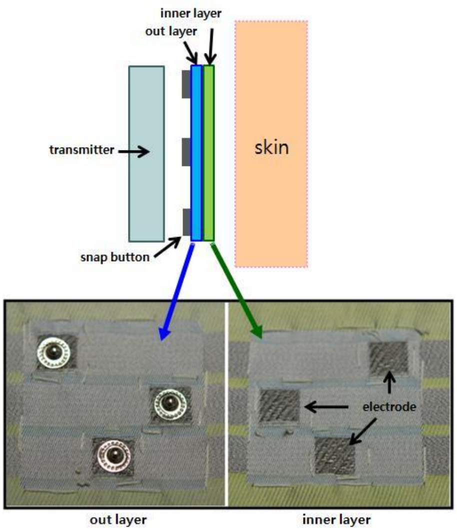
JWFTE consisted of one set of two layers of electrodes, which were to be bilaterally merged. One of them, outer layer was devised to interconnect the electrodes with the transmitter by snap buttons, meanwhile the other one was to directly contact the wearer's skin, as shown in <Figure 7>. JWFTE was the double-cloth weave structure, consisting of a ground layer of a polyester yarn and an effective layer of covered silver yarn in the weft direction. JWFTE was designed to be sensed the convex shape of electrode with the conductive paste, which reduced the contact resistance between the snap connector and the outside of the JWFTE, and therefore improves the measured quality of ECG, as shown in <Figure 8>.



<Figure 6> Interface Design of JWFTE



<Figure 7> Interface Design of JWFTE



<Figure 8> Interface Design of JWFTE Interconnection between JWFTE and ECG transmitter

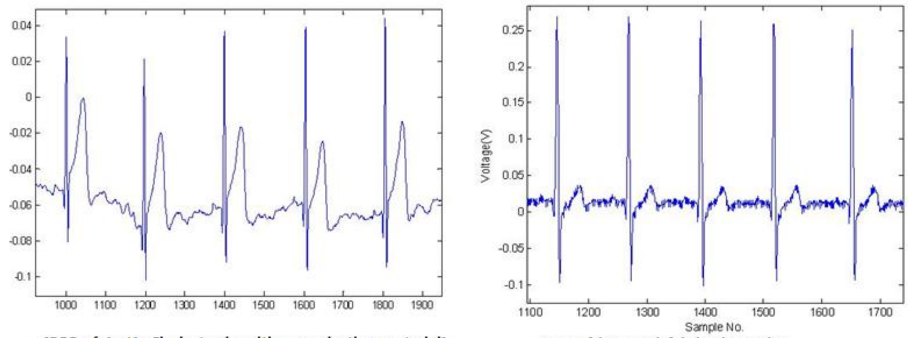
2. ECG Signals from Experiment

The JWFTE were tested to find out the ECG signals, as shown in <Figure 7>. Overally, the JWFTE in SNR (*i.e.,* Signal to Noise Ratio) showed 33.67dB in <Table 3>. That was, the convex shape of JWFTE was helpful monitoring the bio-signals because the convex shape reserved closer and wider contact points to the skin. Also, the conductive paste between the snap connector and the electrode fabric reduced the contact resistance and improved the signal quality. JWFTE of the ECG signals, which were morphologically closer to the ECG signals through the clinical Ag/AgCl electrode, as shown in <Figure 9>. The JWFTE can be used for monitoring the electrical activity of the heart in smart clothing.

<Table 3> Average of the SNR of Jacquard Woven Fabric-based Textile Electrode

Electrode Type		Average 1	Average 2	Average 3	Total Average	SNR (dB)
JWFTE	Signal	0.168	0.356	0.227	0.250	33.673
	Noise	0.003	0.011	0.001	0.005	

* SNR(dB): Signal to Resistance
* JWFTE: Jacquard Woven Fabric-based Textile Electrode



<Figure 9> ECG comparison of the clinical Ag/AgCl electrodes and JWFTE

V. Conclusion

The sensing interface made of the textile electrode is expected to be non-invasive, comfortable to human body and easy to wear, to allow their use during rehabilitation from cardiopulmonary diseased or in the prevention of acute crises. The textile-based electrode to replace the conventional Ag/AgCl electrode, is a new type of electrode, suitable to long-term ECG measurement without skin irritation, long term wearing for its good moisture-absorbance and its lightweight, and repeated used for its washability. However, there have been limited research cases on the textile-based electrode, showing short signal samples which are resistance and impedance measurements.

Therefore, this study aimed to design the woven fabric-based textile electrode with the electrical jacquard weaving system of the constant properties for monitoring the electrical activity of the heart, and it could be integrated into the smart clothing. The sensing factors in textile electrode were considered as the exposure of conductivity of yarn on electrode surface, conductive yarn, insertion of conductive paste, and also related to the way to contact between the electrode and skin, such as 3-D shape of the electrode, weft weave structure, and etc.

To state results quantitatively, the convex shape of jacquard electrode warps with the conductive paste showed 33.67dB of SNR (signal-to-noise ratio) in ECG signal performance. JWFTE of the ECG signals were morphologically closer to the ECG signals through the clinical Ag/AgCl electrode. The final prototype of JWFTE was suggested as a module for monitoring of the electrical activity of the heart, to be applied to smart clothing.

Reference

1) Enzo *et al.* (2005). Performance Evaluation of Sensing Fabrics for Monitoring Physiological and Biomechical Variables. *IEEE Transactions on Information Technology in Biomedicine 9(3)*, pp.345-352.

2) Ching-Tang Huang, Chien-Lung, Chien-Fa Tang, Shuo-Hung Chang. (2007). A wearable yarn-based piezo-resistive sensor. *Sensors and Actuators A 141*, pp.396-403.

3) Van Langenhove, L. (2007). *Smart textiles for medicine and healthcare.* Woodhead Publishing Limited, Cambridge England.

4) De Rossi *et al.* (2003). Electroactive Fabrics and Wearable Biomonitoring Devices. *AUTEX Research Journal 3.*

5) De Rossi *et al.* (2003). Active dressware: Wearable

kinesthetic systems. *in Sensors and Sensing in Biology and Engineering ch.26*, New York: Springer-Verlag.
6) Park, S., Jayaraman, S. (2007). Enhancing the quality of life through wearable technology. *IEEE Eng. Med. Biol. Mag. 22(3)*, pp.41-48.
7) Paradiso, R. *et al.* (2003). Wearable Healthcare System for Vital Signs. *4th International IEEE EMBS Special Topic Conference,* pp.283-286.
8) Loriga, G., Taccini, N., De Rossi, D. and Paradiso, R. (2005). Op. cit., pp.7349-7352.
9) Scilingo, E. P. *et al.* (2005). Performance Evaluation of Sensing Fabrics for Monitoring Physiological and Biomechanical Variables. *IEEE Transactions on Information Technology in Biomedicine 9(3),* pp.345-352.
10) Paradiso, R. *et al.* (2005). A Wearable Health Care System Based on Knitted Integrated Sensors. *IEEE Transactions on Information Technology in Biomedicine 9(3),* pp.337-344.
11) Jango, Seeun. (2007). Effect of fabric elasticity and body movement on performance of electrocardiogram signal monitoring clothing. Master. D. Dissertation. Yonsei University, pp.21-25.
12) Koo, Sumin. (2008). A Study on the Design of Re-modularized Smart Clothing for ECG-sensing. Master. D. Dissertation. Yonsei University, pp.67-79.
13) Karilainen, J., Hansen, S. and Muller, J. (2005). Dry and capacitive electrodes for long-term ECG-monitoring. *8th Annual Work-shopon Semiconductor Advances Nov.17,* p.156.
14) Loriga, G., Taccini, N., De Rossi, D. and Paradiso, R. (2005). Op. cit., pp.7349-7352.
15) Lam Po Tang, S. (2007). Recent developments in flexible wearable electronics for monitoring applications. *Transaction of the Institute of Measurement and Control 29, 3-4,* pp.283-300.
16) Catrysse, M. *et al.* (2003). Fabric sensors for measurement of physiological parameters. *IEEE The 12th International Conference on Solid State Sensors,* Boston, pp.1758-1761.
17) De Rossi *et al.* (2003). Electroactive Fabrics and Wearable Biomonitoring Devices. *AUTEX Research Journal 3.*
18) De Rossi *et al.* (2005). *Electroactive fabrics and wearable manmachine interfaces. In Tao, X., editor, Wearable electronics and photonics*, Woodhead Publishing in Textiles, Chapter 4, pp.59-80.
19) Dunne, L. E., Brady, S., Smyth, B. and Diamond, D. (2005). Initial development and testing of a novel foam-based pressure sensor for wearable sensing. *Journal of Neuro Engineering and Rehabilitation 2(4).* pp.
20) Goulev, P., Stead, L., Mamdani, E. and Evans, C. (2004). Computer aided emotional fashion. *Computer & Graphics 28*, pp.657-666.
21) Lam Po Tang, S. (2007). Op. cit., pp.283-300.
22) Loriga, G., Taccini, N., De Rossi, D. and Paradiso, R. (2005). Op. cit., pp.7349-7352.
23) Park, S., Jayaraman, S. (2007). Op. cit., pp.41-48.
24) Ockerman, J. J., Najjar, L. J. and Tompson, J. C. (1999). Future technology for today’s industry. *Computers in Industry 38,* pp.53-64.
25) Lam Po Tang, S. (2007). Op. cit., pp.283-300.
26) Priniotakis, G. *et al.* (2005). An experimental simulation of human body behavior during sweat production measured at textile electrodes. *International Journal of Clothing Science Technology 17,* pp.232-241.
27) Pola, T. and Vanhala, J. (2007). Textile Electrodes in ECG Measurement. *IEEE,* pp.635-639.
28) Karilainen, J., Hansen, S. and Muller, J. (2005). Op. cit., p.156.
29) Catrysse, M. *et al.* (2003). Fabric sensors for measurement of physiological parameters.

IEEE The 12th International Conference on Solid State Sensors, Boston, pp.1758-1761.

30) Priniotakis, G. *et al.* (2007). Electrochemical impedance spectroscopy as an objective method for characterization of textile electrodes. *Transactions of the Institude of Measurement and Control 29,* pp.271-281.

31) Ibid., p.275.