COTTON FABRIC-BASED FLEXIBLE ELECTRODE FOR ELECTROCARDIOGRAPHY

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Biomedical)

Faculty of Biosciences and Medical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2016

17th February 2016

Librarian

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Please be informed that the above mentioned thesis entitled ***"COTTON FABRIC-BASED FLEXIBLE ELECTRODE FOR ELECTROCARDIOGRAPHY"*** is to be classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are

(i) The project has potential for future publication in certain journals.

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Thank you.

Sincerely yours,

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To my beloved family

ACKNOWLEDGEMENT

Firstly, I would like to express my gratitude to my advisor, Dr. Dedy H. B. Wicaksono for the never-ending support in completing my research. His tireless guidance and motivation have assisted me throughout my days in Universiti Teknologi Malaysia. Besides, I would also like to sincerely thank my co-supervisor, Dr. Hau Yuan Wen for her support and motivation.

In completing this research, I've been assisted by many individuals who have directly or indirectly contributed in my research. I would like to take this opportunity to specially thank Muhamad Firdaus Mohd Rafi, Mohamad Fahmi Hazwan Mohd Fishol, Muhamad Bakhtiar Mohd Yudin and Aldi Michi who have contributed much to the development of the flexible circuit. My gratitude also goes to Dr. Manohar Rao from JPK Instruments and Ms. Siti Hanisah Binti Zainuddin from KL Analytical for their help in atomic force microscopy characterization; and Ms. Nur Farhana Hasmuni for her help in field emission scanning electron microscopy characterization. Besides, I would also like to express my gratitude to members of Bio-Inspired Medical Device Group for their constructive criticism and also their idea to improve this research.

Lastly, I would like to dedicate my gratitude to my lovely family who supported me no matter what I choose to do; and to my late mother, her words of wisdom have kept me going through these years.

ABSTRACT

Early detection of heart abnormalities is one of the proposed methods to reduce number of death due to cardiovascular disease. Electrocardiography (ECG) is one of the commonly used methods in healthcare institution to monitor the heart condition. However, conventional ECG monitoring system is not suitable for long-term monitoring since it is bulky and experienced personnel is needed to interpret the ECG signal. In this study, flexible electrode and circuit using cotton fabric as the substrate material is proposed. Graphene-PEDOT:PSS ink which was synthesized via electrochemical exfoliation of graphite rod was used as the conductive material. The flexible electrode was fabricated using manual immersion of scoured fabric in the ink while wax patterning and pipetting methods were employed for fabrication of electrically conductive pattern for flexible circuit. Sheet resistance of the cotton fabric-based electrode coated with 5 layers of conductive ink is 75.9 Ω/sq. The ECG signal recorded using the cotton fabric-based electrode has similar features to that of using commercial silver/silver chloride electrode. On the other hand, the average resistance of as-fabricated 10 mm long and 1 mm wide conductive pattern is 128.68 Ω. The conductive pattern remained 42.1%, 41.1% and 53.6% of its conductance after 1000 bending cycles at bend radii of 0.50, 0.75 and 1.25 mm, respectively. Besides, the conductive pattern remained 70.4% and 50.8% of its conductance after 10 acute and obtuse folding cycles, respectively. A simple cotton fabric-based operational amplifier with gain of 1.67 was fabricated as an initial proof-of-concept for development of simple processing system on cotton fabric substrate

ABSTRAK

Salah satu kaedah untuk mengurangkan kadar kematian yang disebabkan oleh penyakit kardiovaskular ini adalah melalui pengesanan awal keadaan abnormal jantung seseorang. Elektrokardiografi (ECG) merupakan salah satu kaedah yang biasa digunakan untuk memantau aktiviti jantung seseorang dalam institusi perubatan. Namun, kaedah ECG ini tidak sesuai digunakan untuk pemantauan jangka masa yang panjang disebabkan oleh saiz mesin ECG yang besar dan juga kepakaran diperlukan untuk mengintepretasi maklumat yang diperoleh melalui ECG. Dalam kajian ini, elektrod dan litar fleksibel difabrikasi menggunakan kain kapas sebagai bahan substrat. Dakwat graphene-PEDOT:PSS dihasilkan melalui kaedah elektrokimia menggunakan rod grafit. Elektrod tersebut dihasilkan melalui kaedah pencelupan kain kapas yang telah dirawat ke dalam dakwat konduktif secara manual. Selain itu, litar fleksibel pula dihasilkan melalui kaedah aplikasi lilin ke atas kain dan juga aplikasi dakwat konduktif menggunakan pipet. Rintangan helaian elektrod berasaskan kain kapas yang mempunyai 5 lapisan dakwat konduktif adalah 75.9 Ω/segi. Isyarat ECG yang direkod menggunakan elektrod berasaskan kain kapas mempunyai persamaan dengan elektrod komersial daripada ciri-ciri isyarat yang diperolehi. Selain itu, purata nilai rintangan corak konduktif yang berukuran 10 dan lebar 1 mm ialah 128.68 Ω. Corak konduktif tersebut mengekalkan purata konduktif sebanyak 42.1%, 41.1% dan 53.6% setelah dibengkokkan secara berulang kali selama 1000 kali dengan jejari bengkokan sebanyak 0.50, 0.75 dan 1.25 mm. Selain itu, corak konduktif tersebut mengekalkan purata nilai konduktif sebanyak 70.4% dan 50.8% setelah dilipat sebanyak 10 kali ke arah sudut akut dan cakah. Sebuah litar penguat kendalian dengan nilai penguat sebanyak 1.67 telah direalisasikan atas kain kapas sebagai pembuktian awal penghasilan litar di atas kain kapas.

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V_{meas} represents the output signal from the cotton fabric-based circuit while V_{ref} is the output from similar circuit developed on printed circuit board as reference

LIST OF ABBREVIATIONS

Ag/AgCl	-	Silver/silver chloride
AFM	-	Atomic force microscopy
AgNP	-	Silver nanoparticle
CVD	-	Cardiovascular disease
CNT	-	Carbon nanotube
DIY	-	Do-it-yourself
ECG	-	Electrocardiography
EDX	-	Energy-dispersive X-ray
FESEM	-	Field emission scanning electron microscopy
HSF	-	Human skin fibroblast
LED	-	Light emitting diode
MEMS	-	Micro-electro-mechanical-system
MWCNT	-	Multi-walled carbon nanotube
NECTEC	-	National Electronics and Computer Technology Center
PCB	-	Printed circuit board
PEDOT:PSS	-	Poly(3,4-ethylenedioxythiophene)-poly(styrenesufonate)
SNR	-	Signal-to-noise ratio

LIST OF SYMBOLS

r	-	Bending radius
T	-	Temperature

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, the research background, problem statement, objectives, purpose of study, significance of study and scope of this project will be described. Besides, the flow chart and also Gantt chart to achieve the objectives of this project will also be provided.

1.2 Background of Research

Studies conducted shows that cardiovascular disease (CVD) is one of the leading causes of death even in developed countries such as United States. It is estimated that the prevalence of CVD will increase by approximately 10% over the next two decades should there be no change made to the current prevention and treatment plan [1]. The number of death due to CVD can be reduced through early detection of abnormality of the heart, especially for people with history of CVD or heart related disease [2]. Therefore, there is a need for a long-term ECG monitoring system to detect the temporary change in ECG signal to diagnose CVD such as arrhythmia and cardiac infarction [3].

Several wearable physiological monitoring systems have been developed to monitor the health status of a person including ECG signal. Such wearable systems are small in size, low power consumption and light-weighted [4, 5]. However, the commercially available ECG electrode which is the silver/silver chloride (Ag/AgCl) electrode which is used in these systems is not suitable to be used in long-term ECG monitoring. In this project, the author aims at developing a textile-based ECG electrode to replace the commercially available ECG electrode to monitor the ECG signal of individuals who have a history of heart-related disease or for patients who had cardiac surgery. Besides, another focus of this project is on the development of flexible electronic circuit using cotton fabric as the substrate material. This project serves as an initial proof-of-concept on the possibility to develop a fully functional wearable monitoring system with possibility of integrating both the flexible electrode and circuit on clothing in the future.

1.3 Problem Statement

Conventional electrodes such as Ag/AgCl electrodes are used in electrocardiography monitoring. However, study shows that these electrodes are not suitable for long-term monitoring purpose due to the use of hydrogel which could cause skin irritation and the quality of signal is affected when the hydrogel dries.

Some studies have been conducted to replace the conventional electrodes with dry electrodes made from alternative substrate materials.

While there has been development of wearable devices for biomedical applications, signal processing circuits are still fabricated using conventional printed circuit board (PCB) resulting in a rigid and bulky system. Hence, such wearable systems are not totally portable and may be inconvenient for some people to perform long-term ECG monitoring.

1.4 Objectives

The objectives of this research are as follow:

1) To fabricate cotton fabric-based flexible electrode and electronic circuit using cost effective and easily available materials such as cotton fabric as the substrate material and also graphene-poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (graphene-PEDOT:PSS) ink as the conductive material for biomedical applications such as ECG monitoring.
2) To assess cell viability of human skin fibroblast (HSF) cells on the fabricated conductive cotton fabric *via* MTT assay.
3) To compare the performance of the developed flexible textile-based electrode in measuring biopotential signal such as ECG signal with the quality of signal measured using Ag/AgCl electrode in terms of features of the recorded signal.

1.5 Purpose of Study

The purpose of this study is to develop a low cost flexible electrode to be used in biomedical applications such as ECG monitoring. The novelties of this research are on the material used and also the simple fabrication methods. In this project, a textile-based electrode will be developed using cotton fabric as the substrate material and graphene-PEDOT:PSS as the conductive material to fabricate the sensor. The use of cotton fabric is proposed since it is cost effective and easily available as well as sustainable and environmentally friendly. Some of the commonly used methods to deposit conductive materials on flexible substrate include screen printing, inkjet printing and soft lithography techniques where these methods are costly and require the use of state-of-the-art technology which may not be accessible or affordable by people in some developing countries. Hence, we propose simple methods such as dip coating and drying methods to fabricate the flexible electrode.

Similarly for the second part of this project, we propose the use of cotton fabric as the substrate material for fabrication of flexible electronic circuit. Conventionally, electronic circuits are usually assembled on PCB but the rigidity of the board limits its' versatility. Although much research has been conducted on fabricating flexible electronic circuit on paper substrate, the application is limited due to its' brittleness. Hence, we propose the use of simple fabrication method using wax-patterning and pipetting of the conductive ink on cotton fabric to form a highly flexible electronic circuit.

1.6 Significance of Study

In this project, a cost effective flexible electrode and a preliminary study on the development of circuit on cotton fabric will be developed for ECG monitoring purpose. In this case, this system will enable user to afford to have a portable ECG monitoring system at home where the measurement can be taken by the users or their family members, where this will reduce the time wasted to have a check up at healthcare centre. Should there be any sign or indication of cardiovascular abnormality, the user can then be referred to specialist to have more accurate diagnosis and treatment. This will indirectly contribute to lowering the number of fatality since cardiovascular disease is one of the leading causes of death in the world. This is because the diagnosis could be performed at a lower cost which makes it more affordable to people with lower income where treatment can then be carried out should the person is diagnosed with cardiovascular disease to prevent complication in the future. Besides, the electrode will also be integrated into wearable system where people with history of cardiovascular disease or those who have undergone heart-related surgery could wear the ECG monitoring system integrated on clothing so that the patient or family members could take immediate action should there be abnormality indicated by the system. This could also reduce the risk of fatality since a precaution could be taken before the condition of the patient worsens.

1.7 Scope

Scope of this project includes the development of a cotton fabric-based flexible electrode for biomedical applications which include material processing, fabrication and characterization of the electroconductive fabric, development of electrode and testing of the electrode. Besides, another scope of this project is in the integration of the electronic components on cotton fabric to form a cotton fabric-based circuit which involves material processing, fabrication and characterization of conductive line, integration of components and also testing of the developed circuit.

1.8 Flow Chart

The methodology used in this research is illustrated in the flow charts shown in Figure 1.1 and Figure 1.2.

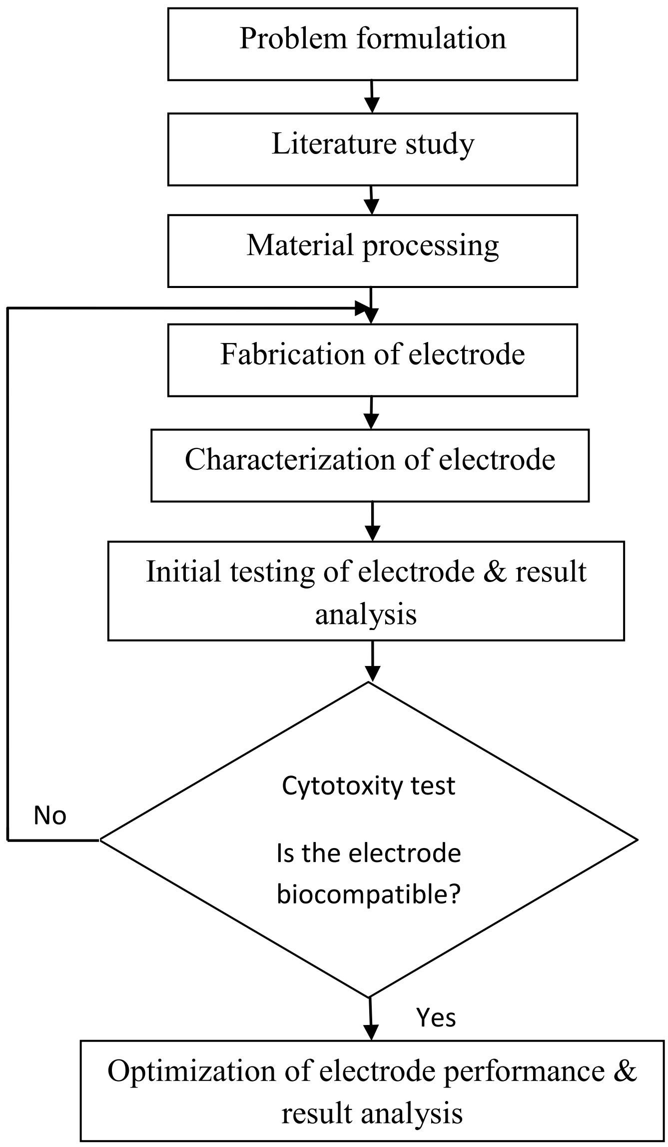

Figure 1.1 Flow chart for development of flexible cotton fabric-based electrode.

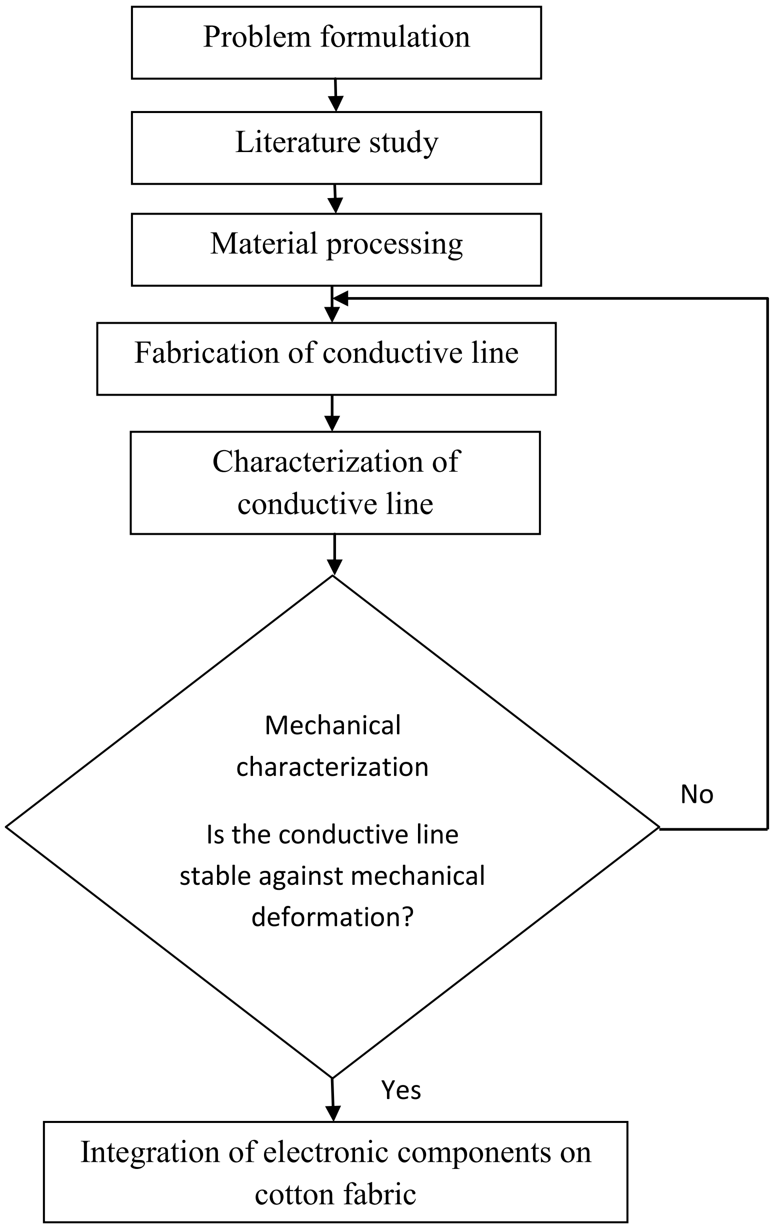

Figure 1.2 Flow chart for development of flexible electronic circuit on cotton fabric.

1.9 Gantt Chart

Table 1.1, 1.2, 1.3 and 1.4 show the Gantt chart for Semester 1, 2, 3 and 4, respectively. This project took a total of 4 semesters to be completed.

Table 1.1 : Gantt chart for Semester 1

Month	Sept 2013				Oct 2013				Nov 2013				Dec 2013				Jan 2014			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Problem Formulation																				
Literature Review																				
Material Processing																				
Electrode Fabrication																				
Characterization																				
Initial Testing of Sensor																				
Analysis of Initial Result																				
Report Writing																				

Table 1.2 : Gantt chart for Semester 2

Month	Feb 2014				March 2014				April 2014				May 2014				June 2014			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Cell Viability Assessment																				
Electrode Optimization and Testing																				
Fabrication of Conductive Line																				
Electrical Characterization of Conductive Line																				
Report Writing																				

Table 1.3 : Gantt chart for Semester 3

Month	Sept 2014				Oct 2014				Nov 2014				Dec 2014				Jan 2015			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Mechanical Characterization of Conductive Line	■	■	■																	
Development of LED Circuit on Fabric				■	■	■	■	■	■											
Testing of Flexible LED Circuit on Fabric										■	■	■	■							
Development and testing of op-amp circuit on fabric													■	■	■	■	■			
Report Writing																		■	■	■

Table 1.4 : Gantt chart for Semester 4

Month	Feb 2015				March 2015				April 2015				May 2015				June 2015			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Circuit Optimization	■	■	■	■																
Final Testing of Circuit			■	■																
Review and Analysis of Result					■	■														
Finalize Project							■	■	■	■										
Thesis Writing											■	■	■	■	■	■				
Thesis Submission																	■	■		

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