REDUCED GRAPHENE OXIDE-BASED ELECTRICAL CIRCUIT TRACE ON FLEXIBLE COTTON FABRIC

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DEDICATION

This thesis is dedicated to my beloved parents, husband, and daughter.

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ABSTRACT

Electrocardiography (ECG) is one of the methods used for monitoring the heart condition. There are increasing demands for the development of wearable and flexible ECG systems to be implemented for long term ECG monitoring. In the development of wearable circuits, polymer material has been widely used to enable the flexibility properties. However, polymer may cause allergy to human skin, and the inability of the polymer to pass through moisture at human skin makes it inappropriate to be used for wearable applications. Cotton fabric is an alternative substrate for the polymer since it is natural, hypoallergenic and able to pass through moisture of human skin. Thus, the objectives of this research were focused on designing and fabricating traces of ECG circuit on cotton fabric; investigating the effects of mechanical characterization on the conductive line; and validating the ECG signal acquisition using the fabricated circuit trace with 0.2 % w/w of graphene oxide ink was used as the conductive material. The fabrication process of conductive line on cotton fabric includes the production of wax impregnated paper, wax transferred from wax impregnated paper onto cotton fabric, pipetting of graphene oxide ink onto the cotton fabric, and reduction of graphene oxide. The resistance of 1.97 kΩ was produced in 1 mm wide and 20 mm long conductive line coated with 30 layers of graphene oxide. Two mechanical characterizations were performed on the conductive line; washing and folding tests. In washing test, three solutions were used including distilled water with pH = 7, detergent solutions with pH = 8 and pH = 9. The conductive line remained 84 % after fifth times of washing using distilled water with pH = 7. In folding test, the conductive pattern remained 73 % after tenth times of -180 ° and 180 ° angles of folding. During ECG signal acquisition using cotton fabric-based circuit trace, the features of ECG signal are successfully acquired and displayed. However, there is a 60 Hz electrical noise included in the signal due to the capacitive component in the cotton fabric-based circuit trace. This research acts as a preliminary phase in developing a flexible and fully functional cotton fabric-based ECG monitoring system which can be used for long term ECG monitoring.

ABSTRAK

Elektrokardiografi (ECG) adalah salah satu kaedah yang digunakan untuk memantau keadaan jantung. Terdapat permintaan yang semakin meningkat untuk pembangunan sistem ECG yang boleh dipakai dan fleksibel untuk digunakan dalam pemantauan ECG jangka panjang. Dalam pembangunan litar yang boleh dipakai, polimer telah digunakan secara meluas untuk memenuhi sifat fleksibiliti. Namun, polimer boleh menyebabkan alergi pada kulit manusia, dan ketidakupayaan polimer untuk mengawal kelembapan kulit manusia juga menjadikannya tidak sesuai digunakan untuk aplikasi yang boleh dipakai. Kain kapas adalah substrat alternatif untuk polimer kerana ia semula jadi, hipoalergi, dan mampu mengawal kelembapan kulit manusia. Objektif penyelidikan ini menumpukan pada merancang dan membuat jejak litar ECG pada kain kapas, menyiasat kesan pencirian mekanikal pada garis konduktif, dan mengesahkan pemerolehan isyarat ECG menggunakan jejak litar dimana 0.2% w / w dakwat grafin oksida digunakan sebagai bahan konduktif. Proses fabrikasi garisan konduktif pada kain kapas merangkumi penghasilan kertas yang direndam lilin, pemindahan lilin dari kertas ke kain kapas, pipet grafin oksida ke kain kapas, dan penurunan grafin oksida. 1.97 kΩ rintangan dihasilkan oleh garisan konduktif berukuran 1 mm dan 20 mm dilapisi dengan 30 lapisan grafin oksida. Dalam ujian mencuci, tiga rumusan digunakan iaitu air suling dengan pH=7, larutan pencuci dengan pH=8 dan pH=9. Garisan konduktif kekal 84% setelah lima kali dicuci menggunakan air suling dengan pH=7. Dalam ujian lipatan, garisan konduktif kekal 73% setelah dilipat menggunakan sudut -180° dan 180° sebanyak sepuluh kali. Semasa pemerolehan isyarat ECG menggunakan jejak litar berasaskan kain kapas, ciri-ciri isyarat ECG berjaya diperoleh dan ditunjukkan. Walau bagaimanapun, terdapat gangguan elektrik 60 Hz yang termasuk dalam isyarat disebabkan komponen kapasitif dalam jejak litar berasaskan kain kapas. Penyelidikan ini bertindak sebagai fasa awal dalam perkembangan sistem pemantauan ECG berdasarkan kain kapas yang fleksibel dan berfungsi sepenuhnya dan dapat digunakan untuk pemantauan ECG jangka panjang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CVD	-	Cardiovascular diseases
ECG	-	Electrocardiography
EAGLE	-	Easily Applicable Graphical Layout Editor
PCB	-	Printed Circuit Board
rpm	-	Revolution per minute
PVC	-	Polymerizing Vinyl Chloride
LED	-	Light Emitting Diode
RA	-	Right Arm
LA	-	Left Arm
RL	-	Right Leg
bpm	-	Beats per minute
FESEM	-	Field Emission Scanning Electron Microscope

LIST OF SYMBOLS

M	-	Molar concentration
n	-	Moles of solute
V, v, S	-	Volume of solution
w, s	-	Mass of solute
W	-	Molar mass of solute
ρ	-	Density of solution
c	-	Mass to volume percent
C	-	Conductance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, the research background, problem statement, objectives of research, purpose of research, and scope of research, and significance of research are described.

1.2 Research Background

Cardiovascular diseases are diseases which are related to heart and blood vessel. Cardiovascular disease has become one of the primary global issues and it is now threatening the economic and social development of the world. According to the Heart Disease and Stroke Statistics 2016 by American Heart Association, cardiovascular disease has been the cause of more than 17.3 million deaths per year, and this number is predicted to increase to more than 23.6 million by 2030 [1]. Cardiovascular diseases are basically of long term and generally low progression [2].

Hence electrocardiography (ECG) scan is used to monitor the heart rhythm and detect any abnormality which might lead to severe heart problems. For that reason, there are increasing demands for the development of high-quality ECG monitoring

systems to be implemented in long term monitoring. There are various types of ECG devices for remote, wearable, or continuous ECG monitoring which have been developed, and since the electronics become miniaturized now, a lot of new concepts and techniques are being practiced in the development process. In the development process, flexible circuits combining printed circuits and flexible substrates are often required in order to allow a better performance during long-term ECG measurement and to enhance patients comfort. In this research, the author aims to develop a flexible electrical circuit trace using cotton fabric as the substrate material. This project serves as a preliminary proof-of-concept on the possibility to develop a cotton fabric-based ECG circuit to be integrated in wearable ECG monitoring system in the future.

1.3 Problem Statement

In the development process of flexible circuits, several types of substrates such as polymers and papers have been used to satisfy the flexibility properties [3] [4]. However, circuit fabrication using polymers are associated with several problems. One of them is regarding the use of the polymer itself as the substrate materials. Polymer is a synthetic product which may cause allergic to human skin. The use of polymer as the circuit substrate may also cause some environmental effects. Besides, the inability of the polymer substrate to control moisture of human skin makes it inappropriate to be used in flexible circuits for long term monitoring since it may cause discomfort to patients. Meanwhile, the conductive connections on the paper-based circuits may easily be affected as they are being folded or crumpled, making them unsuitable to be used for long term monitoring. Based on these shortcomings, cotton fabric is used as the alternative to polymer and paper. The advantages of cotton fabric includes high flexibility, natural material, hypoallergenic to human skin, high durability, and its ability to control moisture of human skin. Therefore, the development of cotton fabric-based circuit trace may be an initial stage to develop a fully cotton fabric-based ECG circuit to allow a better performance during the long-term measurement and improve patients comfort.

1.4 Objectives of Research

The objectives for this research are:

i. to design and fabricate traces of ECG circuit on cotton fabric
ii. to investigate the effects of mechanical characterization on the cotton fabric-based conductive line
iii. to validate the ECG signal acquisition using the fabricated cotton fabric-based circuitry

1.5 Scope of Research

This research is limited on the fabrication of conductive line on cotton fabric which consists of waxing, pipetting and dewaxing processes, and the formulation of the reduced graphene oxide conductive ink as the conductive material. Reduction method using ascorbic acid is used to reduce graphene oxide into reduced graphene oxide. The mechanical characterizations performed on the conductive line are limited to two types, which are folding and washing tests. The design of electrical circuit trace is prepared using Easily Applicable Graphical Layout Editor (EAGLE) software, and it includes three electronic components, which are AD8232 SparkFun single lead heart rate monitor, mini Nano V3.0 ATmega328P microcontroller board and HC-06 wireless Bluetooth serial pass-through module. However, Bluetooth function and power management system are not involved in this research. The fabrication of cotton fabric-based circuit trace is done using similar method as in the fabrication of cotton fabric-based conductive line. Lastly, ECG signal acquisition is performed only using the developed circuit and the commercialized PCB circuit, using patient simulator as the input signal.

1.6 Significance of Research

The development of the flexible cotton fabric-based ECG circuit would be very valuable as the flexibility feature may allow a better long-term ECG measurement together with the enhancement of patients' comfort. Its lightweight feature makes it fit to be integrated in wearable systems, allowing cardiac performance of patients with the risk and symptoms of cardiovascular diseases (CVD) to be monitored at home. This helps in providing information to the doctors and healthcare professionals for symptoms detection of CVDs since early diagnosis is needed to provide early treatment to the patients and to avoid severe clinical outcomes. There are wide-ranging researches regarding cloth-based ECG circuits which have been integrated in different types of devices, such as on vests, belts and shirts. These wearable systems are very useful in long term monitoring compared to the conventional ECG monitoring systems due to their lightweight and mobility.

In this thesis, chapter 2 consists of a brief explanation of cardiovascular disease, the development of ECG monitoring systems used in monitoring the heart activity, the development of ECG circuit on flexible substrate for long-term monitoring, and the use of graphene oxide as the conductive material on the flexible cotton-fabric ECG circuit. Chapter 3 shows the flowchart of research methodology which consists of material processing, fabrication of conductive line on cotton fabric, mechanical characterizations of conductive line, fabrication of cotton fabric-based ECG circuit trace, and ECG signal acquisition. Chapter 4 shows the results and further discussion of the fabrication of cotton fabric-based conductive line, mechanical characterizations of conductive line, fabrication of cotton fabric-based ECG circuit trace and the ECG signal acquisition. Lastly, chapter 5 shows the conclusion and recommendations of the research.

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