DESIGN AND DEVELOPMENT OF A WEARABLE THERMOELECTRIC GENERATOR ARMBAND TO POWER UP LOW POWER ELECTRONIC DEVICES

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Date : 30th MAY 2017

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ABSTRAK

Sejak beberapa dekad lalu, perkembangan pesat dalam pengunaan tenaga di seluruh dunia telah menyumbangkan lebih usaha penyelidikan dibuat untuk menuai tenaga dari alam sekitar. Kini, banyak alat elektronik mudah alih seperti rangkaian sensor badan tanpa wayar (*WBASN*) menggunakan bateri. Bateri mempunyai kelemahan, ia itu mempunyai tenaga yang terhad. Dalam bidang perubatan, *WBASN* digunakan untuk memantau keadaan kesihatan pesakit. Tidak mempunyai kuasa elektrik yang mencukupi untuk memastikan alat-alat elektronik perubatan berfungsi adalah satu masalah yang besar. Selain itu, peningkatan penggunaan bateri juga turut menyumbang kepada pertumbuhan penggunaan tenaga di seluruh dunia. Penjana termoelektrik (*TEGs*) memberikan satu peluang yang sangat istimewa kepada masyarakat untuk mengatasi masalah penggunaan tenaga dunia dengan memberikan tenaga yang bersih dan tenaga yang boleh diperbaharui. Tujuan kajian ini adalah untuk mereka satu lilitan lengan yang menggunakan *TEGs* untuk menghidupkan sensor denyut nadi. Selain itu, sebuah litar telah direka untuk meningkatkan voltan dari *TEGs*. Satu algoritma juga direka bagi sensor denyutan nadi untuk mengesan denyutan nadi lalu menyalurkan data nadi itu melalui Bluetooth ke sebuah *GUI* yang direka. Enam *TEGs* telah digunakan untuk membina prototaip lilitan lengan, dengan campuran selari dan siri konfigurasi haba. LTC3108 dan CE8301 adalah peranti/modul yang digunakan dalam litar untuk meningkatkan voltan dari *TEGs*. Satu 0.5 F kapasitor telah digunakan untuk menyimpan tenaga yang telah ditingkatkan. Algoritma yang telah direka untuk sensor nadi menggunakan cara pencarian masa daripada selang antara nadi dari corak gelombang photoplethysmogram untuk mengesan nadi yang tepat. Perintah automatik (AT) telah digunakan untuk modul Bluetooth supaya penghantaran data tanpa wayar boleh direalisasikan. Akhirnya, prototaip yang dicipta dapat menghidupkan sensor denyutan nadi selepas dipakai di atas lengan sepanjang tempoh enam jam. Juga, sensor nadi dapat mengesan nadi yang tepat dan berjaya menghantar data ke sistem melalui modul Bluetooth. Prototaip yang telah dicipta dapat menjimatkan tenaga bateri sebanyak 44 %.

ABSTRACT

Over the past decades, more and more research efforts have been made to harvesting ambient environmental energy owing to the rapid-growing worldwide energy consumptions. Nowadays, wearables such as wireless body networks are battery-powered, and the battery itself has a limited lifeline. In medical area, Wireless Body Area Sensor Network (WBASN) is used to monitor a patient's health conditions. Not having sufficient portable power electricity to keep these devices powered up is a huge problem these days. Also, increasing battery usage also contributes to the growing of worldwide energy usage. Thermoelectric generators (TEGs) provide a very special opportunity for the society to overcome world energy consumption issue by providing clean and renewable energy to human. The purpose of this study is to design a wearable thermoelectric generator armband for powering low power wireless sensor (pulse sensor). Besides that, A signal conditioning circuit is designed to boost input signals from TEGs and an algorithm is designed for the pulse sensor to detect heart rate before transmitting the data wirelessly via Bluetooth to a designed Graphical User Interface. Six TEGs are used to build the prototype, with a mixture of parallel and series thermal configurations. LTC3108 and CE8301 boost converters are used to construct the signal conditioning circuit. A 0.5 F supercapacitor is used to store harvested energy. The algorithm developed for pulse sensor is by finding successive moments of instantaneous heart beat and measure the Inter Beat Interval by following the predictable pattern of photoplethysmogram wave. The automatic (AT) commands are used in Bluetooth modules for wireless transmission. In the end, the final prototype can power up the pulse sensor after about 6-hour period when it is worn on human arm. The pulse sensor reads accurate data and successfully transmitting it to base station. The prototype extends battery life up to 44 %.

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LIST OF ABBREVIATIONS

TEG	-	Thermoelectric Generator
ECG	-	Electrocardiogram
HSN	-	Healthcare Sensor Network
WBASN	-	Wireless Body Area Sensor Network
AT	-	Automatic
DC	-	Direct Current
CED	-	Consumer Electronic Device
Li-ion	-	Lithium-ion
RF	-	Radio Frequency
PV	-	Photovoltaic
TEC	-	Thermoelectric Cooler
WBAN	-	Wireless Body Area Network
PDA	-	Personal Digital Assistant
LED	-	Light Emitting Diode
LDR	-	Light Dependent Resistor
OP-AMP	-	Operational Amplifier
BPM	-	Beats Per Minute
IR	-	Infrared Receiver
GSM	-	Global System for Mobile
LCD	-	Liquid Crystal Display
PC	-	Personal Computer
PPG	-	Photoplethysmography
GUI	-	Graphical User Interface
SOAs	-	Service Oriented Architectures

ESR	-	Equivalent Series Resistance
CCD	-	Charge-Coupled Device
NI	-	National Instruments
SSOP	-	Shrink Small-Outline Package
DFN	-	Dual-Flat No-Leads
BJT	-	Bipolar Junction Transistor
SCR	-	Silicon Controlled Rectifier
PFM	-	Pulse Frequency Modulation
CMOS	-	Complementary Metal Oxide Semiconductor
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
IBI	-	Inter Beat Interval
MAC	-	Media Access Control
COM	-	Communications
IoT	-	Internet of Things

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CHAPTER I

INTRODUCTION

This chapter will provide an overview about the project where there is an explanation on the project objectives and problem statement. The scope statement of the project is included in this chapter to state the range of work the project covers and will not cover. A brief explanation on the flow of the project is also included in the methodology part to allow understanding on the methods used to complete the project and what will happen throughout this project development. A thesis statement is also included at the end of this chapter to provide an overview of each chapter in this thesis.

Background

Over the past decades, more and more research efforts have been made to harvesting ambient environmental energy owing to the rapid-growing worldwide energy consumptions. To sustain development of human civilization, the search for renewable and clean energy with lesser carbon emission is urgent [1]. Camacho-Medina et al. states that the world energy consumption will be increased by estimated 40 percent in year 2035 [2]. Due to the concerns for environment and climate change, the innovation for new technologies to recover resource and waste treatment is urged [3]. Thermoelectric generators (TEGs) provide a very special opportunity for the society to overcome world energy consumption issue by providing clean and renewable energy to human. It can be worked by converting human warm to electricity for self-powered devices [4]. This topic had attracted research groups' interest and become the focus of several scientific publications [5]. Those studies had proven that TEGs can produce enough power for powering different body sensors like the pulse oximeter and electrocardiogram (ECG) [6].

Recently, global healthcare research is focusing more on quality healthcare service. The paramount research interest is providing affordable quality healthcare to the consumers and reinforce emerging technology of Healthcare Sensor Network (HSN) [7]. HSN is defined as a network of tiny monitoring devices, which can be mounted on people, embedded in people or may be integrated in any surrounding area. Wireless Body Area Sensor Network (WBASN) is the network sensors when worn on human. WBASN constitutes a HSN to be used in diagnostic or rehabilitative monitoring for medical applications. Physical parameters such as acceleration, pressure and muscle performance can be monitored by HSN. Meanwhile, physiological parameters too can be monitored by HSN, such as pulse rate, blood pressure and body temperature. In medical healthcare system, data are gathered from sensor nodes which is worn by a patient, then transmit wirelessly through gateway to clinics or hospitals to allow doctors to monitor patient's health conditions [8].

Objectives

This project is set out to:

a) Design a wearable thermoelectric generator armband for powering low power wireless sensor.
b) Develop a signal conditioning circuit for boosting input signals from thermoelectric generator.
c) Develop an algorithm for pulse sensor to detect heart rate and transmit data wirelessly via Bluetooth to a designed Graphical User Interface.

Problem Statement

Nowadays, wearables such as wireless body networks are battery-powered, and the battery itself has a limited lifeline. Not having sufficient portable power electricity to keep these devices powered up is a huge problem these days. In medical area, Wireless Body Area Sensor Network (WBASN) is used to monitor a patient's health conditions. Without continuous operation from the sensor node could be fatal to the patient, as the sensor node itself responsible to detect failure in patient's health. Network performance had been greatly affected by the limited energy supply, which is battery in most cases. Furthermore, the limited available energy supply has become the bottleneck for measurement, transmission of data, lifetime and connecting network. The simplest way to curb the battery issues is to design devices with larger battery capacity to ensure the device last longer for usage. However, the drawback of this solution is that the battery capacity is proportional to size and weight. Since tiny sensor node is to be worn by human, it should be in small form factor, hence solely dependent on battery will not be able to sustain crucial continuous operation of the sensor node. Due to the fact that increasing battery usage also contributes to the growing of worldwide energy usage, there will soon be global energy crisis and the environmental protection issues.

Scope Statement

This project requires three major hardware circuitries to develop the final wearable prototype; the thermoelectric generator circuit, the boost converter circuits, and wireless pulse sensor node circuit. The pulse sensor node is used with a microcontroller which is powered-up by the harvested energy from TEGs. The pulse sensor is responsible to read patient heart rate and send the data to system base wirelessly via Bluetooth module.

Note that this project is to harvest energy for powering a sensor node. The pulse sensor used is a budget plug and play heart rate sensor which will work easily with a microcontroller. It is made up of a simple optical heart rate sensor with fast and easy to get pulse reading. The sensor does not come with perfect noise cancellation and filtration. Thus, when using the pulse sensor, the reading of heart beat might be affected by some noise. Hence, the accuracy of the sensor is not as accurate as the one used in medical field in the hospital.

Also, the wireless transmission of data is via Bluetooth module. The module used in the project is the normal HC-05 Bluetooth to serial module that can easily obtained online. Thus, the transmission range of data only covered around 100 m radius wide. Meanwhile, this project development is conducted in laboratory and only prototype is produced at the end of the project. Also, the project is aimed to harvest body heat temperature in conjunction with the ambient temperature. Therefore, the prototype only suitable to be used in ambient less than body temperature, best at around 27℃ and below.

Methodology Synopsis

This project required three major hardware circuitries to develop the final wearable prototype; the thermoelectric generator circuit, the boost converter circuits, and wireless pulse sensor node circuit. In this project, thermal energy harvesting using thermoelectric generator is first be studied and experimented to observe the amount of power harvested from human body warmth. TEG circuitry involved the use of a few 40 x 40 mm TEGs connected in electrically series and thermally parallel. A suitable DC to DC converter is used to boost and regulate the harvested energy from tens to hundreds of millivolts to 3.3 V. A suitable heat sink is used on the cool side of the thermoelectric module, to prevent thermal equilibrium.

Then, an energy storage system is designed to store the scavenged power from thermoelectric generator. The designed energy scavenging system is used for powering a pulse sensor, which is used to read patient heart rate. The pulse sensor is used in conjunction with Arduino Pro Mini microcontroller and a Bluetooth Module which is supported by a 9 V battery to detect human's heart rate and send it wirelessly to a system base via Bluetooth. After the pulse sensor finishes the scavenged energy, it is gone back to OFF mode, until the energy storage system is fully charged again. All the algorithms for pulse sensor, data transmission via Bluetooth and the Graphical User Interface is developed. Figure1.1 depicts the flow of the project development to allow simple understanding of the overall design of the prototype and the flow of the project.

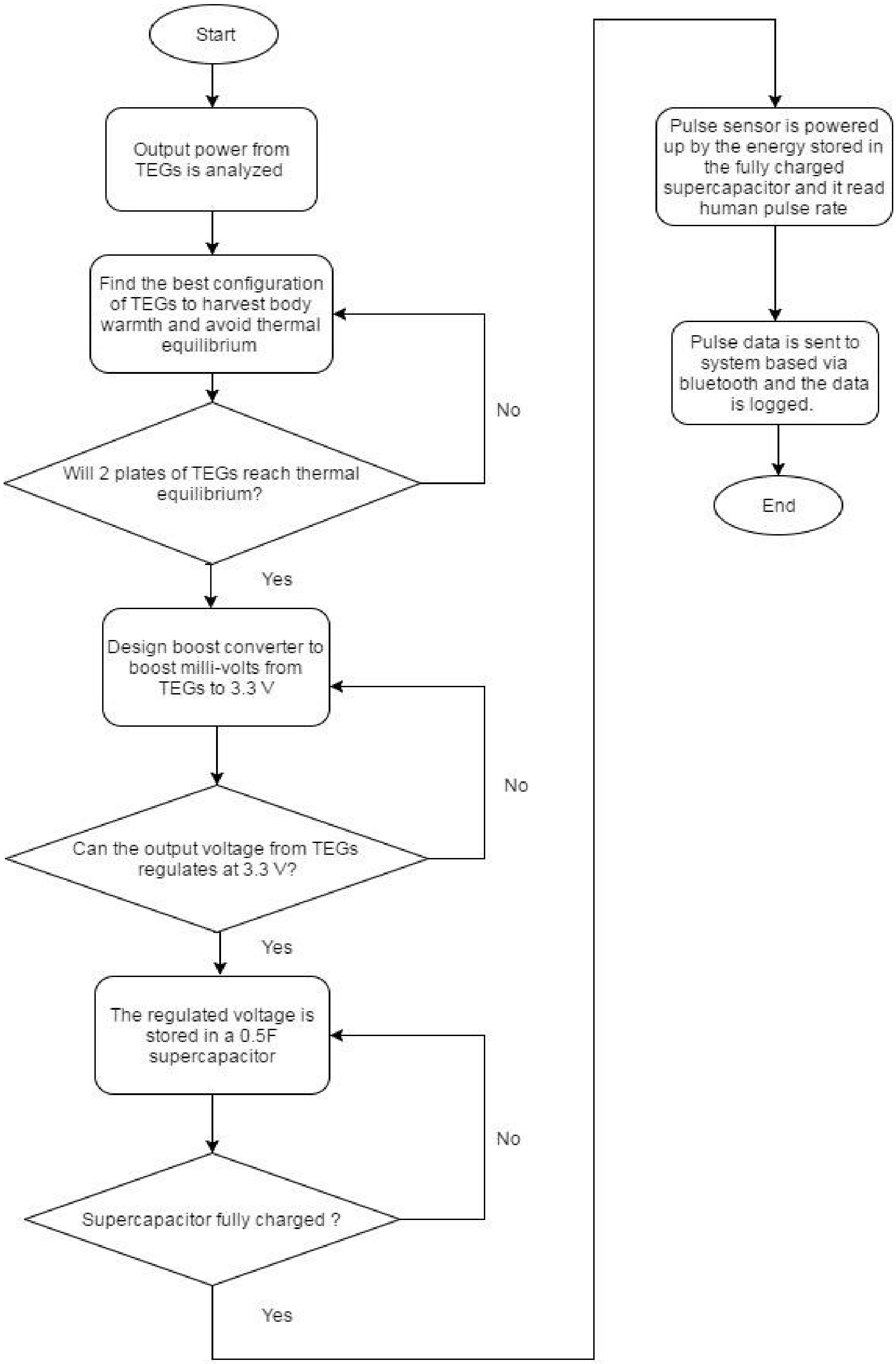

Figure 1.1: Flow chart of the project development.

Thesis Outline

There are total of five chapters in this final year project thesis. The brief summation of each chapter is stated below.