Faculty of Electronic and Computer Engineering

PIEZOELECTRIC BASED SELF-POWERED FORCE DETECTION SYSTEM WITH WIRELESS COMMUNICATION

Ho Wen Quan

Bachelor of Electronic Engineering
(Computer Engineering)

2016

PIEZOELECTRIC BASED SELF-POWERED FORCE DETECTION SYSTEM WITH WIRELESS COMMUNICATION

Submitted By:
Ho Wen Quan
JUNE 2016

This thesis is submitted to
Faculty of Electronics and Computer Engineering,
Universiti Teknikal Malaysia Melaka
In partial fulfillment for Bachelor of Engineering

Faculty of Electronics and Computer Engineering

Universiti Teknikal Malaysia Melaka

June 2016

UNIVERSTI TEKNIKAL MALAYSIA MELAKA

FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN

PROJEK SARJANA MUDA II

Tajuk Projek : Piezoelectric Based Self-Powered Force Detection System with Wireless Communication

Sesi Pengajian : | | | | | |

Saya ……..
(HURUF BESAR)

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

☐	**SULIT***	*(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	**TERHAD****	**(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☐	**TIDAK TERHAD**	

Disahkan oleh:

_____ _____

(TANDATANGAN PENULIS) (COP DAN TANDATANGAN PENYELIA)

Tarikh: ……. Tarikh: …….

DECLARATION

“ I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledge.”

Signature : .....

Author : .....

Date : .....

APPROVAL

"I acknowledge that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering (Computer Engineering) with Honours."

Signature : .....

Supervisor's Name : .....

Date : .....

ABSTRACT

This project is about a piezoelectric based energy harvesting system that able to harvest energy from force produced by human footstep to power up a radio frequency transmitter to transmitter signal to receiver station and trigger nearby electronic devices. The purpose of this project is to design an energy harvesting circuit and integrate it with a wireless module. In this project, three different rectifier circuits were designed, developed and experiment had been carried out to determine the most efficient rectifier circuit. Afterwards, drop test was carried out to determine the optimum resistance of the piezoelectric cantilever used in this project. Next, a piezoelectric energy harvesting circuit was designed to convert the AC voltage that generated by the piezoelectric, into DC voltage for powering RF transmitter which transmits signal to a receiver station within a few meters away. Therefore, piezoelectric was being used as sensor and generator. Full wave bridge rectifier that made of Schottky Diodes was found to be the efficient rectifier circuit with 3% to 6% of voltage drop to be used in this project. On the other hand, the proposed system can produced power up to 8mW at resistance of 2kΩ according to the result of drop test. The system has been proven to function as expected, which can be seen that the security siren and interactive advertisement slides are triggered when the system is being tested by stepping on the piezoelectric harvester unit.

ABSTRAK

Projek ini adalah berkaitan dengan sistem penuaian tenaga elektrik berdasarkan piezoelektrik yang berkebolehan untuk mengumpul tenaga hasil daripada jejak tapak kaki manusia dan seterusnya menjana kuasa elektrik kepada pemancar frequensi radio untuk menghantar isyarat kepada stesen penerima dengan tujuan mengaktifkan peralatan elektronik yang berdekatan. Objektuf projek ini adalah untuk merekabentuk litar pengumpulan tenaga dan menginterasikan ia dengan module wayarless. Tiga jenis litar penerus telah direkabentuk dan ujikaji telah dijalankan untuk menentukan penerus yang paling efektif. Seterusnya, ujian jatuh dijalankan untuk menentukani beban kerintangan optimum piezoelektrik yang digunakan dalam projek ini. Kemudian, litar pengumpulan tenaga dan pemancar frequensi radio telah di reka untuk menukarkan voltan AC yang dijana oleh penuai piezoelektrik, kepada voltan arus terus, DC yang dapat membekalkan kuasa elektrik kepada penghantar RF dan menghantar isyarat ke stesen penerima yang berada dalam lingkungan beberapa meter. Oleh itu, piezoelekrrik telah digunakan sebagai sensor dan penjana kuasa elektrik dalam projek ini. Penerus titi pemenuh gelombang yang terdiri daripada diod schottky adalah palin efektif dengan kehilangan voltan dari 3% hingga 6%. Selain itu, sistem ini berkebolehan untuk menghasilkan kuasa sebanyak 8mW apabila rintangan 2kΩ diaplikasikan berdasarkan keputusan dari ujian jatuh. Sistem ini telah dibuktikan berfungsi seperti yang dijangka di mana penggera keselamatan dan iklan interaktif berjaya diaktifkan apabila sistem tersebut diuji dengan memijak unit penuai tenaga piezoelektrik.

ACKNOWLEDGEMENT

First of all, I would like to express my deepest gratitude to all those who provided me the chance and assistance to complete this project. A special gratitude I give to my final year project supervisor, Assoc. Prof Dr. Kok Swee Leong, who provided valuable guidance, suggestions, advices and encouragements to help me to complete this project. Furthermore, I would like to acknowledge my appreciation to all staffs and assistant engineers at laboratories for the patience and help on how to operate all the equipment properly. On the other hand, I would like to thank to the Faculty of Electronic and Computer Engineering of University Technical Malaysia Melaka for providing me opportunity to learn and complete an engineering project. Other than that, I would like to thank all my friends and course mates who supported me and encouraged me along this project. Last but not least, many thanks go to my family, especially my parents who gave me full support from all aspects along this project and my study life in university.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Project Overview

Recently, the development of ultralow power consuming device, microelectromechanical systems technology and wireless communication technology has leads to the grow of wireless sensor technology. Wireless sensor can be distributed into environment or nature to detect the changes of surrounding such as temperature and force and send the data to a host receiver. These data can be used to design a system that is interactive with environment. Hence, the concern on energy harvesting technology is raised to improve the efficiency of wireless sensor technology. Energy harvesting is a process of collect ambient energy from environment and convert the energy into usable electrical energy. Energy

harvesting increases the efficiency of self-powered system since the system can function for lifetime without maintainence.

Basically, there are many ambient energy sources can be used for energy harvesting including heat, wind, solar energy, hydro and mechanical force. Mechanical force such as vibrations, fluid flow and impact are the most attractive ambient energy source among all because they can be found or obtained easily. For example, mechanical force can be found in most machine, conveyor or even force produced by human step while walking. Mechanical forces have high energy density and suitable for embedded wireless sensor system that is implemented indoors or overcast areas. There are three main mechanisms to be used to harvest mechanical energy and convert into electrical energy which are piezoelectric, electromagnetic and elecstatic. Among three mechanisms, piezoelectric is suitable to be implemented in wireless sensor system because piezoelectric material ables to directly convert mechanical energy into electric energy without external power source. Piezoelectric molecular structure allows piezoelectric material to produce a local charge separation which is known as electric dipole. When mechanical force is applied to piezoelectric material, deformation of dipole occur and charge generated can be extracted from the material and use to power up devices.

This project aims to design a force detection system that used piezoelectric plate as force sensor and low power generator to supply power to wireless transmission system. As mentioned previously, piezoelectric can convert mechanical energy into electrical energy without external power source, so it can be used as a self-generating sensor and small power generator in low power consuming electronic application. Next, to implement piezoeletric plate as low power generator, a energy harvesting system which consists of piezoelctric transducer, rectifier and voltage regulator need to be designed. Besides, a ultrolow power consuming microcontroller unit will be chosen to integrate with energy harvesting system. The performance of system will be verified.

1.2 Motivation

The application of wireless sensors and mobile electronic device are increased greatly in these few years. Most of these sensors and devices use battery as power source to supply electrical energy to them. However, the development of battery technology is slow compared to development of computing technology such as computing speed, disk capacity and RAM available. The growth of computing technology caused the raise of power consumed for electronic devices. This reduce the battery life of devices and limit the efficiency of electronic devices especially for wireless sensor system. Since battery life is limited, replacement or maintanence of battery is needed for wireless sensor system when the battery is drained. However, the environment that the sensor node embedded such as underground might caused the maintanence process to be time consuming and costly. Other than that, usage of electrochemical battery is not environemental friendly since battery is non disposable. Therefore, application of piezoelectric energy harvesting in wireless sensor system can overcome the limitation of battery by reducing the maintanence cost and time, avoid environment pollution and thus increase the efficiency and functionality of electronic devices.

1.3 Problem Statement

Energy harvesting using piezoelectric plate will only generate a small amount of AC voltage, probably less than 0.7 V. The energy produced by piezoelectric plate need to be converted into DC voltage before it can be used to power up electronic devices. However, the low AC voltage produced by piezoelectric plate may not enough to activate conventional rectifier circuit since the diode need at least 0.7 V to be activated. Therefore, design of rectifier with low voltage drop is necessary for piezoelectric energy harvesting system. This issue can be solved by designing a efficient rectifier circuit.

Other than that, there are many types of rectifier can be implemented in energy harvesting system. However, different rectifier have different voltage drop.

Hence, an experiment and analysis is required to determine the suitable rectifier circuit to be used in this system. Lastly, a wireless module is required in order to design a system with wireless communication. The wireless module used must be able to powered up using the designed energy harvesting system. Integration of system is required to ensure the functionality of energy harvesting system and wireless communication.

1.4 Objectives

The objective of this project is to design a piezo electric energy harvesting circuit which includes low voltage activated rectifier circuit that able to rectify the low AC voltage. Other than that, the voltage drop of schottky diode rectifier, IC based rectifier and LTC 3588 chips are analyzed. On the other hand, the last objective of this project is to integrate the energy harvesting circuit with a wireless transmitter to transmit the signal to the receiver station.

1.5 Significant of Project

The piezoelectric energy harvesting system proposed can generate electrical power that is sufficient to support the functionality of force detection system which include energy harvesting circuit and wireless transmitter. Hence, the maintanence and replacement of conventional battery can be minimized and thus increased the efficiency and allow the system sustain for lifetime. The system can function and opearate as long as there is mechanical force produced from the surrounding.

On the other hand, the self-powered force detection system can be implemented in industry that needs to monitor the force or mechanical condition of machine such as compressor of oil and gas industry. The system can function by using the energy produced by vibration of machine. Implementation of this system minimize the risk of technician to get hurt or injured when performing checking of mechanical

condition of machine. This is because the mechanical condition can be monitored by analyzing the data sent by the wireless sensor system at receiver.

Lastly, this system is environmental friendly since it does not produced any waste that will pollute the surrounding. Mechanical forces from surrounding of the system is harvested and then used to power up the system. It reduces the wastage of energy and avoid the usage of electrochemical battery which will pollute the surrounding after the battery power is drained.

1.6 Scope

The energy harvesting circuit will be designed using EAGLE software and analysis of efficiency of different rectifier circuit is included in this project. The performance of energy harvesting circuit will be verified based on the experimental result in lab. The system is expected to produce power up to 100 microwatt which is sufficient to support the operation of radio frequency transmitter.

Other than that, piezoelectric plate used in this project is cantilever based made by PZT material will be used in this project. Wireless communication module used in this project is radio frequency module while microcontroller used is Arduino Due. The power produced by piezoelectric will only be used to power up the RF transmitter to send signal. The remaining part of the system including RF receiver, Arduino Due, Siren system and Laptop will be powered up using external power source. The distance between transmitter and receiver is expected to be around 10 meters.

1.7 Thesis Outline

Introduction of this project presents a general overview to reader to understand the background and problem statements of this project. Objective of this project is provided to allow reader to know how this project solved the proposed problems. Besides, the motivation and project significant are included to point out the

benefits of this project. The last part of introduction will discuss about project scope which include the limitation of the projects.

The literature review chapter provides some information about the evolution of piezoelectric energy harvesting technology and different types of rectifier circuits used by other researchers to convert the low AC voltage. This allows reader to have a brief understanding on current technology and works done by other researchers.

Methodology of projects presents the details procedure or process to complete this project. This process includes the design and build of energy harvesting circuit, integration of energy harvesting circuit with microcontroller unit and verification of result in experimental lab. This helps reader to understand the step by step procedures take to build the system.

Result and discussions provides all the finding in this project and tabulated in form of graphs or tables for ease of understanding of reader. The result will be used to justify whether the objective is achieved or not. Besides, analysis of data obtained will be included in this part.

Lastly, conclusion will outline and provide a summary of this project. Besides, recommendation of future research of piezoelectric based wireless sensor system will be provided.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Energy Harvesting

Recently, wiressless sensor node techonology had developed rapidly and implementation of wireless system are becoming widespread in many fields. For example, portable wireless system embedded with Bluetooth standard and wireless network system based on IEEE 802.11 protocol. The implementation of wireless systems is a great revolution of technology and provides many benifits compared to conventional wired system. Firstly, wireless system is more flexible and can be embedded in any area including underground and outdoor environment without the limitation of wire connection. By implementing laerge amount of wireless sensor nodes in a particular area, a condition based maintencance system can be built to collect data, transmit the data to host receiver and monitor the changes of environment with lower maintanence cost since installation of cables and wires is excluded [1]. Thoudsands of distributed wireless sensor nodes can be

embedded anywhere such as civil structure, industrial automation, health care, agriculture and structural health monitoring [2].

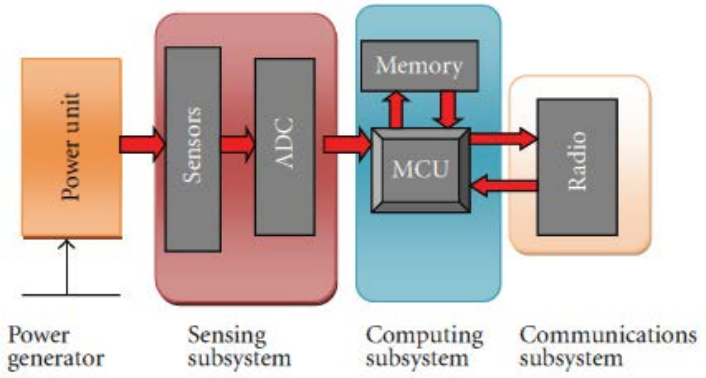

Figure 2.1: Main Subsystems of Wireless Sensor Node [2].

Figure 2.1 shows the subsystem in a wireless sensor node that consume power. The first subsystem is sensing subsystem which includes sensors and analog to digital convertor which is used to convert the physical changes of environment into digital data. Most of the power consumed in sensing subsystem is used in sensor sampling which consists of wake up time for sensor to collect the data. The sensor will remain off when no changes in environment [3]. Next, computing subsystem that consists of a microcontroller unit consumes power also. The major function of microcontroller is to control the wireless sensor node activity and process the data collected from sensor. When the microcontroller is not operating or not processing data, it is remain in low power sleep mode [4]. Table 2.1 shows the power needed of some microprocessor that is used in wireless sensor systems.

From Table 2.1, MSP430 family microcontrollers manufactured by Texas Instrument is a suitable choice of microcontroller to be used as computing subsystem in wireless sensor node. [4] It is implemented with a ultralow power consuming core and only consumes 0.4 mA at 1 MHz. Besides, it only consumes a few microamperes when it is in low power sleep mode.

Table 2.1: Power Parameter of Some Microprocessor Used in Wireless Sensor [4].

Microprocessor	Supply Current (mA)	Supply Voltage (V)	Run Freqeucncy (MHz)	Power Down Mode Current (µA)
C8051F930	4.25	0.9	25	0.05
PIC18F4620	16	4.2	40	0.1
MC9s08GT	6.5	3	16	2.5
AMTEGA128L	5.5	3	4	<5
MSP430CG4618	0.4	2.2	1	0.35
ML610Q431	0.65	1.1	4	0.25

Lastly, the most power consuming subsystem in wireless sensor node is communication subsystems. Communication subsystem mainly consists of a wireless tranceiver with amplifier to amplify and transmit the processed data signal. Similarly, when the transceiver is not transmitting any data, it will remain in low power sleep mode.

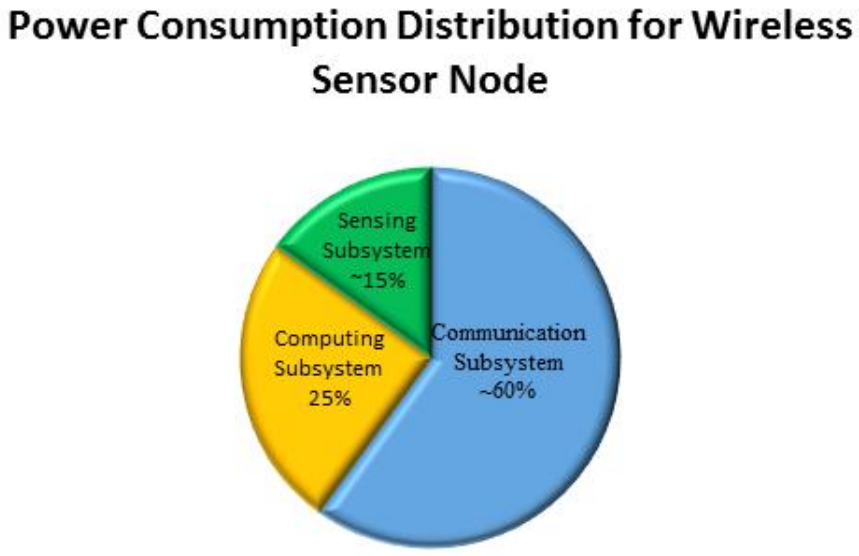

Figure 2.2: Power Consumption Distribution for Wireless Sensor Node [3].

Figure 2.2 shows the power consumption distribution for wireless sensor node. Communication subsystem consumes the largest amount of energy which is around 60% of

total available energy [4]. Power consumption of wireless sensor node can be minimised by maximizing the time of low power sleep mode. In other word, the node remain sleep most of the time and only activated when data is received by sensor. During low power sleep mode, only real time clock (RTC) of the system is awake to avtivate the sensor node when there is input. With proper power management mechanism implemented, a wireless sensor node can function for lifetime with power supply of 100μW [5].

Currently, many wireless sensor nodes used batteries as their electrical power supply. However, the lifespan of batteries is limited and it might be costly and time consuming to replace the batteries of wireless thousands of wireless sensor nodes [3]. Hence, batteries is not a long term viable source of power for wireless sensor nodes system [2]. Basically, a wireless sensor node consists of four main function, which are monitoring or sensing, data collection, data processing and wireless transmission. All of these function need electrical power supply from batteries. However, a power generator which has the ability to harvest energy from ambient environment can be used to power up the wireless sensor node independently. Therefore, in order to expand the lifespan of wireless sensor node and improve its effiency, energy harvesting technology is being focused in the past decade [6].

2.2 Kinetic Energy Harvesting

Energy harvesting can be defined as a process that extract or harvest energy from ambient environment through different energy sources such as solar, temperature, hydro, wind, radio freqeucncy and mechanical energy. The major energy harvesting technology hierachy is shown in Figure 2.3.