

**DESIGN OF ENERGY HARVESTING POWERED WIRELESS
SENSOR NETWORK FOR MACHINERY HEALTH MONITORING**

CHEN WEI PING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN OF ENERGY HARVESTING POWERED WIRELESS SENSOR NETWORK FOR MACHINERY HEALTH MONITORING

CHEN WEI PING

**This report is submitted in partial fulfilment of the requirements
for the degree of Bachelor of Electronic Engineering with Honours**

**Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka**

MAY 2018

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Design of energy harvesting powered wireless sensor network for machinery health monitoring
Sesi Pengajian : 2017/2018

Saya CHEN WEI PING 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)

Alamat Tetap: Universiti Teknikal Malaysia Melaka,

Hang Tuah Jaya, 76100 Durian Tunggal, Melaka.

Tarikh : 25 Mei 2018

Tarikh : 25 Mei 2018

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this report entitled “ Design of Energy Harvesting Powered Wireless Sensor Network For Machinery Health Monitoring ” is the result of my own work except for quotes as cited in the references.

Signature :

Author :

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name :

Date :

Thanks to my supervisor, family and all lecturers who willing to guide me and support me throughout this final year project.

ABSTRACT

Wireless Sensor Networks or WSN mainly consists of huge amount of miniature sensor nodes or SNs with certain limitation of computer resources which capable for sensing, gathering, data processing and wireless communication. Since most of the SNs are powered by traditional batteries, it can be inconvenient due to their limited lifespan. In this project, a thermoelectric generator (TEG) is used as thermal energy harvester with the intention to extend the SN lifespan. Since the output voltage produced by this TEG is insufficient to power up the node, a DC-DC step-up converter circuit based on MAX757 integrated circuit is designed to step up the output voltage produced from TEG up to 3V. Besides, the sensor node is programmed and configured by using the MEMSIC Mote View software. The SN consumed an average power of about 25mW in the active mode and 60 μ W when it is in sleeping mode. This node is able to transmit data whenever there is at least a temperature gradient of 15°C between the hot and cold surface of TEG. This project is conducted indoor by utilizing two SNs with one of them is powered by traditional battery and the other one is powered by TEG. The measured data is collected for every 10 minutes and displayed in Mote View, where the data is analyzed and compared.

ABSTRAK

Rangkaian Sensor Tanpa Wire “Wireless Sensor Network” atau WSN terdiri daripada pelbagai jenis nod sensor (“Sensor Node”) atau dikenali sebagai SN yang kecil dengan had keupayaan komputer dalam penginderaan, mengumpul maklumat, pemprosesan data dan mengutamakan komunikasi tanpa wire. Kebanyakan SN dijana oleh bateri dan ini menyebabkan kesukaran serta menyekat keupayaan SN untuk berfungsi dalam keadaan baik malah jangka hayat bateri adalah singkat. Dalam projek ini, kajian terhadap Thermoelectric Generator (TEG) telah diguna sebagai sumber penuaian tenaga terma dengan tujuan meningkatkan jangka hayat SN. Memandangkan voltan keluaran yang dijana oleh TEG ini tidak memenuhi keperluan voltan SN, satu litar DC-DC penukaran dan peningkatan telah direka bentuk berasaskan MAX757 litar yang diintegrasikan untuk menjana voltan sehingga 3V. Kemudian WSN diprogramkan dan diconfigurasi dengan menggunakan perisian MEMSIC’s MOTE VIEW. Purata kuasa elektrik yang diguna oleh SN adalah 25mW dalam keadaan aktif dan 60 μ W dalam keadaan rehat. Nod ini berupaya untuk menghantar data pada situasi kecerunan suhu antara 15°C pada permukaan berusur TEG. Projek ini dikaji dalam makmal dengan penggunaan dua SN yang setiap satu menggunakan kaedah penjanaan kuasa yang berlainan. Di antara kedua-

dua SN yang diimplikasi dengan kaedah penjanaan kuasa yang berlainan , salah satu SN menggunakan kaedah penjanaan kuasa menggunakan bateri manakala SN yang satu lagi menggunakan kaedah penjanaan kuasa menggunakan teknologi TEG. Setiap 10 minit, data yang diukur akan direkodkan dan ambil dan dipaparkan di perisian Mote View. Data yang dikumpul dari kedua-dua SN dianalisis dan dibandingkan.

ACKNOWLEDGEMENTS

First of all, I would like to express an appreciation to people supporting and aiding me to complete this study and report. Thank to my family members for encouragement and support me in term spiritual and advises to complete my project with any concern.

Nevertheless, a thousand thanks to my supervisor, Prof. Madya Dr. Kok Swee Leong who contributes in suggestion in term of knowledge and experience, helped me along my final year project. PM Dr. Kok Swee Leong always gave good motivation and suggestion to complete this project.

Lastly, a big thanks to Ali Mohammed Abdal-Kadhim for sharing the ideas and knowledge for the circuit design and provide guide to finish the project in time. He had given me a lot of encouragement and tips to improve my project. Last but not least, I would like to thanks PSM lab assistant, Encik Imran Bin Mohamed Ali who help and guide during etching process.

TABLE OF CONTENTS

Declaration.....	
Approval.....	
Dedication.....	
Abstract.....	i
Abstrak.....	ii
Acknowledgements.....	iv
Table of Contents.....	v
List of Figures.....	x
List of Tables.....	xiv
List of Symbols and Abbreviations.....	xv
List of Appendices.....	xvii
CHAPTER 1 INTRODUCTION.....	18
1.1 Project Background.....	18
1.2 Problem Statement.....	19

1.3 Objective.....	21
1.4 Scope of Work.....	21
1.5 Report Overview.....	22
CHAPTER 2 Literature review.....	24
2.1 Machinery Health Monitoring.....	24
2.1.1 Manual Inspection.....	25
2.1.2 Automated Monitoring.....	26
2.1.3 Wired or Cable Monitoring System In Industry.....	27
2.1.4 Wireless Monitoring System in Industry.....	27
2.2 Wireless Sensor Networking.....	29
2.2.1 Protocol Stack of WSN.....	30
2.2.2 Wireless Sensor Communication Standard.....	31
2.2.3 Wireless Sensor Network Topology.....	33
2.3 Wireless Sensor Node.....	35
2.3.1 MICAZ Sensor Node (MPR2400).....	36
2.3.2 Sensor Board (MDA100CB).....	37
2.4 Power source.....	37
2.4.1 Battery.....	37
2.4.2 Energy Harvesting Technique.....	38
2.5 Thermoelectric Generator (TEG).....	39

2.5.1 Thermoelectric effect.....	40
2.5.2 Peltier Effect.....	41
2.5.3 Thomson Effect.....	42
2.5.4 Power and Efficiency measurement.....	44
2.5.5 Related Work.....	44
2.6 Power Conditioning Circuit.....	57
2.6.1 Boost Converter.....	57
2.7 MEMSIC Mote Work.....	60
2.7.1 Sensor devices.....	60
2.7.2 Server gateway.....	60
2.7.3 User Interface.....	61
2.8 Conclusion.....	61
CHAPTER 3 METHODOLOGY.....	62
3.1 Project Methodology.....	62
3.2 Characterize the output voltage from TEG.....	64
3.3 Design of DC-DC Step Up Converter Circuit.....	66
3.4 Breadboard Test of the Step Up Circuit.....	67
3.5 Fabrication of Circuit and Etching Process.....	68
3.6 Integrate the DC-DC Boost Converter to Sensor Node.....	71
3.7 Mote Work Installation.....	71

3.8 Program the Sensor Node.....	72
3.9 Sensor Data Collection.....	74
3.10 Conclusion.....	78
CHAPTER 4 RESULTS AND DISCUSSION.....	79
4.1 Characterization of Output Voltage from TEG.....	80
4.2 Design of DC-DC Converter Circuit.....	86
4.3 Development of Hardware Prototype.....	89
4.4 Integration of DC-DC Step-up Converter Circuit with Sensor Node.....	92
4.5 Sensor Data Collection and Statistical Analysis.....	93
4.5.1 Data Display.....	94
4.5.2 Chart.....	97
4.5.3 Histogram.....	99
4.5.4 Scatter-plot.....	100
4.5.5 Topology Map.....	101
4.5.6 Alert Message.....	102
4.6 Conclusion.....	103
CHAPTER 5 CONCLUSION AND FUTURE WORKS.....	104
5.1 Conclusion.....	104
5.2 Future Recommendation.....	105
REFERENCES.....	106

APPENDICES.....111

LIST OF FIGURES

Figure 1.1 Block diagram of the system	21
Figure 2.1 : Wireless Sensor Network	29
Figure 2.2 : Protocol stack of WSN	30
Figure 2.3 : Common WSN Topology	34
Figure 2.4 : Architecture of a wireless sensor node	35
Figure 2.5 : MICAz (MPR2400)	36
Figure 2.6 : MDA100CB	37
Figure 2.7 : Thermoelectric Seebeck effect	39
Figure 2.8 : Charge carrier flow in response to temperature gradient	40
Figure 2.9 : Illustration of Peltier effect	41
Figure 2.10 : Illustration of Thomson effect	43
Figure 2.11 : Schematic of TE powered wristwatch	45
Figure 2.12 : Diagram of power source system	45
Figure 2.13 : Schematic of the device	46
Figure 2.14 : Device half embedded in Casted aluminum	47
Figure 2.15 : Block diagram of the sensor node	48

Figure 2.16 : Schematic diagram of the autonomous telemetric sensor node	48
Figure 2.17 : Architecture of the thermal energy harvesting system	49
Figure 2.18 : Schematic diagram of power management circuit	50
Figure 2.19 : Block diagram of autonomous sensor system	51
Figure 2.20 : Measured output voltage of TEG	51
Figure 2.21 : Proposed wireless sensor node architecture	52
Figure 2.22 : Schematic diagram of proposed autonomous sensor node	53
Figure 2.23 : Schematic diagram of boost converter.....	58
Figure 2.24 : Circuit at switch on.....	58
Figure 2.25 : Circuit at switch off.....	59
Figure 2.26 : Boost converter waveform.....	59
Figure 3.1 : Flow Chart.....	63
Figure 3.2 : TEC Structure.....	64
Figure 3.3 : Illustration of energy harvesting system.....	64
Figure 3.4 : Assembly set-up of TEG.....	65
Figure 3.5 : Block diagram of the breadboard testing.....	67
Figure 3.6 : Breadboard testing.....	67
Figure 3.7 : Expos-ion of PCB to UV light.....	68
Figure 3.8 : Remove the unexposed region with developer.....	69
Figure 3.9 : Dipping the circuit into chemical solvent.....	69
Figure 3.10 : Drill the hole onto PCB.....	70
Figure 3.11 : Soldering the component onto PCB.....	70
Figure 3.12 : Block diagram of integration between circuit and sensor node.....	71

Figure 3.13 : XMeshBase application.....	73
Figure 3.14 : XMDA100CB application.....	73
Figure 3.15 : Block diagram of thermal energy harvesting powered wireless sensor network.....	74
Figure 3.16 : Data Tab.....	74
Figure 3.17 : Command Tab.....	75
Figure 3.18 : Chart Tab.....	75
Figure 3.19 : Health Tab.....	76
Figure 3.20 : Histogram Tab.....	76
Figure 3.21 : Scatterplot Tab.....	77
Figure 3.22 : Topology Tab.....	78
Figure 4.1 : Experimental set up.....	80
Figure 4.2 : Heater layout.....	81
Figure 4.4 : Output voltage of TEG versus temperature gradient.....	82
Figure 4.5 : Experimental set up.....	84
Figure 4.6 : Relationship between TEG2 output current and voltage with RL.....	85
Figure 4.7 : Output power of the TEG	85
Figure 4.8 : Circuit diagram of DC-DC converter circuit.....	88
Figure 4.9 : PCB layout of the designed circuit.....	89
Figure 4.10 : Fabricated DC-DC converter circuit.....	89
Figure 4.11 : DC-DC step up graph.....	91
Figure 4.12 : Connection between DC-DC converter with sensor node.....	92
Figure 4.13 : Experimental set up.....	93
Figure 4.14 : Data tab.....	94

Figure 4.15 : Voltage level received by both sensor nodes over time.....	95
Figure 4.16 : Temperature and light intensity received by both sensor node over time	96
Figure 4.17 : Chart of voltage level from Node 1 and Node 2.....	97
Figure 4.18 : Chart of voltage level from Node 1.....	97
Figure 4.19 : Histogram for percentage of voltage level received by Node 1 and Node 2.....	99
Figure 4.20 : Scatter-plot of the light intensity over time.....	100
Figure 4.21 : Topology view of Node 1 and Node 1.....	101
Figure 4.22 : Alert Form.....	102

LIST OF TABLES

Table 2.1 : Comparison between manual inspection and automated monitoring.....	26
Table 2.2 : Comparison between wired monitoring system and wireless monitoring system.....	28
Table 2.3 : Comparison between Wifi, Bluetooth and Zigbee.....	33
Table 2.4 : Comparison between the thermal energy harvesting techniques.....	56
Table 4.1 : Characterize the output voltage produced by TEG1.....	81
Table 4.2 : Characterize the output voltage produced by TEG2.....	82
Table 4.3 : The output power generated by TEG when different load resistance is applied	84
Table 4.4 : DC-DC step up reading.....	90
Table 4.5 : Measured data from both of the sensor nodes.....	94

LIST OF SYMBOLS AND ABBREVIATIONS

WSN	:	Wireless Sensor Network
SN	:	Sensor Node
TEG	:	Thermoelectric Generator
ADC	:	Analog-Digital Converter
L	:	Inductor
C	:	Capacitor
MAX	:	Maxim Integrated
DC	:	Direct current
V	:	Voltage
A	:	Ampere
M	:	Mega
C	:	Giga
m	:	Millie
W	:	Watt
Hz	:	Hertz
MHM	:	Machinery Health Monitoring

MCM	:	Machinery Conditioning Monitoring
RCS	:	Rohrback Cosasco System
DARPA	:	Defense Advanced Research Project
QoS	:	Quality of service
bps	:	Bit per seconds
I/O	:	Input and Output
MPR	:	Minnesota Public Radio
MIB	:	Management information base
ISM	:	International Safety Management
MDA	:	Management Data Acquisition
UART	:	Universal asynchronous receiver-transmitter
I ² C	:	Inter-Integrated Circuit
s	:	Second
GND	:	Ground
S	:	Seebeck Coefficient
T	:	Temperature
K	:	Thomson coefficient
IoT	:	Internet of Things
Wi-Fi	:	Wireless Fidelity

LIST OF APPENDICES

Appendix A: MAX757 Data Sheet	112
Appendix B: MICAz Data Sheet	117

CHAPTER 1

INTRODUCTION

Energy harvesting technique is one of the alternative way to replace the battery as it will deplete with time. However, it is quite challenging for us to power an electronic devices by using the energy harvesting technique. Therefore, an energy harvester is used with the help of a power conditioning circuit to power the sensor devices in order to prologue the life span of sensor.

1.1 Project Background

In this modern day, most of the electronic devices and systems included wireless sensor nodes are powered by electrical power source such as battery. However battery's life span is short termed. When the batteries deplete, they definitely need to be replaced over certain period. In remote area, people unable to access the places hence battery replacement is impossible, especially for hazardous environment. In