BENDING MECHANISM FOR PIEZOELECTRIC TRANSDUCER FOOTSTEP ENERGY HARVESTING USING PIEZOELECTRIC TILE

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"I hereby declare that work in this thesis report is my own except for quotations. and summaries which have been duly acknowledged".

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For my beloved parents, En Mohd Asry Mustafa and Pn Norhini Noh,
and my supporting supervisor
Ts. Dr Farahiyah Mustafa

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ABSTRACT

The technologies for energy harvesting technologies using human body action have attracted much attention as alternative resource to replace the common energy resources that have been exhausted in these few decades. Piezoelectric material that has been widely used in sensor technologies is able to produce electrical energy from mechanical energy. Therefore, this transducer can be used to harvest the wasted mechanical energy from human body action. Many researchers use this piezoelectric transducer to harvest the mechanical energy from human footsteps by inserting this transducer in shoes. However, the designated shoes sometimes are not convenient to wearers. In this research, the mechanical energy from the human footstep was harvested using floor tile inserted with piezoelectric transducers. Typically, the output of the piezoelectric transducer is low. Hence a bending mechanism which is divided into two parts, namely support housing and presser was designed to enhance the output piezoelectric transducer in this research. The piezoelectric transducers were connected in a parallel configuration and inserted in the piezoelectric tile together with bending mechanism. The drop test was employed to test this piezoelectric tile with various weight loads and speeds. The highest output power generated was 634.54 µW when 6 kg load was released at 2 drop/sec with 1.89 N average force applied on each piezoelectric transducer. The mechanical energy from the human footstep was intermittent, thus it needed a storage device to store the energy before being used. The full-wave bridge rectifier rectified the output from the piezoelectric tile before being stored in a supercapacitor. The 5.5 V, 1.5 F supercapacitor can be used to charge up to 10.48 V when 60 kg subject pressed the piezoelectric tile with an increment of 60 steps. This tile also can be placed in the ticket counter, walking pavement, dancing floor or exercise instruments to harvest more energy from the footsteps.

ABSTRAK

Teknologi tenaga diperbaharui dengan menggunakan gerak tubuh manusia menjadi tumpuan sebagai sumber alternatif bagi menggantikan sumber biasa yang telah habis sejak beberapa dekad ini. Bahan piezoelektrik yang telah digunakan secara meluas dalam teknologi pengesan mampu menghasilkan tenaga elektrik dari tenaga mekanikal. Oleh itu, transduser ini dapat digunakn untuk menuai tenaga mekanikal yang terbuang dari gerak tubuh manusia. Ramai penyelidik menggunakan transduser piezoelektrik untuk mendapatkan tenaga mekanikal dari langkah kaki manusia dengan memasukkan transduser ke dalam kasut. Walau bagaimanapun, rekaan kasut kadangkala memberi tidak keselesaan kepada pemakainya. Dalam kajian ini, tenaga mekanikal dari langkah kaki dituai menggunakan jubin lantai yang diletakkan transduser piezoelektrik. Biasanya, keluaran transduser piezoelektrik adalah rendah. Mekanisme lenturan dibahagikan kepada dua bahagian, iaitu perumah sokongan dan penekan.yang direka untuk meningkatkan keluaran transducer piezoelektrik dalam kajian ini. Transduser piezoelektrik ini dihubungkan dalam konfigurasi selari dan diletakkan di dalam jubin piezoelektrik bersama dengan mekanisme lenturan. Ujian penurunan digunakan untuk menguji jubin ini dengan pelbagai berat beban dan kelajuan. Daya keluaran tertinggi yang dihasilkan adalah 634.54 µW apabila beban sebanyak 6 kg dilepaskan pada 2 titis/saat dengan purata daya 1.89 N dikenakan pada setiap transduser piezoelektrik. Tenaga mekanikal dari langkah kaki manusia tidak berterusan dan dengan itu, tenaga ini memerlukan peranti simpanan untuk menyimpan tenaga sebelum digunakan. Keluaran dari jubin piezoelektrik diluruskan menggunakan penerus titi gelombang penuh sebelum disimpan di dalam kapasitor luar biasa. Kapasitor luar biasa 5.5 V, 1.5 F boleh dicas hingga 10.48 V apabila subjek 60 kg menekan jubin piezoelektrik dengan kenaikan 60 langkah. Jubin ini boleh juga diletakkan di tiket kaunter, tempat pejalan kaki, lantai menari atau pada alatan senaman untuk menghasilkan tenaga dengan lebih banyak dari langkah kaki.

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LIST OF SYMBOLS AND ABBREVIATIONS

α	-	Alpha
β	-	Beta
γ	-	Gamma
δ	-	Delta
ε	-	Epsilon
RF	-	Radio frequency
AC	-	Alternating current
DC	-	Direct current
3D	-	3 Dimensional
CFC	-	Chlorofluorocarbon
CO_2	-	Carbon dioxide
PEH	-	Piezoelectric energy harvester
MEMS	-	Mircoelectromechanical system
LGS	-	Langasite crystal
Cz	-	Czochralski
Fz	-	Floating zone
μ-PD	-	Micro-pulling down
SAW	-	Surface acoustic waves
NFMRC	-	Near- field microscopy resonant cantilevers
PLA		Polylatic acid
PZT	-	Lead zirconatetitanate
PVDF	-	Polyvinylidene fluoride
MPB	-	Morphotropic phase boundary
MFC	-	Macro fibre composites
CAD	-	Computer-aided design
CAE	-	Computer-aided engineering

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter starts with the research background, problem statement, research objectives, scope of research and organisation of the thesis.

1.2 Background of Study

In this 21st century, electrical energy becomes the most basic need in our daily activities. The existing non-renewable energy cannot fulfil the demand due to lack of resources and its negative impacts on the environment and society. To overcome this problem, researchers seek an alternative approach to harness energy from renewable energy resources such as thermal, hydropower, wind and solar. Unlike non-renewable energy, the renewable energy resources will not diminish run out as it can be rapidly replenished. Renewable energy resources are more socially and environmentally friendly. However, the renewable energy resources are irregular and intermittent as they are also vulnerable to weather and climate changes. Alternative methods should be proposed as climate and weather changes are random and unpredictable.

The human body contains massive amounts of energy produced by metabolism, thus offering alternative source of energy. This energy steams from typical body movements and essential body functions such as arm and legs swings, bending joints and elbows, finger movements while typing, blood movements, air movement while breathing and energy while walking. Figure 1.1 illustrates the daily power generation with different human body actions.

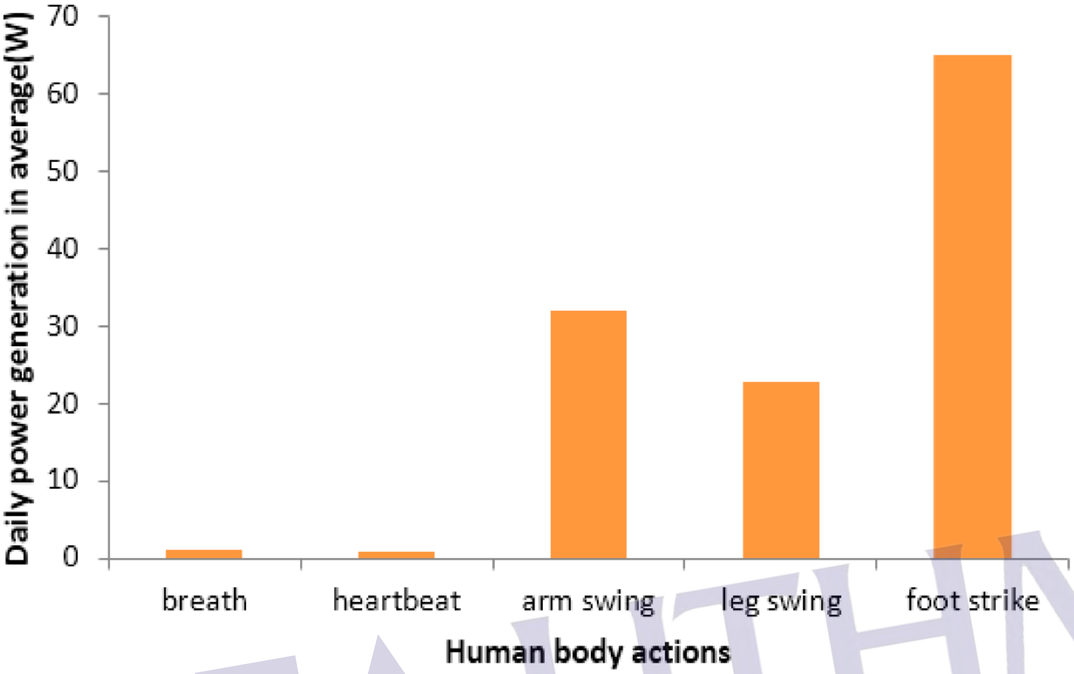


Figure 1.1: Energy generated by typical human movements [1]

Usually, such energy is wasted as heat and other types of energy, but this wasted energy can be converted into useful energy by means of energy harvesting. Energy harvesting or energy scavenging is a method to generate electrical energy from resources available in our surrounding. The harvest of wasted energy from human is more reliable than other natural resources as it is not dependent on climate change or location [2]. Walking is a daily activity in our life and the average step for an individual in a day is around 3000 to 5000 steps. Moreover, based on Figure 1.1, the highest average daily power is generated from foot strike. This human body action becomes the most suitable for energy harvesting as great resource for renewable energy. The mechanical energy produced by the footsteps can be used to generate electrical energy. There are three types of mechanical energy that can be converted to electrical energy, namely electromagnetic, piezoelectric and electrostatic but piezoelectric is the most prominent [3]. To harvest this energy, the most suitable transducer that can be used is piezoelectric transducer. This transducer detects the vibration or pressure that is applied to it and then converts it to electrical energy [4].

1.3 Problem Statement

The piezoelectric transducer is able to harvest the mechanical energy and convert it into electrical energy. The piezoelectric transducer is small in size, available in desired shape, excellent in frequency response and also pollution-free. However, the piezoelectric crystal is prone to crack if overstressed. The amount of output voltage depends on the strength of the stress. However, if too much stress is applied, it tends to break. This is its main shortcoming as piezoelectric transducer is expensive and used in large quantities.

The total energy generated by a piezoelectric transducer depends on the pavement compression or mechanical energy produced by human footsteps. The piezoelectric transducer is connected in a parallel connection to obtain the necessary output power. The footstep exerts pressure or force to the pavement that creates mechanical energy as people passing by. Significant electrical output power will be generated when each piezoelectric transducer absorb pressure exerted on it from the footstep. There will be some losses as each piezoelectric transducer receives uneven pressure on it.

The ideal concept or constraint of harvesting piezoelectric energy is that the mechanical energy or compression on the pavement is stable and continuous. However, in real life, the mechanical energy is intermittent as the compression from the human footstep through the pavement is non-continuous. Therefore, this energy harvest needs a storage device to store the energy that has been harvested before use.

The main reason is to use storage technologies as the renewable energy is intermittent. The typically used storage technologies are superconducting magnetic energy storage systems, hydrogen-based storage systems, compressed air storage systems, batteries, flow batteries, pumped hydro storage system flywheels and supercapacitors [5]. Supercapacitor is used as the storage device in this research due to its faster charging time compared to common battery.

1.4 Significance of Study

In the future, footstep power generation using piezoelectric transducer tiles will be a great replacement for non-renewable energy. In this research, the piezoelectric transducer is used to harvest the wasted energy from human movement and convert it into electrical energy. To generate electrical energy, the piezoelectric transducer will undergo the bending process. If the piezoelectric transducer is placed on a flat surface, then the bending process does not occur, and the piezoelectric transducer only generate low power output. To increase the output from the piezoelectric transducer, some space needs to be provided for the bending process to take place. This research had designed a bending mechanism that will enhance the bending process of the piezoelectric transducer to increase the output power. This mechanism is divided into two parts. The first part is used to provide support and space for the piezoelectric transducer during the bending process, which is known as the support housing. The second part is known as the presser to provide pressure to the piezoelectric transducer in the support housing. Then, this bending mechanism is attached to the piezoelectric tiles before being compressed or tested with various weight loads.

The contribution of this thesis is the bending mechanisms. This bending mechanism was designed to provide support, space and pressure during bending process. It is designed based the shape and size of the piezoelectric transducer. The support housing is designed with middle hole to provide space for the piezoelectric transducer to bend at its middle part and support the transducer from break by limiting the bending process with height of the support housing. The presser is designed follow the concept of heels and bullets shape to provide pressure to the piezoelectric transducer for bending process take place.

1.5 Research Objectives

The main aim of this research is to harvest energy from the human footsteps using piezoelectric tiles. Thus, a few objectives are summarized as follows:

i. To harvest the energy from human footsteps using piezoelectric transducer
ii. To design a bending mechanism to maximize the output voltage from the piezoelectric transducer.
iii. To validate the ability of bending mechanism to increase the output of piezoelectric transducer by placing in the piezoelectric tile to charge the supercapacitor.

1.6 Research Scope

The scope of the research are as follows:

i. A round-shaped piezoelectric generator with a diameter of 5 cm was used to harvest the mechanical energy from the footstep.
ii. Nine pieces of piezoelectric generator were used to form tile in square shape with wooden blocks.
iii. A 3D model was designed using a 3D printer to enhance the output of the piezoelectric transducer.
iv. Full-wave bridge rectifier was used to convert alternating current (AC) to direct current (DC) and to filter the ripple.
v. The storage system used a 5.5 V, 1.5 F supercapacitor to store the energy harvested from the piezoelectric tile.

1.7 Thesis Outline

This thesis is organised into five chapters. Chapter 1 contains the background of the project, problem statement, objectives, and scope of research. Chapter 2 highlights the review on related works that have been carried out by previous researchers on energy harvesting using piezoelectric, bending mechanism design and testing the piezoelectric output. Chapter 3 describes the research methodology, which includes the bending mechanism design, testing method and experimental setup. Chapter 4 outlines the experimental results and discussions. Chapter 5 concludes the research findings.

1.8 Chapter Summary

This chapter presents the general background of this study by introducing renewable energy and the technique for harvesting energy from human body actions. It also emphasizes the problems of piezoelectric transducer that usually produces low power output and low durability of the piezoelectric transducer. Besides harvesting the energy from human footstep, design of the bending mechanism to enhance the harvested energy is also one of the objectives of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This section primarily introduces the concept of harvesting energy using piezoelectric energy and the feature of the piezoelectric transducer. It also outlines the design of the bending mechanism and techniques to test the piezoelectric output.

2.2 Energy Source and Its Demand

Energy refers to the ability to do work as it is a vital source to complete all the daily life activities [6]. An exact amount of energy is necessary so that all activities in a human life can be activated or functioning. Energy can be harvested from many various sources in our environment and this energy can be converted into usable electrical energy. Currently, the conversion of energy to electrical energy involves renewable energy, non-renewable energy and waste energy. Figure 2.1 shows the energy source diagram in various forms.

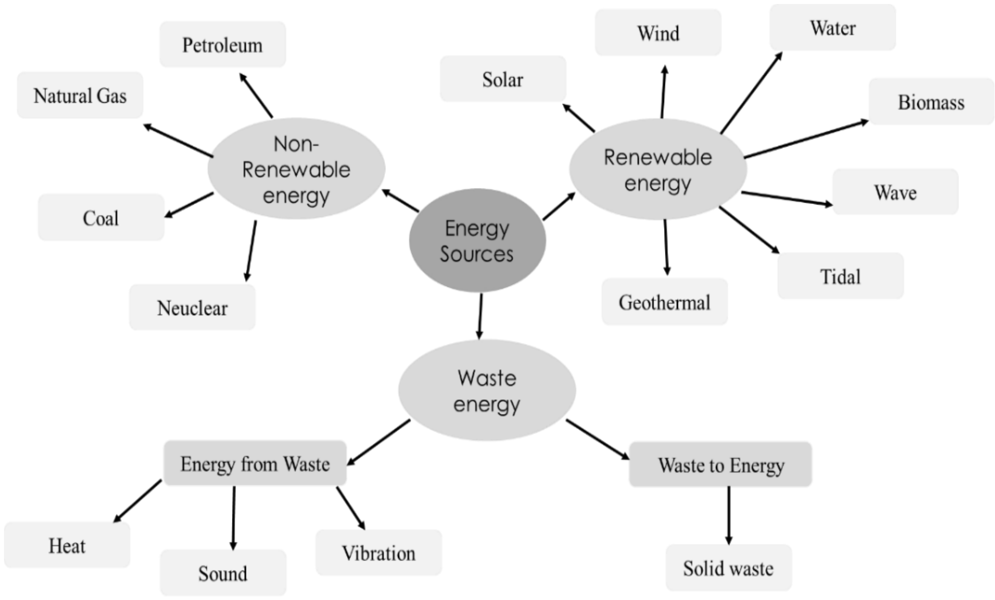
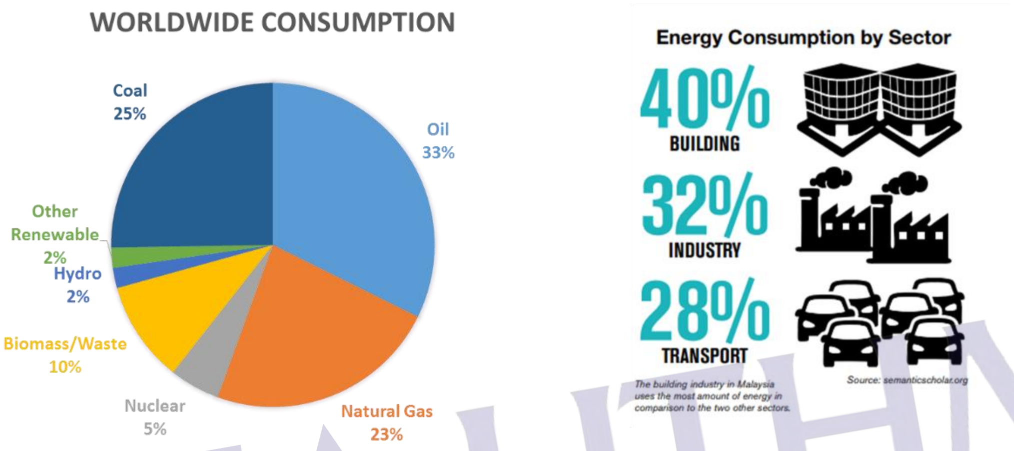


Figure 2.1: Energy source diagram [7, 8].

One of the ways to provide a promising, continuous, and ubiquitous energy supply is to harvest renewable energy such as solar, thermal, hydro, mechanical and motion. However, fossil fuel, petroleum and natural gas are still the main energy sources, and the endless use of this energy will exhaust the resources sooner or later. The main issue is how the world is going to satisfy the hunger for energy usage in the next few decades with the increasing of human population if there is a lack of awareness among current generation and few new strategies implementation in solving this problem.

As human population increases, housing development and building sector in developing countries is rapidly increasing all over the world and leads to an increase in energy demand. These two aspects are the major issues that contribute to the huge energy demand and consumption. Energy demand will continue to escalate by 56 % between 2010 and 2040 based on a report published by International Energy Outlook on the current position of global energy consumption [9]. It has been reported that in the year 2016 oil is still the major source of energy used worldwide at 33 %, followed by natural gas by 23%, coal by 25%, nuclear by 5%, biomass/waste by 10%, hydro by 2% and other renewable energy by 2% as shown in Figure 2.2(a) [10]. The same trend occurs for energy demand in Malaysia is expected as it is one of the rapidly developing countries.

The increase of building sector has significant impact on the increase in energy [11]. About 40% of energy consumption in Malaysia stems from the building sector as reported by Suruhanjaya Tenaga Malaysia in the year 2017 as shown in Figure 2.2(b) [12]. Human population growth is expected to be around 36 million by the year 2030 [13]. Based on this, the rate of energy consumption will increase due to the use of many applications in the buildings.



(a) (b)

Figure 2.2: (a) Worldwide energy consumption [10], and (b) energy consumption according to sectors in Malaysia [12]

2.3 Renewable Energy

As energy demand increases, the use of non-renewable energy also increases to generate electricity, which have gained attention awareness from the community by supporting the use of renewable energy have got extra attention from. Thus, the exploitation of free and natural resource to generate electricity has been emphasized. Figure 2.3 shows the trend of primary energy consumption by sources over the years. In the early years, oil was the main source followed by coal and gas. In the recent decades, the use of renewable energy has increased with oil is still being the dominant source.

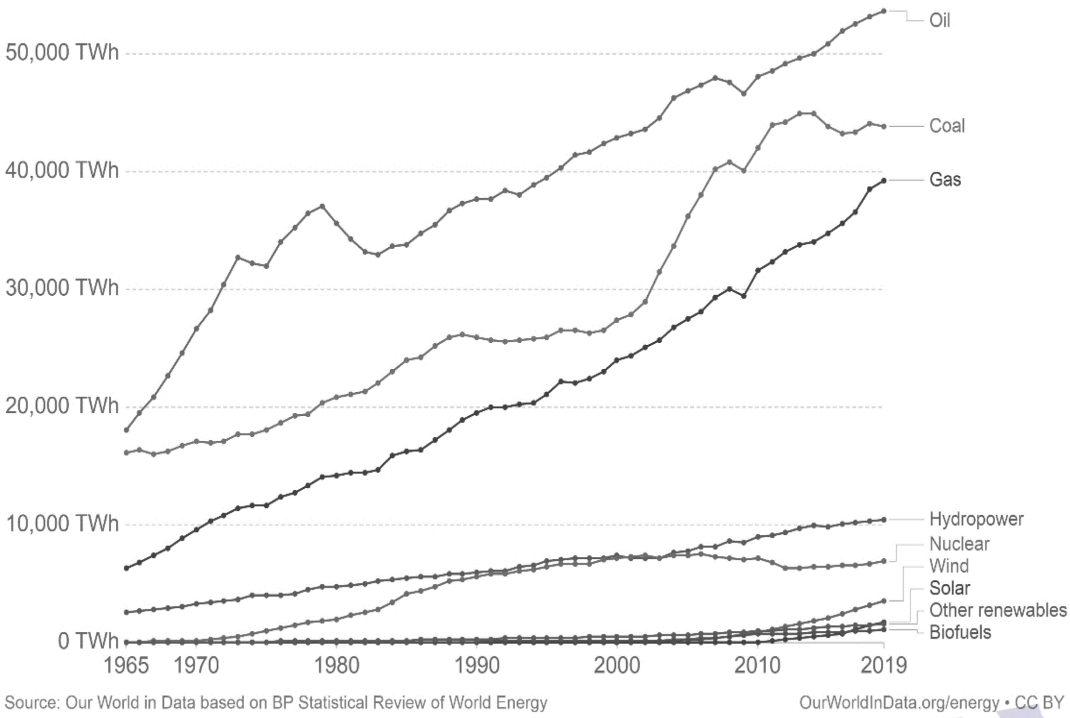


Figure 2.3: Global primary energy consumption (TWh) against year from 1965 to 2019 [14]

Renewable energy is used to replace fossil fuel and other natural gas in generating electricity. The utilization of this alternative energy benefits the environment and people, but it also has its shortcomings. Table 2.1 shows the advantages and disadvantages of renewable energy.

Most of the energy harvesting today use renewable and non-renewable energy but rarely used waste energy to generate electricity. Waste energy comes in various forms around us which can be converted into usable energy. There are also waste to energy and energy from waste, which are rarely used to meet the demand of electrical energy. Waste to energy is an energy that comes from various wastes, such as agriculture waste, municipal solid waste, industrial waste and commercial waste [18, 19]. In contrary, energy from waste refers to the energy from reaction of primary source, such as vibration in the form of mechanical energy, heat and sound [20]. It needs specific device, transducer or system to harvest and convert it to useful electrical energy and store it. This energy can be considered as green energy as it is not produced by or involve the use of any fuel and gas that pollute the environment.

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