# DESIGN AND DEVELOPMENT OF HUMAN-POWERED WEARABLE ELECTRONICS BASED ON PIEZOELECTRIC GENERATION SYSTEM

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"I declare that I have read this work and in my opinion this work is adequate in terms of scope and quality for the purpose of awarding a Bachelor's Degree of Electronic Engineering (Computer Engineering)."

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*To Mak and Abah*

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## ABSTRACT

Battery has always been the conventional option to supply power in electronic systems, particularly mobile devices. However, it's no longer feasible to use battery in mobile and wearable electronic as it is bulky and heavy to be carried around with mobile devices. These days with the development of mobile and wearable technology, the demand for low-power and portable energy sources can no longer be avoided. This project aims to design and develop a human-powered wearable electronics based on piezoelectric generation system. By this, it aims to power a simple computer system with a ceramic piezoelectric material based on impact from the users. With impact from the user's feet, the piezoelectric generates electricity that is channeled into the circuit. The computer system detects the temperature of the shoes by use of a temperature sensor and processes the information in a microcontroller. The microcontroller coded in C++ then triggers the LED when it detects the temperature above 25°. A prototype of this wearable electronic is then fabricated to demonstrate the ability of the piezoelectric in powering a simple computer system. More importantly, the proposed power generation system will contribute to the green technology application in our daily life. Experiments and tests were carried out to measure the effectiveness of the system.

# ABSTRAK

Bateri sentiasa menjadi pilihan konvensional untuk membekalkan tenaga elektrik kepada sistem elektronik, terutamanya untuk peranti mudah alih. Bagaimanapun, ia tidak lagi munasabah untuk menggunakan bateri untuk peranti elektronik mudah alih dan boleh pakai kerana ia sangat besar dan berat untuk dibawa bersama dengan peranti mudah alih. Dengan pembangunan teknologi mudah alih, kepentingan sumber-sumber tenaga mudah alih dan kuasa rendah tidak boleh lagi dipertikaikan. Projek ini bertujuan untuk mereka bentuk dan membangunkan satu peranti elektronik boleh pakai yang bergantung kepada pergerakan dan kuasa manusia dan berdasarkan sistem penjanaan piezoelektrik. Dengan ini, ia bermatlamat untuk menjana dan membekalkan tenaga elektrik kepada satu sistem komputer yang asas dengan menggunakan satu bahan piezoelektrik seramik. Dengan kuasa pergerakan dari pengguna, piezoelektrik menjana tenaga elektrik yang disalurkan ke sistem komputer. Sistem komputer mengesan suhu kasut melalui satu pengesan suhu dan memproses maklumat dengan satu mikropengawal. Mikropengawal yang dikodkan dalam C++ kemudian menghidupkan LED apabila ia mengesan suhu di atas 25°. Sebuah prototaip kemudian di reka dan di bina untuk mendemonstrasikan keupayaan piezoelektrik dalam menjana sistem komputer mudah. Lebih penting,sistem penjanaan kuasa dicadangkan akan menyumbang kepada pembangunan teknologi hijau dalam kehidupan harian kita. Eksperimen dan ujian telah dijalankan untuk mengukur keberkesanan sistem.

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# CHAPTER I

# INTRODUCTION

In this chapter, the motivation and basic background of this project is discussed. The discussion includes the background of the project, problem statement, objectives, and the scope of the project. At the end of the chapter, we conclude the overall report structure.

## 1.1 GENERAL BACKGROUND

Throughout the years of science, we have witnessed the growth of technology and the rapid size reduction of computers and devices. Computer-controlled devices also become more adapatable to the human lives resulting in engineers and scientists pushing the boundaries of electronic possibilities.

One of the best examples for the advancement of technology is the invention of wearable electronics. Wearable electronics is extremely necessary in today's world as it provides greater user-friendliness, user-empowerment, and more efficient services support [15]. Simply, electronic devices are embedded into clothes and wearable accessories to provide better access and movement for the users as it reduce the weight and increase the mobility of such devices. From initial discoveries, we have now reached the rapid phase of development in wearable electronics. This is because the cost of some of the most significant microelectronic components is low enough and the available technologies are mature enough to execute this vision [15].

Many issues have been raised in the development of wearable electronics and one of the most significant one is related to the issue of energy and power supply and management. Energy has always been an intergrated part of human population. With the rise of wearable electronics, the need for a mobile and compact power supply becomes very significant.

In most wearable electronics available in the market nowadays, the standard method of power supply is the conventional battery; however, problems can occur when using batteries because of their finite lifespan. For portable electronics, replacing the battery is problematic because the electronics could stop operating at any time and replacement of the battery can become a tedious task. Another problem when using conventional battery for wearable electronics is the process of replacement of batteries. [3]

One of the proposed solution for this issue is energy harvesting. Energy harvesting is the current prominent reasearch area as it complements not only the wearable technology but also other systems and fields that need a smarter power management system. Some of the best examples are energy harvesting through solar power and impact on piezolectric materials, which will be used and futher explained in this thesis.

In 2050, children will grow up with electrotextiles, thermo- electricity, and thin solar film that will cover everything from portable electronics to parking lots. Energy harvesting will be ubiquitous, inexpensive, and practically invisible [6].


Figure 1.1: Energy harvesting products: (a) the Summit, a windup-powered radio; (b) theFreeCharge, a windup charger for cell phones; (c) the NightStar, a magnetic-forceflashlight; (d) Nanosolar's thin-film solar-cell material. [6]

## 1.2 PROBLEM STATEMENT

With the current technological development, the battery as a power supply is not sufficient. The first and main problem with the DC voltage source also known as battery is the depleting current and voltage source over time. The battery is not able to provide a constant voltage and current to any system when measured against time. This means that after a certain period where the battery's power is diminishing, the user would need to change or recharge the battery. This is not only troublesome to the user but could also be dangerous as the chemicals in the battery could potentially leak out causing environmental and health problems. The use of alternative power sources is only a fraction to worldwide power generation, and the harm on the environment is still increasing. Every year, billions of batteries are discarded. [6]

Following this, researches have been greatly focused on reducing the size of power supplies and at the same time, increasing the power output of these supplies. Indeed, the first prototype of ‘wearable computers’ in the early 1990s required users to pun on a visor and carry heavy battery packs in their garments, leading some groups to question the accuracy of the term ‘wearable’. [19]

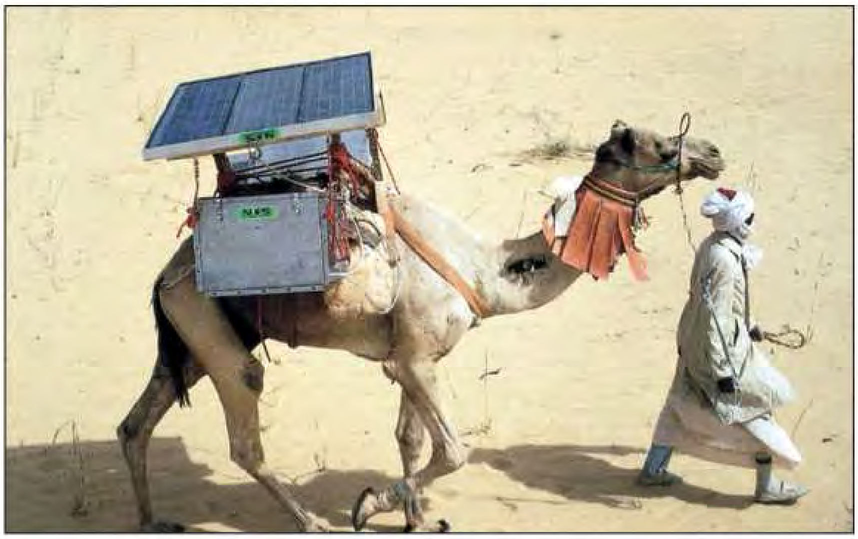

Figure 1. 2: Naps Systems of Finland used solar-powered refrigerators to deliver vaccines to hundreds of remote villages in the central Chad in the 1980’s

This is the main motivation that leads to the consideration for energy harvesting in electronic devices. Hundreds of companies and research institutes in leading countries are working on energy harvesting technology, which drives millions of dollars in venture capital into the industry. [6]

## 1.3 OBJECTIVES

The objectives to be aimed from this project;

a. To design a human-powered wearable electronics based on pizeoelectric generation system complete with power storage unit including it’s specifications and limitations.
b. To simulate the designed system using electronic simulation tools (LTSpice).

c. To fabricate the wearable electronic circuits based on the simulation done during the simulation phase, using conductive threads and modular circuits.

## 1.4 SCOPE OF THE PROJECT

This project will include an energy harvesting system, a power management unit, a measurement and monitoring computer system plus a system to display accurately calculated data. The power management unit will include measuring, calculating, and controlling the amount of voltage input into the system. Power will be generated by the impact from user's movements and will be supplied to the system through a storage system (supercapacitor). This project will be limited to computing data through measurement of biological conditions and displaying the data accurately. The sensors, piezoelectric and other components to be use in this project are obtained off the shelf and are ensured to follow the electrical requirements of the system.

## 1.5 REPORT STRUCTURE

This thesis includes five chapters with its own specific scope of explanation regarding the project.

The first chapter is the introduction to the project, which includes the general bankground, motivation deduced from the problem statement, objectives and scope of project.

The second chapter compiles the literary work that is related and referenced to the project. This chapter focuses on other professional researches and work that has been documented as to provide a prespectives to this project.

Chapter three recorded the methodology used in the completion of this project. It detailed the reasearch approaches and testing strategy that has been executed in achieving the outcome.

The outcome and observation from this project is carefully recorded and compiled in chapter four. The design, simulation and result from the fabrication of the wearable electronics are recorded in this chapter.

Finally, this project is concluded in chapter five, which provides the overall analysis and conclusion on the objetives and achievements of this project.

# CHAPTER II

# LITERATURE REVIEW

This chapter provides an overview of relevant literatures as well as the basic theoretical idea of an energy efficient wearable electronics and the concept of energy harvesting. The chapter begins with the description of the concept of energy harvesting, followed by studies on the related scope of wearable electronics.

## 2.1 ENERGY HARVESTING

Energy harvesting is the process of acquiring the energy surrounding the system and converting it into usable electrical energy [3]. This concept is thoroughly applied in this project.

### 2.1.1 PIEZOELECTRIC

As technological development rapidly grows, energy sources have become a central issue as devices and systems become more complicated and complex. The most important trend in the electronic equipment technology from its beginning has been the reduction in size and the increase of the functionality. Power sources such as batteries are a significant source of size, weight and inconvenience to present-day portable, handheld and wearable systems [7]. With this, a portable energy source becomes increasingly significant. This portable energy source must also provide a stable power supply and self-sustaining.

To overcome this issue, we look at a few of the possible portable power sources currently available. The following table shows the options available to power a portable system.

| Power Source | Power ($\mu W/cm^3$) | Energy ($J/cm^3$) | Power/yr ($\mu W/cm^3/yr$) | Need of secondary Storage | Need of Voltage regulation | Commercially available |
|---|---|---|---|---|---|---|
| Primary battery | N/A | 2880 | 90 | No | No | Yes |
| Secondary battery | N/A | 1080 | 34 | N/A | No | Yes |
| Micro fuel cell | N/A | 3500 | 110 | Maybe | Maybe | No |
| Ultracapacitor | N/A | 50-100 | 1.6-3.2 | No | Yes | Yes |
| Heat engine | $10^6$ | 3346 | 106 | Yes | Yes | No |
| Radioactive ($^{63}Ni$) | 0.52 | 1,640 | 0.52 | Yes | Yes | No |
| Solar (outside) | 15000[1] | N/A | N/A | Usually | Maybe | Yes |
| Solar (inside) | 10[1] | N/A | N/A | Usually | Maybe | Yes |
| Temperature | 40[1,2] | N/A | N/A | Usually | Maybe | Soon |
| Human power | 330 | N/A | N/A | Yes | Yes | No |
| Air flow | 380[3] | N/A | N/A | Yes | Yes | No |
| Pressure variation | 17[4] | N/A | N/A | Yes | Yes | No |
| Vibrations | 375 | N/A | N/A | Yes | Yes | No |

Table 2.1: Comparison between potential portable power sources [2]

From Table 2.1, we could easily identify human power as the best practical consideration for portable power source. Although solar power shows the most power generated per $cm^3$, it is not suitable for wearable electronics that is not constantly exposed to sunlight. It would need a large power storage system that is not suitable for small, portable wearable electronics.

Piezoelectric has been a strong candidate for energy generation and power supply to a portable system [2]. A material is called piezoelectric when it shows the ability to convert mechanical energy to electrical energy [2]. Piezoelectric rely on piezoelectricity of crystals to supply power to portable systems. Piezoelectricity is the ability of certain crystalline materials to produce electric charge proportional to mechanical stress [23].

To obtain the maximum electric charge from the piezoelectric, maximum mechanical stress can be achieved by;

1. Vibrations

   a. Piezoelectric materials are vibrated on a set frequency to produce desired power for portable systems.
2. Impact
   a. Piezoelectric materials are deformed on impact from human movements; eventually producing electrical energy.

Between these two options, the only practical method to harvest electrical energy for wearable electronics would be from human movement instead of vibrations. The impact for human movement can be obtained from limb movements; tapping or walking/running).

| Description | Maximum Voltage | Calculated Pressure |
|---|---|---|
| Tap, Finger | 6.875 V | 390.0 kPa |
| Tap, Hammer | > 20 V | 1134.6 kPa |
| Bend, Smooth | 843.7 mV | 47.9 kPa |
| Bend, Abrupt | 2.906 V | 164.9 kPa |
| In-shoe, No movement | 118.7 mV | 6.7 kPa |
| In-shoe, Stamping | 968.7 mV | 55.0 kPa |
| In-shoe, Jumping | 843.7mV | 47.9 kPa |
| In-shoe, Running | 375.0mV | 21.3 kPa |

Table 2.2: Comparison of maximum voltage from different impact of limb movements [5]

Approximately 60–70 W of power is consumed during walking and a piezoelectric material in a shoe with a conversion efficiency of 12.5% could produce 8.4 W of power. [1] Average piezoelectric could operate from temperature of -40°C to +125°C, and average shoe temperature when walking is +30°C to +40°C, with maximum error of ~2% [5]. This enhances the justifications for the suitability of piezoelectric in portable systems. The output electrical potential difference produced from the impact applied on piezoelectric materials can be calculated from the following mathematical formula;

$$\mathbf{V_o = (g_{33}) \times (X_3) \times (t)}$$

Where;

$g_{33} = -339 \times 10^{-3}$ (V/m) / (N/$m^2$)

$X_3$ = load applied to piezoelectric film (third axis), N/$m^2$

t = thickness of piezoelectric film, m

[5]

### 2.1.2 FOOT STRIKE

The positioning of the piezoelectric materials in wearable electronics plays a very important part because the electrical energy generated is proportional to the mechanical stress applied to the piezoelectric materials. The piezoelectric materials should be placed where it could be deformed the most by impact so the maximum electrical potential difference could be harvested.

To harvest the maximum electrical energy from piezoelectric in footwear, we have to understand the motion of walking and running. When running, the leg performs a cyclic motion. With one foot in front of the other, the back foot strike the ground, moving forward and beneath the body before lifting and prepare for landing [5]. This motion can be broken down into three different phases to better understand the force and motion involved in running and walking;

1. Supporting phase
   a. begins when the foot lands and ends when the user's center of gravity passes forward of it

2. Driving phase
   a. begins as the supporting phase ends and ends as the foot leaves the ground

3. Recovering phase
   a. begins when the foot is off the ground and is being brought forward preparatory to the next landing [5]

From these phases, we can better analyze the force and motion when walking and running, thus assisting us in making decisions in placement of the piezoelectric. Before we conclude the placement of the piezoelectric, we also need to better understand the correlation between the electrical displacement and the mechanical stress of the piezoelectric.

$$\mathbf{D = dX + \varepsilon^{X} E}$$

Where;

D = Electrical displacement

X = Mechanical stress

E = Electrical field

$\varepsilon^{X}$ = dielectric constant measured at constant stress

[7]

Different types of shoes could also affect the output electrical energy we get from the piezoelectric. This is because different types of shoes, particularly the material of the sole, exert different levels of force on the feet. The force on the feet when walking is highly dependent on the hardness and the thickeness of the sole of the shoes.

From these considerations, it can be concluded that the piezoelectric is best installed on the heel and insole of shoe to harvest energy from walking while minimizing effects on shoe feel and comfort. The force is more dissapitated on the heel of the feet than anywhere else when walking [1]

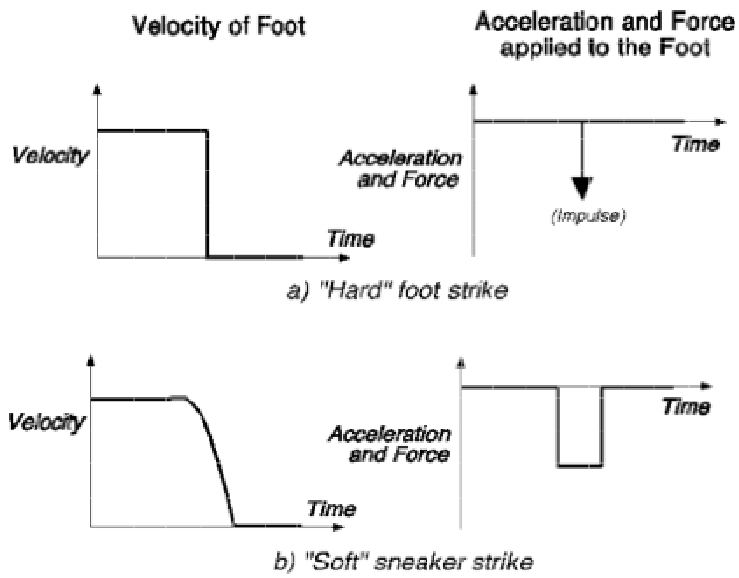


Figure 2.1: Comparison between the force applied on the foot in sneakers with soft soles and shoes with hard soles

## 2.2 WEARABLE ELECTRONICS

A wearable is a device that is always attached to a person, but easy and comfortable to keep and use. Wearable electronics is defined by a wearable which carries the functions related to generation, transmission, modulation and detection of electrons [24]. Simply put, a wearable electronics is an electronic device that is always comfortably attach to the user for mobility purposes.

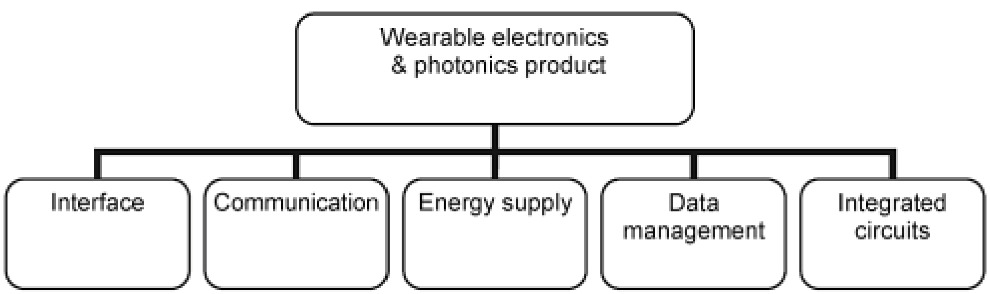


Figure 2.2: General System Configuration of A Typical Wearable Electronics [24].