Energy Harvesting from Fingers Motions Using a Wearable System: An Experimental Analysis

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Abstract. An experimental analysis is presented in order to assess the best conditions for energy harvesting from the movement of the fingers using a glove-shape wearable system. Polyvinylidene Fluoride (PVDF) piezofilms were used as piezoelectric generators; they were mounted on the glove so they coincide with different interphalangeal joints on both sides of each finger of the right hand. Two scenarios have been carried out for five minutes each and the root-mean-square (rms) voltage of each piezofilm was measured. Scenario 1 consisted in the use of a computer mouse for browsing different web-sites on the internet; scenario 2 consisted in the use of a keyboard to write a text of 190 words. Scenario 2 produced the greater voltage because the number of keys depressed was higher in comparison with the number of clicks on the computer mouse. In the Scenario 1, the greater voltage was obtained from the piezofilm located on the thumb which is a finger not involved with the click action when using a computer mouse so, in this case, it is possible to harvester energy from three fingers instead of two, as have been reported in previous studies. From the results obtained in both scenarios, the best location to place the piezofilms to increase energy harvesting is the posterior side of each finger, specifically on the proximal interphalangeal and metacarpophalangeal joints. Placing the piezofilms on the fingertips did not produce an increase in the generated voltage.

Keywords: Energy harvesting · Biomechanical energy · Fingers motions · Wearable system

1 Introduction

Continuous progress in reducing the size and power consumption of electronic systems has allowed a fast-growing development of wearable technology. One of the aims of wearable systems is to offer basic healthcare monitoring to the people in nonhospitalary environments. However, if long-term monitoring is desired, the limited power source (typically a battery) becomes a handicap. Thus, there is a tradeoff between the operating time and the mass of the system because of the size of long-term batteries [1]. Additionally, some batteries cause other problems due to their short-life cycle, high maintenance costs, and their environmental impact because of toxic materials that they

C. A. González Díaz et al. (Eds.): CLAIB 2019, IFMBE Proceedings 75, pp. 866–873, 2020.
https://doi.org/10.1007/978-3-030-30648-9_113

contain. To tackle these, in the last decades, energy harvesting systems have been proposed in order to develop more autonomous systems [2].

Energy harvesting consists in transform the environment energy into electrical energy to be stored later. The main sources for energy harvesting are light, temperature differences, electromagnetic radiation, and movement; each one with its respective advantages and disadvantages [3]. Starner [4], published one of the first works that discuss the possibility of harvest energy from human activities such as: movement of the upper and lower limbs, breathing, blood pressure, body heat and the movement of the fingers. Numerous wearable biomechanical energy harvesters have been reported. To name a few, there has been mounted piezoelectric generators in shoes [5–8], backpacks [9, 10], watchstraps [8] and clothes [11, 12], all of them oriented to harvester energy from the movement of different parts of the human body. Recently, there have been efforts to collect energy from the movement of the fingers when a subject manipulates a keyboard or a computer mouse, which are daily common activities of many people. For this, glove-shape wearable systems have been developed, where piezoelectric generators are placed on the fingers [13–15], being the common options the use of Lead Zirconate Ti-tanate (PZT) and Polyvinylidene Fluoride (PVDF). The PZT is a ceramic characterized for having good piezoelectric coefficients, but it is brittle, which is an unwanted feature for a wearable system. The polymer-based PVDF exhibits excellent mechanical flexibility, which makes it a good option to be integrated into wearable systems, but it has lower piezoelectric coefficients [16].

Many efforts have been made to improve the performance of harvesting systems, focusing on the materials, circuits, and conversion methods [2]. However, few studies have focused on determining the optimal placement of the piezoelectric generators on a glove-shape wearable system. In this work, the amount of voltage generated is evaluated when the piezofilms are placed on the distal, proximal and metacarpal interphalangeal joints of the right hand including both anterior and posterior side of the fingers. The intention is to determine the best location of the piezofilms on the fingers to increase the generation of voltage. The results obtained in this work are the starting point to assess the best conditions to increase the energy harvesting from fingers motions that allow us to supply a batteryless wearable system that detects the cardiac activity in the wrist or, in the worst case, to extend the period of battery replacement used as a power source of the system.

2 Energy Harvesting

At first instance, some energy can be produced when depressing the keys of a keyboard or the buttons of a computer mouse. According to [4], a typical keyboard requires between 40 and 50 g of mass to depress a key, which represents forces between 0.392 and .490 N. According to [17], the minimum force necessary to activate a button of a standard size computer mouse is about 0.65 N. So, it is possible to estimate the power, *P*, that can be generated when using a keyboard or a computer mouse, that is:

$$P = F \cdot d \cdot \left(\frac{\#\ keystrokes\ or\ \#\ clicks}{s} \right) \mathrm{mW}, \tag{1}$$

where F is the force necessary to depress a key of a keyboard or a button of a computer mouse the distance d necessary to register a keystroke or a click. The greater the number of keystrokes or clicks the greater the power generated.

3 Materials and Methods

The piezoelectric generators used in this work are the LDT1-028K from Measurement Specialties. This is a multi-purpose PVDF piezoelectric film commonly used for detecting physical phenomena such as vibration and impact. This piezofilm produce a voltage (Voltage Mode) or a charge (Charge Mode) in the direction i according to the intensity and the direction j of the deformation of the active area. The main characteristics of the piezofilms used are presented in Table 1.

Table 1. Electrical characteristics and dimensions of the LDT1-028K [18].

Property	Value	Units
Output resistance, R_o	10 (max)	MΩ
Capacitance, C_o	1.38	nF
Piezoelectric voltage constant, g_{ij}	$g_{31} = 216 \times 10^{-3}$ $g_{33} = -330 \times 10^{-3}$	Vm/N
Piezoelectric charge constant, d_{ij}	$d_{31} = 23$ $d_{33} = -33$	pC/N
Large	41.40	mm
Width	16.26	mm
Thickness	28	μm

We used the piezofilms in Voltage Mode in order to estimate the voltage generated in each test. For this, the output of each piezofilm was connected independently to the analog inputs of a 16 bits Data Acquisition System USB-6341 from National Instruments. The system was connected to a laptop and was configured to acquire data during 5 min at 1 kSa/s. The procedure was repeated 5 times for each test and the data were stored in a laptop for further analysis.

In order to assess the voltage generated by the piezofilms located on the fingers, two different test scenarios were carried out: Scenario 1: the subject browsed different web-sites on the internet using a computer mouse M310 from Logitech for 5 min. There were no restrictions about the number of clicks executed by the subject. Scenario 2: the subject used a laptop keyboard Inspiron 7559 from Dell to write a text of 190 words for 5 min (3.97 keystrokes/s). According to [4], the subject who made both tests is considered a moderately skilled QWERTY typist.

The piezofilms were mounted on a right-hand glove; once the glove was put on the right hand of the subject, the positions of the piezofilms coincide with different interphalangeal joints of the hand. The interphalangeal joints used in each test were (Figs. 1 and 2):

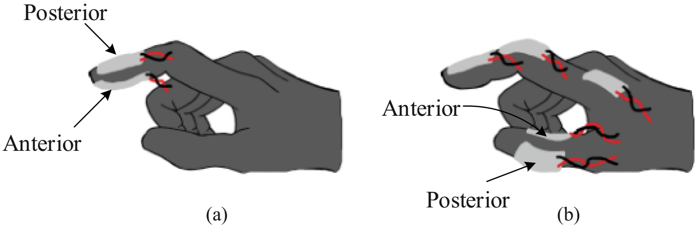

Fig. 1. Configuration of the piezoelectric generators on the glove used for the computer mouse test: (a) $ADIP_i$ and $PDIP_i$; (b) $PPIP_i$, $PMCP_i$ $PDIP_i$, $APPIP_t$ and $PPIP_t$.

Scenario 1: Using a computer mouse

(a) Anterior distal interphalangeal joint ($ADIP_i$) and posterior distal interphalangeal joint of the index finger ($PDIP_i$) (Fig. 1a).
(b) Posterior proximal interphalangeal joint of the index finger ($PPIP_i$) (Fig. 1b).
(c) Posterior metacarpophalangeal joint of the index finger ($PMCP_i$) (Fig. 1b).
(d) Anterior proximal interphalangeal ($APIP_t$) and posterior proximal interphalangeal of the thumb ($PPIP_t$) (Fig. 1b).

Scenario 2: Using a computer keyboard:

(a) Anterior distal interphalangeal joint of the index, medium, ring and little fingers ($ADIP_f$) and anterior proximal interphalangeal joint of the thumb ($APIP_t$) (Fig. 2a).
(b) Posterior distal interphalangeal joint of the index, medium, ring and little fingers ($PDIP_f$) and posterior proximal interphalangeal joint ($PPIP_t$) (Fig. 2b).
(c) Posterior proximal interphalangeal joint of each one of the five fingers (PPIP) (Fig. 2c).
(d) Posterior metacarpophalangeal joint of the index, medium, ring and little fingers ($PMCP_f$) and posterior proximal interphalangeal joint ($PPIP_t$) (Fig. 2d).

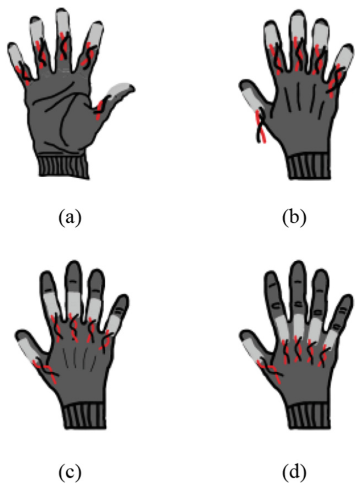

Fig. 2. Configuration of the piezoelectric generators for the computer keyboard test: (a) $ADIP_f$ and $APIP_t$; (b) $PDIP_f$ and $PPIP_t$; (c) PPIP; (d) $PMCP_f$ and $PPIP_t$.

4 Results

The use of the computer keyboard produced more rms voltage than that produced with the use of the computer mouse. According to (1), this is an expected result because, during the tests, the number of keystrokes was greater than the numbers of clicks. In the Scenario 1, the piezofilm located on the posterior side of the index finger produced a root-mean-square (rms) voltage of 0.834 V, while the voltage obtained from the piezofilm located on the anterior side (fingertips) was 0.847 V. One would expect to obtain a much higher voltage from the piezofilm located on fingertips, where the impact between the finger and the surface of the mouse button is sensed. However, the results reveals that there is no significant difference between the voltages obtained when the piezofilms were placed on the anterior and on the posterior side of the index finger.

Figure 3 shows the average and the standard deviation of the rms voltage obtained from each piezofilm in the scenario 1, where some interesting conclusions can be drawn. Paradoxically, the greater rms voltage (1.218 V) was obtained from the piezoelectric generator located on the posterior side of the thumb, which is a finger that is not involved with click action of the computer mouse, so (1) does not apply here. This result can be attributed to the muscular activity involved in the process of moving the mouse, where slight movements of the wrist and of the ring and thumb fingers are required, being the thumb one of the most used finger. With this finger, a significant difference was obtained between the rms voltage obtained from the piezofilm located on the posterior side of the thumb and that located on the anterior side. In regards to the index finger, the higher voltage (0.944 V) was generated when the piezofilm was located on the posterior distal interphalangeal joint.

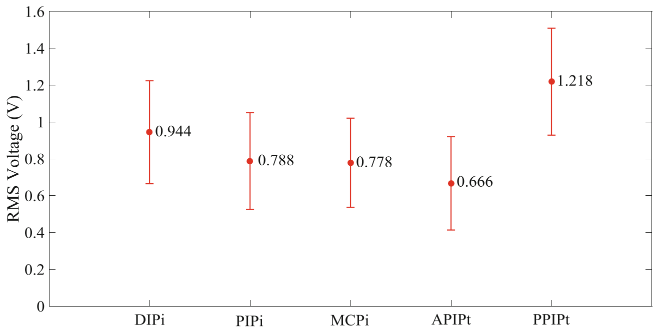

Fig. 3. RMS voltage generated by each piezofilm located at different interphalangeal joints on the posterior side of the index finger and on the anteroposterior sides of the thumb at the proximal interphalangeal joint. Test: Scenario 1.

Figures 4 and 5 show the results obtained in the Scenario 2, where in Fig. 4 are presented the average and the standard deviation of the rms voltage generated from each piezofilm located on the anterior side of each finger, while Fig. 5 shows the results obtained when the piezofilms were located on the posterior side of each finger. Firstly, comparing the results of both figures, there is a significant difference between the rms voltages generated. We obtained 2.329 V from the piezofilms located on the anterior side and 1.180 V from the piezofilms of the posterior side of the proximal interphalangeal joint of the thumb. That is, changing the side of the location of the piezofilm in the same finger and interphalangeal joint, we gained 1.149 V. Secondly, the higher rms voltages were obtained from the piezofilms located on the posterior side of the metacarpophalangeal and the proximal interphalangeal joints of the other four fingers. In our case, the highest voltage was produced with the piezofilm located on the proximal interphalangeal joint of the little finger (3.044 V). The average rms voltage obtained in this test is greater than that presented in [15], where PZT generators (with

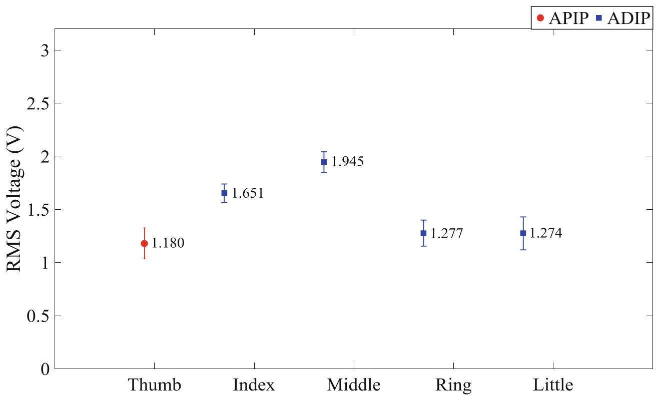

Fig. 4. RMS voltage generated by each piezofilm located at different interphalangeal joints on the anterior side of each of the five fingers. Test: Scenario 2.

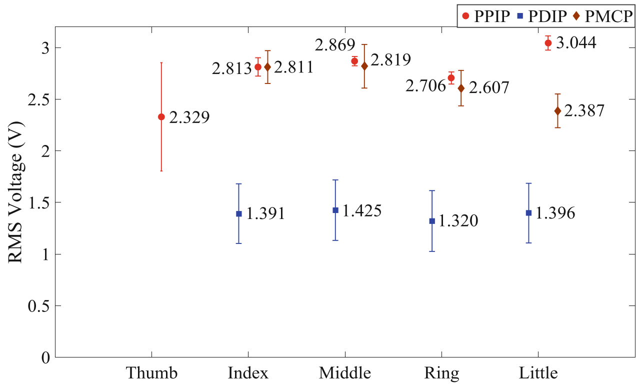

Fig. 5. RMS voltage generated by each piezofilm located at different interphalangeal joints on the posterior side of each of the five fingers. Test: Scenario 2.

higher piezoelectric coefficients) were placed on the fingertips of a QWERTY typist who wrote a text of 602 words. The fact of placing the piezofilms on the fingertips, makes it difficult for them to make correct contact with the keys of the keyboard due to the design of the glove [15]; therefore, placing the piezofilms on the posterior side of the fingers gives more freedom to the subject to use the keyboard without any restrictions.

5 Conclusions

In this work, we assessed the best conditions to increase the voltage generated from the movement of the fingers using piezoelectric generators when a subject use a computer mouse and a keyboard. In both scenarios, the greater rms voltages were obtained when the piezofilms were located on the posterior sides of the fingers, specifically on the proximal interphalangeal and the metacarpophalangeal joints. When the subject used the computer mouse, the greater voltage was obtained from the piezofilm located on the thumb, which is a finger not involved with the click action, but it does contribute to the movement of the mouse where a not negligible force must be applied by the ring and the thumb fingers. This reveals that, in this scenario, a quantifiable energy can be harvested not only from the fingers involved with the click action as has been reported in [15], but also from the fingers involved with the movement of the mouse. Placing the piezofilms on the posterior side of the fingers, not only achieves more rms voltage, but also does not restrict the use of the keyboard or the computer mouse to depress a key or a click.

Acknowledgment. This work has been partially funded by PRODEP and UACJ, Mexico.

Conflict of Interest. The authors declare that they have no conflict of interest.

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