Human Motion to Recharge Implantable Devices

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Abstract- **This paper discusses the ability to generate energy from the human body without using any external power source by using a piezo-element sensor. The replacement procedure of the batteries in implantable medical devices may apply risk to the patient's life, to avoid this risk many methods exist one of them is proposed in this work. The piezo-element is designed to be attached into the patient's shoes and while the patient is walking energy is generated from the pressure applied on the sensor. The generated energy is then harvested by using the MAX1675, the CLC filter, and the voltage regulator. The harvested energy is transmitted to charge the battery of an implantable medical device. Transmission takes place wirelessly with causing minimal risk to the patients' life. The achieved results in this work prove that the idea of wirelessly charging an implantable medical device with moderate economical expenses is applicable. The results are promising and need more improvement.**

Keywords - **Piezo-electric element, Human motion, Rechargeable battery, Energy harvesting, Transmission.**

I. Introduction

Implantable devices nowadays have become a major-medical cure for many patients with different medical conditions. They vary in their functions and uses, but they are similar in one main characteristic "their battery". The battery is considered one of the major drawbacks since with time it needs to be replaced; the most common method of replacement is through surgical procedures that might endanger the patient's life and may lead to surgical complications not to mention the physical and financial burden on the patient.

The method that is followed in this paper is recharging the implantable medical device through musculoskeletal motion. There are various other methods that use the human body as an energy source such as utilizing the chest movement, or the knee movement [1-3]. In this paper, the recharging process depends on the walking mechanism of the human being.

Walking is one of the activities that are carried out daily. Therefore utilizing this simple movement to generate energy would solve many electrical related issues faced in the present days.

Implantable medical devices are initially designed for assuring the wellbeing of patients' life and therefore developing a method that allows recharging the battery of an implantable medical device instead of replacing it would add a benefit to the patient's life and adds an additional feature to the device. One step in this direction is designing implantable devices with rechargeable batteries [4,5] and recharging these batteries wirelessly through the human body motion [6, 7].

The structure of this paper is presented in the following manner; section II gives a brief explanation on how the human body acts as an energy source. The hardware design is explained in section III. Section IV sums up the results and analysis attained and the conclusion is presented in section V.

II. Human body as an energy source

The human body represents a complete energy source, it is an energy conversion machine; it can produce, supply, and emit energy. Conservation of energy implies that the chemical energy stored in food is converted into work, thermal energy, or stored as chemical energy in fatty tissue. Chemical energy is produced from reactions in the human body cells and it's supplied to the rest of the body for sustaining human life. By far the largest fraction goes to thermal energy, although the fraction varies depending on the type of physical activity [8].

All bodily functions, from thinking to lifting weights, require energy. The many small muscle actions accompanying all quiet activity, from sleeping to head scratching, ultimately become thermal energy, as do less visible muscle actions by the heart, lungs, and digestive tract. Shivering, in fact, is an involuntary response to low body temperature that pits muscles against one another to produce thermal energy in the body. The kidneys and liver consume a large percentage of energy, but the largest percentage of energy is consumed by the body to maintain electrical potentials in all living cells (Nerve cells use this electrical potential in nerve impulses (25%)) [8]. This bioelectrical energy ultimately becomes mostly thermal energy, but some are utilized to power chemical processes such as in the kidneys and liver, and in fat production.

Another form of energy in the human body that should not be ignored is mechanical energy. Throughout the day the human body is in constant movement and while the muscles are moving the chemical and thermal energies produced are not being utilized. When the human body is in motion, force is exerted on the surfaces that is in contact like the foot on the ground when walking, the persons back when leaning on a chair, or the hand when touching a desk. These simple daily movements produce pressure on random surfaces. Thus, the pressure produced is also not being utilized.

In this paper, various methods are presented to utilize the different energy forms produced from the human body. Thermal energy is used to generate electricity using arrays of thousands of thermoelectric generators built into an implantable chip [9]. Mechanical energy comes in different forms, since it can be taken from different muscles in the body. If the chest muscles are taken for an example; through the breathing mechanism they contract and relax thus causing a movement that can be utilized by using a chest belt [1]. The most vital muscle for survival is the heart muscle. The SA node generates a nerve impulse, just a certain amount of it is used by the heart to work, and the rest is utilized by using an intelligent monitoring module. The amount of nerve impulses that are generated are compared with a threshold nerve impulse value, the excess nerve impulses are stored [10]. Another muscle that can be used is the gastrocnemius muscle which is a powerful superficial bipennate muscle that is at the back part of the lower leg. It runs from its two heads just above the knee to the heel, a two-joint muscle. Electrical stimulation excites contraction of the muscle. In this process, the chemical energy of the glucose and oxygen in the body is converted into kinetic energy. The kinetic energy of the muscle contraction drives a generator and generates electrical energy [11]. The knee movement can also be utilized to generate electricity [2, 3]. There are many more muscles in the human body that can be used to generate electricity. Several methods can be used to obtain energy from non-utilized energy forms that are naturally generated by the human body.

III. Hardware Design

Patients with implantable medical devices suffer from the need to undergo an additional surgery to replace the consumed battery after a few years of the original surgery of implanting the medical device. Therefore, in this paper a method to replace the conventional battery replacement surgery that is noninvasive to recharge the batteries of implantable medical devices is proposed. This technique is safer for the patient's life, more convenient for the patient, and also economically affordable. The proposed method is fulfilled by three stages: Energy Generation, Energy Harvesting and Energy Transmission. A complete Hardware structure is shown in Fig. 1 to present an overview of the proposed design.

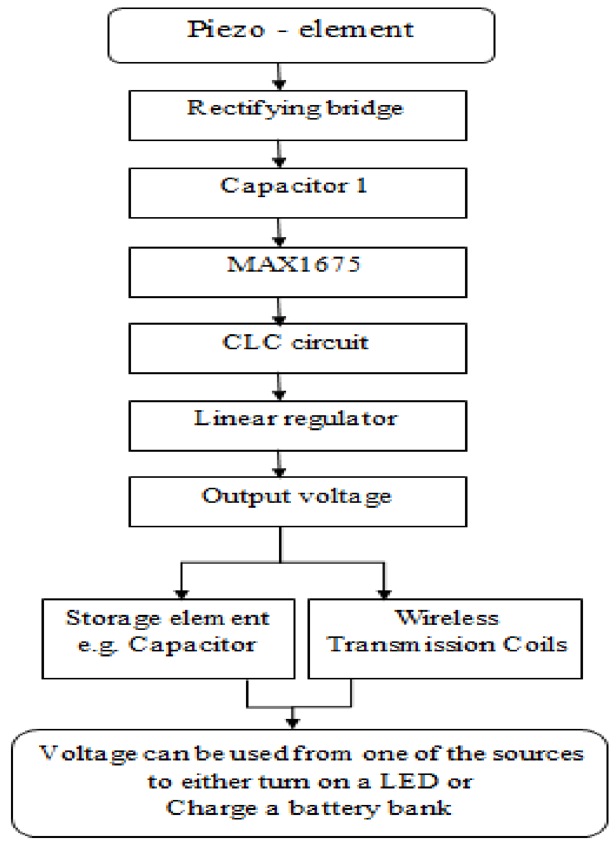

Fig. 1 Block Diagram of Hardware Design

A. *Energy Generation Stage*

The piezo-electric element SEN-10293 is the input that converts mechanical energy to electrical energy [12, 13]. The output attained from the piezo-electric element is alternating current (AC) which cannot be used to charge a battery. Therefore, this output needs to be rectified to meet the desired task. The rectifying circuit used is the full wave bridge rectifier using zener diodes.

The AC voltage generated is passed through a circuit of four zener diodes (1n4148F) and is converted into the desired direct current (DC) output. The DC voltage is fed into a capacitor of 470µF with voltage capacitance of 25V which represents the first storage element in this work.

B. Energy Harvesting Stage

The energy harvesting stage is divided into three consecutive parts: the MAX1675, CLC filter, and the voltage regulator (7805cv).

The MAX1675 is a compact, high-efficiency, step-up DC-DC converter. The MAX1675 has a built-in synchronous rectifier, which improves the efficiency and reduces size and cost by eliminating the need of a schottky diode. It has a passive current supply of 16µA. It can take input voltages ranging from 0.7V to V_{OUT}, where V_{OUT} can be set from 2V to 5.5V. The MAX1675 has a 0.5A current limit, which permits the use of a smaller inductor [14, 15].

The CLC filter consists of one inductor and two capacitors connected across each end of the inductor. The input capacitor is selected to offer very low reactance to the repel frequency, major parts of filtering is done in the input capacitor. Most of the remaining repels are removed by the combining action of the inductor and second capacitor. This circuit gives better filtering results than the LC filtering circuit. The main use of CLC filter in this proposed design is to purify the DC signal [16].

The linear regulator (7805cv) is a voltage regulator integrated circuit. It is a member of 78xx series of fixed linear voltage regulator ICs. The voltage source in a circuit may have fluctuations and would not give a fixed voltage output. The voltage regulator IC maintains the output voltage at a constant value. The 7805 provides +5V regulated power supply. Capacitors of suitable values can be connected at input and output pins depending upon the respective voltage levels. The different linear regulators require different minimum input voltages. In this proposed design the 7805 requires a minimum of 7-8V [17].

The voltage after being harvested can either be stored in a storage element such as a capactor then transmitted or direclty transmitted through the energy transmission stage.

C. Energy Transmission Stage

The energy transmission stage is divided into two parts: transmission (primary) and receiving (secondary) coils. The primary and secondary coils are made up of thin copper wires. A transistor (2N2222) is connected as a common emitter. The base is connected to a resistor then to one end of the primary coil, the second end of the primary coil is connected to the collector of the transistor. This arrangement of the primary coil allows forming a loop, which allows the transmission of DC voltage since coils in their nature transmit AC voltages only. The coil assembly can attain its input from a battery to transmit energy but in this work the battery is replaced by the output achieved from the voltage regulator. This configuration is shown in Fig. 2. In the receiving stage, the receiving coil ends are connected to either a Light Emitting Diode (LED) used as an indicator for successful energy transmission or to a storage element such as a capacitor for storing energy. The number of turns in the receiving coil is greater (48 turns) than in the transmission coil (12 turns) to enhance the voltage [18, 19].

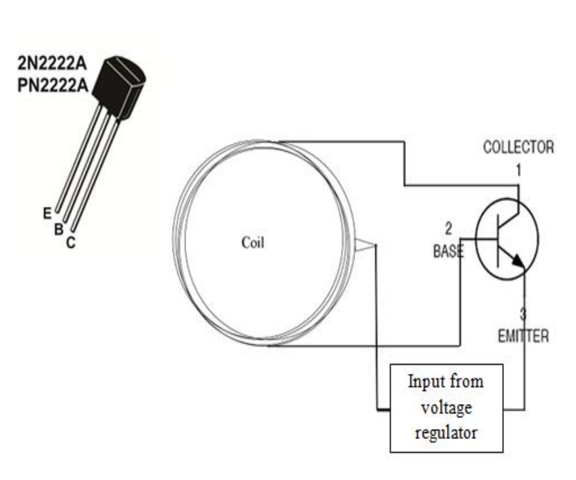

Fig. 2 Transmission Coils Configuration

Fig. 3 shows the overall design of the transmitting (Tx) and receiving (Rx) coils.

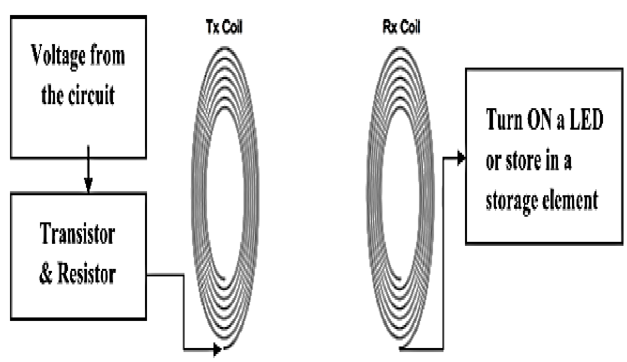

Fig. 3 Transmission and Receiving coils

IV. Results and analysis

A. Results from Energy Generating Stage

The piezo-electric element is placed in the shoe sole. Through the walking mechanism pressure is applied to the piezo-element causing the generation of an AC voltage; the output is obtained when stress is applied as demonstrated in Fig. 4. The electric charge accumulates in the crystals in the piezo-electric element in response to applied mechanical stress. The AC voltage is converted to DC voltage by passing through a rectifying bridge, the resulting voltage is stored in a capacitor as mentioned earlier.

Fig. 4 Demonstration of the pressure applied by the foot on the piezo-element

B. Results from Energy Harvesting Stage

MAX1675 provides a steady output of 5.5v that is fed to the input of the CLC filter. The CLC filter minimizes ripples resulting in an almost pure DC output. The CLC circuit consists of two capacitors and one inductor; the first capacitor should be of a smaller value than the second in order to remove almost all the ripple in the DC signal. In the inductor and the second capacitor known as the LC circuit, more filtration takes place in addition to the storage of the purified DC signal. Noting that having a larger capacitor as an output allows better storage and a lower rate of energy loss (discharge) [16]. Now, the output from the second capacitor of the CLC filter is the input signal of the voltage regulator (7805cv).The configuration of the voltage regulator consists of the linear voltage regulator and two capacitors one on the input and the other on the output. The reason for this configuration is that the capacitor on the input of the voltage regulator is used to reduce the voltage transients on the input and improve the stability of the output achieved. The capacitor on the output of the voltage regulator is used to reduce transient voltage fluctuations on the output side caused by rapid changes in load current. The linear voltage regulator also converts nearly half of the energy in the input as wasted heat energy to allow the regulation of the output, therefore the presence of the capacitors act as a protection for the circuit from over-heating [17].

C. Results from Energy Transmission Stage

The output of the voltage regulator can be used to turn on a LED, charge a battery power bank, or transmit energy wirelessly. The wireless transmission method used in this work is made up of two copper wire coils acting as a transmitting (primary) and receiving (secondary) coils. The diameter of the coils doesn't have an effect on neither the transmitting stage nor the receiving stage rather the number of turns represents the true effectiveness of the transmitting and receiving efficiency as shown in equation (1). The fewer number of turns in the transmitting coil meanwhile a greater number of turns in the receiving coil gives the best result. The reason for the success of this configuration is that the coils act as step-up transformers. Whereas when a different configuration was used to transmit voltage, with an equal number of turns on the transmitting and the receiving coils it wasn't sufficient enough for completing the task, the reason for the failure of this configuration is that the voltage transferred from the transmitting to the receiving coils was in an equal value, no voltage step-up occurred. Successful transmission of the voltage can take place through different types of barriers separating the transmitting and receiving coils such as air, bones, skin and soft tissue even through ceramic barrier transmission is possible.

Faraday's law (Mutual Inductance):

$$\frac{Vp}{Vs} = \frac{Np}{Ns} \quad (1)$$

Vp: Voltage on the transmitting coils (primary)
Vs: Voltage on the receiving coils (secondary)
Np: Number of turns of the transmitting coils
Ns: Number of turns of the receiving coils

The energy is seen in the form of pulses since the voltage regulator gives an output with a minimum voltage of 7 volts input. Therefore, in this paper the main idea for energy generation from the human body is presented and with further investigation and modification the proposed design can be a valid method for wirelessly charging the battery of an implantable medical device. The proto-type of the proposed idea is demonstrated in Fig. 5.

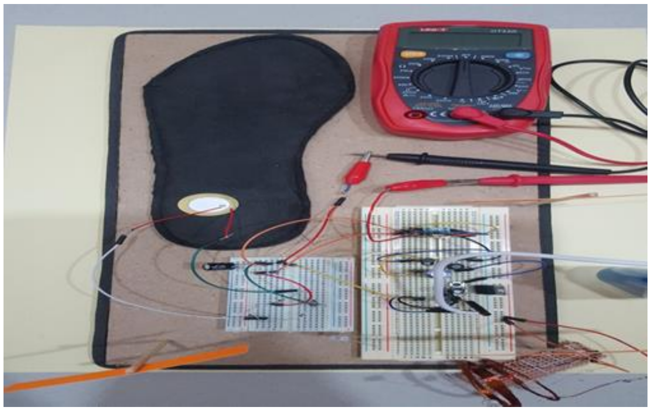

Fig. 5 Proto-type of proposed project

The results shown in Table 1 demonstrate an average of results obtained from the walking mechanisms of more than one person wearing the prototype.

Table 1 Generating/Harvesting versus wear-ability demand

Energy Stored (Volts)	Time Duration (Seconds)	Number of Steps
1v	25s	50
2.5v	55s	137
5v	110s	260
7.5v	210s	370
10v	300s	630

The analysis of results obtained from Table 1, as the energy stored exceeds 50% of the storage capacity of the capacitor, charging takes longer time. The main factor that determines how much energy is needed and how long the implantable medical device needs to get fully charged is the battery type of the implantable medical device [4,5]. The shoe sole is preferred to be more cushioned in the heel section to allow better performance of the piezo-element. For providing continuous charging, duplication of the harvesting stage should be done.

V. Conclusion

According to the achieved results in this paper a conclusion was made that generating energy from the human body is a valid idea. In earlier discussion this paper was summed up into three stages: energy generation, energy harvesting, and wireless energy transmission. The method that is used presents good efficiency, effectiveness, and is economically considered one of the best options for recharging implantable medical devices. The output of the proposed design is achieved in the form of pulses, thus it is not continues unless the harvesting stage is duplicated once or multiple times, where charge and discharge occur in an alternating manner. Finally, the transmission method demonstrated in this work is considered preliminary; the achieved results are promising and need further investigation.

References

[1] Robert J., hunt. "Chest Motion Electricity Generating Device". 1981

[2] Pozzi, Michele and Meiling Zhu. "Characterization Of A Rotary Piezoelectric Energy Harvester Based On Plucking Excitation For Knee-Joint Wearable Applications". Smart Materials and Structures 21.5 (2012): 055004.

[3] Donelan, J. M. et al. "Biomechanical Energy Harvesting: Generating Electricity During Walking With Minimal User Effort". American Association for the Advancement of Science 2008.

[4] Batteryuniversity.com. N.p., 2017

[5] MOND, HARRY G. and GARY FREITAG. "The Cardiac Implantable Electronic Device Power Source: Evolution And Revolution". Pacing and Clinical Electrophysiology 37.12 (2014): 1728-1745.

[6] Camilloni, Enrico et al. "Piezoelectric Energy Harvesting On Running Shoes". (2016)

[7] face, Bradbury. Footwear Incorporating Piezoelectric Energy Harvesting System. 1st ed. 2006.

[8] “Humans: Work, Energy, and Power.” Boundless Physics Boundless, 08 Aug. 2016

[9] Bhatia, Dinesh et al. "Pacemakers Charging Using Body Energy". Journal of Pharmacy And Bioallied Sciences 2.1 (2010): 51

[10] Thangaraju, shyam, Siva S. Sakthivel, and Vishal Chandhary. "Systems And Methods For Generating Electric Charges From Heart To Power Implantable Medical Devices". 2016

[11] Sahara, G. et al. "Implantable Power Generation System Utilizing Muscle Contractions Excited By Electrical Stimulation". Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine 230.6 (2016): 569-578.

[12] Piezo-electric sound component datasheet available online: (https://www.sparkfun.com/datasheets/Sensors/Flex/p37e.pdf)

[13] Kossoff, G. "The Effects Of Backing And Matching On The Performance Of Piezoelectric Ceramic Transducers". IEEE Transactions on Sonics and Ultrasonics 13.1 (1966): 20-30.

[14] The MAX1675 datasheet available online: (http://html.alldatasheet.com/htmlpdf/72896/MAXIM/MAX1675/126/1/MAX1675.html)

[15] Ottman, G., Hofmann, H. and Lesieutre, G. (2003). Optimized piezoelectric energy harvesting circuit using step-down converter in discontinuous conduction mode. *IEEE Transactions on Power Electronics*, 18(2), pp.696-703

[16] "Filter Circuits - Inductor Filter, LC Filter, CLC Or PI Filter, Capacitor Filter". *Daenotes.com*. N.p., 2017. Web. 6 Mar. 2017.

[17] "7805 Voltage Regulator IC | 7805 Datasheet | Pin Diagram & Description - Engineers garage". Engineersgarage.com. N.p., 2017. Web. 6 Mar. 2017.

[18] "Mutual Inductance". Hyperphysics.phy-astr.gsu.edu. N.p., 2017. Web. 6 Mar. 2017.

[19] Campi, Tommaso et al. "EMF Safety And Thermal Aspects In A Pacemaker Equipped With A Wireless Power Transfer System Working At Low Frequency". IEEE Transactions on Microwave Theory and Techniques (2016): 1-8