Research Article

Development of Alternative Energy Harvesting Storage Device for Wearable Electronics

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Abstract: This paper presents the result of generated electrical energy from mechanical energy using an electromagnetic generator. This generated energy is very low. Efforts are made to develop an energy storage device for this generated energy. Capacitor bank and rechargeable batteries are used for store energy. This stored energy is used to recharge the battery of wearable electronic devices for extending battery discharging time. Diode pump and voltage booster circuit are developed to enlarge output voltage. The voltage booster a circuit reaches to the maximum level of 5V at 1.2V input voltage. This generated voltage is stored in the capacitor bank and rechargeable battery.

Keywords: Alternative energy harvesting, booster circuit, diode pump, electromagnetic generator, storage device and wearable electronics.

1. Introduction

The term energy harvesting is popularly used when electricity is generated from sources such as ambient temperature, vibrations, solar energy or movement of the human body like pendulum [1-2]. Since there are now electronic circuits whose power requirement is of the order of mill watts, even though its energy yield is relatively low. The French scientist Abraham-Louis, is invented self-powered electronic devices. It is a completely autonomous, self-powered pedometer watch that gathers power from an individual's arm movements. However, the development of energy harvesting had been somewhat slow until recent research began seeking alternative power sources for wireless sensor networks and portable electronics. The dramatic reduction in power consumption of these circuits makes various forms of energy meant to be harvested. Now a day, there has been enormous growth in the smart electronic device market and its applications. However, typically not much energy is harvested in a small device, so the use of a battery, primary or rechargeable, is beneficial from a practical point of view [3].

Energy harvesting is nothing but energy conversion. Ambient / External energy is converted into electrical energy. Converted energy is used for wearable electronics device and health monitoring sensors. Advantage of energy harvesting is, it converting wasted ambient energy into usable electrical energy. This has been attracted much interest in both the communication and commercial sectors [4]. Energy harvesters provide a very small amount of power for low-energy and miniaturize electronics devices. Another application of energy harvesting devices in wearable electronics is that it can power or recharge cell phones, mobile, radio communication equipment, etc [5]. The different type of energy harvesting depends on the kind of energy resources [6-7].

Energy storage device stored electrical energy in the battery, capacitor, and supercapacitor. Capacitors are used for very low powered electrical devices. The batteries are used to store large power. This power is provided for wearable devices and the smart electronic device. The leakage current of the battery is very less as compared to the capacitor. Therefore battery is providing a constant supply at the output.

The capacitor or supercapacitor is the passive element that accumulating electric charge between two conducting plates. The capacitor is an electronic component used to store electrical energy. The effect of this capacitor is known as capacitance. Materials commonly used for manufacturing dielectric material are ceramic, mica, air, glass, and film. The capacitance of a capacitor is the ratio of positive and negative charge on each conductor plate to the potential difference between them.

Batteries are used for storing the electrical energy generated from generator. This energy is available for shorter time span. Hence battery is used for wearable electronic device which are relatively taking more power. So selection of battery is playing important role in wearable and biomedical devices. Capacity of battery, life of battery, load current of wearable devices, size and leakage current are key factors to run device more and more times. The battery life of device depends on capacity of battery and load of device. The relation between battery utilization time and battery capacity is shown in following formula

$$Battery\ Utilization\ Time\ = \frac{\text{Battery Capacity in mAh}}{\text{Load Current in mA}}$$

Battery life is a pain point right now in the smart wearable electronic device. The wearable device's physical requirement is the device should be small, thin, and lightweight. It's no problem only for those who are wearing wearable devices but it occurs in electronic companies as well. Many companies are updating the software tools and processor instead of battery life improvement. One of the reasons for this is extending the battery life of the electronic device is critical. Even extended battery life has limitation and ultimately need to replace the battery. This is not only increasing the cost of devices but also harmful to the environment. To overcome this problem companies now using a rechargeable battery.

The term wearable electronics is a working small electronic gadget which wears on the body in day to day life. Wearable electronics is a general term for the systems or appliances that contain electronics and that are carried during usages. Wearable technology, on other hand, does not define the type of technology utilized, i.e. electronics are not necessarily needed [8]. A mainly wearable electronic device contains small sensors for sensing data and communicates wirelessly.

Wearable electronics is the well-designed, strong implementation of electronic circuits into a modern electronic device. Wearable electronics is a system that includes electronics circuits, components, and controllers. The wearable electronic system is an emerging trend and is expected to be revolutionary in many application areas like sports and medicine. New technology is needed for eliminating motion artifact and recovering signals corrupted with human body motion. This is a rapidly growing product sector. Large numbers of up-and-coming tech companies are investing heavily in this area, along with networks, device makers, and venture capitalists. As a result, within a decade of year, things will look a lot different than they do today. It isn't uncommon to see a person wearing a heart rate monitor when exercising, a pedometer when dieting, or a watch with ambient temperature sensors.

Wearable electronics is a fairly new field of research and as a result, much of the terminology has still to gain widespread acceptance [9]. The history of wearable electronics goes back to the 1960s when the first wearable computer was designed [10]. So far, a few surveys on wearable electronic systems and energy harvesting have been written and extended. Some of them propose their standards and this is useful for people already working on the problem of wearable electronic systems and energy harvesting.

In the last few years, there has been an enormous growth in the diversity and market penetration of small electronic appliances like wearable electronics gadgets. Wearable electronics and technology are the new technology areas today. Wearable Electronics refers to any electronic device or products which can be worn by a person to integrate computing in his daily activity or work and used technology to avail advanced features & characteristics.

2. Electromagnetic Generator Based Energy Storage Device

Self powered wearable devices are work on energy conservation principle. Mechanical energy converts into suitable range of wearable device using electromagnetic generator and energy storage device.

2.1 Energy Conversion Principle

Energy is available in many forms such as potential, kinetic, electrical and various other forms. Electrical energy is fundamental need of electronic device. Portable electronic device have limitation to store electrical energy in battery. To extend lifespan of electronic device need to convert other source of energy into electrical energy. Energy conservation law plays important role while converting any form of energy into electrical energy. The energy conservation law state that energy can neither be created nor be destroyed; it can only transformed from one form of energy into another form of energy. This means that total energy isolated in system is always constant.

2.2 Source of Energy Harvesting

The sources of ambient energy are solar energy, thermal energy, vibration energy and Radio Frequency (RF). Electrical energy is captured from mechanical to electrical (ME), RF energy to electrical (RFE), thermal energy into electrical energy (TE) or chemical energy into electrical energy (CE) [11]. Sources of energy harvesting are categorized as ambient and man-made [12]. Environmental energy is a part of ambient energy which converts into electrical energy. Sources of man-made energy harvesting or external energy harvesting are mechanical sources or human.

Different energy sources are available for generating electrical energy. This are converting ambient exist energy into electrical energy. This electrical energy is dependent on efficiency and output power. The comparative study helps to predict energy generation. Table 1 shows comparative study energy sources efficiency and maximum generated power.

Table 1. Energy sources and its parameters [13]

Energy Sources	**Parameters**		**References**
	Efficiency	Output Power	
Solar (Outdoor)	6% - 35%	1350mW	14-17
Solar (Indoor)	3%-7%	621mW	18-19
Vibration (Human Motion)	10% - 30%	0.84mW – 4.13mW	20-22
Vibration (Machine Motion)	20%-40%	200mW-400mW	23-27
Wind	7%-20%	0.77mW-439mW	28-30
Thermal (Human)	0.8%-4%	0.5mW-5mW	31-32
Thermal (Industry)	1%-7%	3mW-50mW	
RF-GSM/WiFi	5%-25%	10nW-1mW	33-36

Comparisons of energy sources based on different energy harvesting technique are available and practically possible to convert it into usable energy discussed. Main components are RF, solar, vibration, wind and thermal energy harvesting techniques compared with efficiency and possible power get from that source. The vibration energy from human motion is focused here to provide alternative energy for wearable electronics. Electromagnetic generator is used for that purpose.

2.3 Electromagnetic Energy Generator

Renewable energy harvesting is also known as alternative energy. Basic sources of this energy harvesting system are solar energy, thermal energy, radiation energy and vibration energy. Vibration energy harvesting is basically divided into three types namely: Electromagnetic, Piezoelectric and Electrostatics.

Electrical energy for smart electronic device is harvested from electromagnetic generator. Electromagnetic generator is based on Faraday’s Law. Electromagnetic energy harvesting is a process for generating voltage by changing magnetic field around copper coil. This harvester has high output current at the expense of small voltage. Generator is designed using insulated coils of wire and magnet for producing electrical energy. For body movement electromagnetic generator, the coils are fixed and magnet is moving inside coil. One more electromagnetic generator is used to convert mechanical energy into electrical energy. While movement of shaft of generator, it generate electrical energy. Continuous movement of shaft, it generate maximum spike of voltage and this spike reach to 0.81V.

This voltage is low voltage and it also very difficult to store for long time. For continuously charging wearable device require sufficient amount of current and voltage. Switch operated diode pump circuit is used for increasing current of circuit. Voltage booster circuit is used for increasing output voltage of circuit.

Accumulated of small amount generated energy is used for wearable device [37]. The most important trend in energy harvesting from its beginning is wearable electronics devices. Wearable electronics have many advantages over traditional electronic systems. Every wearable electronics device requires energy. This energy is captured from the battery. Energy requirements and consumption of such devices are depending on the number of devices as well as their mode of operation.

2.4 Switch Operated Diode Pump

The diode pump circuit is used to accumulate small amount of energy generated from electromagnetic generated. The switch is used to control the current pass to electromagnetic generator to diode pump. This switch operated diode pump circuit is also used to increase current and kept constant in desired range. This circuit working is decided by the switch operation. The output voltage of this circuit is dependent on input voltage of circuit and switch position. When switch is open, impendence of circuit is very high. Inductor current (I_L) is discharge through diode and its charge capacitor C. The voltage source and inductor is in series generate higher voltage and charges the capacitor through semiconductor diode. Another way, if switch is closed then current is passes in clockwise direction and stores energy in inductor I_L. As a result current passing through inductor increases. Quick switching cycle helps inductor not to fully discharge and this rate of change of current is directly proportional to voltage across inductor. Effectively the overall voltage of booster circuit is always greater than input voltage applied to circuit. This integrate diode pump to accumulate voltage and then DC-DC converter to create single power supply for wearable device. Figure 1 shows the current in booster circuit and switching state.

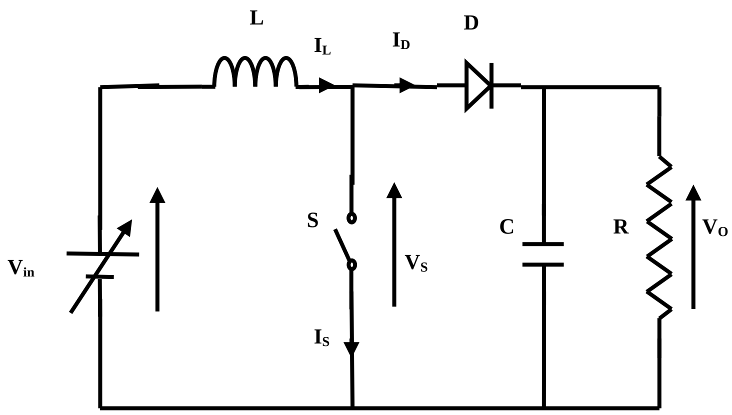

Figure 1. Switching state current booster circuit

Switching boosting circuit is used to boot current. Current is playing driving role in charging circuit. The energy generator is the device which converts the body movement mechanical energy into electrical energy. This harvested signal from energy harvester is regulated using regulator. Large value of capacitor i.e. 1000µF is used for this purpose to store maximum charge. Current response of switch operated diode pump is shown in figure 2.

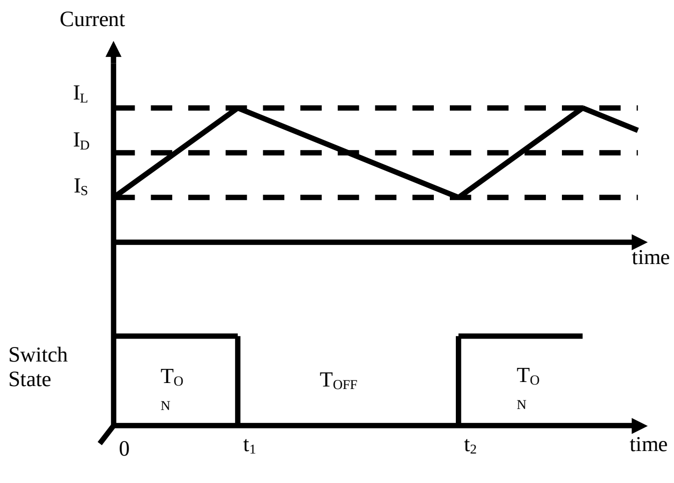

Figure 2. Current response of diode pump circuit

Current response of switch operated diode pump circuit is changed the mode of charging and discharging while changing the state of switch. The graph of current vs switch time indicates that while switch triggered to ON mode then current linearly start to increase till maximum load current. Capacitor is charging while switch is open through diode. Capacitor discharges through load while switch is closed.

3. Voltage Booster Circuit using IC MAX756

Voltage booster circuit is used in this research work because it is important in wearable devices to increase operating time of battery. This IC not only adds voltage but also multiply voltage because of this it is also known as voltage multiplier. To charge wearable health monitoring devices, it is needed to boost generated voltage. DC – DC converter is used for increasing voltage in also known as voltage booster. This booster is placed in between the battery and capacitor bank to store electric charge. The figure 3 shows voltage booster circuit using IC MAX 756.

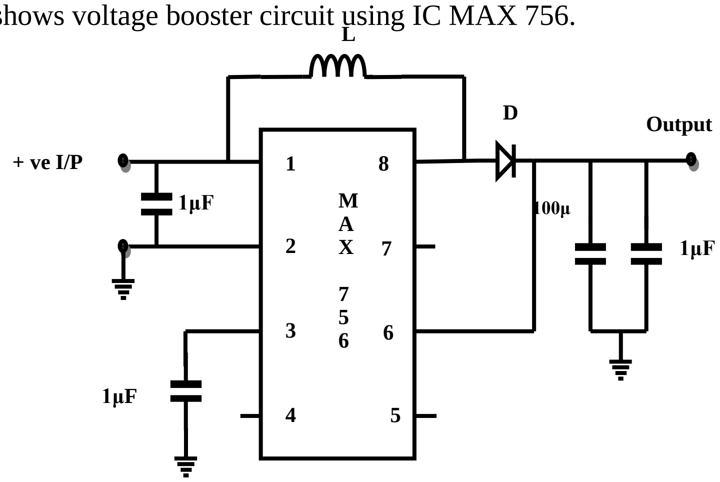

Figure 3. Voltage booster circuit using MAX 756

The diode pump voltage is not sufficient to operate wearable electronic device. The DC booster circuit is enhancing input voltage also known as DC-DC Converter. This circuit is used to charge rechargeable battery from small amount voltage generated from electromagnetic generator. The key component of this circuit is IC MAX756 which accepts input voltage down 0.7V and generates higher voltage upto 5V. This boosted voltage is sufficient to charge small powered wearable device. Negative input is applied to pin 2 which change from ground (0V) to positive and output of circuit is 5V which charge battery. The voltage booster circuit waits till 0.7V or more than that to reach the maximum voltage. The power consumption of this CMOS IC is very low and efficiency is in the range of 87% to 95%. This step up circuit is use in medical instruments, wearable device, personal data communicator and other electronic device. In this circuit positive voltage from 0.1V to 1.2V is applied to voltage booster circuit and the result this is shown in table

Table 2. Response of voltage booster circuit

Input Voltage (V)	Output Voltage (V)
0.1	0.15
0.2	0.25
0.3	0.42
0.4	0.7

0.5	1.2
0.6	1.57
0.7	2.0
0.8	2.5
0.9	3.2
1.0	3.74
1.2	4.98

For charging wearable device needs to increase generate voltage. The booster is a device which converts small voltage into the voltage range which wearable device can charge. Table 2 indicates the response of circuit; input voltage increases after 0.7V and output reaches near to 2V. At 1.2V the device shows maximum voltage which is sufficient to recharge small powered wearable device. The nature of response of booster circuit is shown in figure 6.

3.1 Energy Storage

Energy storage is next step voltage booster circuit which is used to charge wearable device. A battery is commonly used to energize most of these applications, but they have a finite lifetime. As wearable devices tend to be relatively power hungry, a trade-off between battery capacity and size has governed the lifespan, dimensions, and capabilities for battery-powered devices. New technologies such as energy harvesting have the capability to effectively power electronic instruments. Harnessing energy from sources such as motion, sunlight, and temperature changes has been employed respectively on electronic self-winding wristwatches, solar-powered calculators, and thermal powered wristwatches. Therefore, energy harvesting is an alternative to batteries for energizing electronic devices. The energy stored in capacitor is work done by battery. Capacity of capacitor to store the electric charge is known as capacitance of capacitor. This capacitance is dependent upon area of plates and properties of material in the plates. The following figure 4 shows the block diagram of energy hervesting and storage device.

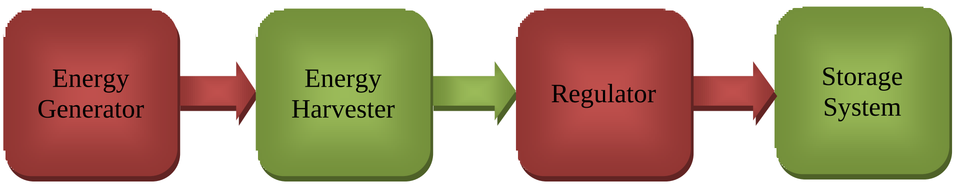

Figure 4. Block Diagram of energy storage

The electric energy generated from different generator is harvest at energy harvester. This energy is converted into dc source using regulator. This storage system is mainly focused on storing the electric charge. Two capacitors are used to store electric charge. The charging current from regulator charge the capacitor until the voltage across the two plates of capacitor is 3.3V. The charging current of capacitor is stopped when capacitor is fully charged. Once the capacitor is fully charged then capacitors maintain steady voltage. The capacitor starts discharging while load voltage is higher than input voltage of device. The capacitor also discharges because of leakage current. In this

experimentation large value capacitors are used to maintain the significant amount of charge.
The energy storage device stored the electrical charge into a capacitor bank which is connected at the output of the harvesting circuit. Capacitor bank is made by connecting the capacitor in series. In this circuit energy packet comes in the form of voltage. The variation in generated voltage also stored in the circuit. Small button cells also used to avoid batteries because it is easy to install in location for chronic diseases. Rechargeable batteries are widely used to generate electrical energy generated from vibration in large quantities to power the wearable device. Batteries are widely used for long duration energy stored. The figure 5 shows the series parallel RC model for storing energy generated from electromagnetic generator.

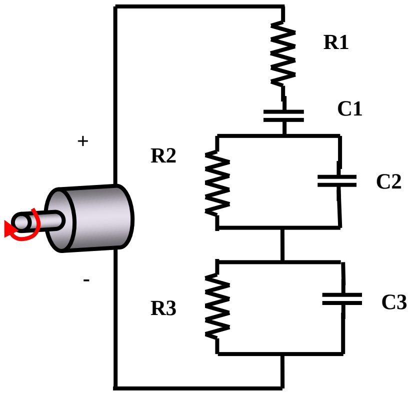

Figure 5. RC model of electromagnetic generator

The resistor capacitor arrangement in series and parallel is used to store generated voltage from generator. It also increases current which is sufficient to trigger a diode.
This RC model has two resistor capacitor parallel pairs and one series resistor capacitor pair. This series parallel combination is used to balance the current and voltage of the circuits. This RC parallel-series have fixed resistor and capacitor value which is used to store the electrical energy generated from electromagnetic generator [38-40]. The values of resistors and capacitors are selected in such a way that the circuit generates maximum energy.

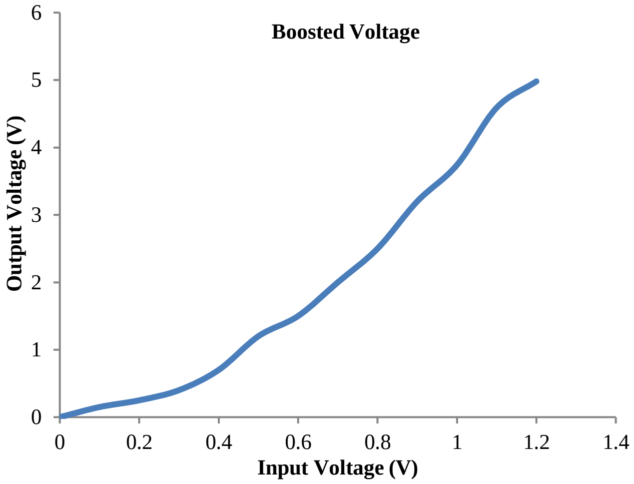

Figure 6. Output voltage of booster circuit

The voltage generated from electromagnetic generator and processed by diode pump circuit is in range of 0V to 1.2V is shown in figure 6. This voltage is increased using voltage booster circuit. This voltage increases while increasing input voltage applied to circuit. The response of this circuit reaches to 4.98V. This voltage is easily charge wearable device. The nature of graph shows that while increasing input voltage output voltage also increases linearly.

4. Conclusion

The electrical energy is harvested using electromagnetic generator. Electromagnetic generator is used to convert vibration or motion into electrical energy. This generated energy is very low. It rectified and then amplified to store in capacitor bank. Diode pump is device used for rectifying voltage and also used to store. The diode pump circuit developed with two capacitors and two rectifier diode. Output voltage generated from electromagnetic generator is provided to diode pump circuit. This voltage is accumulated in capacitor for short time duration. Long time storing electrical charge used battery. The voltage stored in diode pump isn't charging wearable device. For charging wearable device or store charge in battery of wearable device developed voltage booster circuit. This voltage booster circuit is developed using IC MAX756. This circuit is accepts voltage from 0.7V and generate voltage maximum 5V. The voltage drop of this circuit is negligible and efficiency is upto 95%. The voltage booster circuit reaches to maximum level 5V at 1.2V input voltage. This generated voltage is stored in capacitor bank and rechargeable battery. Boosted voltage is work as source of energy for wearable electronic device or health monitoring device.

References

[1] S.Nithiya, K.Sadhuna, A. Saravanan "Energy Harvesting Using Oscillating Pendulum" International Journal for Research and Development in Engineering (IJRDE) ISSN: 2279-0500 Special Issue: pp-017-019

[2] Paul D. Mitcheson, Eric M. Yeatman, G. Kondala Rao, Andrew S. Holmes, Tim C. Green," Energy Harvesting From Human and Machine Motion for Wireless Electronic Devices "Proceedings of the IEEE Vol. 0018-9219/$25.00 _2008 IEEE 96, No. 9, September 2008

[3] Evans Sordiashie,"Electromagnetic Harvesting To Power Energy Management Sensors In The Built Environment "University of Nebraska – Lincoln Digital Commons@University of Nebraska – Lincoln 2012.

[4] L.Ashok Kumar"Teleintimation Garment: A Wearable Electronic Garment For Soldier's Status Monitoring Applications "RMUTP international Conference: Textiles & Fashion 2012 Bangkok Thailand, July 3-4, 2012

[5] Zdenek Hadas, Vojtech Vetiska, Vladislav Singule, Ondrej Andrs, Jiri Kovar and Jan Vetiska,"Energy Harvesting from Mechanical Shocks Using A Sensitive Vibration Energy Harvester" Int J Adv Robotic Sy, Vol. 9, pp.225:2012, 2012

[6] Robert GHERCA, Radu OLARU "Harvesting Vibration Energy By Electromagnetic Induction "Annals of the University of Craiova, Electrical Engineering series, No.35; ISSN 1842- 4805, 2011

[7] S P Beeby, M J Tudor and N M White," Energy harvesting vibration sources for Microsystems applications" Institute of Physics Publishing Measurement Science and Technology Meas. Sci. Technol. 17 PP175–195, 2006

[8] Thomas Martin, Mark Jones, Josh Edmison, Ravi Shenoy, "Towards a design framework for wearable electronic textiles" Bradley Dept. of Electrical and Computer Engineering Virginia Tech Blacksburg, VA 24061

[9] Vladimir Leonov "Energy Harvesting for Self-Powered Wearable Devices "Smart Systems and Energy Technology Imec, Kapeldreef 75, 3001 Leuven, Belgium pp 27-49

[10] Jaana Hannikainen," Electronics Intelligence Development for Wearable Application "Tampereen Teknillinen yliopisto Tampere University of Technology Julkaisu 630 Publication630 Tampere 2006

[11] Jiao, P.; Borchani, W.; Hasni, H.; Lajnef, N. Enhancement of quasi-static strain energy harvesters using non-uniform cross-section post-buckled beams. Smart Mater. Struct. 2017, 26, 085045.

[12] Shaikh, F.K.; Zeadally, S. Energy harvesting in wireless sensor networks: A comprehensive Shaikh, F.K.; Zeadally, S. Energy harvesting in wireless sensor networks: A comprehensive Renew. Sustain. Energy Rev. 2016, 55, 1041–1054.

[13] Shihua Cao and Jianqing Li, "A survey on ambient energy sources and harvesting methods for structural health monitoring applications ",Special Issue Article in Advances in Mechanical Engineering 2017, Vol. 9(4) 1–14, DOI: 10.1177/1687814017696210

[14] Fei F, Zhou S, Mai JD, et al. Development of an indoor airflow energy harvesting system for building environment monitoring. Energies 2014; 7: 2985–2986.

[15] Musiani D, Lin K and Rosing TS. Active sensing platform for wireless structural health monitoring. In: Proceedings of the 6th international symposium on information processing in sensor networks (IPSN'07), Cambridge, MA, 25–27 April 2007, pp.390–398. New York: IEEE.

[16] Tan YK and Panda SK. Energy harvesting from hybrid indoor ambient light and thermal energy sources for enhanced performance of wireless sensor nodes. IEEE TInd Electron 2011; 58: 4424–4435.

[17] Green MA, Emery K, Hishikawa Y, et al. Solar cell efficiency tables (version 36). Prog Photovolt: Res Appl 2010; 18: 346–352.

[18] Vijay Devabhaktuni, Mansoor Alam, Soma Shekara Sreenadh Reddy Depuru, Robert C.Green, Douglas Nims and Craig Near, "Solar energy: Trends and enabling technologies" Renewable and Sustainable Energy Reviews, ELSEVIER, Volume 19, March 2013, Pages 555-564, http://dx.doi.org/10.1016/j.rser.2012.11.024

[19] Davide Brunelli, Clemens Moser, Lothar Thiele and Luca Benini, "Design of A Solar-Harvesting Circuit for Batteryless Embedded Systems", IEEE Transactions On Circuits and Systems—I: Regular Papers, Vol. 56, No. 11, November 2009, Pp 2519-2529

[20] Hendijanizadeh M, Sharkh SM, Elliott SJ, et al. Output power and efficiency of electromagnetic energy harvesting systems with constrained range of motion. Smart Mater Struct 2013; 22: 125009.

[21] Ylli K, Hoffmann D, Willmann A, et al. energy harvesting from human motion: exploiting swing and shock excitations. Smart Mater Struct 2015; 24: 1–3.

[22] Winter DA. Biomechanics and motor control of human movement. 3rd ed. Hoboken, NJ: John Wiley and Sons, 2005.

[23] Discenzo FM, Chung D and Loparo KA. Pump condition monitoring using self-powered wireless sensors. Sound Vib 2006; 40: 12–15.

[24] Wang L and Yuan FG. Vibration energy harvesting by magnetostrictive material. Smart Mater Struct 2008; 17: 045009.

[25] Zucca M and Bottauscio O. Hysteretic modeling of electrical micro-power generators based on Villari effect. IEEE T Magnet 2012; 48: 3092–3095.

[26] Hadas Z, Vetiska V, Vetiska J, et al. Analysis and efficiency measurement of electromagnetic vibration energy harvesting system. Microsyst Technol 2016; 22:1768–1772.

[27] Xie Y, Wang S, Niu S, et al. Grating structured freestanding triboelectric layer nanogenerator for harvesting mechanical energy at 85% total conversion efficiency. Adv Mater 2014; 26: 6599–6607.

[28] Park JW, Jung HJ, Jo H, et al. Feasibility study of wind generator for smart wireless sensor node in cable-stayed bridge. Proc SPIE: Int Soc Opt Eng 2010; 7647: 764747.

[29] Tan YK and Panda SK. Self-autonomous wireless sensor nodes with wind energy harvesting for remote sensing of wind-driven wildfire spread. IEEE Trans Instrum Meas 2011; 60: 1367–1377.

[30] Park JW, Jung HJ, Jo H, et al. Feasibility study of microwind turbines for powering wireless sensors on a ablestayed bridge. Energies 2012; 5: 3450–3464.Tan YK. Energy harvesting autonomous systems: design, analysis, and practical implementation. Boca Raton, FL: CRC Press Taylor & Francis Group, 2013, pp.37–62.

[31] Vladimir L. Thermoelectric energy harvesting of human body heat for wearable sensor. IEEE Sens J 2013; 13: 2284–2287.

[32] Vullers RJM, Schaijk R, Visser HJ, et al. Energy harvesting for autonomous wireless sensor networks. IEEE Solid-State Circuit Mag 2010; 2: 29–38.

[33] Liu V, Parks A, Talla V, et al. Ambient backscatter: wireless communication out of thin air. ACM Sigcomm: Comput Comm Rev 2013; 43: 39–50.

[34] Visser HJ, Reniers ACF and Theeuwes JAC. Ambient RF energy scavenging: GSM and WLAN power density measurements. In: Proceedings of the 38th European microwave conference (EuMC), Amsterdam, 27–31 October 2008, pp.721–724. New York: IEEE.
[35] Bouchouicha D, Latrach M, Dupont F, et al. An experimental evaluation of surrounding RF energy harvesting devices. In: Proceedings of the 2010 European microwave conference (EuMC), Paris, 28–30 September 2010, pp.1381–1384. New York: IEEE.
[36] Kenneth G, Chemishkian S, Hull JJ, et al. Feasibility of wireless sensors using ambient 2.4 GHz RF energy. In:Proceedings of the 2012 IEEE sensors, Taipei, Taiwan,28–31 October 2012, pp.1–4. New York: IEEE
[37] Kiziroglou, M. E., & Yeatman, E. M. (2012). Materials and techniques for energy harvesting. Functional Materials for Sustainable Energy Applications, 541–572. doi:10.1533/9780857096371.4.53
[38] A. Guerrero, E. Romero, F. Barrero, M. I. Milanés, E. González “Power Electronics & Electric Systems (PE&ES), School of Industrial Engineering” (University of Extremadura)
[39] D. McIntosh, P. Mars, "Using a Supercapacitor to Power Wireless Nodes from a Low Power Source such as a 3V Button Battery", Sixth International Conference on Information Technology: New Generations, 2009. ITNG '09. Page(s): 69-78, 27-29 April 2009
[40] Tongzhen Wei, Xinchun Qi, Zhiping Qi, “An Improved Ultracapacitor Equivalent Circuit Model for the Design of Energy Storage Power Systems”, IEEE Conference on Electrical Machines and Systems, Page(s):69 - 73, October 2007