Review and Future Trend of Energy Harvesting Methods for Portable Medical Devices

J. Paulo and P.D. Gaspar

Abstract— **Portability improvement of technological devices have not been followed by energy availability of its batteries. Considering the low power consumption features of a variety of portable devices, the concept of energy harvesting from environmental sources and human body has gained a new relevance. In the search of methods and materials that suit this need, are the energy generated from the piezoelectricity, thermoelectricity and electromagnetism, among others.**

This paper reviews the advantages, disadvantages and future trend of energy harvesting methods, as well as its mechanisms in portable medical devices with low power consumption. The medical field is a promising sector for the use of these technologies by the need to extend the energy availability for several parameter monitoring as too allow various forms of continuous therapy.

Therefore, coupling a energy harvesting system to existing battery in these devices may significantly improve their energy sustainability that at present, is one of its biggest limitations.

Index Terms—**Energy harvesting, portable medical devices, sustainability.**

I. Introduction

Since ancient times the demand for new energy sources and forms of energy use are a constant. Even more nowadays, with the need to reduce global dependency on energy sources based on fossil fuels and the awareness of their harmful effects on the environment. In this context, appears the energy harvesting concept. From a broader perspective, systems for energy harvesting may be based on several sources, including kinetic energy (wind, waves, gravity, vibration), electromagnetic energy (photovoltaic, radio-frequency), thermal energy (solar-thermal, geothermal gradients of temperature, combustion), atomic energy (nuclear, radioactive decay) or biological energy (biofuels, biomass) [1].

Currently, all portable electronic devices are powered only by batteries. However, the energy harvesting from human or environmental sources has proved to be an effective alternative or complement. As the electronics' scale decreases, so does the energy consumption. In this sense, it is should expect that batteries were also produced in smaller size providing more energy storage availability. However, due to technical and technological issues, the batteries have not been following by the same evolution trend, limiting the operational time and performance of portable devices as it need to be replaced or recharged periodically, adding also unwanted weight and volume. The increase in computer performance for portable equipment since 1990 is shown in Fig. 1. As shown, the battery technology had the slowest evolution in the context of portable devices [2].

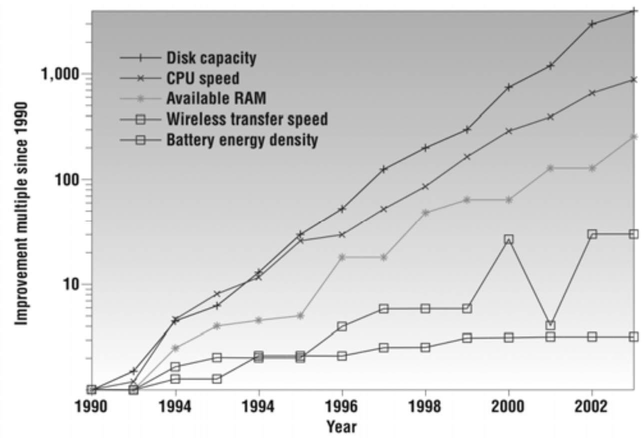

Fig. 1 - Electronic evolution since 1990 [2].

To solve these problems, there are several alternatives batteries on the market that replace or complement the current ones, such as on radios, flashlights and phones that through rotation can be manually loaded. These mechanisms are not fully sustainable for all applications, because it require low energy inputs and active participation of the user.

The energy concept has fundamental importance in physics of the human body. All activities, including thinking, involve energy exchanges. Energy conversion in work represents only a small fraction of the total energy spent by the body. According to [3], even at rest, the body continues to expend approximately 100 W to maintain internal organs, tissues and cells functioning. About 25% of this energy is used by the skeleton and heart, 19% by the brain, 10% by the kidneys and 27% by the liver and spleen.

The human body during various activities produces power ranging between 81 (sleep) and 1630 W (sprint walk). The human body is a system able to maintain its temperature even when the temperature of the environment varies. This allows the maintenance of metabolic processes of energy production even in cold climates.

The proportion of heat dissipated by different procedures

Manuscript received March 18, 2010.

P. D. Gaspar is with the Electromechanical Engineering Department, University of Beira Interior, Rua Fonte do Lameiro – Edifício 1 das Engenharias, 6201-001 Covilhã, Portugal (corresponding author to provide phone: +351 275 329 925; fax: +351 275 329 972; e-mail: dinis@ubi.pt).

J. Paulo is with the Electromechanical Engineering Department, University of Beira Interior, Rua Fonte do Lameiro – Edifício 1 das Engenharias, 6201-001 Covilhã, Portugal. (e-mail: joana.mrpaulo@gmail.com).

from sleeping to a sprinting run depend on several factors such as temperature, humidity, air velocity, environment, physical activity, body, body area exposed and its thermal insulation, such as clothing and fats [3-4].

Research on this topic has examined various techniques of passive energy harvesting for portable devices like thermocouples to collect energy through thermal gradient of the body, mechanical vibration and also the implementation of piezoelectric materials in the body subject to mechanical deformation/vibration [5].

II. Harvesting Methods

A. Piezoelectricity

Brothers Pierre and Jacques Curie discovered the piezoelectric effect in quartz crystals in 1880. In general, can be defined as the conversion of mechanical energy into electrical energy (direct effect) or conversion of electrical energy into mechanical energy (inverse effect) [6]. The direct piezoelectric effect provides that an electrical charge is generated when it subjected to a mechanical energy, whether delivered from compression, traction or just vibration. In turn, the inverse piezoelectric effect is the ability of the piezoelectric material to produce mechanical energy when subjected to an electrical charge in opposite sides [6].

B. Thermal Energy

The body temperature changes when it receives or provides energy. In this situation, the molecules are in constant motion, and this agitation is measured by temperature.

Only by temperature difference can energy extraction from a thermal reservoir (e.g. body) be guaranteed. The possibility of conversion between heat and work has been restricted to thermal machines. The Second Principle of Thermodynamics, developed by Sadi Carnot in 1824, is stated as follows [3]: *"To be continuous conversion of heat into work, a system must perform cycles between hot and cold sources continuously. In each cycle, is extracted a certain amount of heat from the hot source (useful energy), which is partially converted into work, being the remainder rejected to the cold source (energy dissipated)"*.

Carnot's equation, based on the 1st and 2nd law of thermodynamics, is a reference mathematical expression for the conversion of thermal energy into work. Its theoretical maximum efficiency in a steam engine is related to the thermal reservoirs kept at hot, T_h, and cold, T_c, temperatures [7]. The thermoelectric conversion works by absorbing and releasing heat in the connection interface between different electrical conductors (thermocouples or thermojunctions). A thermocouple is defined as a transducer composed by two metals or alloys, electrically joined at its ends, resulting in two junctions. When these joints are subjected to different temperatures, the thermocouple circuit has an electrical current. One of these joints is called the measurement junction and is subjected to temperature to be measured, while the other junction, reference junction, is applied to a known temperature, usually the temperature of a ice bath [6]. The electromotive force, which generates electric current, is generated by the difference between the joints temperatures. To measure this thermal electromotive force, the thermocouple circuit is opened at some point, where a voltmeter is introduced.

After the discovery of Thermoelectricity by Alexandre Volta (1800), other studies have been developed on the effects of thermal electricity generation, which stand to Thomas Seebeck (1821), Jean Peltier (1834) and William Thomson – Lord Kelvin (1848-1854). These scientists have led to names of the three basic effects of thermoelectricity thermometry, which although different, are related among them. These effects are known as thermoelectric effects, getting these names because involve either temperature or electricity.

The Seebeck effect transforms thermal energy into electricity, while the Peltier effect is related with the absorption or emission of heat in presence of an electric current in the junctions. However, both effects act in different materials. Finally, the Thomson effect presents similarities to the Peltier effect as electrical current produces a different heating effect, according to the direction of hot/cold source, but in the same material [6].

C. Electromagnetic

An electric field always produces a magnetic field and, conversely, a time variable magnetic field always produces an electric field. The induction law of Faraday describes the modification that a magnetic field will induce in an electric current. In turn, the equation of Ampere-Maxwell states the modification generated by an electric field into a magnetic field.

There are already several types of electrical generators that use mechanical vibrations, including those who are present in watch and radio frequency circuits. These are able to use the energy recovered from the natural environment. There are two types of mechanical generators: those who use the relative motion of objects in which the generation system is connected and those that use rigid body motion. Its basic settings are shown in Fig. 2.

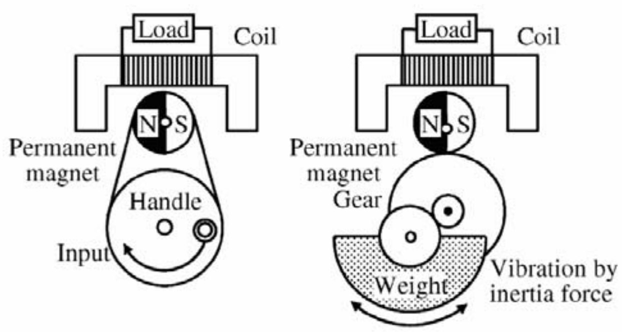

Fig. 2 - Types of mechanical generators: a) relative movement, b) rigid body [8].

Both systems use the electromagnetic induction principle to convert movement into electric power. The relative motion of the armature corresponding to the permanent magnet is

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

given by the object relative motion in which the generating system is fixed. In the case of rigid body motion, the inertia force of the weight is installed on the generator. These relative movement systems are employed on bicycles' generators, radios and mobile phones. When the handle is moved 10 cm (diameter) by a force of 10 N at a rate of 3 rev/sec is produced 9.3 W (neglecting losses), 10 times higher than the power produced by the rigid body [8].

The rigid body motion type is more susceptible to vibratory movements than to constant movements, since it uses inertia, i.e. the resistance to movement. The power available for each vibration cycle is just the kinetic energy that remains in the system. Assuming that the equipment is attached to the body of a person and considering that the weight movement is equivalent to the human body motion, the kinetic energy is about 10 μJ and the electric power generated is about 10 μW, which are lower values than those produced by relative motion. Thus, this generator can operate unconsciously and can be installed anywhere, obtaining a considerable amount of energy. There are some effective methods for this mechanism, as resonance generators, self-excitation generators and rotational generators as gyroscopes.

III. Industrial Applications

In the 80's, *Seiko* developed a kinetic watch powered by human movement. It dispensed the conventional batteries, being the human arm movement used instead. Since then, several kinetic watches were developed, but the potential of this system to power larger devices is limited by the slowness how people move and consequently reduced arm movement.

According to [2], the American and British armies have tried to power up sensors placed in soldiers' boots. These devices allow radiotelephone operation, which is often equipped with heavy batteries. However, the energy harvesting devices were not sufficiently robust to withstand extreme conditions [4]. In the early 90's, *Freeplay* marketed devices such as radios, lamps and lanterns with handles to provide increased capacity of energy availability through the incorporation of this type of energy harvesting systems. Since then it has developed generators with cranks to charge mobile phones, foot pumps capable of powering larger appliances and a series of prototypes of medical equipment with handles.

The introduction of piezoelectric materials, as Polyvinylidene fluoride (PVDF), in shoes in order to recover some power from walking offers several advantages. Note that a piezoelectric plate is only 1.1 mm thick (without electrodes), having a reduced weight and high duration, thus promoting the flection needed for power generation by the natural deformation of the shoe during walking [9]. In order to regain power by the force exerted on the heel and toes, [10] integrated piezoelements in the shoe's removable sole. Fig. 3 shows this type of material and how it is designed to be placed in a shoe. Due to the limited efficiency of the electromechanical conversion, the average power produced is respectively 8.3 mW on heel and 1.3 mW on toes during a walk.

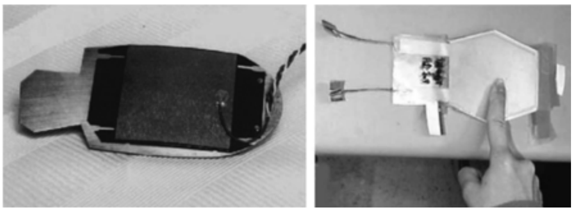

Fig. 3 - Piezoelectric application [10].

In order to improve these results, [11] applied an elastomer generator in the heel of a boot, as shown in Fig. 4.

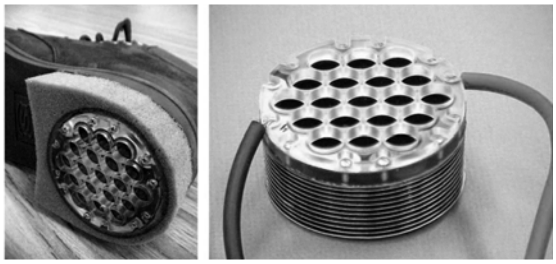

Fig. 4 - Electrostatic generator based in the compression of a dielectric elastomer [11].

When the heel is pressed against the ground, the pad compresses the implemented elastomeric membrane producing a voltage. When a voltage is applied across the electrodes, it produces energy. Another application that uses the walk movement to generate energy considers the insertion of the piezoelectric materials in the floor. In this case, the floor beneath our feet acquires, accumulates and converts into electricity the energy generated by the passage of people, rather than applying it to the shoe [6].

According to studies conducted by [12], each step produces 8 W. This power is absorbed by the floor, being possible to capture at least 30% of that energy. In this context, it is possible to imagine a dance floor where the floor is designed to reduce vibration and disperse energy, capturing it and generating electricity, as it is equipped with energy scavengers under the surface.

Considering the natural walk movement, [14] tried to implement magnetic generators in shoes, as shown in Fig. 5. This prototype is implemented in a shoe only with a spring, a pendulum and a generator system that produces a peak power near 1 W, i.e. enough energy to power a radio during a walk. However, these generators are difficult to integrate in shoe, without causing discomfort to the user, since the mechanical system has proved quite intrusive.

Fig. 5 - Rotating generator adapted in a shoe [14].

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Thus, [15] developed a model to improve the integration of the generator in the shoe's sole, as shown in Fig. 6. As the rotating generators need to turn quickly to achieve the desired efficiency, all other systems that involve significant gear relationships, make a considerable mechanical complexity and a reasonably high torque, leading to a high probability of collapse.

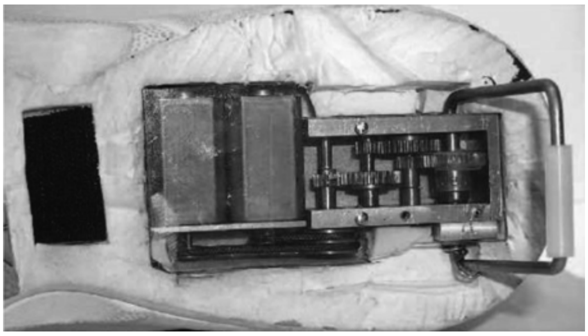

Fig. 6 – Improvement of the rotational generator, with two magnetic generators built in the shoe's sole [15].

Since the electromagnetic systems can be made of a coil and a permanent magnet attached to a spring, this mechanical movement caused by structural vibration, induces a voltage at the coil's terminal that converts it into an electric charge. The magnetic field in the coil will be easily induced if the magnet is large. However, the size and layout of the magnet is limited by the spring and the structure of the device itself.

IV. Medical Applications

According [16], persons with pacemakers powered by lithium batteries require surgery each 8 years for battery replacement. Likewise, implantable neurostimulator and infusion pumps demand more energy than pacemakers, having an estimated lifespan from 3 to 5 years [17]. Thus, it is important to reduce the dependence of batteries in this field, since it will boost several benefits for the user. Regarding this, and based on the methods already mentioned, [18] created an electrical nanogenerator that will be use in the manufacture of medical implants and sensors.

The nanogenerator is capable to convert the mechanical energy of human body motion into electricity through muscles lengthening and even through blood flow.

The nanogenerator is built with nanowires of zinc oxide - a material that is piezoelectric and semiconductor. The electricity is generated when the nanowires are bent and return to its original position, a movement of "come and go". The result is a charge separation in the nanowire - positive charge on the folded side and a negative charge on the compressed side - caused by the piezoelectric effect. Even as a ceramic material, the zinc oxide nanowire can be bent to 50° without breaking. Zinc oxide is not toxic, unlike batteries components, making it ideal for use inside the human body. According to [18], the veins beat can be used to generate power and supply medical nanodevices and sensors designed to monitor vital signs such as heartbeat and blood pressure.

Another application in medicine is the wireless sensors use for various applications requiring self-sustained power sources. Thus, thermoelectric devices are very attractive as an energy source because it directly convert temperature gradients in power supply. While some thermoelectric generators are available in the market sometime ago, the development of low power medical implants has only recently been initiated. Two cases of interest to biomedical devices are considered: those implanted at the skin surface and the subcutaneous ones [19]. A practical use of these energy sources requires proximity to the mechanical target. [19] performed some experimental studies in order to evaluate the feasibility of thermoelectric generators to power medical devices and found that were available temperature difference ranging from 1 to 5 K in the fat body. In an *in vivo* experimental test was implemented a common thermoelectric device into the rabbit's abdomen being measured 1.3 K at rest. With these results, the feasibility of using thermoelectric generators to power medical implants is quite enlightening. However, it is necessary to increase the research of more advanced biological heat transfer models along with experimental tests of the body temperature variations. As mentioned previously, physiological characteristics such as height, weight, body fat percentage and skin tone are other characteristics that may affect the thermal gradient in the subcutaneous layers of the body.

Trying to engage thermoelectric generators with biomedical applications requires taking into account the biocompatibility of the materials. The biggest concern about this issue is the toxicity of bismuth telluride used as thermoelectric material. Although the bismuth telluride has a relatively low toxicity, its components are known to cause kidney damage. Thus, in large quantities, can be fatal [20].

However, when this method is applied properly within the human body, the temperature difference between the inner surface of the skin and the core body temperature can be used, for example, to produce electricity and increase the battery life of a pacemaker [22], as shown in Fig. 7.

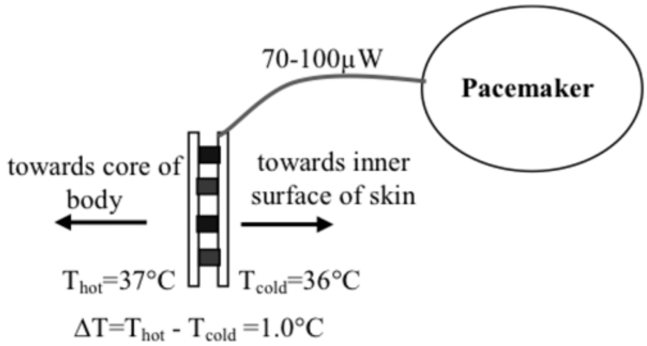

Fig. 7 - Thermoelectric device supporting a pacemaker [22].

With a thermoelectric thin film is possible to generate more than 100 μW of power, with only a small temperature difference of 0.3 to 1.7 º C [21]. Pacemakers are low energy consumption devices, not requiring a continuous battery loading as a totally artificial heart. However, as already stated, the battery has a limited operation time. Thus, it was proposed an electromagnetic method to charge the battery through a low frequency rotating magnetic field [22]. This

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

system consists of a micro-generator with gear, a magnet and two-phase excitation of a coil, which is installed outside the human body, as shown in Fig. 8.

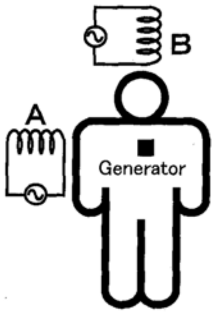

Fig. 8 - Magnetic field in the human body [22].

When exciting the coils, a rotating magnetic field is applied to the magnet that is implanted in the body, triggering the micro-generator. The rotation speed of the micro-generator is about 100 times higher than the rotation speed of the magnet, since the gear system is installed between them, thus obtaining a high voltage used to charge the battery of the pacemaker. [22] developed an energy converter based on micro-electromagnetic that is able to store energy in an AA battery. The converter is capable of charging a capacitor with 1.6 V DC in less than 1 min. This device was used to support a wireless system in a temperature sensor.

V. Future

Since it is possible to capture energy from various parts of the human body such as walking, cycling, arm movements, finger pressure, respiration and blood pressure, one of the future associated applications will be the development of a human battery that extracts electricity from glucose of the blood, capable of generating up to 100 W [23]. The human battery is based on an enzyme with the ability to extract electrons from glucose, i.e., feeds on sugar. Once the monitoring devices of Type I diabetes are in constant contact with blood to control the glucose levels, this interaction can be used to generate energy to sustain the device. As the device to monitor and assists therapy is portable, a battery is needed for its operation. Thus, this bio-nanobattery could be implemented at the infusion therapy pump. All implantable medical devices (IMD), including pacemakers, defibrillators, infusion pumps, and neuro-stimulators require electric power. The non-rechargeable batteries are used as source of energy for these devices. One of the IMD limitations is the energy life span of the power source. When the battery is unable to sustain the device, the IMD must be removed and/or the battery or the device must be replaced often risking the health and well being of the patient. Still, the battery life depends on the power required by the IMD and the amount of energy stored in it [24]. So, after analyzing the technical characteristics of some portable medical devices, it were found some equipments that can attach human body energy harvesting system due to their low power consumption. These typical values are shown in Table I.

Table I - Energy consumption of some medical devices.

Equipment	Power (W)
Insulin infusion pumps	12
Arterial pressure monitor	3
Blood coagulation monitor	0.5
Pacemaker	5.6
Glucose level monitor	0.5

After a survey of portable medical devices and how them work, it was possible to foresee some applications of energy harvesting for them.

Insulin infusion pumps may also be charged by temperature difference, since these devices need a subcutaneous needle. Thus, they are in constant contact with blood, as well as with the core body temperature. Using the thermoelectric method, it is likely that the temperature difference between tissues can at least load the battery of the glucose monitor in order to increase its operational life.

The sudden death syndrome in newborns and infants is a major concern for child health, appearing suddenly when they are asleep. It is impossible to predict as it has not prior symptoms. The existing devices monitor breath and movement of the baby. A beep signal is activated when the baby stands still in bed for a certain time.

Thus, other way to monitor this condition can make use of a piezoelectric strap around the chest of the newborn. A mechanical deformation is obtained with the thorax volume change caused by inhalation and exhalation, producing energy and being able to charge the batteries of the monitoring system.

Making use of the method, it is also feasible to use braces with piezoelectric properties in pregnant women that in advanced gestation period need to control the movements and heart beat of the baby.

Currently there are several ways to measure blood pressure, one being the use of a pulse device, such as watches. Thus, by the same method of micro-inertial systems, it is possible to produce energy for this device as to clocks. Since this device is worn on the wrist, is subject to movements throughout the day. Thus, people suffering from hypertension or hypotension may constantly check the blood pressure levels without needing to change the battery with a regularity so pronounced.

One method that is most used at industrial level is the piezoelectric, since the mechanical deformation of the material is not easy to achieve. With the introduction of this type of material in the shoe, as mentioned, satisfactory amount of energy can generate. Thus, besides being able to apply this energy in MP3 players and mobile phones will be also possible to use, not only for IMD, but for any kind of portable device.

The walk is also effective in other methods, such as in the electromagnetic method. The application of a permanent magnet in a shoe can be viable since walking provides a shift in the magnet coil causing a magnetic field that generates energy.

In medicine, these methods of energy harvesting could be quite profitable in the control of athletes' physical tests. As athletes are in constant motion, they can produce, for example, deformation of piezoelectric materials or magnetic stirring in the magnet. However, both energy harvesting mechanisms would have to be installed in sneakers or arms. The challenge here is, once again, to apply these devices without causing significant weight changes in the athlete, so as not to induce erroneous results.

Another form of energy use in athletes is the temperature difference that arises during exercise.

The disadvantages that arise on the application of some energy harvesting devices, is that can be very expensive and non-profitable for portable medical devices.

For example, although it is possible to implement a system to harvest energy in a relatively inexpensive glucose monitor that does not need to be constantly connected is not justified by now since it will be quite expensive.

In turn, the insulin pump for monitoring Type I diabetes is an expensive instrument (more than €2000) and in some cases showing an average lifetime of only 2 years [25]. In this particular case, applying a system to capture energy and extend the average battery life may be a benefit.

Thus, it is necessary to take into account the type of device to which the energy harvesting device is applied. This can only benefit financially if placed on devices that are constantly connected and subject to body movement to use its energy.

A. Conclusion

This paper discusses several methods of energy harvesting from the environment and the human body with greater relevance to low power devices, particularly portable devices, and primarily for medical applications in terms of monitoring physiological signals and for assisted therapy. With this aim, the main characteristics of physical-mathematical methods of harvesting energy by piezoelectricity, by thermoelectricity and by electromagnetism are presented. The applications of piezoelectric systems, thermoelectric and electromagnetic energy harvesting systems are divided in the industrial/domestic and medical applications. A future trend on the applications of energy harvesting methods in portable medical devices is performed.

It is highlighted the dependence of portable devices from batteries. The increased weight and the reduced energy storage capability turn in a shorter period for continuous use of the devices. Given the growing availability of technological solutions, methods must be found through environmental and human resources to meet the users' needs both in industrial and medical fields. The need to extend the availability of various energy devices is vital. However, the portable and low power medical devices field, either to monitor various vital parameters or to perform a particular therapy represents a promising sector for the use of these technologies.

References

[1] Chapman, P. and Raju, M., "Designing power systems to meet energy harvesting needs", *TechOnline India* 8(42), 2008.

[2] Paradiso, A., Energy Scavenging for Mobile and Wireless Electronics. Massachusetts Institute of Technology Media Laboratory Thad Starner, Georgia Institute of Technology, GVU Center, 2008.

[3] Okuno, E., Caldas, I. and Chow, C., "Conservação de Energia". In Física para ciências biológicas e biomédicas, vol II, pp. 103-105. Lisboa: HARBRA, 1986.

[4] Morton, D., Human Locomotion and Body Form. The Williams & Wilkins Co., Science Education vol. 36, n.º 312, 1952.

[5] Amirtharajah, R., Collier, J., Siebert, J., Zhou, B. and Chandrakasan, A., DSPs for Energy Harvesting Sensors: Applications and Architectures; Intel & Massachusetts Institute of Technology, IEEE 1536, pp. 72-74, 2005.

[6] Casimiro, F., Gaspar, P.D. and Gonçalves, L.C.C., "Aplicação do princípio piezoeléctrico no desenvolvimento de pavimentos para aproveitamento energético", In III Conferência Nacional em Mecânica de Fluidos, Termodinâmica e Energia: MEFTE - 2009, Bragança, Setembro, 2009.

[7] Monteiro, M.S., Avaliação metrológica da estabilidade termoeléctrica de termopar AuPt. Tese de Mestrado, Pontifícia Universidade Católica do Rio de Janeiro. pp. 32-36, 2002.

[8] Hosaka, H., "Personal electric power generation technology for portable information equipamention", Micro Mechatronics - Journal of the Horological Institute of Japan vol. 47, n.º 3, pp. 38-46, 2003.

[9] Kagetsu, Y., Osaki, Y., Hosaka, H., Sasaki, K. and Itao, K., "Research on automatic power generator using self-exciting rotation", Micro Mechatronics - Journal of the Horological Institute of Japan, vol. 48, n.º 4, pp. 22-33, 2004.

[10] Paradiso, J. and Shenck N., "Energy Scavenging with Shoe-Mounted Piezo-Electrics", IEEE Micro, vol. 21, n.º 3, pp. 30–42, 2001.

[11] Kornbluh, R., "Electroelastomers: Applications of Dielectric Elastomer Transducers for Actuation, Generation, and Smart Structures", In Proc. SPIE 4698, pp. 254–270, 2002

[12] http://www.sustainabledanceclub.com/, 11/02/2009.

[13] Vining, C., "Semiconductors are cool", Nature, vol. 413, pp. 577-578, 2001.

[14] Paradiso, J., Kymissis, J., Kendall, C. and Gershenfeld, N., "Parasitic power harvesting in shoes", In IEEE Intl. Symp. On Wearable computers, vol. 24, pp. 132-139, 1998.

[15] Hayshida, J., Unobtrusive integration of magnetic generator systems into common footwear. MIT Department of mechanical engineering, pp. 98-104, 2000.

[16] Parsonnett, V., Cheema, A., "The nature and frequency of postimplant surgical interventions: A realistic Appraisal", Pace vol. 26, pp. 2308-2312, 2003.

[17] Lanmuller, H., Sauermann, S., Unger, E., Schnetz, G., Mayr, W., Bijak, M. and Girsch, W., "Multifunctional implantable nerve stimulator for cardiac assistance by skeletal muscle", Artificial Organs vol. 23, pp. 352, 1999.

[18] Yang, R. Qin, Y., Li, C., Zhu, G. and Wang, Z., "Converting Biomechanical Energy into Electricity by a Muscle-Movement Driven Nanogenerator", NanoLett, vol. 9, n.º 3, pp. 1201-1205, 2009.

[19] Yang, Y., "Suitability of a thermoelectric power generator for implantable medical electronic devices", Physics, vol 40, pp. 5790-5800, 2007.

[20] Rom, N. Environmental and Occupational Medicine. Philadelphia, Pennsylvania: WoltersKluwer/Lippincott Williams & Wilkins, 2006.

[21] Rowe, D. Handbook of Thermoelectric, CRC, 1995.

[22] Suzuki, S., Katane, T., Saotome, H., and Saito, O., "A Proposal of Electric Power Generating System for Implanted Medical Devices", IEEE transactions on magnetic, vol. 35, n.º 5, pp. 21-23, 1999.

[23] Yuen, S., Lee, J., Lee, M., Chan, G., Lei, F., Leong, P., Li, W. and Yeung, Y., "AA size Micro power Conversion Cell for wireless applications", Proc. of the world congress intelligent control and automation (WCICA), vol. 6, pp. 5629-5634, 2004.

[24] http://www.inovacaotecnologica.com.br/noticias/noticia.php?artigo=010115030819Abril, 09.

[25] Wahlstrand, C., "Kind Code. Headset recharger for cranially implantable medical devices". U.S. Pat. Aplication20050004619, 2005.

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)