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Human Power Harvesting

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***Abstract*— Since ancient times the demand for new energy sources and forms of energy use are 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. Energy Harvesting is the process of extracting small amount of energy from ambient environment. Reduction in size and shape of the electronic components make the power requirements down to the scale of mW. Due to this fact, Energy harvesting techniques and their applications gain much more attraction. Many techniques are being developed to gain energy from various available sources viz. wind, vibration, solar, biological, chemical etc. Out of these, human energies are being the point of interest for many years. This paper presents you the amount of energy produced by general movement of our body e.g. arm movement or heavy breathing by mathematical or calculative way. This paper reviews the advantages and future trend of energy harvesting methods and also acknowledges on-going project and research.**

I. INTRODUCTION

Since ancient times the demand for new energy sources and forms of energy use are a constant. Energy sources have been known to mankind from a long time in the form of thermal, light, mechanical and wind. 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. The harnessing and collection of this ambient energy into a useful form is called Energy Harvesting. Indeed, by relying on energy scavenged from the environment and human, such electronics are no longer restricted by the periodic maintenance that batteries demand. In particular, energy harvested parasitically from human movements has garnered much discussion. Reduction in size and shape of the electronic components make the power requirements down to the scale of mW. Due to this fact, Energy harvesting techniques and their applications also gain much more attraction.

II. HUMAN ENERGY HARVESTING DEVICES

A. *Piezoelectric Energy Scavenging Shoes*

The piezoelectric affect- a material's capacity to convert mechanical energy into electrical energy and the inverse- are observable in a wide array of crystalline substances that have asymmetric unit cells. When an external force mechanically strains a piezoelectric element, these polarized unit cells shift and align in a regular pattern in the crystal lattice. The discrete dipole effects accumulate, developing an electrostatic potential between opposing faces of the element. Relationships between the force applied and the subsequent response of a piezoelectric element depend on three factors: the structure's dimensions and geometry, the material's piezoelectric properties, and the mechanical or electrical excitation vector.

We explored two main methods, of piezoelectrically scavenging shoe power in bending. One method is to harness the energy dissipated in bending the ball of the foot, using a flexible, multilaminar polyvinylidene fluoride (PVDF) bimorph stave mounted under the insole. The second method is to harness foot strike energy by flattening curved, prestressed spring metal strips laminated with a semiflexible form of piezoelectric lead zirconate titanate (PZT) under the heel. This device, which we call a dimorph, consists of two back to back, single-sided unimorphs.

After improving the shoe-generator designs, we must integrate them with useful body-worn systems. The RFID transmitter is one example of a simple and practical application of scavenged shoe power. However, at such low power levels, embedded batteries might be a viable (but environmentally unfriendly) alternative, depending on the frequency of use and product lifetime. Other possibilities include a personal positioning system for military or police units, personal navigator or smart pedometer, a data collection tool for monitoring an athlete's movements, and a child-tracking device. There are countless other potential applications.

As the power yield increases and wearable electronics become more efficient, foot-powered energy-harvesting systems can drive more components of wearable computers, eliminating the need for batteries or enabling them to be charged "on the hoof." These systems would open a host of applications in situations where power grid access is often unavailable, such as extended hiking expeditions or military missions.

B. *Flexible Integrated Energy Device (FIED) - Wearable Rechargers*

The FIED has been designed to be integrated into a soldier's clothing and / or equipment. It is comprised of three components; a battery, a vibration energy harvesting system and advanced, conductive fabric.

The battery is used to store and provide energy over a continuous period of time and can be charged by plugging into an electrical power point or through vibration energy harvesting. As the wearer of the garment moves, the vibrations created can be harvested and channelled into recharging the battery or powering a plug-in electronic device.

The key to the effective integration of these two components is the advanced fabric with embedded electronic functionality. The fabric provides a conductive material for the flexible battery and contributes to its mechanical strength and stability by allowing the system to flex and fold. The fabric is engineered to produce a garment that is comfortable, light weight and durable. The only visible feature that will distinguish this piece of clothing from any other is a number of small outlets in which to plug electronic devices.

The FIED is designed to improve the energy options available to field soldiers. The technology has synergies with a range of applications including small electronic devices such as MP3 players, communication devices including mobile phones and radios, medical devices such as vital sign monitoring systems and sportswear.

C. Pacemakers charging using body energy

Life-saving medical implants like pacemakers face a big drawback that their batteries eventually run out and patients require frequent surgery to have these batteries replaced. With the advent of technology, alternatives can be provided for such surgeries. To power these devices, body energy harvesting techniques may be employed. Some of the power sources are patient's heartbeat, blood flow inside the vessels, movement of the body parts, and the body temperature (heat). Different types of sensors are employed, such as for sensing the energy from the heartbeat the piezoelectric and semiconducting coupled nanowires are used that convert the mechanical energy into electricity.

Similarly, for sensing the blood flow energy, Nano generators driven by ultrasonic waves are used that have the ability to directly convert the hydraulic energy in human body to electrical energy. Another consideration is to use body heat employing bio thermal battery to generate electricity using multiple arrays of thermoelectric generators built into an implantable chip. These generators exploit the well-known thermocouple effect. For the bio thermal device to work, it needs a 2°C temperature difference across it. But there are many parts of the body where a temperature difference of 5°C exists – typically in the few millimetres just below the skin, where it is planned to place this device. This study focuses on using body heat as an alternative energy source to recharge pacemaker batteries and other medical devices and prevent the possibility of life-risk during repeated surgery.[6]

III. POWER GENERATED FROM THE PEOPLE

Potentially, there is a way around the limitations of batteries and the very restricted amount of energy available to siphon off common ambient environments: scavenge power from the user . The human body is a tremendous storehouse of energy. Just one gram of fat stores nine dietary Calories, which is equivalent to 9000 calories or

$$(9{,}000\text{calories} \div 1\text{g fat})(4.19\ \text{J/calorie}) = 37{,}700\ \text{J/gram of fat}$$

An average person of 68 kg (150 lbs.) with 15% body fat stores energy approximately equivalent to

$$0.15(68\ \text{kg})\ (1{,}000\ \text{g/Kg})\ (37{,}700\ \text{J/g fat}) = 384\ \text{MJ}$$ [1]

IV. POWER PRODUCES FROM BODY HEAT

Since the human body emits energy as heat, it follows naturally to try to harness this energy. However, Carnot efficiency puts an upper limit on how well this waste heat can be recovered. Assuming normal body temperature and a relatively low room temperature (20 C), the Carnot efficiency is

$$[T_{body} - T_{ambient}] \div T_{body} = (310K - 293K) \div 310K = 5.5\%$$

In a warmer environment (27 C) the Carnot efficiency drops to

$$(310K - 300K) \div 310K = 3.2\%$$

Table 1: Human energy expenditures for selected activities

Activity	Kilocal/hr	Watts
Sleeping	70	81
Sitting	100	116
Standing at ease	110	128
Conversation	110	128
Eating meal	110	128
Driving car	140	163
Carpentry	230	268
Swimming	500	582
Mountain climbing	600	698
Long distance run	900	1,048
sprinting	1400	1,630

Table 1 indicates that while sitting, a total of 116W of power is available. Using a Carnot engine to model the recoverable energy yields 3.7— 6.4 W of power. In more extreme temperature differences, higher efficiencies may be achieved, but robbing the user of heat in adverse environmental temperatures is not practical.

Evaporative heat losses from humans account are 25% of their total heat dissipation (basal, non-sweating) even under the best of conditions. This consists of water diffusing through the skin, sweat glands keeping the skin of the palms and soles pliable, and the expulsion of water-saturated air from the lungs. Thus, the maximum power available without trying to reclaim heat expended by the latent heat of vaporization drops to 2.8-4.8W.

The above efficiencies assume that all of the heat radiated by the body is captured and perfectly transformed into power. However, such a system would encapsulate the user in something similar to a wetsuit. The reduced temperature at the location of the heat exchanger would cause the body to restrict blood flow to that area. When the skin surface encounters cold air, a rapid constriction of the blood vessels in the skin allows the skin temperature to approach the temperature of the interface so that heat exchange is reduced. This self-regulation causes the location of the heat pump to become the coolest part of the body, further diminishing the returns of the Carnot engine unless a wetsuit is employed as part of the design.

While a full wetsuit or even a torso body suit is unsuitable for many applications, the neck offers a good location for a tight seal, access to major centres of blood flow, and easy removal by the user. The neck is approximately 1/15 of the surface area of the “core” region (those parts that the body tries to keep warm at all times). As a rough estimate, assuming even heat dissipation over the body, a maximum of 0.20-0.32W could be recovered conveniently by such a neck brace. The head may also be a convenient heat source for some applications where protective hoods are already in place - the head is also a very convenient spot for coupling sensory input to the user. The surface area of the head is approximately three times that of the neck and could provide 0.60-0.96W of power given optimal conversion. Even so, the practicality, comfort, and efficacy of such a system are relatively limited. [1]

A. Heavy Breathing: Power from Respiration

An average person of 68 kg has an approximate air intake rate of 30 litres per minute. However, available breath pressure is only 2% above atmospheric pressure. Studies indicate that the power consumed by pulmonary ventilation (breathing) is between 0.1 and 40 Watts. Increasing the effort required for intake of breath may have adverse physiological effects so only exhalation will be considered for generation of energy. Thus, the maximum available power is

$$W= p\triangle V$$

$$0.02\ (1.013\times10^5\ Kg/ms^2)\ (0.5\ litre/second)\ (1\ m^3/1{,}000\ litre) = 1W$$

During sleep, the breathing rate, and therefore the available power, may drop in half, while increased activity increases the breathing rate. Forcing an elevated breath pressure with an aircraft-style pressure mask can increase the available power by a factor of 2.5, but it causes significant stress on the user.

For some professionals such as military aircraft pilots, astronauts, or handlers of hazardous materials, such masks are already in place. However, the efficiency of a turbine and generator combination is only about 40%, and any attempt to tap this energy source would provide additional load on the user. Thus, the benefit of the estimated 0.40 W of recoverable power has to be weighed against the other, more convenient methods discussed in the following sections. [1]

Another way to generate power from breathing is to fasten a tight band around the chest of the user. From empirical measurements, there is a 2.5 cm change in chest circumference when breathing normally and up to a 5 cm change when breathing deeply. A large amount of force can be maintained over this interval. Assuming a respiration rate of 10 breaths per minute and an ambitious 100 N force applied over the maximal 0.05 m distance, the total power that can be generated is

$$(100N)(0.05m)(10breaths/min.)(1min./60sec.)= 0.83W$$

B. Power Typing

Keyboards will continue to be a major interface for computers into the next decade. As such, typing may provide a useful source of energy. On a one-handed chording keyboard, it is necessary to apply 130 grams of pressure in order to depress a key the required 1 mm for it to register. Thus,

$$(0.13kg/keystroke)(9.8m/s^2)(0.001m)= 1.3mJ/keystroke$$

is necessary to type. Assuming a moderately skilled typist (40 wpm), and taking into account multiple keystroke combinations, an average

$$(1.3mJ/keystroke)(5.3keystrokes/second)= 6.9mW$$

of power is generated. [1]

C. Hand Waving: Power from Arm Motion

While finger motion might allow for powering buttons or keyboards, intentional arm motion might generate enough power for notebook computing. The comparison of the activities listed in Table 1 indicates that violin playing and housekeeping use up to 30 kcal/hr., or

$$(30kcal./hr.)(4.19J/cal.)(1hr./3{,}600sec.)= 35W$$

more power than standing. Most of this power is generated by moving the upper limbs. Empirical studies done at the turn of the century show that for a particular 58.7 kg man, the lower arm plus hand masses 1.4 kg, the upper arm 1.8 kg, and the whole arm 3.2kg. The distance through which the centre of mass of the lower arm moves for a full bicep curl is 0.335 m, while raising the arm fully over the head moves the centre of mass of the whole arm 0.725 m. Empirically, bicep curls can be performed at a maximum rate of 2 curls/sec and lifting the arms above the head at 1.3 lifts/sec. Thus, the maximum power generated by bicep curls is

$$(1.8kg)(9.8m/s^2)(0.35m)(2curls/sec)(2\ arms)= 24W$$

while the maximum power consumed by arm lifts is

$$(3.2kg)(9.8m/s^2)(0.725m)(1.3lifts/sec)(2\ arms)= 60W$$

Obviously, housekeeping and violin playing do not involve as much strenuous activity as these experiments. However, these calculations do show that there is plenty of energy to be recovered from an active user. The task at hand, then, is to recover a useful amount of energy without burdening the user. A much more reasonable number, even for a user in an enthusiastic gestural conversation, is attained by dividing the bicep curl power by a factor of eight. Thus, the user might make one arm gesture every two seconds. This activity, then, generates a total of 3 W of power. By doubling the normal load on the user's arms and mounting a pulley system on the belt, 1.5W might be recovered (assuming 50% efficiency from loss due to friction and the small parts involved), but the system would be extremely inconvenient. [1]

D. Power from Walking

Using the legs is one of the most energy consuming activities the human body performs. In fact, a 68 kg man walking at 3.5mph, or 2 steps per second, uses 280kcal/hr. or 324W of power. Comparing this to standing or a strolling rate implies that up to half this power is being used for moving the legs. While walking, the traveller puts up to 30% more force on the balls of his feet than that provided by his body weight. However, calculating the power that can be generated by simply using the fall of the heel through 5cm (the approximate vertical distance that a heel travels in the human gait) reveals that

$$(68kg)(9.8m/s^2)(0.05m)(2\ steps/sec)= 67W$$

of power is available. Even though walking is not continuous like breathing, some of the power could be stored, providing a constant power supply even when the user is not walking. The 67W result above is a truly maximum number, in that utilizing the full 5-cm stroke
would result in significant additional load on the user, and would result in the feeling of "walking in sand". [1]

V. PROJECT RUNNING IN THE WORLD

- Power harness from footsteps of revellers for nightclub's dance floor and their lights.
- Telecom giant Nokia recently filed a patent for a cell phone powered by kinetic energy (one of our favourite kinds of energy here at Inhabitant). The conceived phone would charge via built-in piezoelectric generators that will convert the user's motions into power. Nokia is taking interest and has gone so far as to file a patent is significant evidence that we may soon be seeing these types of electronics hit the market.
- When the East Japan Railway Company (JR East) decided to invest in alternative energy sources, it only had to look to its users for the perfect source of energy. Recently the company decided to update their Tokyo Station with a revolutionary new piezoelectric energy generating floor. The system will harvest the kinetic energy generated by crowds to power ticket gates and display systems. [5]
- A brilliant invention that makes people wonder is piezoelectric tiles. POWERleap is a floor tiling system that converts wasted energy from human foot traffic into electricity. [2]

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