Chapter 26
Biomechanical Energy Harvesting:
Design, Testing, and Future Trends in Healthcare and Human-Machines Interfacing

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ABSTRACT

Portable electronic systems and wearable sensor networks are offering increasing opportunities in fields like healthcare, medicine, sport, human-machine interfacing and data sharing. The technological research is looking for innovative design solutions able to improve performances and portability of wearable systems. The power supply strategy is crucial to improve lifetime, reduce maintenance, preserve the environment and reduce costs of smart distributed electronic systems applied to the body. The conversion of biomechanical energy of limbs and joints to electricity has the potential to solve much of the actual limitations. The design and building of wearable energy harvesters for wearable applications require different approaches respect to traditional vibratory energy harvesters. This chapter focuses on transduction materials, modeling strategies, experimental setups, and data analysis for the design of biomechanical energy harvesters; a case study based on system integration and miniaturization is also described for applications in the field of human-machines interfacing.

INTRODUCTION

Many industrial and academic researches are currently addressed to design and to optimize the technologies related to portable and wireless electronics. Some of the fields mainly attracted by this category of devices are health care, medicine, bioengineering, human-machine interface (HMI), insurance, military, sport and entertainment. In medical applications, for instance, distributed remote sensors for body monitoring with self-powering can reduce sensitively the cost of medical services. The repetitive and

DOI: 10.4018/978-1-5225-5484-4.ch026

scheduled procedures of patients health monitoring normally performed in hospitals could be replaced with automatic detections of physiological parameters by smart self-powered sensors. Remote sensing techniques applied to biological parameters of people are now feasible by using diagnosis devices for patients with specific pathologies that do not require permanence inside hospitals. In those cases, the remote monitoring of specific physiological parameters, through wireless sensors powered with rechargeable batteries, allows to monitor the evolution of clinical processes staying at home with increased comfort, wellness and cheapness. The "cloud data management" of the remotely sensed information could be used for normal patients, civilians, soldiers, etc. and save much of the doctors' time and healthcare costs. In US, for instance, more than 3 million nurses are spending at least 5 minutes a day each on one patient to check basic vital parameters (Clanaman, 2013). This corresponds to millions of hours that can be potentially saved by adopting wearable sensors networks in hospitals, for instance in the fields of mental health (Barak et al., 2008), respiratory conditions (Jaana et al., 2009), smoking cessation (Myung et al., 2009), cardiovascular diseases (Neubeck, 2009), diabetes (Tran et al. 2008), etc.

The design constraints characterizing wearable devices are generally the small size, the light weight and the low power consumption. This last specification, in particular, suggests using energy harvesting from human body motion to generate the required power to supply the worn electronic devices. The design and building of sensing nodes characterized by high integration and reliability, self-powering, low cost, and wearability have the potential to extensively detect biological parameters of people for the mentioned fields. Furthermore, they will allow size and weight reduction of devices, prevention of batteries recharge, replacement and disposal. In portable sensing nodes, the battery duration is generally short, due to the size and weight constraints. The biomechanical energy harvester (EH) makes the nodes energetically autonomous in normal conditions, and slows down the battery discharge in critical situations of limited mobility.

The main research efforts are currently focused on efficiency improvement, electronics miniaturization, improvement of biocompatibility and portability (small invasiveness on body motions) and data communication and management according to clinical requirements.

About the working principles of biomechanical energy harvesting, the general approach is to convert the kinetic energy associated to the motion of limbs and joints to electricity by appropriate transducers. These electro-mechanical transducers are based on piezoelectric materials and on electro-magnetic inductors. Within this frame, many different design solutions can be conceived, depending to the requirements of the measurement and to the application. Some examples are the extended monitoring of body temperature, the calculation of mobility indexes, the monitoring of breathing, metabolic functions, etc. In most clinical practices, the wireless detection is already used, for instance with telemetry strategies; the physiological parameters of interest are measured in remote by wireless sensors and then stored. In this case, present limitations are the reduced portability of devices, which are uncomfortable to wear, large and heavy because of the batteries. The batteries need periodic recharge or replacement, and in case of discharge, the data acquisition is stopped. However, the main limitation is the reduced portability of data: the measured values are transmitted to a receiver that stores them in a local memory, from where they are downloaded by the medical staff. Instead, the internet connection of the wearable sensors, for instance by using portable devices like smartphones, will make the data accessible everywhere in real time. This improvement could eliminate completely the restrictions to the mobility of those patients who need permanent medical supervision or periodic monitoring of physiological data. Of course, the described technology makes sense only with local power generation to guarantee the system supply and

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