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Wearable power Harvester for medical applications

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Abstract. Intelligent biomedical clothes combine health problem prevention, comfort, convenience, entertainment and communication with fashion and make everyday life easier. Homecare and healthcare applications wireless, mobile networks and wireless sensors improve the existing monitoring capabilities especially for the elderly, children, chronically ill and also for athletes. Sensor nodes are generally battery-powered devices. Batteries add size, weight and inconvenience to portable electronic devices and require periodical replacement. Nowadays the human power is an alternative and attractive energy source. Energy, which is generated during routine and seemingly insignificant human motions, shows promise as an alternative to power embedded wireless, mobile networks and wireless sensors. This paper describes the prototype of a smart garment and offers several alternative integration places of generator's parts, which are based on the principle of operation of the electromagnetic generator. Seven variants of location are proposed, which are tested and analysed. During the research, analysis of the most optimal placement of generator's part in garment has been performed.

Introduction

Both the textile sector and healthcare medical sector are looking with great interest at the innovative products and applications that could result from the integration of microsystems, nanotechnologies, biomedical sensors, textiles, and mobile telecommunications. For health monitoring, disease prevention and management, rehabilitation, and sport medicine (Lymberis and Olsson, 2003).

On the one hand, clothing is an environment that we need and use every day. Clothing is special because it is personal, comfortable, close to the body, and used almost anywhere at any time (Kirstein, 2005). Traditionally clothing helps people to survive in the surrounding climate and social environments. Clothing performs a physiologically hygienic function ensuring the normal functioning of physiological processes. On the other hand, depending on the application, the clothing performs aesthetic social and other functions. In recent decades garment features significantly expanded. Clothing with integrated communications, environmental identification and dislocation determining system, other systems and medical application has been created.

Integrated in garment for homecare and healthcare applications, wireless, mobile networks and wireless sensors improve the existing monitoring capabilities especially for the elderly, children, chronically ill and also for athletes. Such pervasive systems allow the monitoring of daily living

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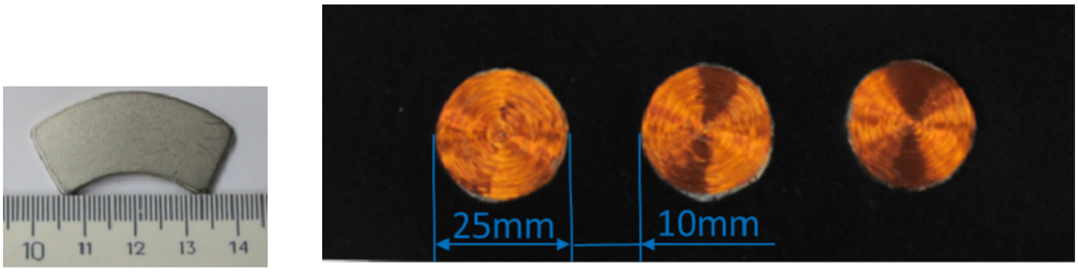

a b

Figure 1. Structure of the Energy Harvester: a – lightweight, small and strong neodymium magnets ($Nd_2Fe_{14}B$); b – the inductive element consists of three groups of spiral-shaped coils connected in the series with same polarity.

activities, fall and movement detection, location tracking, disease prevention medication intake monitoring and medical status monitoring (Vouyioukas, Karagiannis, 2011), (Wong 2011), (Liu, 2010).

Intelligent biomedical clothes combine health problem prevention, comfort, convenience, entertainment and communication with fashion and make everyday life easier (Luprano, 2004). There are numerous research projects on the medical application such as The LifeShirt (Grossman, 2004), SmartShirt (Park, Mackenzie, Jayaraman, 2002), biomedical clothing VTAM (Axisa et al., 2005) and WEALTHY (Paradiso, 2005), MyHeart (Paradiso, Rossi, 2006) and other (Lymberis; Dittmar, 2007), (Norgall, Schmidt, Grün, 2004).

Primary batteries are mainly used for powering most wireless devices and sensor nodes. However, batteries usually are the most expensive part of the system, they add size, weight and inconvenience to wearable device and main disadvantage – they require periodical replacement. Exploit power from the ambient sources (photovoltaic cells (Bedeloglu, 2011), thermoelectric elements (Leonov, 2011) and mechanical energy harvesters from human movement (Mitcheson et al., 2008) is an alternative solution for to replacing batteries in portable electronic devices.

Nowadays, the human power which is generated during routine and seemingly insignificant human motions, is an attractive energy source. Scientists from around globe are creating human powered wearable energy harvesting device which differ on the type of energy and in the power of generated energy (Krupenkin, Taylor, 2011), (Li, Naing, and Donelan, 2009), (Rome, 2005), (Chiba and Waki, 2011). One of solutions in this area is at Riga Technical University based on the interdisciplinary cooperation developed an electromagnetic human motion energy harvester for generating electricity during human walking without extra effort. Our device has a planar structure and consists of inductive element and an arc-shaped magnet (see Fig. 1) with total volume about 4.63 cm^3 and all elements can be deployed on a variety of clothing items (Blums 2011), (Terlecka et al. 2011).

The aim of the research is to determine the optimal placement of the electromagnetic human motion energy harvester's parts in clothing.

Experimental

Several conditions should be executed to assure effective work of energy harvester:

- parts of energy harvester should be placed in such a way that, during motion. they would move in relation to one another together with the corresponding garment details;
- while the details pass near one another, they must pass as near as possible;
- dispose the coils there is needed to the utmost even place which is not subjected to deformation during movement;

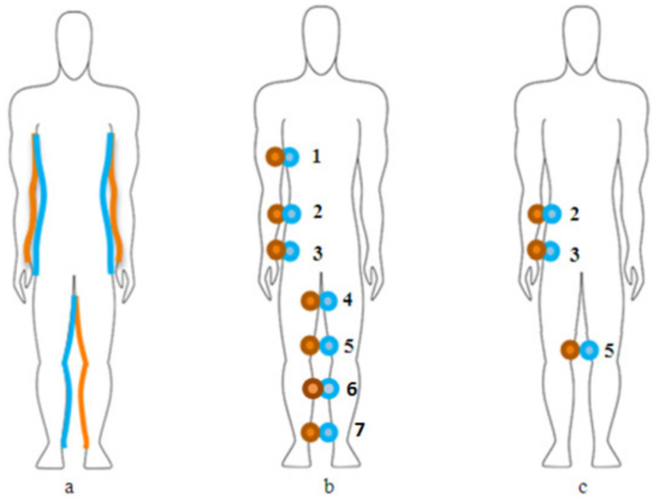

Figure 2. Location of the energy harvester's parts: a – possible location, b – places of primary test and c – selected places of re-testing.

- details of energy harvester should not change properties and outside appearance of the garment;
- to assure maximal speed of the magnet passing along the set of coils, as the quantity of generated energy is directly-proportional to the energy of motion of the magnet (Terlecka, Viïumsone, Blūms, 2011).

Elements of the construction of the energy harvester are not united under one frame and can be located almost in every garment and/or accessories (for example, bag), where the necessary conditions can be executed and where the two are close to each other moving parts of clothes during the natural human motion. That assures to transfigure mechanical human movement into electric power.

Possible places of location for the elements of the electromagnetic energy harvester: places of contact between inner sides of arms and torso, as well as inner sides of the legs. The location of magnet is indicated with orange colour and the location of inductive elements with a blue one (see Fig. 2a).

Exact location of the energy harvester elements are found by an experimental approach. At the clothes, along the would-be places of integration of pieces of electromagnetic energy harvester, there were fixed magnets together with the markers, and with help of these markers the trajectory of the magnets moving were traced and indicated, while imitating human walking. The achieved trace of trajectory of the magnet corresponds to the location of inductive elements of the electromagnetic energy harvester.

Primary testing was held in seven places (see Fig. 2b). There were measured values of voltage impulses of the electromagnetic energy harvester. As a result there were selected best places for integration of the parts of the electromagnetic energy harvester taking into account the values of impulse (see Fig. 2c). That is wrist girth level, anterior superior iliac spine level and knee level of the tested person.

In the places number 1, 4 and 6 the values of pulse voltage were either absent or minimal because of insufficient amplitude of moving magnets along the inductive elements (places 1 and 4) and because of a big distance between the pieces of electromagnetic energy harvester (places 6 and 7), that is caused with the anatomical features and manner of walking of the individual.

The further experiment took place at Riga Stradiņš University in "Laboratory of research in rehabilitations", where there was possibility to measure value of voltage impulses of electromagnetic

a b c d

Figure 3. Energy harvester testing in garment: a – first jacket prototype, b -second jacket prototype, c – insulated outerwear, d – bag-belt and wristband.

energy harvester during walking with different fixed speeds 3, 4.5, and 6 km/h for men and speeds 2.6, 3.4, 4, and 6 km/h for women, that corresponds to slow, medium and fast walking of the tested person.

Men's garments have been tested: two prototypes of jacket, the ready-made insulated outerwear, and prototype of set consisting of the belt-bag and removable cuff (wristband). Women garment under testing: jeans, the ready-made fitting silhouette jacket with a chest easy allowance 5 cm and prototype of the belt-bag and wristband.

The first men's prototype of a loose jacket with a chest easy allowance 14 cm (see Fig. 3a), the second men's prototype of a jacket with half-fitting silhouette with a chest easy allowance 7 cm (see Fig. 3b), and the ready-made men's insulated outerwear with a chest easy allowance 7.5 cm (see Fig. 3c). On the first prototype, the inductive elements and magnets are located anterior superior iliac spine level un wrist girth level, on the second prototype, they are located at hand girth level un anterior superior iliac spine level, on the third prototype of ready-made jacket anterior superior iliac spine level, on the women ready-made jacket they are located at anterior superior iliac spine level and at jeans – knee level. In a prototype of set (bag-belt and wristband) for both wearers the inductive elements and magnets are located at wrist girth level.

Results

The generator was tested on a wearer during walking at fixed speeds. By means of digital oscilloscope Picoscope 2205 there were fixed voltage pulses. Having known the meanings of voltage during the movement the produced energy, and by dividing it into the time of motion – average power was calculated. The numerical data of harvester's relevant characteristics for the full walk cycle is shown in *Table 1* and *Table 2*. The full motion cycle – the period of double step – is formed for each arm from both forward and reverse movement.

The best result of mean power of 0.27 mW is observed at the speed of motion 6 km/h for women jacket at anterior superior iliac spine level, the second one result is 0.18 mW for jeans at knee level and at speed motion 4 km/h.

The best result of mean power of 0.50 mW is observed at the speed of motion 6 km/h; the second one result is 0.26 mW at the speed motion 4km/h for men's insulated outerwear at anterior superior iliac spine level in both cases.

Table 1. Electromagnetic energy harvester prototype in use at women garment.

Type of clothing	Speed of motion km/h	Coil placement	Mean power, mW	Mean power density, mW/cm^3
Jeans	4	Knee level	0.179	0.039
Women jacket	6	Anterior superior iliac spine level	0.269	0.058
Women jacket	4	Anterior superior iliac spine level	0.135	0.029
Women jacket	4	Wrist girth level	0.133	0.029
Women jacket	3.4	Wrist girth level	0.074	0.016
Women jacket	2.6	Wrist girth level	0.120	0.026
Belt bag and wristband	4	Wrist girth level	0.091	0.020

Table 2. Electromagnetic energy harvester prototype in use at men garment.

Type of clothing	Speed of motion, km/h	Coil placement	Mean power, mW	Mean power density, mW/cm^3
First men's prototype (with reduce volume jacket bottom and sleeve bottom)	3	Anterior superior iliac spine level	0.043	0.009
		Wrist girth level	0.011	0.002
	4.5	Anterior superior iliac spine level	0.014	0.003
		Wrist girth level	0.026	0.006
	6	Anterior superior iliac spine level	0.051	0.011
		Wrist girth level	0.002	0.000
First men's prototype	4.5	Anterior superior iliac spine level	0.060	0.013
		Wrist girth level	0.003	0.001
Second men's prototype	3	Hand girth level	0.006	0.001
		Anterior superior iliac spine level	0.033	0.007
	4.4	Hand girth level	0.014	0.003
		Anterior superior iliac spine level	0.054	0.012
	6	Hand girth level	0.015	0.003
		Anterior superior iliac spine level	0.053	0.011
Men's insulated outerwear	3	Anterior superior iliac spine level	0.181	0.039
	4.4	Anterior superior iliac spine level	0.261	0.056
	6	Anterior superior iliac spine level	0.502	0.108
Belt-bag and wristband	4.5	Wrist girth level	0.237	0.051

Discussion

Mean power of 0.50 mW is observed at the speed of motion 6 km/h, which is suitable for powering wireless sensor node (Vullers et al., 2009). The statistical deviation of generated energy due walking is about 20%.

Comparison all result can be seen that maximal generated mean power was achieved at a speed of walking 6 km/h at anterior superior iliac spine level. However, possible to say that, all result at anterior superior iliac spine level has best indicators for any speed motion. The achieved value of power was the biggest, because the distance between the elements of the electromagnetic energy harvester is minimal due to the anatomical features of human.

In men's insulated outerwear good results are obtained by minimal distance between the elements of the electromagnetic energy harvester due to the anatomical features of human and voluminosity of the jacket.

Minimal value of power 0.002 mW was distinguished at a speed of walking 6 km/h with location of pieces of electromagnetic energy harvester at wrist girth level.

Comparing the results of integration of pieces of electromagnetic energy harvester into the different garment at wrist girth level at a speed of 4.4–4.5 km/h, maximal result 2.64E-04 J of generated energy was achieved with the set (belt-bag and wristband). In the set magnet is located in the removable cuff (wristband) that closely embraces the wrist of a hand, inductive elements are located in the bag-belt that is snug closely against the thigh. During the walking, the movement trajectories of pieces of electromagnetic energy harvester were stable and did not possess any additional amplitude, thus providing exact trajectory of motion of the magnet that pass through the centers of inductive element.

Despite the fact that the knee level showed a good result 0.18 mW, it is not subject to further consideration by nonuniversality due to the anatomical features of human legs and individual dynamic stereotypes of motion.

Compared to other investigations (Mitcheson et al., 2008) published data on power density (from 0.8 to 0.07 mW/cm^3) of different constructions of harvesters, the power density of the present harvester (0.11 mW/cm^3) is comparable, but provided at significantly lower frequency and is completely integrable into the clothes due to the planar structure.

Conclusions

During the research analysis, of the most optimal placement of energy harvester's part in garment has been performed.

The optimal placement for integrating the elements of the electromagnetic energy harvester is anterior superior iliac spine level in the outer garment especially insulated outerwear and wrist girth level in the set bag-belt and wristband.

Anterior superior iliac spine level is a better location of pieces of electromagnetic energy harvester than wrist or hand girth level.

The set bag-belt and wristband can be replaced with the set trousers or skirt and removable wristband, as in this case electromagnetic energy harvester will be at the same wrist girth level. However, bag-belt and wristband are universal and can be used for different tested persons, and the second set only for the concrete individual.

The investigated generator can be used as a mobile and ecologically clean source of energy, easy in use, and not changing substantially visual properties of textile structures, its sizes and weight.

The generated energy can be used for running different integrated medical sensors and/or can be stored for later usage.

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