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Human-powered inertial energy harvesters: the effect of orientation, location and activity on obtainable power

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Abstract

Inertial energy harvesting is an emerging technology that can power electronic devices using energy scavenged from the motion of the human body. Owing to the relatively low frequencies associated with body motion (<3 Hz), the generated electrical power is typically in the range of a few μW; hence transduction must be optimized. Previous studies have investigated the effect of activity and harvester location on the obtained power; this work evaluates how power is also affected by the harvester's orientation. Ten participants performed walking and running exercises, while tri-axial acceleration data were sampled at five locations on the body. The results show consistency in the optimal orientation of the harvester between people, but this orientation is not aligned with the axes of the body and limbs. During walking, the power harvested from the upper and lower body differs by an order of magnitude; however, this difference is less significant when running.

Keywords: energy harvesting; body sensor networks; micropower generator

1. Introduction

To allow measurements to be made over sustained periods, body-worn sensors are required to have a long lifetime. The procedure for replacing their batteries is often cumbersome and, on rare occasions, may not even be possible. A promising way of addressing such problems is to use inertial energy harvesting [1], which converts the motion of the human body into electric energy. Inertial energy harvesters are usually designed to harvest energy from accelerations in a single axis. Existing studies into available power levels have analyzed data in a limited number of directions [2,3] and have therefore not fully

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examined the effect of harvester orientation. This paper describes how the obtainable electrical power is influenced by the participant, the nature of the activity, and both the generator's location and orientation.

2. Experimental Method

Data were collected from ten participants wearing wireless tri-axial accelerometers (Microstrain G-Link) sampling at 128Hz. The accelerometers were mounted at five locations: the ankle, knee, waist, elbow and wrist (Fig. 1). Participants (8 male, 2 female, aged 24-33yrs) were asked to run and walk on a treadmill for 30 seconds at a rate which they found comfortable. Participants' step frequencies were recorded, and observed to have a mean of 1.80±0.12Hz when walking and 2.64±0.19Hz when running.

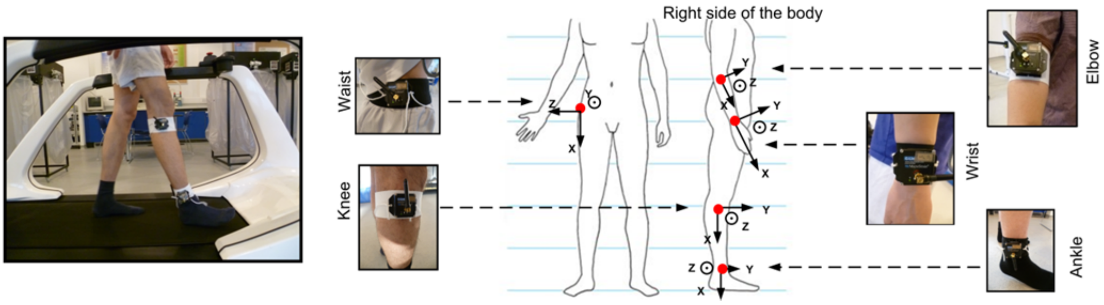


Fig. 1. Five data collection locations around the body, showing the directions of the accelerometers' axes.

3. Data Analysis and Results

Obtained acceleration data were resolved onto unit vectors in a sphere with an angular resolution of 5°, and transformed into the frequency domain. Maximum output power was calculated for discrete frequency ranges {0.5-1, 1-1.5, 1.5-2, 2-3, 3-50}Hz, using Equ. 1 [4].

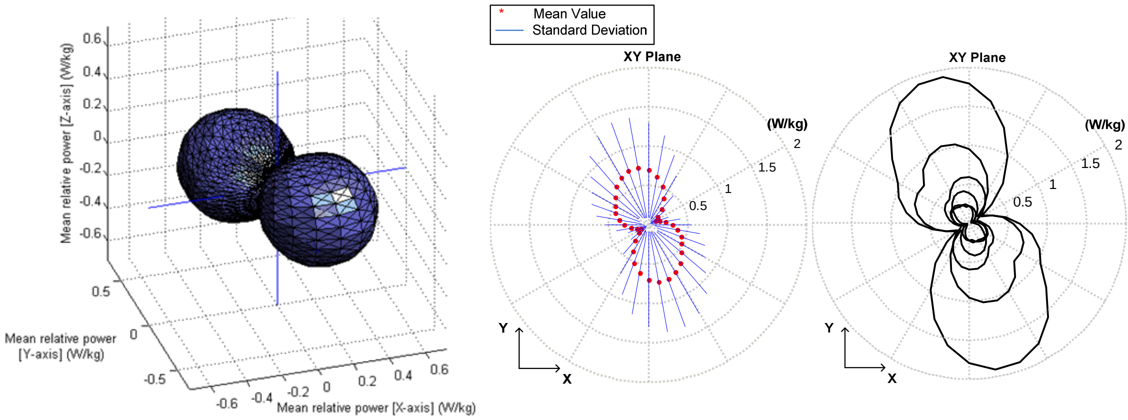
$$P = \frac{mA^2}{8\pi f_0 \xi} \tag{1}$$

In this paper, 'relative power' is used for comparison, and is defined with m/ξ set to unity (Equ. 2).

$$P_{rel} = \frac{A^2}{8\pi f_0} \tag{2}$$

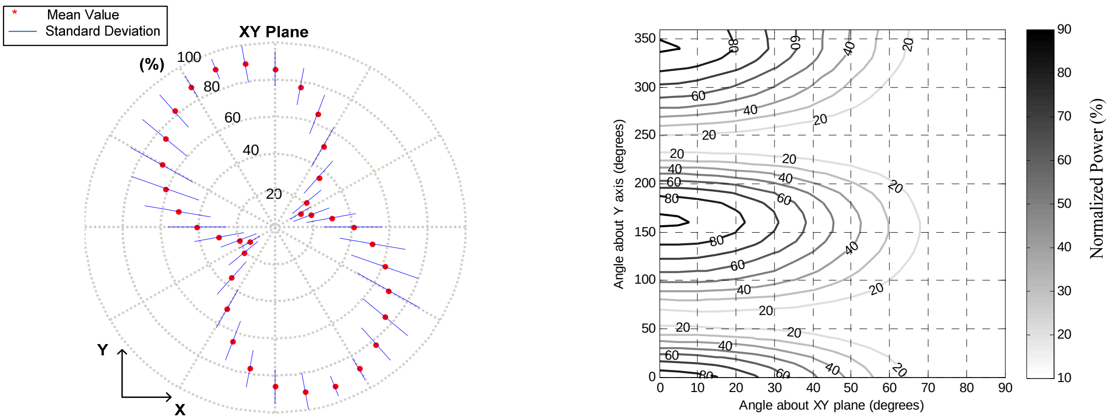
Using the collected data, the effect of harvester orientation was explored; in this paper the ankle location is used to illustrate this analysis. Fig. 2a shows the mean relative power obtainable (across all participants) with different harvester orientations, while Fig. 2b shows the mean and standard deviation through the X-Y plane. In these results, significant variation can be observed, which could be attributed to a poor correlation between participants, hence limiting the identification of an 'optimal' orientation. However, as shown in Fig. 2c (which overlays the relative powers for each participant), acceleration vectors for different participants exhibit a wide range of magnitudes, but similar directions.

To identify the optimal orientation, relative powers at different orientations are normalized to each participant's maximum; we refer to this as the normalized power. Fig. 3a shows the mean and standard deviation of the normalized power for all participants for the XY plane; the reduction in the standard deviation is obvious when comparing this to Fig 2b. Each orientation was defined by the angles about the XY plane and about the Y axis. It was discovered that a vertical angle of 5°±5° and horizontal angle of 160°±10° results in over 90% of the maximum output to be obtained for each person (Fig. 3b).



(a) *(b)* *(c)*

Fig. 2. Relative power obtainable from the ankle while walking, (a) mean for all participants in 3-dimensions; (b) mean and standard deviation for all participants in the X-Y plane; (c) mean for each participant.

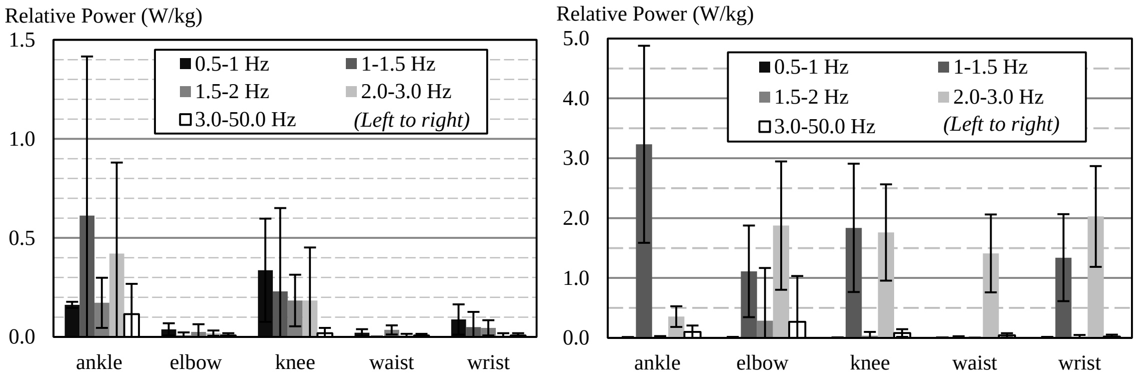


(a) *(b)*

Fig. 3. Normalized power obtainable from the ankle while walking across all participants, (a) mean and standard deviation in the X-Y plane; (b) mean, highlighting angle tolerance.

To investigate the influence of the generator's resonant frequency on output power, relative power in each frequency range is also considered (shown in Fig. 4). This identifies the relative power available in different frequency ranges and locations on the body, for both walking and running. While walking (Fig. 4a), it can be seen that the average output power obtainable from the lower body (ankle and knee) is an order of magnitude greater than that from the upper body (elbow, waist and wrist). It can also be noticed that a greater output power is accompanied by a higher standard deviation regardless of activity.

This difference between available power on the upper and lower body is, however, less significant while running (Fig. 4b); this is presumably due to increased movement of the upper body during higher activity exercises such as running. While running, the 1-1.5Hz and 2-3 frequency ranges provide the highest output power, while very little is observed between 1.5-2Hz. On the ankle, the predominant frequency is in the 1-1.5Hz range (an order of magnitude higher than other frequency ranges). This is because the accelerations are a result of the impact between the ground and foot, and is hence half the of the step frequency, i.e. 1.32Hz. On the waist, the acceleration is a result of both feet striking the ground, and is hence at the step frequency, i.e. 2.64Hz.



(a) *(b)*

Fig. 4. Relative power available across different frequency ranges for (a) walking; and (b) running.

4. Conclusions and Future Work

This paper has described how the obtainable electrical power from a body-mounted generator is influenced by the diversity of participants' motions, the nature of the exercise undertaken and both the generator's location and orientation. The latter of these had not, to our knowledge, been investigated before. The analysis and results show the optimum orientation and position for inertial energy harvesters when walking and running, and the relative power generated in each frequency range. During walking and running, frequencies <3Hz show a useful contribution to output power. While walking, we have shown that the obtainable power is an order of magnitude higher at locations on the lower body (ankle, knee) when compared to the upper body (waist, elbow and wrist).

Our on-going research is designing, fabricating and evaluating a human-powered inertial energy harvester. These results have given an indication of the optimum location, orientation and resonant frequencies that should be accommodated.

Acknowledgements

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