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Increased energy harvesting and reduced accelerative load for backpacks via frequency tuning

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ABSTRACT

In this research, a backpack-based frequency-tuneable harvesting device was developed to harvest part of the human kinetic energy during walking and to relieve part of the accelerative load of the backpack from the bearer. The harvester employed a tuning mechanism to adjust the stretch ratio of the springs to adjust the system's stiffness so that the harvesting device can work in an appropriate status to generate more power and relieve a greater load from the bearer. The analysis indicates that adjusting the stiffness harvesting system to fit well with various external excitation conditions, can not only achieve more power output but also relieve part of the accelerative load from the bearer; and the experimental results agreed with the simulation. Compared with previous work, the harvester in this work had a higher efficiency in energy harvesting and could relieve an increased accelerative load from the bearer.

1. Introduction

Wearable computing devices have developed rapidly in recent years and are widely used in both daily life and research or military work in remote areas. Although such devices make our daily lives or work more convenient, they also require greater battery capacity for their power supplies. However, the limited energy storage of a battery and its considerable weight have hindered the extensive use of electronic devices, especially when humans work with these computing devices in remote area. Therefore, alternative methods of solving the energy problem associated with mobile electronic devices must be developed. One possibility to overcome the power limitations is to extract energy from the environment, either to recharge a battery or directly power the electronic device. Several environmental sources have been proposed in recent years, such as vibration [1–4], light [5], and others.

Human motion is rich in kinetic energy, which can be utilised in the design of wearable computing devices. Several studies have been conducted to investigate harnessing human power from walking, joint motion, and footsteps, to charge electronics. Donelan [6] and Li [7] have developed a regenerative biomechanical energy harvester that is mounted on a human knee for harnessing joint motion during walking. Shenck [8] and Kornbluh [9] have designed insole-like harvesting devices to convert human kinetic energy from footstep motion. Backpacks containing heavy equipment are often used in field work for long periods of time, and many of these portable electronics have higher power supply requirements. Feenstra [10] employed a mechanically amplified piezoelectric stack to replace the strap buckle of a backpack for harvesting backpack oscillations during human walking. Rome [11] presented another successful example of a backpack employed to harvest

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human kinetic energy from body trunk motion. This example used a suspended-load backpack weighing 38 kg to convert human vertical movement at a walking speed of 5.6 km/h and generated a maximum of 7.4 W of electric power, or approximately 0.5 W of electric power at a walking speed of 4.0 km/h with a 29-kg load. The above-mentioned harvesting devices were specially designed for a certain human walking velocity and external load and cannot be applied to a range of walking velocities and external loads; thus, the efficiency of energy harvesting from a backpack-based harvester can still be improved. Therefore, to improve energy harvesting efficiency through a backpack, the frequency of the harvesting device should be tuneable to match the human walking velocity and external load.

Energy harvesting from dynamic systems can also influence their vibration performance due to the variation of the total damping of the harvesting system, and hence, the energy harvesting can be an effective method to regulate the system vibration. Cassidy et al. [12] designed an electromagnetic transducer for energy harvesting from, with simultaneous vibration control of, large structures. Harne [13] studied concurrent attenuation of, and energy harvesting from surface vibrations. And Tang et al. [14] investigated the simultaneous energy harvesting and vibration control of structures with tuned mass dampers. Inspired from these prior studies, the suspended backpack can be also designed to relieve part of the accelerative load from the bearer.

In this paper, we developed a frequency-tuneable oscillating device embedded into a backpack that can not only efficiently harvest human biomechanical energy at various walking velocities and various external loads but also relieve part of the accelerative load from the bearer. In the proposed harvester, the stiffness is adjustable through a tuning mechanism such that it fits the oscillation excited by the human body. Aside from the tuneable stiffness mechanism, a spring-mass-damping oscillating mechanism was used to transfer a human's vertical movement to generators to produce electricity. The study demonstrated that carefully tuning the system's stiffness can effectively improve the power output with various walking velocities and various external loads and can also relieve part of the accelerative load from the bearer.

The paper is organised as follows. Section 2 describes the frequency-tuneable backpack model and Section 3 discusses the performance of the harvester. Section 4 presents an experimental validation of the theoretical analysis. Section 5 provides the conclusions drawn from the study.

2. Frequency-tuneable backpack model

2.1. Backpack-based harvester prototype

A mass-spring-damping oscillating mechanism is used to harness human kinetic energy to harvest biomechanical energy from the human body with a loaded backpack during walking, as shown in Fig. 1. The special backpack has two containers: one to hold the harvesting device and the other to carry an external load. The harvester framework is assembled in the device container, and the suspended container is fixed on the supporting board of the harvester, which can freely slide along the framework. Therefore, during walking, the harvester framework moves with the human trunk and the carrying load can also oscillate relative to the framework.

In this oscillating system, the framework is attached to the human body and can move with the trunk of the human body. The external carrying load in the backpack serves as the oscillating mass, which is connected to the framework through transversely stretched springs. Finally, a generator is used to convert relative mechanical motion between the oscillating mass and framework into electricity. The damping in the oscillating system comes from both the mechanical friction among mechanical components and the generator, which removes mechanical energy out of the oscillating system and produces electricity.

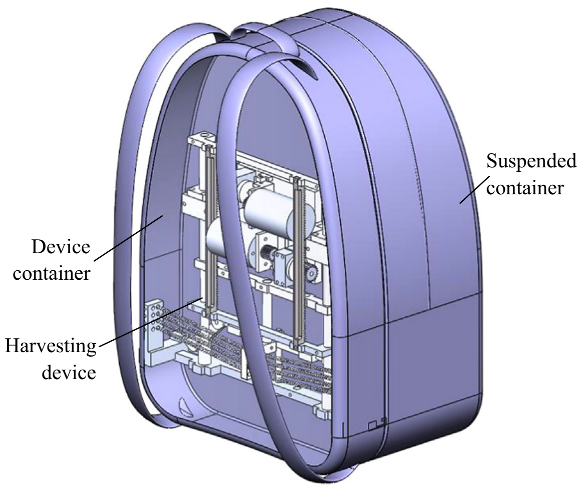

Fig. 1. Backpack and energy-harvesting device.