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A multiple energy-harvester combination for pattern-recognizable power-free wireless sensing to vibration event

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ABSTRACT

By using combination of multiple energy-harvesters, a novel self-powered wireless-sensing-node is proposed and developed for event-driven autonomous alarming, where the vibration pattern can be recognized. The energy-harvester based wireless-sensing-node has three unique advantages of (1) vibration pattern distinguishable sensing, (2) event-driven autonomous wireless monitoring and alarming, and (3) no electric-power supply needed. In the sensing microsystem, two threshold-triggered harvesters are designed and fabricated to monitor vibration in a vibration pattern distinguishable way. Each of the two threshold-triggered harvesters can independently switch into electric-generating state only when the monitored acceleration exceeds the preset-threshold. In the dual-harvester array, one threshold-triggered harvester is more sensitive to low-frequency shake and the other is triggered more easily by high-frequency knock, thereby, both vibration amplitude and frequency can be distinguished that allows vibration pattern identification. For quick wireless-transmission, another electromagnetic energy-harvester is involved to rapidly generate electric-power. The wireless-sensing-node is installed onto a protection-fence for engineering protection. In this experiment, the device can clearly distinguish the vibration patterns between hand-shake and hammer-knock. The vibration-event induced alarm messages together with the vibration pattern information is wirelessly sent to a phone. The developed technique is really promising for smart wireless-monitoring where no on-site power can be supplied.

1. Introduction

Wireless-sensing-nodes have recently attracted increasing interest for monitoring safety of environmental situation and intrusion detection systems [1,2], etc. However, many fieldwork wireless-sensing-nodes are often restricted by inadequate or even no on-the-spot electric-energy supply. In many cases, on-site battery replacement or re-charging is also inconvenient. To solve the problem, energy harvesters that convert ambient energy into electric-power are expected to long-term supply the on-site wireless-sensing-node [3].

To use vibration energy that exists pervasively around us, most of miniaturized harvesters generate electric-power via electrostatic induction effect [4], piezoelectric effect [5] or Faraday's law [6], respectively. However, those harvesters are still limited to narrow frequency-band applications [4,5]. And some electromagnetic energy-harvesters which are capable of generating enough electricity are often too large to be integrated into wireless-sensing-microsystems [6,7]. More importantly, most of self-powered wireless-sensing-nodes consist of sensors and signal processing circuits. Such regular sensing modules are difficult to be immediately power supplied by harvesters when the monitored-event suddenly occurs. At the initial stage of a vibratory event, the on-site harvested electric-energy from the vibration is often insufficient to sustain the whole sensor/circuit system. Only until enough electric-energy have been generated and stored, the sensing module could not be activated. This usually causes discontinuous monitoring and omission of the important initial-stage event signal [8,9]. To address the problem, a "near-zero-power" sensing system was proposed that can keep sleeping in normal times but is awakened when the event occurs [10]. Unfortunately, such system is com-

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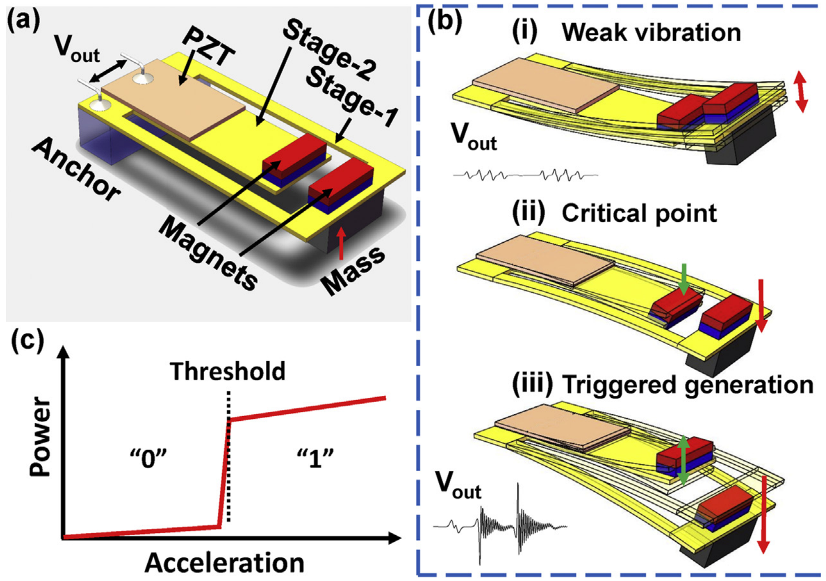

Fig. 1. (a) Schematic and (b) working principle of a threshold-triggered harvester. (c) Relation between generating-power and acceleration that illustrates the threshold-triggered generating function. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article).

plex which contains linear harvester arrays and massive circuits. Recently, a threshold-triggered harvester was proposed to simultaneously generate energy and sense vibration strength [11]. Such event-driven harvester only generates considerable electric-power when vibration exceeds the threshold-acceleration. However, such device can only sense the vibration acceleration but not the frequency. This shortage seriously degrades the sensing capability to detail information of wide-band and frequency-discontinuous vibratory events.

In this study, a self-powered wireless-sensing-node with vibration-pattern distinction capability is proposed, which is based on combination of multiple harvesters. For distinguishing vibration-patterns that include both the strength and the frequency, two threshold-triggered harvesters with different designed parameters collaborate together. One threshold-triggered harvester for pattern distinction is a piezoelectric harvester for low-frequency vibration (named as PHL), and the other is a piezoelectric harvester for high-frequency vibration (named as PHH). Calculation and experiment mutually verify the recognition function. Besides, a non-resonant electromagnetic energy-harvester is involved into the system to enhance electric-generating for quick wireless transmission/alarming. In spot-test, the device is installed onto a defensive-fence. Two vibration-patterns of hand-shake and hammer-knock are clearly recognized by the self-powered wireless-sensing-node and the alarm messages are sent to a phone.

2. Design of energy-harvester array

2.1. Threshold-triggered harvesting

The designed threshold-triggered harvester [shown in Fig. 1(a)] can passively detect a certain vibration level, since the device can be triggered from idle-state into generating-state once the vibration-amplitude reaches the preset-threshold [11]. A U-shape copper micro-cantilever (Stage-1) is attached with a mass-block at the free end to respond to low-frequency (<100 Hz) ambient vibration. Another piezoelectric copper-cantilever (Stage-2), which is with a Lead-Zirconate-Titanate (PZT) piezoelectric thin-film bonded on top surface, is designed to feature much higher frequency (>100 Hz) for resonant electric-power generating. Stage-1 and Stage-2 mechanically couple with each other via repelling force between two magnets that are mounted at the end of the two cantilevers, respectively. Herein, the two magnets are laid along the same direction with each other to form repulsive coupling, as is denoted in Fig. 1(a) with the red/blue color. The magnetic barrier that is formed from the magnetic-repulsion induces the vibration threshold-triggered generating function. The voltage V_{out} can be generated from Stage-2 and outputted from the two electrodes of the PZT-film.

Fig. 1(b) illustrates the working principle of the threshold-triggered generating process. (i) Under no or weak vibration, the movement of Stage-1 cannot go pass Stage-2 to drive Stage-2 into resonance, since the weak movement cannot overcome the magnetic-repulsive force between the two magnets. Stage-2 can only keep static or very weakly vibrate around its equilibrium position that causes almost zero generating-power and V_{out}, thereby the harvester is trapped in the idle-state. (ii) Along with continual increase of external vibration strength, the response amplitude of Stage-1 increases accordingly until it reaches the critical point of the preset-threshold. (iii) Once the external vibration exceeds the threshold, Stage-1 will overcome the magnetic barrier to go pass and trigger Stage-2 into generating-state, where Stage-2 resonates at its high resonant-frequency to output high generating-power. Fig. 1(c) schematically shows the generated electric-power vs. acceleration. Once the excitation exceeds the preset-threshold, the high-efficiency generating-state can be considered as logic 1. Otherwise, the harvester is at null or low generating-efficient as logic 0.

2.2. Vibration-pattern distinction

As for many safety-protection facilities like the protection-fences, destroy or cross the fence is expected to be detectable. In order to distinguish different invasive behaviors and tell the difference between severe invasion and weak disturbance, two most frequently happened patterns of action on the fence, i.e., shake and knock, needs to be distinguished [1]. Our on-site experiment finds that shake to a fence mainly causes low-frequency sinusoidal vibration. In contrast, knock to a fence generally induces narrow acceleration-pulse that contains more high-frequency components. To distinguish the two vibration-patterns, both vibration acceleration and frequency should be taken into consideration