Regular paper

Journal of the KIECS. pp. 225-234, vol. 14, no. 1, Feb. 28. 2019, t. 93, pISSN 1975-8170 | eISSN 2288-2189
http://dx.doi.org/10.13067/JKIECS.2019.14.1.225

IoT 및 웨어러블 시스템을 위한 멀티 소스 기반 에너지 수확 구조

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Multi-Source Based Energy Harvesting Architecture for IoT and Wearable System

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요 약

마찰 나노 발전을 활용한 TENG(: Triboelectric nanogenerators)는 작은 진동에서 높은 변환 효율과 지속적인 전력을 얻을 수 있는 장점이 있다. 하지만, 마찰 전기 에너지 수집을 위해서는 비선형 에너지 추출 기술이 요구되며, 연결 인터페이스 회로를 통한 동기화 기반의 능동적인 스위치회로가 요구된다. 본 연구는 사람으로의 움직임으로부터 발생한 비선형(non-linear) 에너지를 효율적으로 저장하는 기법을 제시하였다. 또한, 개발된 보드는 서로 다른 방향으로 움직이는 동작으로부터 발생하는 에너지를 효율적으로 수확하고 저장할 수 있다. 본 연구에서 개발된 실리콘기반 압전기반의 TENG 셀과 다중모듈이 연결 가능한 에너지 하베스팅 보드의 측정하였다. 결과적으로, 다중입력 에너지 수집환경에서 안정적인 에너지의 저장 유지를 통해 약 49.2mW/count를 발전하였다.

ABSTRACT

By using the Triboelectric nanogenerators, known as TENG, we can take advantages of high conversion efficiency and continuous power output even with small vibrating energy sources. Nonlinear energy extraction techniques for Triboelectric vibration energy harvesting usually requires synchronized active electronic switches in most electronic interface circuits. This study presents a nonlinear energy harvesting with high energy conversion efficiency to harvest and save energies from human active motions. Moreover, the proposed design can harvest and store energy from sway motions around different directions on a horizontal plane efficiently. Finally, we conducted a comparative analysis of a multi-mode energy storage board developed by a silicon-based piezoelectricity and a transparent TENG cell. As a result, the experiment showed power generation of about 49.2mW/count from theses multi-fully harvesting source with provision of stable energy storages.

키워드

Triboelectric source, energy storage, energy harvesting, DC-DC booster, non-linear energy power
마찰 발전 소자, 에너지 저장, 에너지 하베스팅, DC-DC 부스터, 비선형 에너지 발전

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· 접 수 일 : 2018. 11. 22
· 수정완료일 : 2019. 01. 03
· 게재확정일 : 2019. 02. 15

· Received : Nov. 22, 2018, Revised : Jan. 03, 2019, Accepted : Feb. 15, 2019
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Ⅰ. Introduction

Energy harvesting (EH) related technologies is attractive as inexhaustible replacements for batteries of the IoT device, wearable device and have received intense research interest in recent years. The human motion is one of the main sources of energy for harvesting, and a wide range of motion powered energy harvesters have been proposed to the alternative wearable energy device platform [1-5]. The wearable energy device is an energy harvesting circuit and a capacitor-based energy storage saving system for the IoT device, and some also use capacitors instead of batteries to discuss the battery life-time problem. And then, wearable to use for selecting an appropriate harvesting architecture and dimension for its components, an effective method for system implementations is required. Advances have been made in miniaturizing EH devices to supply wearable devices by exploiting ambient energy in the form of human a motion, thermal gradients and sun light. However, the electric power output of those wearable energy harvesters varies from few microwatts or less, highly depending on the size of energy harvesters and sources. Unfortunately, when energy harvesters are small source, the harvest source cannot harvest energy received from the human motion that required for powering the wearable device. For this reason, it has a limitation in miniaturization of EH wearable device. The most important feature of the EH wearable device is energy conversion efficiency. In order to achieve sufficient efficiency, it is necessary to couple energy transducers with specific power conversion, management and store circuits, with very low power consumption on the EH wearable device. Accordingly, in energy harvesting systems, an energy conversion efficiency is very important essential to convert, store and adjust power from energy harvesting sources to loads such as the MCU. In this context, many energy conversion techniques and circuits have been developed in the last years [6-10].

In real-life of application environment, the design of a wearable device that relies on a single harvesting source can be quite challenging from human motion limits. The single harvesting source can exhibit long periods of energy shortage which users can use to the wearable device can be drastically reduced device life-time. In addition, wearable energy harvesting makes to the energy generation of mostly non-linear power generate. In most cases, the harvesters generate power in non-linear manner by human motion. In order to solve this problem, collecting energy from multi-sources turns to be a more reliable approach for powering wearable device. In detail, the wearable system that gives drive to be very low power, also referred to as multi-source energy harvesters based on solar, piezo, TENG source in low-power semiconductors. And for the most part, wearable energy harvesting makes to the energy generation of mostly non-linear power generate. In fact, realistic vibrations of structure and EH system to be monitored contain stochastic kinetic energies. On the other hand, for nonlinear EH system, superposition does not immediately hold. Specifically, the AC(:Alternating Current) power output from non-linear EH's are revealed to be substantially governed by a human motion. The EH's from human motion has been successfully harvested to power a small device. The non-linear EH from human motion attestation the potential functions to be constant with time [11-12, 14].

We suggest a design for circuit board prototype the capability to accomplish this in an accurate and efficient manner from an EHSS(: EH multiple Source and Store) electronic circuit in the EH system. Due to the non-linearity of certain classes of multi-fully energy harvesters, predictions of device performance under such complex excitation scenarios are easily achieved using principles of linear superposition by Store (as Capacitor). We validate the effectiveness of test in two ways. First, the non-linear EHSS from human motion attestation the potential functions to be constant with time with proposed multiple storage. Therefore, we implemented and experimented device platforms utilizing natural frequency of around 3~4Hz. Second, the practical implementation of nonlinear EHSS requires consideration of direct current (:DC) power delivery to the PMIC, in which case the non-linearities of the rectification circuitry can be neglected. We discuss the structure of the proposed integrated energy harvester and multiple store system in Section 2. It also discusses the monitoring environment used in this work to study and evaluate various energy harvester designs and result within Section 3. This is devoted to designing and analyzing the effect of parallel operation of multi-source and store energy harvesting system for effectively improving the energy harvesting. The design of multi-source store and their performance evaluation are presented in Section 4. The conclusions are summarized in Section 5.

Ⅱ. Multi-source and storage EH system architecture

2.1 Multi-source Energy Harvesting Techniques

In real environments, a TENG harvester energy is usually on the bottom of micro-watt that it is more than or equal to the same order of active power mode, and it varies considerably over time and is sporadic on some occasion. A harvested energy should be accumulated in a storage interaction over time and the store capacitor should be disconnected from the load during the energy accumulation stage to prevent energy leakage to the load. The store interaction is supposed to be connected to the load only if the accumulated energy is large enough to drive it. In addition to this means that the accumulated energy should be monitored all the time. In an EHSS system the functions Harvester supervisor, storage interaction, Energy Extraction, Voltage Monitoring and Switch Selection show in black are realized with power management or conversion block

2.2 Prototype EHSS system architecture

In case of a load device, after it completes data transmitting, data processing, transmitting, the store area should be disconnected again from load device for the next accumulating stage energy. The storage interaction is supposed to be connected to the load only if the stored energy is large enough to drive it. That is why we proposed to the structure shown respectively in Fig. 1. In Fig. 1 show, depicts a EHSS system architecture that is powered by multiple energy harvested. The Energy harvester's interaction with the motion environment is provided by EHSS system and the transducer power are processed and used by the AC-DC converter, capacitor, PMIC end device circuit. The flow of energy harvester of power energy shows in clearly separated from the UVLO (:Under Voltage Lock-Out) and the Cold Start Up signal shown in the black line.

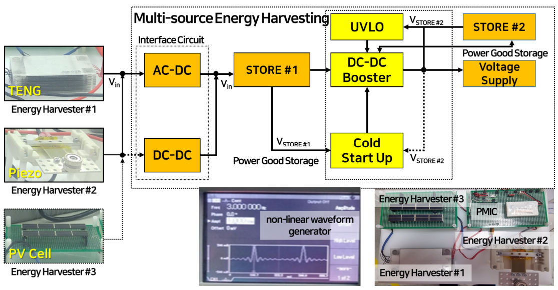

그림 1. 제안된 EHSS 시스템 구조
Fig 1. Proposed EHSS system architecture

The prototype model practitioner is involved with the yellow and orange color functional blocks that the Fig. 1 only conversion energy is explained in the following:

Interface Circuit Extraction, it is required that an AC-DC conversion as much energy from a harvester as possible. The AC-DC converter is used for efficient energy harvesting from the voltage generator output to a voltage that can be fed to the load such as MCU or sensor device. In this of the Energy Extraction, the AC-DC circuits are split into two parallel connected storage interaction and each of these Energy Extraction is charged and conversion for saving storage interaction

Store interaction, it is connecting several multiple capacitors in parallel. The store is measured using an under-voltage monitoring circuit which enable the function of the output harvester supervisor when the storage interaction is enough for converting to the output. An energy harvester behaves as a current source with a high internal resistance. The EHSS device with multi-capacitor energy storage does require more frequent charging than the battery system, but energy conversion efficiency is very high. If the STORE #1 pin voltage didn't reach the STOREVOUT maximum voltage, the path between the STORE # 1 and the DC-DC Booster is not connected with the Cold Start UP. This starter responds the switching frequency, which is constant for state operating conditions, and provides immediate link via the switch of block according to load change with the STORE #1 and 2 by charge state.

DC-DC Booster supervisor, the EHSS for recognizing two main phases in energy harvester functionality: energy charging/switching and output power-off/on. Harvester supervisor is the main function of choice of better power effective management from charging, save and conversion of energy harvester source. The harvester supervisor is blocking the function of the storage interaction when the stored energy is not sufficient for conversion. Conversely, it's an output energy when the stored energy is good for converting. For example, a depleted store element has been attached, the DC-DC booster that requires only microwatts of power to begin operating in cold-start-up mode.

Cold Start Up, it's a block that takes in reporting, a switch activates at a behavioral voltage as an element that provides a constant voltage when the storage voltage surpasses a certain level. If the storage interaction is over the limit-voltage changed, it will report to the DC-DC Booster as a powerful state. When a switch selection operates at high speed as a switching block, a store interaction is choosing different select switch depending on voltage monitoring with a Cold start of the store interaction. The Cold Start Up is closely related to usable-voltage in the store interaction. During the Cold start-up process, the UVLO block monitors the output voltage level at the store #1 and #2 element, and when the minimum operating value is reached, it sends a control signal to the DC-DC Booster to start its operation.

Voltage Supply, it is required to supply a convert voltage to a load by a micro-controller and a sensor. It is linked to the storage interaction and switch selection. And the voltage supply is related to switch connection time of the switch selection, it is related to current required by the load. The difference between the output voltage setting and the feedback voltage. For this kind of application, the voltage supply can be used as an always-on supply for the main system, such as an MCU and Sensor.

Ⅲ. Prototype EHSS system architecture

The EHSS board is stamped sized at 28x12mm. Despite the size an EHSS board is a complete system with a two-store interaction, AC-DC rectifier, DC-DC booster based on PMIC for TENG, Piezo source with energy harvesting.

In an EHSS hardware platform the functions: the EHSS device provides three distinct vital functions, (i) DC-DC Booster supervisor, (ii) Cold State Up, iii) Multi-Store. This is useful for several other configuration parts available to store interaction, energy extraction and voltage monitoring with multi-source EH. The voltage and current and the operation time of load block are measured. So, we need to know about energy consumption on the application platform. When checking the waveform of current in the VSTORE line is divided into parts.

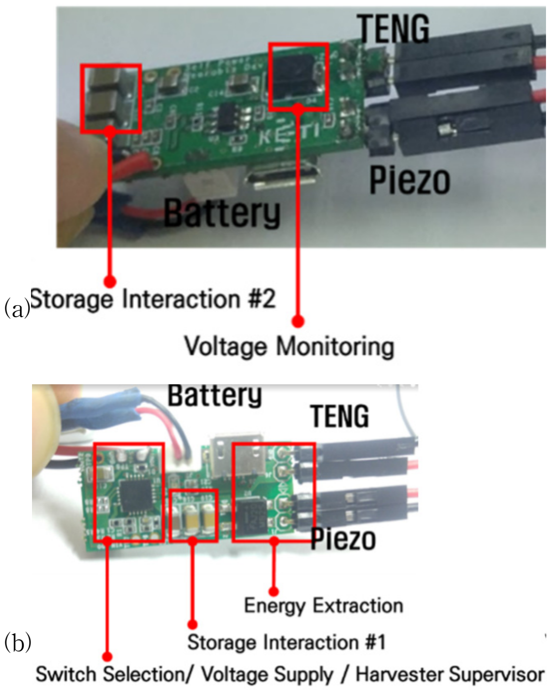

그림 2. 다중 하베스터 입력이 가능한 EHSS 하드웨어 모듈 (a) 모듈 뒤 (b) 모듈 앞
Fig 2. The EHSS hardware module with multi-Harvester inputs (a) front of module (b) back of module

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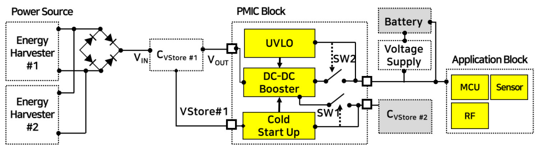


그림 3. EHSS 시스템 상세 구조
Fig 3. Detailed structure of the EHSS system

Comparison of configuration between Fig. 2 and Fig. 3 the same between them. As shown in Fig. 3, all the energy coming from two different sources is added in power form by connecting the output of individual non-linear regulators. The diode bridge of the EHSS system is that has a convert mechanical energy into electric AC voltage, and a set of energy harvesting circuit that converts the AC voltage into regulated DC(Vin) input. The first store First store interaction (as external capacitor) is used to store the energy and stabilizing the DC-DC booster. Second store interaction, the stored energy will be used to power external user loads when sufficient amount of energy has been accumulated. This proposed hardware is configured by default to PMIC, multiply-capacitor, bridge rectifier and n-mosfet. The PMIC is functioning as (i) DC-DC Booster supervisor, (ii) Cold State Up,

iii) UVLO. This PMIC has a power gating switch, SW1 and SW 2 for the application block. The TENG and Piezo interface is functioning as energy extraction. The bridge rectifier function is AD to DC voltage conversion. The store interaction consists of two areas parallel construction of the multiply-capacitor. First store interaction is power charged of electric energy generation by TENG and Piezo harvester. It is voltage reaches maximum voltage, the path between the first storage is connected by the PMIC. The internal SW1 is switched by the secondary store in PMIC, this is store space of secondary store interaction is more than double. This PMIC has a switch, SW2, for charging the capacitor efficiently. After starting up the internal circuit of the PMIC, the path between the voltage monitoring mosfet and the Store Interaction #2 is connected by the SW2. When the store integration #1 voltage reaches a threshold maximum voltage, the SW2 connects the path. When the store integration #1 voltage reaches the VIN reconnect under minimum voltage, the SW disconnects the path.

Ⅳ. The EHSS hardware solution test

The harvester switching frequency for this circuit was experimentally determined to be about 3 ~4Hz. A recent study found [12,13,15] that most EH generate the step frequency (around 2.7 Hz at 4.8 km/h) being the fundamental one. This figure's analysis and measurement how proposed system behaviors influence EH performance. The EHSS measuring system consists of a vibrator, vibrator controller and DMM analyzer. Before presenting the non-linear harvester proposed method, it is useful to provide an estimation of the electrical power that can be produced from a given human mechanical stimulation for the experimental testing by using the vibrator. As show Fig. 4, an easily-measurement approach consists in considering the power provided by a hypothetical inertial non-linear vibrator and controller undergoing the same mechanical stimulation. The input source is AC or DC; a diode rectifier converts an AC voltage at the input to a DC voltage at the output. Since the inputs and outputs are DC, then you can use a DMM(:digital multi-meter) to measure the input voltage and input current and calculate input power. But be warned, it has to be measured as a whole on the basis of the same time to compare the results among measurement equipment. Provided that experimental harvester-source measurements are performed while characterizing a vibrator, its performance can be assessed by comparing the experimental output power with the simulated output power of the "equivalent" no-linear vibrator controller.

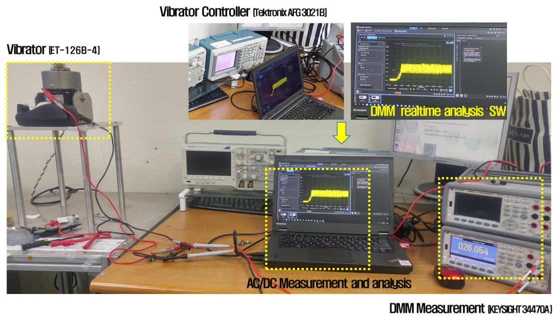


그림 4. 측정과 분석을 위한 EHSS 시스템 구성
Fig 4. the EHSS system configuration for measurement and analysis

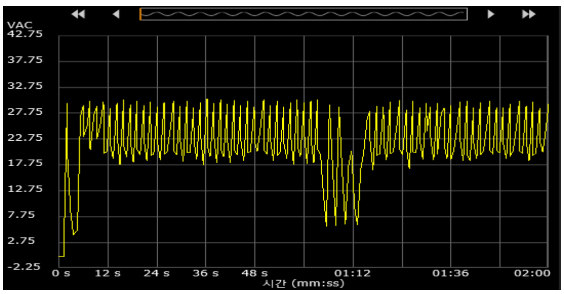


그림 5. EHSS에 연결된 하베스터들의 전압 측정
Fig 5. Circuit measurement of an input voltage on the EHSS with harvesters

Fig 5 shows the input voltage of various energy harvesters based on the EHSS system. As shown in Fig. 5, it shows constant power generation that have certain characteristics in common. Fig. 6 shows ac-dc conversion power as a function of the excitation level. Furthermore, the relations between the harvester input power and store interaction #1 are measured and shown as Fig. 6. The store integration #1 voltage charging is graphed in fig. 6. Due to the nature of the capacitor, the charging slope is proportional to the input harvester generation.

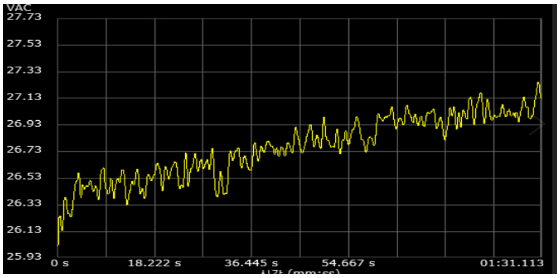
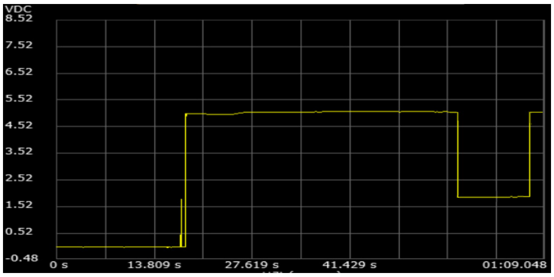
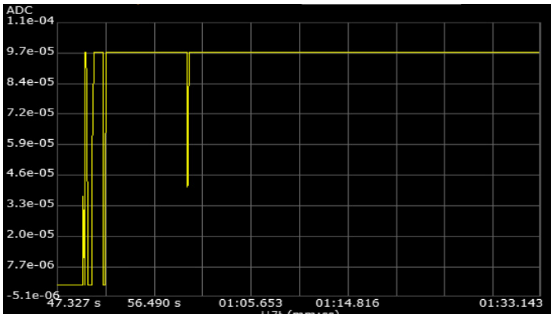


그림 6. 하베스터로부터 저장되는 저장소 #1의 전압 변화
Fig 6. Voltage change of the STORE #1 stored from harvester source.

Fig. 6 shows, a power wave is produced when a voltage slowly increases with time as a yellow line. When the input power increases the proposed EHSS system remains advantageous, even if less efficient, for a range of input harvester voltage up to the Store Interaction. The store voltage at store interaction #1 is 27.13V, and the voltage at store interaction #2 is 4.70V, which is 1/5 of the storage interaction voltage. The trace shows the capacitor voltage when same output the store integration #1 and transfer input PMIC voltage. Shows that as the storage interaction#1 is decreased above voltage, the current power increases. This proposed multi-stage store reduces the voltage under at load steps from light to heavy load. As a result, this is an equal energy power of storage interaction#1and storage interaction#2 in the EHSS. The Circuit measurement result was performed with yellow line shown Fig. 7. Startup time-domain waveform. The voltage has negligible negative peaks. At a harvester energy of store interaction#2 voltage is 4.60~4.70V and the current is 0.965mA. The total power, output power level peaked at 4.4~4.5mW/s and so the output power will be transferred for the load in the PMIC. In 60 seconds, the store integration #2 an energy corresponding to a total energy of about 260mW(at 4.4~4.5mW/s × second).



a) 2차 저장소의 전압 변화
a) Voltage changes of the STORE #2 stored from harvester source.



b) 2차 저장소의 전류 상태
b) Current changes of the STORE #2 stored from harvester source.

그림 7. PMIC로 인해 저장되는 저장소#2의 DC 전압과 전류의 변화
Fig 7. Change DC voltage and current states of the STORE #2 stored from the PMIC

This means that on average, each harvester generated 4.3mW/s (current × voltage / 60 second) at one second. Fig 8 and 9 shows a result of this output current and voltage. The PMIC voltage at the output is 3.28V, and the current output is 15mA. At the same time, the energy conversion efficiency can be calculated by final output of the PMIC. The PMIC provides a final output supply that energy corresponding to a total energy of 136.92mW/min

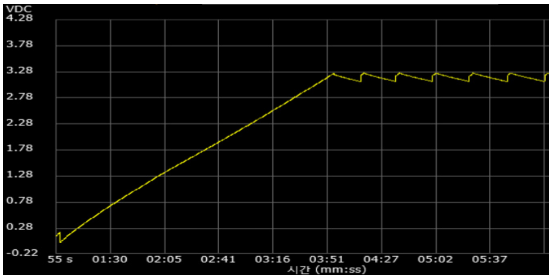


그림 8. PMIC에서 최종 출력되는 DC 전압 변화.(3.28V 출력)
Fig 8. The DC voltage change states of ultimately output from the PMIC (swing out 3.28V)

그림 9. PMIC를 통한 최종 출력
Fig 9. The PMIC output current status

Fig. 7, 8, and 9 show the results, a power converter's efficiency can be calculated that divide store #2 power into last output power. This platform a power converter's efficiency is determined by comparing its store #2 power to its last output power. Therefore, the energy efficiency is described as 52.6%. We proposed that two stage energy storage schemes with 52.6% tracking efficiency is also introduced. This means that on average, each harvester generated 2.3mW. If a human subject worm walking and slow running on a 3~7km/h, the power output of EHSS between 2.3 to 4.3mW. We will have to get used to device that the energy harvester to power the IoT device to work in limited duty cycles. As a result, we will develop new IoT devices based on energy harvester. This proposed PMIC is an ultra-low quiescent current, high efficiency step-up DC-DC converter. Maximum load is reached when this discharge time has shrunk to the Maximum allowed value store #2 as shown charging current of Fig. 9. The store integration #2 shows, the power level rms(:root mean square) current about 0.965mA. In additional, the PMIC shows a maximum peak voltage is less than 3.28V when the load current is 15mA.

This proposed method has demonstrated used of two step energy efficient, saving systems better performances than the classical one store solution for changing voltage. In fact with these signals the peak voltage is lower than the PMIC operation or conversion threshold voltage and the storage interaction can efficiently transfer any power to the load.

Ⅴ. Conclusion

This paper introduced the basic structure of energy, capacitance, and charging time for an energy harvesting application based on self-powered system. The most important to be gained from this wearable EH is to figure out a balance of charge energy with energy consumption. In this paper a new energy harvester device is presented. We also present the result of an experimental validation on a prototype EHSS board. The EHSS idea avoids the use of two step storage interaction as not limits voltage threshold. The prototype EHSS system generated 2.3 to 4.3mW when placed in the simulate vibratory system which was worn walking and slow running(2~4Hz). These results indicate that a useful amount of voltage and power could be generated from the human body vibration. This device is optimized such as the TENG and the piezoelectric generator source. By simply using the voltage reading of the store integration at 2 to 4Hz, the store integration is able to daily activities with 52.6% energy conversion efficiency. In fact, this is an issue that must be addressed with microwatt power energy harvesting systems in which the dimension shrinkage will. The working principle has been confirmed through extensive experiment environment. Further work is in progress in order to develop an integrated IoT system.

감사의 글

본 논문은 2018년도 산업통산자원부 및 산업기술평가관리원(KEIT) 연구비 지원에 의한 연구임 (‘10065730, 웨어러블 디바이스용 플랙서블 전원 공급 모듈 및 장치 개발’)

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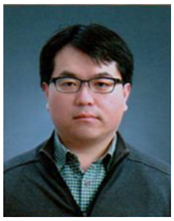

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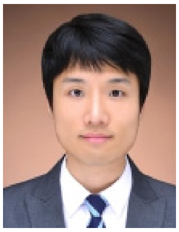

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