Energy Harvesting Sensor Node Toward Zero Energy In-Network Sensor Data Processing

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Abstract. In this paper, we aiming to realize near-zero energy distributed IoT systems that do not need a battery, we design and implement a novel energy harvesting (EH) sensor node. The proposed EH sensor node consists of a solar panel, an energy charging/discharging circuit and a SenStick, an existing sensor node including 8 different types of sensors and BLE communication interface. We demonstrate that the proposed EH sensor node works in an indoor environment by harvesting power from indoor lights, periodically measuring sensor data (temperature, humidity, atmospheric pressure, UV, and illuminance) and by sending the data by BLE communication. The received information is visualized through a web application running on a PC.

Keywords: Internet of Things (IoT) · Wireless sensor networks
Distributed processing · Energy harvesting · PV system

1 Introduction

In recent years, thanks to the advancement of MEMS (Micro Electro Mechanical Systems) and wireless communication technologies, Internet of Things (IoT) has been attracting considerable attention. Cisco predicted that 50 billion things would be connected to the Internet by 2020 [1]. IoT devices will come into popular use in various environments such as homes, buildings, towns, and so on. On the other hand, new issues such as dramatic increase of data traffic and power consumption by those IoT devices arise. The left side of Fig. 1 shows the outline of the centralized architecture. At present, most of the IoT-based services are realized based on the centralized architecture at cloud servers. In the centralized architecture, however, each IoT device uploads data to the cloud server and data is processed on the cloud and finally, the result is delivered to the user. Accordingly, not only does the user suffer from large delays to get the service but also the data traffic to the cloud as well as the power consumption of the cloud is quickly growing.

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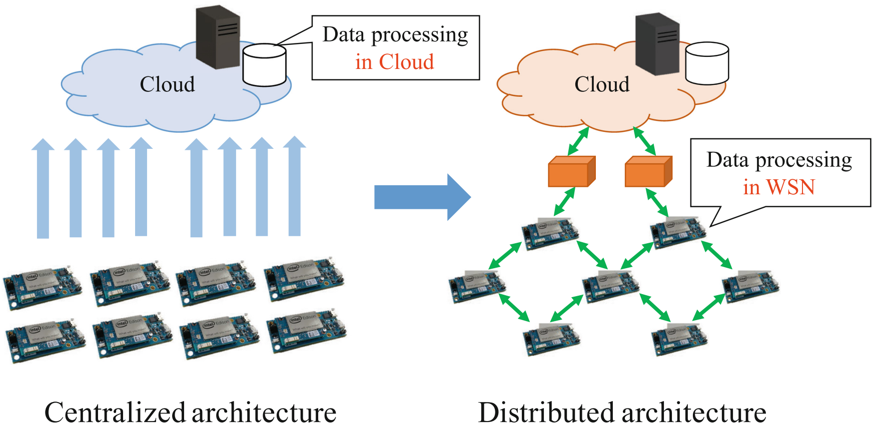

Fig. 1. Data processing architecture

To solve this problem, distributed edge/fog computing architectures have been proposed such as IFoT [2] and DIAT [3]. The right side of Fig. 1 shows the outline of the distributed edge/fog computing architecture. In the distributed architecture, since data is processed in the wireless sensor network (WSN), only the result of processing is uploaded to the cloud, leading to a reduction in bandwidth and power consumption to/at the cloud. On the other hand, the distributed edge/fog computing architecture needs processing at sensor/IoT nodes which are typically driven by a battery. How to reduce the power consumption at sensor nodes is an emerging issue to be solved.

Energy harvesting is an important technique to solve this issue. Sensor nodes that generate power by harvesting energy have been released [4], but many of them use CPUs with low processing performance to reduce power consumption. In the distributed architecture, the sensor node processes and learns data. Therefore, the sensor node is required to have high processing performance and wireless communication capability. As a result the power consumption increases. Also, we must assume both indoors and outdoors use.

In this paper, aiming to realize near-zero energy distributed IoT systems, we design and implement a novel energy harvesting (EH) sensor node. The proposed EH sensor node consists of a solar panel, an energy charging/discharging circuit and SenStick [5], an existing small sensor node that embeds 8 different types of sensors, a relatively high performance processor, and BLE communication interface. In the demonstration, we show that the proposed EH sensor node works in an indoor environment by harvesting power from indoor lights, periodically measuring sensor data (temperature, humidity, atmospheric pressure, UV, and illuminance) and by sending the data by BLE communication. The received information is visualized through the web application running on a PC.

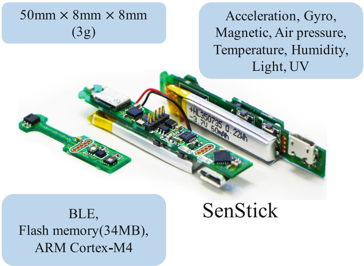

Fig. 2. Overview of SenStick

Table 1. Energy harvesting sources

Harvesting method	Power density
Solar cells	15 mW/cm^3
Piezoelectric	330 $\mu W/cm^3$
Vibration	116 $\mu W/cm^3$
Thermoelectric	40 $\mu W/cm^3$

2 Development of EH Sensor Node

2.1 Survey of EH Technology and EH Sensor Node

Energy harvesting is a technology that converts natural energy sources such as light energy, mechanical energy, thermal energy, and environmental radio energy into electrical energy. The energy harvesting technology allows us to reduce the cost of charging and/or replacing rechargeable batteries used in the system. Therefore, energy harvesting technology has drawn attention in the field of sensor networks [6]. Table 1 shows some popular energy harvesting sources [7]. The solar cell has the highest power generation capacity compared to other methods. IoT devices need stable electric power supply both indoors and outdoors. Therefore, we use the solar cell as an energy source for the proposed EH sensor node.

Next, we describe the EH sensor node. Data processing and wireless communication capabilities are required in each node of our target distributed edge/fog computing architecture. It is also desirable to be compact and power-saving. Sensor nodes that generate electricity through energy harvesting are available [4], but many of them use CPUs with low processing performance to reduce power consumption.

Therefore, we use a comprehensive sensor node called SenStick [5]. Figure 2 shows the overview of SenStick. SenStick is an ultracompact and low power consumption node, which has BLE (Bluetooth low energy) connectivity and ARM Cortex-M4 as a micro control unit. Eight different sensors: accelerometer, gyrometer, magnetmeter, illuminance, pressure, temperature, humidity, and UV sensors are embedded in a tiny board with the size of 50 mm (W) $\times$ 10 mm (H) $\times$ 5 mm (D) and the total weight is around 3 g.

2.2 Design and Implementation of EH Sensor Node

In this demonstration setup, we use Intel Edison equipped with Intel Atom as a processing unit which processes the sensor data received from the EH sensor node. Since SenStick has ARM Cortex-M4 as CPU and it can perform simple data processing, our EH sensor nodes will be able to directly form a mesh network and process the sensed data by distributed processing among them in the future.

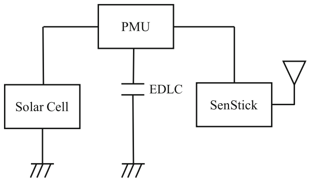

Fig. 3. Circuit diagram

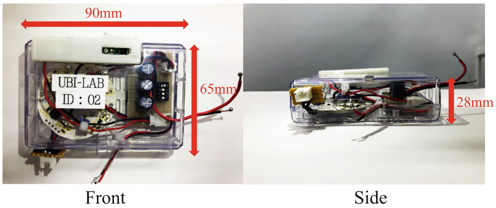

Fig. 4. Overview of the EH sensor node

Table 2. Operatin result of EH sensor node

Illuminance (lux)	Operating interval (min)	Operating time (min)
450–560	100	1
850–980	30	1
4500–5500	5	1

It is difficult to continuously operate EH sensor nodes in an indoor environment even with solar cells [8]. Therefore, we developed a system to intermittently operate EH sensor nodes. Figure 3 shows the circuit diagram of the proposed sensor system. In the intermittent operation, first, the electric power converted by the solar cell is charged in the battery (capacitor). When electric power is charged enough to activate the sensor node (SenStick), the system discharges the power and activates the sensor node. When the electric power becomes insufficient to drive the sensor node, electricity is charged in the capacitor (rechargeable battery) again. These charging and discharging operations are repeated. Power control is performed by the PMU (Power Management Unit). EDLC (Electric Double-Layer Capacitor) is used for the battery because frequent charge and discharge operations have no influence on the electrode and its cycle life is long.

The EH sensor node developed based on the above design is shown in Fig. 4. We also have a video demonstrating, how EH sensor node works[1]. The size of the device is 90 mm (W) × 65 mm (H) × 28 mm (D). To easily change the battery capacity, three EDLCs of 1 F are connected in parallel as the storage battery. When the EDLC voltage exceeds 2.55 V, it is boosted to 3.6 V by the DC-to-DC converter, and the EH sensor node automatically starts sensing. The EH sensor node stops and recharging when the EDLC voltage drops to 1 V.

When the processing unit (Edison) detects BLE advertisement of the EH sensor node, it establishes a connection and receives data. It is possible to connect with multiple EH sensor nodes, process data and upload the result to the cloud according to the situation.

The operation result of the EH sensor node measured by preliminary experiment is shown in Table 2. The measurement was carried out with three luminance patterns of (a) 450–560 lux (dark indoor), (b) 850–980 lux (bright indoor), (c)

[1] Operation of the EH sensor node: https://youtu.be/_NsDvc8eiXE.

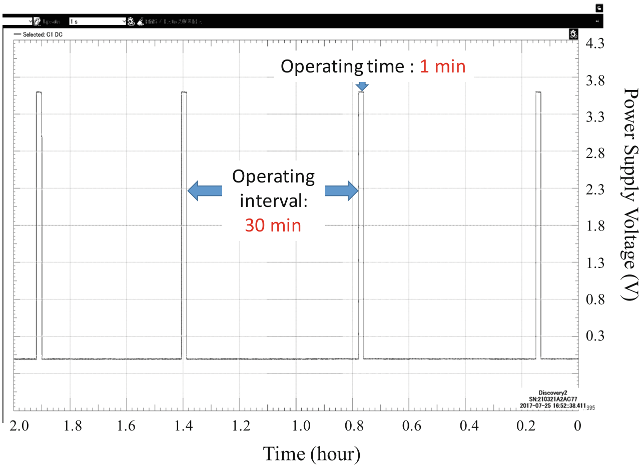

Fig. 5. Operation result of EH sensor node (850–980lux)

4500–5500 lux (near a window at the cloudy weather outside), and the shortest operation interval and operation time were confirmed. As a result of measurement, the operation intervals under each condition were (a) about 100 min, (b) about 30 min, (c) about five minutes. Also, the operation time was about one minute in all conditions.

The operation result at (a) is shown in Fig. 5. It was confirmed that about one minute operation can be repeated at an interval of 30 min. We also confirmed that the acquisition of sensor data by the processing unit was successfully done within the one minute operation time.

3 Demonstration Description

In the demonstration, we show that the proposed EH sensor node works in the indoor environment by harvesting power from indoor lights. Specifically, the EH sensor node periodically operates to acquire environmental information such as temperature, humidity, atmospheric pressure, UV, and illuminance. The acquired information is transmitted to the processing unit by BLE communication and uploaded to the cloud server. On the cloud side, the status of the current room is displayed by the web application. In addition, if an anomaly situation is detected, an alert is displayed.

4 Conclusion

In this paper, we designed and implemented a novel EH sensor node to realize near-zero energy distributed IoT systems that do not need a battery. In the demonstration, we showed that the proposed EH sensor node works in the indoor environment by harvesting power from indoor lights and periodically measures sensor data and sends the data by BLE communication. The received information is visualized through the web application running on a PC. In this demonstration setup, we used the Intel Edison as a data processing unit that receives the sensor data from our EH sensor node. For future work, we plan to implement mechanisms for a simple data processing and mesh-networking in the EH sensor node so as to realize in WSN processing with only EH nodes.

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