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Battery-free smart-sensor system for real-time indoor air quality monitoring

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ABSTRACT

Indoor air pollution is one of the serious issues that affect public health nowadays. Therefore, indoor air quality needs to be monitored by a real-time system for early air pollution warning. Until now, most wireless sensors used for air quality monitoring have required power supply from a battery for sensor operation and wireless data communication. This battery, which is attached to a sensing module, makes the wireless sensing module larger and requires regular replacement efforts and high costs. The present study proposes a novel battery-free sensor module to measure the concentration of volatile organic compounds, ambient temperature, relative humidity, and atmospheric pressure for monitoring air quality in indoor environment. The proposed system comprises a smart-sensor tag, and a radio frequency (RF) energy harvester. The sensing circuit, designed using ultra-low power sensors and a microcontroller unit (MCU), consumes low average power of only 0.5 mW. The MCU collects data from the sensors and writes the sensing data to the memory in the form of an Electronic Product Code (EPC) Class 1 Generation 1 compliant identification (ID) of the tag. The RF energy harvester with a highly efficient buck–boost converter and a 50-mF supercapacitor for real-time saving of the collected power can sufficiently collect the available RF energy from the reader within a maximum distance of ~250 cm from the reader to supply power for sensing and wireless communication operation of the smart-sensor tag. Therefore, the proposed smart-sensor module can be a battery-free sensor device for monitoring environment parameters in indoor condition. Experiments are conducted to validate and support the developed system for real-time air quality monitoring and warning.

1. Introduction

Indoor air quality (IAQ) is one of the critical factors that affect the health, safety, and comfort of occupants. Nowadays, indoor air pollution is a growing concern, and people are paying more attention to air pollution as an issue of global warning because individuals spend ~90% of their time indoors [1]. Temperature, relative humidity, and atmospheric pressure are factors considered for evaluating IAQ. However, the most important factor is the volatile organic compounds (VOCs) that are produced from building materials such as paints, solvents, and composite wood products as well as activities such as cooking, smoking, using wood-burning stoves, and reading newspapers [2]. Detecting VOC gases with low-concentration odor is difficult, and other VOC gases are odorless. IAQ problems lead to many symptoms, including headaches; dizziness; and irritation of eyes, nose, and throat; etc. Further, they increase the risk of cancer, liver, and kidney damage, etc. [3]. Therefore, a good solution for early warning of air pollution needs to be developed.

Recently, IAQ monitoring devices that can operate as an individual sensor node or a node in a wireless sensor network have been developed [4–6]. Some good studies that can measure CO, CO_2, VOC, temperature, relative humidity, etc., with low cost, compact size, and low-power consumption have been conducted [7–9]. However, the IAQ monitoring devices consume much power for sensing and wireless communication operation; therefore, the abovementioned devices require a battery to power the system. Moreover, these sensor devices simultaneously measure the sensing signals; thus, the power sources must supply power to all sensors at the same time. Hence, the sensor systems require that their battery be replaced after a short time.

To overcome the limitations of the typical battery-powered sensor module, we propose a novel battery-free smart-sensor module for an IAQ monitoring system. Realizing an IAQ monitoring system without extra power source or battery is a big challenge. This study proposes a battery-free sensor device to monitor IAQ in real time. The proposed sensor system consists of three main com-

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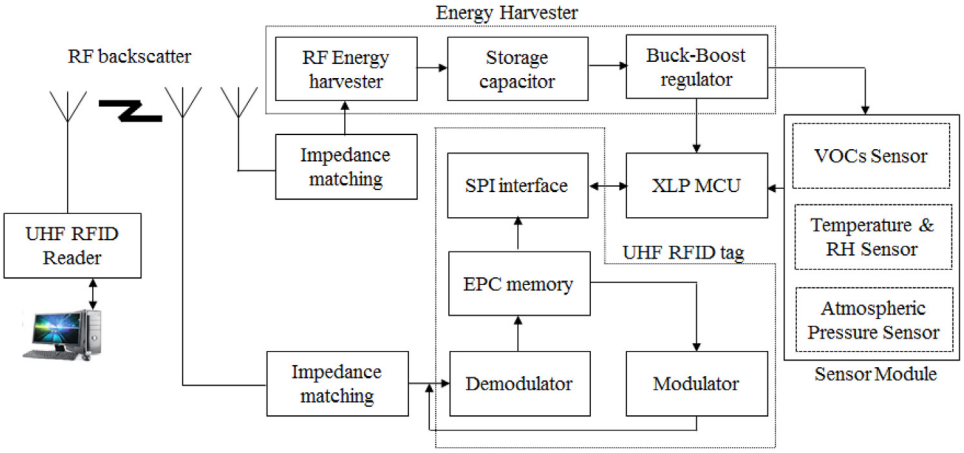

Fig. 1. Block diagram of the proposed battery-free smart-sensor system.

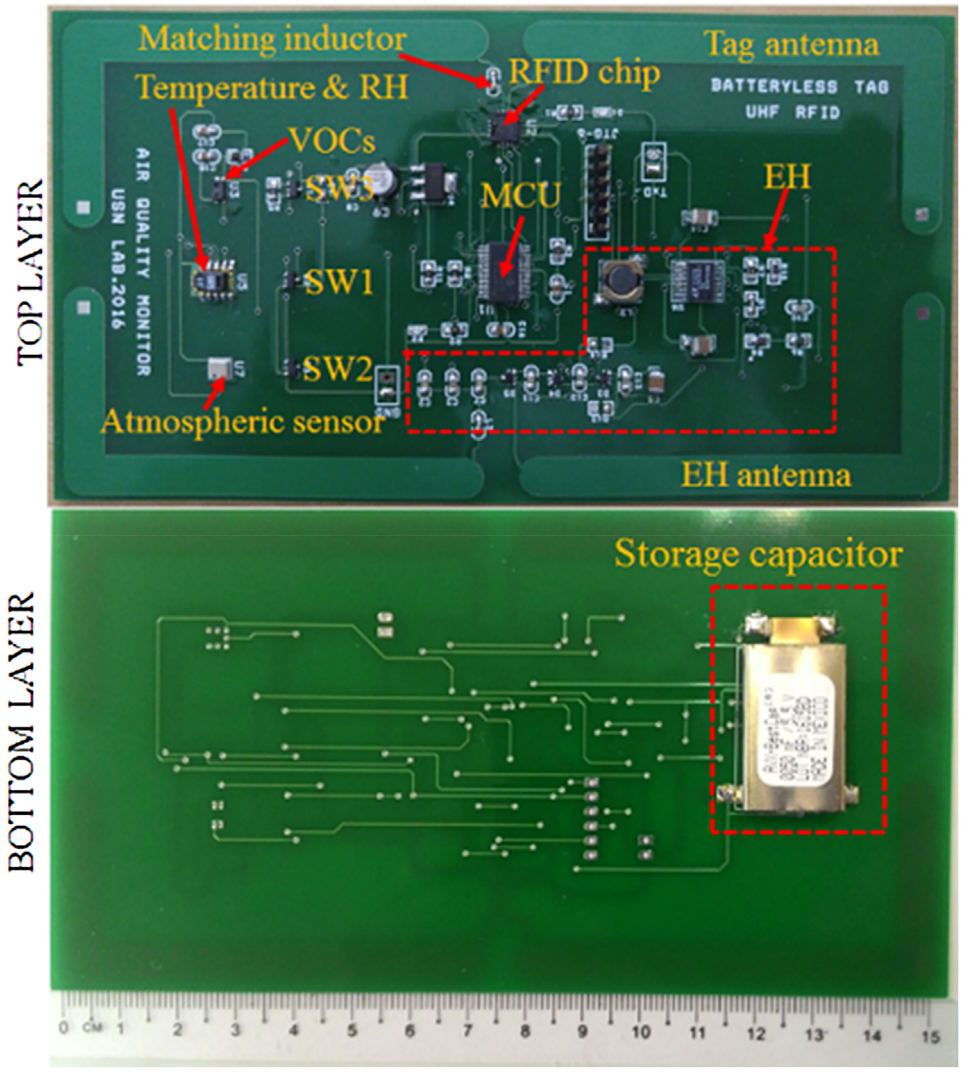

Fig. 2. Photograph of the smart-sensor tag, including the top and bottom layers.

ponents: a fully passive ultra-high frequency (UHF) smart tag for communication with an UHF radio frequency identification (RFID) reader, a smart sensing module with ultra-low power sensors and a microcontroller unit (MCU), and an RF energy harvester. The smart sensing module can collect with high accuracy a wide range of VOCs, temperature, relative humidity, and atmospheric pressure.

The rest of this paper is structured as follows: Section 2 presents the design and implementation of the sensor system, Section 3

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