Self-powered wireless sensor node for flow and temperature sensing

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Abstract. This paper presents the implementation and test of a self-powered wireless sensor node using enhanced triboelectric nanogenerator (E-TriG) as both energy harvester and wireless sensor node for flow rate and temperature detection. RF microcontroller with low power consumption is included for data conversion, signal processing and wireless signal transmission. The flow-rate detection is based on the maximum voltage of a capacitor, which is charged by E-TriGs during certain period. Experiment results show that this flow sensor is capable of detecting flow rate from 5.8 m/s to 17.3 m/s with a standard deviation of 0.3% and the temperature of 24.2 °C (±0.3 °C) in the actual test. Each operation requires less than 40 ms for data sampling, processing and transmission. With a Raspberry Pi, the wireless signal can be received and delivered to Internet and therefore, can be monitored easily from any portable terminal with internet-access.

1. Introduction

Energy harvesting devices have been recently developed to provide power supply for wireless sensors with low power consumption [1-2]. Power has been generated from thermal source [3], vibration source [4-5] and wind flow [6-8], at a range from nW to mW. Due to the fact that the energy generated from triboelectric nanogenerator is irregular and insufficient to directly power the embedded chip, a power management circuit combined with a large capacitor is typically needed [9].

Temperature and air flow monitoring are important for smart buildings, especially for a central air conditioning system. Herein, we proposed a self-powered wireless sensor node with compact size, short preparation time (including analog to digital conversion and signal processing) and low power consumption. A temperature sensor is embedded with the power management chip. Furthermore, triboelectric generator (TENG) is used not only as a power source, but also a flow rate sensor in this design. With this design, two different types of sensor can be integrated into the same node with self-powered wireless sensing function, which could be explored to more environmental information monitoring in the near future. The flow rate and temperature sensor node could be helpful to adjust the energy distribution and task allocation problems between different nodes in a more reasonable way.

2. Method

The power management circuit rectifies the output voltage from nanogenerator, stores that energy in
Figure 1. Principle of TENG devices. A soft film driven by wind periodically contacts the top/bottom layer. These layers and the soft film are fabricated with special material so that when they contact, the surface potential changes due to triboelectric effect. As a result, the voltage across the top/bottom layer and film serves as a voltage source.

Figure 2. (a) Four TENGs are used in our experiment, (b) wireless sensor node with power management circuit, flow detection capacitor and MSP430 chip are shown in the bottom, server (raspberry pi) plus a receiver are shown on top.

Full experiment setup is shown in Figure 2. Four E-TriGs were used to charge for storage capacitor, power management accumulated the energy until it reached a certain voltage. Then power management would release part of the energy for sensing process. Two MSP430s with ultra-low power consumption were used as transmitter and receiver Micro Controller Units (MCUs), respectively. The transmitter can read and send both the flow sensor signal and temperature sensor data simultaneously. Although four E-TriGs are used here to power the sensor node more efficiently, it is also possible to use fewer devices except that a longer charging time would be required.
mainly consists of a rectifier bridge and a Ch1-flow capacitor, while all the rest part of the circuit can be seen as an equivalent load resistor R.

3. Discussion and experiment result

Figure 4 demonstrates the charge and discharge cycles during operation. When the storage capacitor (yellow line) starts charging, the voltage of flow detection capacitor (blue line) remains stable. This voltage is what we called $V_{\text{max}}$. Once the energy stored in that capacitor is enough to power MCU and data processing, MCU can read the voltage of flow detection capacitor ($V_{\text{max}}$). The ADC process only takes less than 35 milliseconds so that any disturbance, which might due to the variation of equivalent resistance between MCU input ports, can be ignored. Theoretical study about the relationship between air-flow rate and maximum power output of TENGs has been conducted in [12], which gave the formula below:

$$\frac{V^2}{R} = P_{\text{max}} = K \times U^3$$  \hspace{1cm} (1)

Here, $U$ is the flow rate, and $K$ is a coefficient related to the material, structure and size of nanogenerator. $P_{\text{max}}$ is maximum power output of TENG when TENG works in the steady state at a certain flow speed. The voltage $V$ across the capacitor of equivalent circuit remains unchanged at steady state when the generated power equals to the consumed power.

According to the analysis above, we may use

$$V = A \times (U^2) + B$$  \hspace{1cm} (2)

to fit the test results. Moreover, due to the noise from measurement, a constant $B$ is added to the data fitting model.

Quadratic relationship, therefore, can be achieved between maximum voltage and flow rate, which has been presented in Figure 5. According to the model for generated power, the test results from a few cycles were fit as the red line and the standard errors were also shown in the Figure 5. For faster calculation and data fitting from the MCU at lower power consumption, a linear model can also be used instead of Equation 2. The dash line in Fig 5 shows the fitting result with acceptable accuracy, especially for high flow rate range, as shown in the inset table bottom-right. The prototype application of this wireless sensor node is shown in Figure 6. This sensor node can send out 12 signals per an hour. According to the measurement, the temperature data fluctuates in a normal range at 24.2 °C ($\pm$ 0.3 °C). When we gradually moved the wireless sensor node towards the air blower, the flow rate was increased from 9.7 m/s to 13.2 m/s during half an hour, which agrees well with the previous results shown in Figure 5.

4. Conclusion
This paper presents a self-powered wireless sensor node with both temperature and flow rate detection. With electret enhanced triboelectric nanogenerator, the quantitative relationship between air-flow rate and maximum voltage of charged capacitor has been studied, with implementation details, power consumption, preparation time, and accuracy evaluation. With the self-power supply, this wireless sensor node could be promising for large scale network application in smart building and smart city.

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