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Abstract

A Low-Cost, Self-Powered, Plantar Pressure Distribution Sensing Insole †

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Abstract: Energy-autonomous wireless sensors are a promising solution for developing wearable medical, lifestyle- and performance-monitoring systems. This paper presents a low-cost, low-power and self-powered wearable intelligent pressure monitoring system based on flexible piezoresistive sensors. The encapsulated insole with an 8 × 2 sensor matrix is powered by a flexible solar panel and connected to a rigid electronic board. Data acquisition occurs via Bluetooth low-energy transmission (BLE), and the average power consumption of the insole is 113 µW.

Keywords: low power; smart insole; Bluetooth low energy; piezoresistive sensors; plantar arch

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1. Introduction

Nowadays, using smart insoles to monitor plantar motion is becoming increasingly important. These insoles are renowned for their importance in the sport and medical fields [1]. Some devices are already commercially available (Moticon, Pedar, F-scan etc.); however, these solutions are lacking in terms of energy consumption, comfort, cost and mechanical robustness. Thus, researchers are making significant advances in the development of this kind of device [2]. In this context, the study of a low-cost, low-power and self-powered wearable intelligent pressure monitoring system based on flexible piezoresistive sensors is presented in this paper. A synoptic diagram of the system is presented in Figure 1.

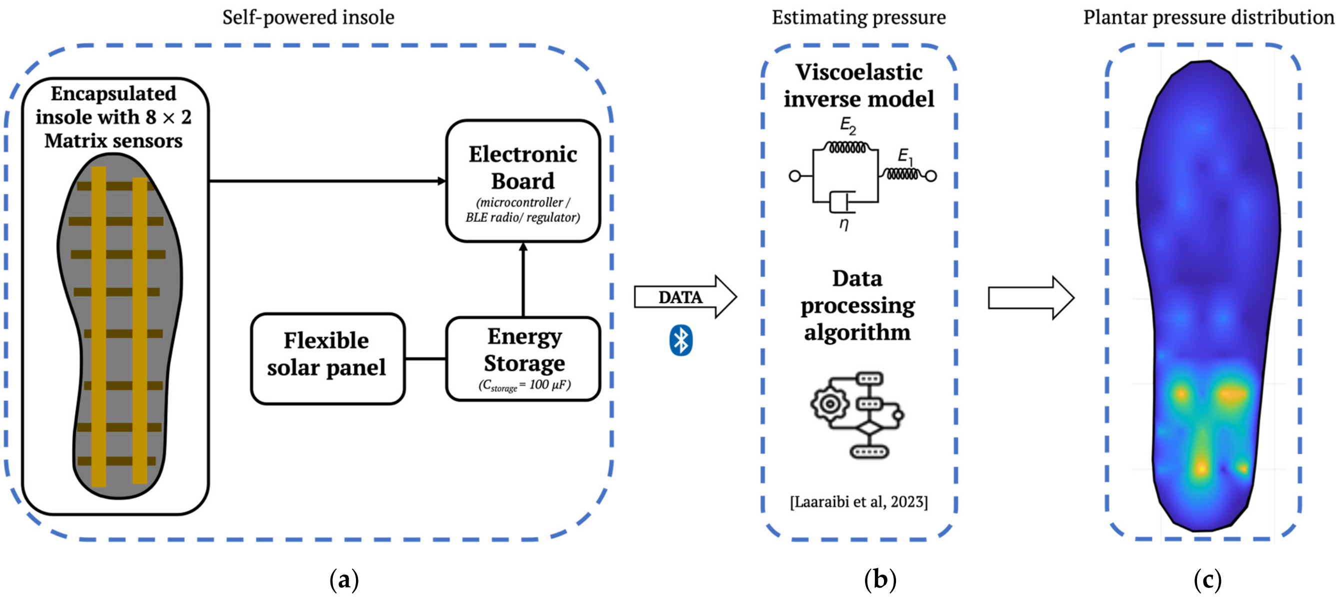

Figure 1. System diagram. (**a**) Self-powered encapsulated insole using a flexible solar panel; (**b**) inverse viscoelastic model [3]; (**c**) plantar pressure distribution sensing.

2. Materials and Methods

To measure pressure distribution throughout the foot, we design an insole with an 8 × 2 sensor matrix [3]. The structure of this insole is multi-layered, with a single layer of carbon black (Velostat). The electrode structure is based on lines on one side and on columns on the other side of the Velostat layer, as shown in Figure 1a. We then sufficiently measure the resistance between the lines and columns, mainly at the intersection to measure the change in resistance due to applied pressure. The insole is encapsulated in a 27 cm size shoe mold with flexible and biocompatible polydimethylsiloxane (PDMS), RTV 615, to protect the electrode and insole from external influences, such as moisture, mechanical stress, fluctuating voltage, temperature and vibrations.

The insole is connected to an electronic board. Data acquisition is performed using an Arduino nano 33 BLE device, and the data are transmitted through a BLE radio integrated within the microcontroller. The electrical energy provided by the flexible solar panel (MPT3.6-150 PowerFilm©, 100 mA@3.6 V) is stored in a capacitor called $C_{storage}$, which powers the entire electronic board (V_{stor}).

The collected data are processed with a computer using an inverse viscoelastic model [3] to estimate the plantar force. The error of the measurements is below 2% of the full scale.

3. Discussion

Figure 2 shows the voltage V_{stor} across the capacitor $C_{storage}$ using a PV panel to provide indoor lighting. The value chosen for this capacitor was 100 µF to allow a margin and extra energy capacity to supply the whole system, and I_{syst} represents the current flowing through the system.

The developed smart system features power consumption $P_q \approx 62.8$ mW, which is given in Equation (1) as follows:

$$P_q = \frac{1}{\tau} \int_0^{\tau} V_{stor}(t) \cdot I_{syst}(t) \cdot dt, \quad (1)$$

where τ is the time of the measurements and data transmission via BLE.

The average power consumption of the insole is 113 µW in the active mode; in fact, the system takes full advantage of the low-power characteristics of the components used.

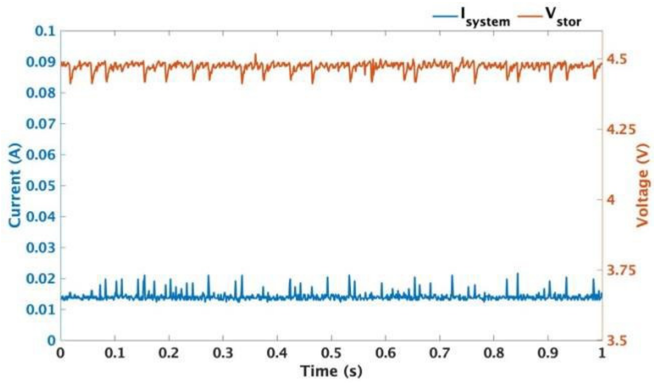

Figure 2. Functional evolution of the supply voltage V_{stor} versus time.

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