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Proceeding Paper

E-Textile Breathing Sensor Using Fully Textile Wearable Antennas †

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Abstract: E-textile sensor networks enable a variety of applications including pervasive monitoring for distributed healthcare. While commercial wearables can now measure various quantities such as heart rate and activities in a real-time, robust, and pervasive manner, breathing sensors remain an ongoing research challenge. In this paper, the use of wearable antennas for respiration monitoring is investigated based on a low-profile broadband fully textile antenna. It is demonstrated that the antenna, suitable for operation on different substrates and body parts, exhibits over 2 dB wireless gain sensitivity to normal breathing. Unlike recent wearable breathing sensors, the proposed antenna has a very simple structure and does not rely on active mechanical sensing elements or specific materials. A simple peak-detection algorithm is investigated showing a nearly 100% breath detection accuracy in line-of-sight. Based on the experimental results, it can be concluded that e-textile antennas can be utilized as highly accurate sensors for respiration monitoring, without the need for specific sensing elements or materials.

Keywords: wearable sensor; antenna sensor; RF breathing sensor; wireless sensors; textile sensors; vital sign monitoring

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1. Introduction

Owing to our ageing population, remote healthcare technologies have attracted significant research interest. At the forefront of enabling technologies is wireless vital sign monitoring, where body-centric wearable sensors could report information such as the heart rate or breathing rate of a subject, yielding valuable information for evaluating their health condition [1].

Electronic textiles (e-textiles) are the closest non-invasive interface to the user, where textile-based sensors can be used to monitor a variety of parameters including daily activities, vital signs [1], as well as environmental conditions such as moisture [2]. Furthermore, extensive research efforts have demonstrated methods of reliably connecting and powering e-textile systems using wearable antennas for information and power transmission [3], as well as using on-body energy storage devices, capable of powering low-power sensor nodes based on off-the-shelf components such as Bluetooth transceivers [4].

With the increased popularity of radio frequency identification (RFID) as a ubiquitous technology in retail and asset-tracking, several research efforts have demonstrated passive RFID sensors [5]. In a passive RFID or antenna-based sensor, the parameter-under-test (PUT) is detected through a change in the antenna's gain, which can be determined through the received signal strength indicator (RSSI) value [5]. RFID sensors have several advantages, such as wireless battery-free operation, where they harvest RF power from the reader, as well as being ultra-low-cost systems, with the only active electronic component being the RFID integrated circuit (IC).

In this paper, we propose a flexible all-textile broadband antenna as a passive e-textile breathing sensor. Unlike existing approaches where the antenna relies on a special fabric or material to realize a stretchable or compressible element, the proposed sensing approach relies on the human body-antenna interaction. The sensor is experimentally characterized and combined with a simple peak-detection algorithm for post-processing, demonstrating high accuracy in detecting breaths.

2. E-Textile Sensing Antenna

To realize an e-textile sensing antenna for vital sign monitoring, the antenna needs to maintain its operation in proximity with the human body. This is evaluated through the antenna's radiation efficiency and reflection coefficient, where a sufficiently low reflection (under 10%) indicates that the antenna is suitable for integration with different transmitters. Moreover, the antenna needs to be unisolated from the human body in order to detect the changes in dielectric properties, induced by breathing, through its gain. Therefore, the sensing antenna is based on a broadband monopole antenna, previously demonstrated with relatively high gain and efficiency on the body [6]. Furthermore, as the antenna is low-profile and does not require a specific substrate thickness to radiate efficiently, the selected design is suitable for implementation on different textile substrates. Figure 1a,b show the layout and photograph of the antenna, respectively.

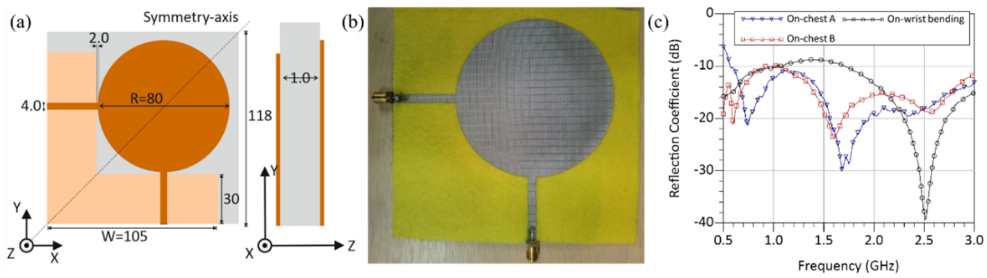

Figure 1. The proposed e-textile sensing antenna: (**a**) layout and dimensions (in mm); (**b**) photograph of the fabricated prototype; (**c**) measured reflection coefficient of the antenna on different body parts showing a matched impedance.

The antenna was fabricated using conductive fabric from P&P Technology (Metweave), laser cut to the antenna's dimensions. The conductive fabric was then attached to the textile substrate using its adhesive backing. The substrate used in this work was felt fabric, which maintains a relative permittivity of 1.2 and a dielectric loss dissipation factor of 0.02. The antenna's impedance bandwidth was experimentally characterized to demonstrate its suitability for interrogation across different frequency bands. The reflection coefficient was measured using a Rohde and Schwarz ZVB4 vector network analyzer (VNA) calibrated using a standard Through, Open, Short, Match (TOSM) calibration. Sub-miniature type-A (SMA) connectors were soldered directly onto the conductive fabric microstrip feed, as shown in the photograph in Figure 1b. Figure 1c shows the measured reflection coefficient of the antenna from 0.5 to 3 GHz, for different on-body positions, where the antenna was placed on both sides of the user's chest. For the breathing sensor application, the antenna will be mounted on the user's chest, where it can be observed that under −10 dB reflections were measured. Therefore, the antenna can be interrogated wirelessly in either the sub-1 GHz (868/915 MHz) or 2.4 GHz license-free bands, for wider compatibility with off-the-shelf RFID readers as well as Bluetooth or Wi-Fi transceivers.

3. Breathing Sensor Characterization

The proposed antenna-based sensor relies on the gain to detect the PUT, i.e., the breathing rate. To explain, as the user inhales, the antenna's gain increases, which is attributed to the reduction in the dielectric losses in the antenna. The antenna's gain, in-turn, affects the measured channel gain which can be detected wirelessly using the RSSI value. To evaluate the antenna's response as a sensor, the VNA was used to measure the channel gain through the forward transmission (S21) between the textile sensing antenna on the user's chest and a reference directional antenna as a transmitter. The transmitting and receiving antennas were separated by distance d = 1.0 m. The experimental setup is illustrated in Figure 2a.

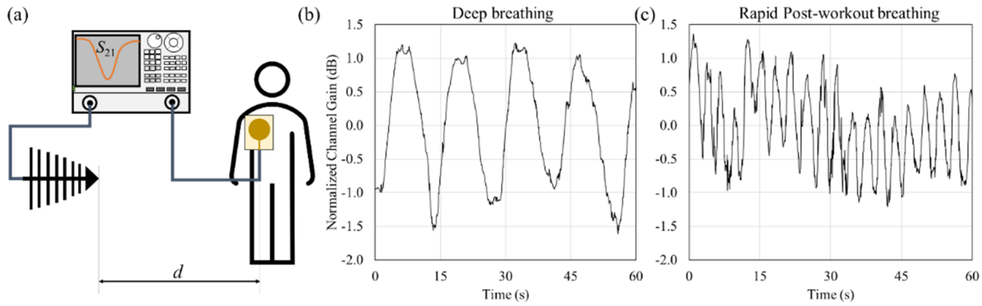

Figure 2. Antenna gain measurements showing the breathing patterns: (**a**) measurement setup; (**b**) measured channel gain during deep breathing; (**c**) measured channel gain during rapid breathing.

The channel gain was measured over a period of 60 s. Two breathing patterns were measured: slow, deep breathing, and rapid breathing post-activity. Figure 2b,c show the measured channel gain response for both breathing patterns. Each peak observed corresponds to a single breath, where the total number of counted breaths, from the RF sensor, matches the manual breath count. To further demonstrate the suitability of the proposed sensing method for detecting the breathing rate of the user, the measured traces were post-processed using a simple peak detection algorithm. Figure 3 shows the successful breath-rate detection using the peak detection algorithm.

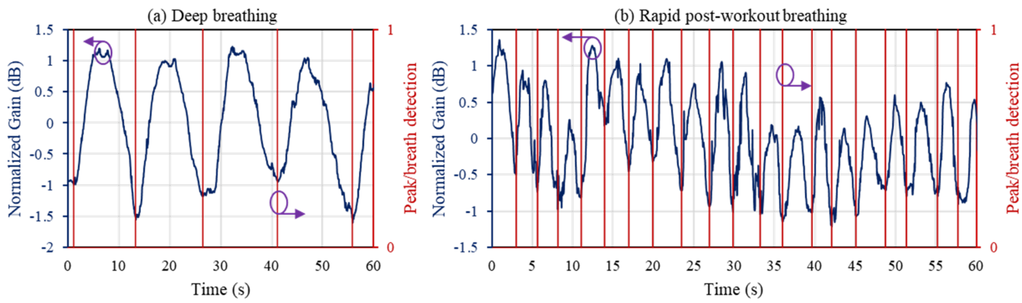

Figure 3. Successful breath rate measurement using a peak-detection algorithm.

The proposed sensor is compared in Table 1 to recently reported wearable breathing sensors. While it can be seen that other sensors have been demonstrated based on e-textile antennas with a higher gain change in-response to breathing [7,8], the antennas in previous works required stretchable or compressible elements to detect the breathing rate through a sufficiently large gain change (in dB). The variation in the measurement range in the compared studies can be linked to the sensitivity of the wireless receiver, where the maximum read range of the sensor is determined by the sensitivity of the reader, as well as the transmitted power level, limited by the radiated power regulations.

Table 1. Comparison of the proposed e-textile breathing sensor with related work.

	This Work	[1]	[7]	[8]
Antenna Material	Textile (felt)	PCB	Stretchable textile	Textile + compressible foam
Sensing mechanism	Dielectric sensing	Dielectric sensing	Strain sensing	Compression sensing
Sensitivity	~1.5–2.5 dB	~10%	1.5–7 dB	3–9 dB
Data post-processing	Peak-detection	N/A	N/A	N/A
Specific fabric required	No	Non-textile	Yes	Yes
Measurement range (m)	1.5	1–1.5	0.5	4–4.5

4. Conclusions

In this paper, the use of a broadband wearable textile antenna as a breathing sensor was proposed. The antenna maintains a stable bandwidth over the human body and on-chest, making it suitable for wearable sensing. Combined with a simple peak detection algorithm, the proposed sensor exhibits high accuracy in detecting the breathing rate and pattern of the user. It is concluded that passive wireless breathing sensors can be developed and integrated on different textiles without the need for specific materials or fabrication methods.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets underpinning this work are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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