DOI 10.5162/eurosensors2026/1.3.2

# Continuous Respiratory Rate Monitoring Using a Flexible Thermoelectric Sensor

*Abi Johnson-Brett, Aimilios Angelopoulos, Rafail Zafeirelis, Harry Akerman, Ioannis Zeimpekis, Nick Harris, Neil White, Katrina A. Morgan*
*University of Southampton, Southampton, SO17 1BJ, United Kingdom*
*A.JohnsonBrett@soton.ac.uk*

**Summary:**
Respiratory rate is an early indication of patient decline. A key limitation of continuous respiratory monitoring for hospital use is providing a non-invasive, low cost and easy to use system. Wearable sensors offer a continuous, lightweight and an unobtrusive solution. The proposed system combines a thin flexible thermoelectric sensor into a standard hospital grade oxygen mask with continuous Bluetooth connectivity and a selected algorithm. The proposed system is compared to a medical standard with a bias of -0.04, limits of agreement of -0.34 and +0.26 breaths per minute and successful apnoeic detection.

**Keywords:** Thermoelectric, Respiratory Monitoring, Clinical Comparison, Wearable, Flexible

## Respiratory rate monitoring

Respiratory rate (RR) is a key physiological signal that can determine the beginning of patient deterioration for a significant number of medical conditions and if effectively monitored could allow for earlier intervention and improved patient outcomes [1]. Retrospective reviews show that abnormal vital signs including RR is prevalent up to 4 hours before an in hospital cardiac arrest [2]. Respiratory monitoring in hospitals is one of the most underdeveloped monitoring systems. General wards rely on nurses manually observing the RR of each patient. This measurement exhibits systematic bias with abnormal RR being underreported whilst causing a significant burden to clinical nursing staff.

Wearable sensors offer a continuous monitoring solution. They can spot abnormalities as they occur and reduce the burden on nursing staff by removing the need for spot checks. These sensors can improve patient comfort by improving mobility allowing for continuous monitoring whilst in the hospital. Fabricating a flexible, light, and sensitive sensor is a challenge. Current wearable respiratory sensors often require extra equipment leading to patient discomfort. Additionally commercial wearable devices have a focus on fitness which promotes miniaturisation over clinical accuracy.

Thermoelectric (TE) sensors convert the temperature gradients into a voltage output. During breathing, the temperature around the mouth fluctuates which produces a readable varying voltage output signal. TE sensors are self-powered therefore only the data logging and wireless connectivity require power producing a low power system. TE sensors can be flexible and lightweight hence easily integrable into wearable systems.

RR algorithms tend not to be publicly available, making comparison between different sensor systems difficult. This leads to problems in directly comparing the efficacy of a proposed system with a reference technology [3].

In summary, this work presents the development of a thin, lightweight TE sensor integrated into a standard oxygen mask providing wireless data transmission to a phone or laptop. The TE sensor and system layout is optimised for increased sensitivity whilst being easy to use. The RR algorithm, results and apneic detection is compared to a medical standard whilst maintaining a low power, low cost system.

## RR sensing system development

A TE sensor with a planar structure has a high surface area allowing for a large active area which increases the sensor's sensitivity to small temperature fluctuations [4]. The optimum system layout includes a 3 TE pair in a planar structure with an active area thickness of 135μm and a Seebeck coefficient of 94 μV/K. The flexible sensor is integrated into a standard hospital grade oxygen mask through the ventilation gap. The location and adjustments of the sensor within the mask is optimised to maintain mask integrity whilst improving sensitivity and stability.

An external pcb (45mm x 25mm) is attached to the mask providing Bluetooth datalogging capabilities. The sensor system breathing detection and RR algorithm is compared to a medical standard. Final sensor system shown in figure 1.

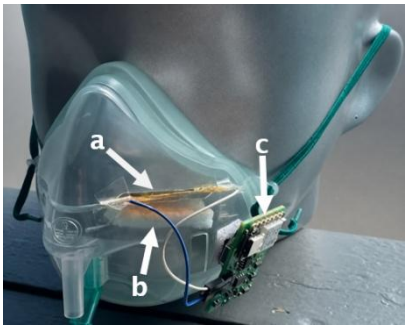



*Figure 1. Image of TE based respiratory monitoring system in a standard oxygen mask worn by a life size mannequin. a - TE sensor. b - Foam barrier. c - External pcb.*

### Respiratory rate algorithm

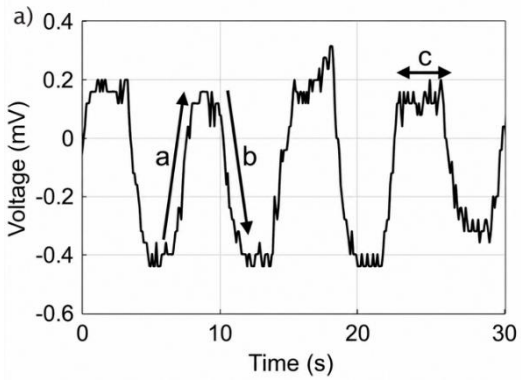
The RR analysis was performed in MATLAB using a frequency-domain approach based on the fast Fourier transform (FFT) technique. The TE sensor voltage is detrended using a mean moving average as the baseline to remove any slow drift. A single sided FFT is applied to convert the time domain to frequency domain spectrum where the dominant frequency peaks correspond to the majority RR.

### Respiratory rate measurements and results

The output respiratory signal of the complete sensor system (figure 2a) displays the key respiratory details including the expiratory pause.

The TE respiratory system is compared against the capnography machine, showing a bias of -0.04bpm (breaths per minute) and limits of agreement of [-0.34, +0.26] bpm for the RR algorithm calculations over a range of 8 to 18 bpm on one subject. The post-processed results from the TE sensor system (figure 2b) are compared with the proprietary post-processed results from capnography.

Testing abnormal respiratory breathing patterns is representative of real-world critical scenarios.



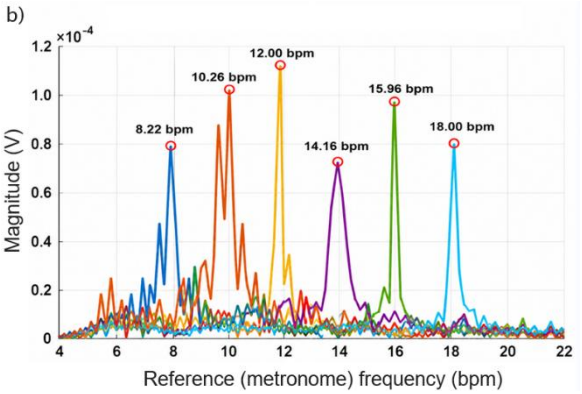




*Figure 2. a) Output respiratory signal. a - Exhale. b - Inhale. c - Expiratory pause. b) Post processed RR FFT from range of 8 to 18 bpm.*

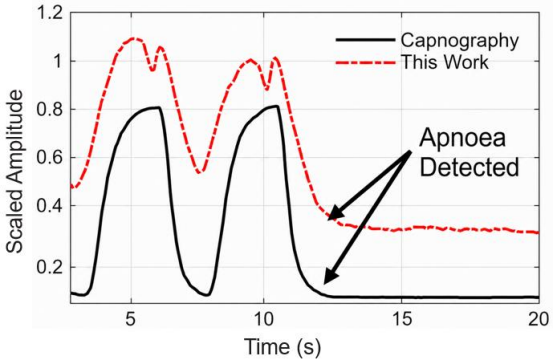



*Figure 3. A comparison of the TE sensor system and the capnography results detecting apnoea.*

The proposed sensor system closely matches the detection of the apnoea onset, figure 3. This demonstrates that the system can provide clinically relevant respiratory data while being minimally obtrusive. Future work will investigate a comparison between different respiratory algorithms for different respiratory types.

### Funding

UKRI is funding Abi Johnson-Brett's PhD.

### References

[1] S. A. S. Aglen et al., 'Respiratory Rate as a Predictor of Clinical Deterioration and Mortality: A Scoping Review', *Acta Anaesthesiol. Scand.*, vol. 69, no. 8 (2025) doi: 10.1111/aas.70113.

[2] L. W. Andersen *et al.*, 'The Prevalence and Significance of Abnormal Vital Signs Prior to In-Hospital Cardiac Arrest', *Resuscitation*, vol. 98, pp. 112–117 (2016) doi: 10.1016/j.resuscitation.2015.08.016.

[3] A.Nicolo et al., 'The Importance of Respiratory Rate Monitoring: From Healthcare to Sport and Exercise'. Sensors (2020) doi: 10.3390/s20216396

[4] X. Tang et al., 'Recent progress of biosensors based on thermoelectric effects for monitoring physical activity and environment monitoring', *Soft Sci.*, vol. 5, no. 1 (2025) doi: 10.20517/ss.2024.62.