

News & Views

Open Access

Specialty optical-fibre sensors enable real-time contact measurement of multiple physiological parameters: towards all-fibre wearable devices

Daniele Tosi^{1,2*}, Carlos Marques^{3,4}, Arnaldo Leal-Junior^{5,6} and Aliya Bekmurzayeva²

Abstract

The real-time measurements of surface physiological parameters, such as body temperature, cardiorespiratory rates, and sweat, is of increasing importance in healthcare. Optical fibres can offer an effective solution for contact sensing, as they enable multi-parameter and multi-point sensing while maintaining a compact form factor. Recent advances using chalcogenide and other specialty fibres represent a substantial step towards all-fibre wearable devices.

Keywords: Optical fiber sensors, Wearable sensors, Chalcogenide fibers, Optical biosensors, Smart textiles, Physiological measurements

Assessing the physiological properties of the human body in real time using a contact measurement device is a key asset in modern healthcare¹. Through the skin, we can assess a plurality of thermal, cardiovascular, and metabolic properties of the body using arrays of miniaturized sensors that are arranged in smart textiles and wearable devices^{2,3}.

Optical fibres provide an alternative approach to electric sensors⁴. Several optical-fibre sensors, such as fibre Bragg gratings, enable the multiplexing of multiple sensing locations along a single optical fibre and localised detection⁵. The design of the fibre also plays a crucial role in these devices: while single-mode fibres have a miniaturised design that allows integration with fabric⁶,

multi-mode fibres with larger cores facilitate light coupling, and therefore, can operate with small and low-cost hardware, such as smartphones^{7,8}.

From a systems standpoint, several studies have been conducted for the realisation of physiological and biological contact measurements of body properties. Smart textiles integrate optical-fibre sensors into clothes, garments, or accessories using flexible optical fibres. Examples of these structures have been proposed using optical fibres that are sewn into everyday and sports clothes^{9,10}, integrated into garments¹¹, or embedded into shoes¹². Another approach relies on the fabrication of wearable elastic bands with integrated sensors, which are used in thoracic devices⁵ or wristbands¹³.

In terms of application, three major domains can be identified. The most common use of fibre-optic sensors in wearable devices exploits the sensitivity to strain, using either wavelength-shifting sensors (such as Bragg gratings)¹⁴ or intensity sensors that detect fibre stretching¹⁵.

Correspondence: Daniele Tosi (daniele.tosi@nu.edu.kz)

¹School of Engineering and Digital Sciences, Nazarbayev University, Astana 010000, Kazakhstan

²Laboratory of Biosensors and Bioinstruments, National Laboratory Astana, Astana 010000, Kazakhstan

Full list of author information is available at the end of the article.

© The Author(s) 2025



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

The first approach has been proposed for real-time breathing analysis, relying on multi-point sensing by leveraging the high accuracy and large multiplexing capability. The second approach offers several low-cost opportunities, as it can rely on battery-powered hardware or smartphones in either single-point or multiplexed networks¹⁶. Strain sensing has been employed mainly in heartbeat rate and respiratory detection, as proposed by Leal-Junior et al. for digital discrimination in the frequency domain¹⁷, and in rehabilitation, as proposed by Li et al. using surface-treated plastic fibres¹⁸. A second application measures the body temperature, usually through Bragg gratings that inherently have thermal sensitivity; this is usually achieved by embodying the sensors into an elastic band or fabric that enables full contact with the skin in the sensing zones⁶. Other studies have relied on the online measurement of blood pressure using wearable fibre-optic devices¹³.

The most significant emerging trend is the use of optical-fibre sensors to exploit the biological properties of the skin through sweat sensing¹⁹. Sweat is rich in biomarkers that can be assessed on the surface of the skin, during both sporting activities and daily routines^{2,20}. In sweat, we can assess glucose levels that can be associated with diabetic diseases, though still with limited specificity²¹, while high levels of metabolites such as azelaic acid and suberic acid in sweat can be associated with cancer cell proliferation²². Very few works have addressed wearable fibre-optic devices for sweat sensing:

the most recent work was reported by Zhang et al.²³ using a fingertip mount for a fibre-optic sensor that is capable of detecting motion and sweat pH.

The future of the field will largely revolve around the properties of optical fibres used in wearable and contact sensors. If engineering works have substantially addressed the size, function, and operation of wearable devices, as well as their hardware (compactness, power consumption, and connectivity), there is much room for optimising the fibre itself, tailoring it to specific sensing and transmission properties. Polymer fibres and coatings have represented the current direction to date. Li et al.⁶ presented a polymer-coated glass fibre with a thermal sensitivity that was 15 times higher (150 pm/K). Notably, Leal-Junior et al.⁷ introduced a light polymerisation spinning process that is capable of extending the stretchability of fibres by up to 17%, which is an excellent property for sensors that are embedded in clothing.

A change in scenario was recently reported by Fu et al. in their newly published paper in *Light: Science & Applications*²⁴. The scope of this work, as displayed in Fig. 1, combines the measurement of physiological properties of the body with the interrogation of sweat biomarkers using a single optical fibre. To the best of our knowledge, this is the first study to demonstrate multi-parametric sensing with a single fibre for wearable devices.

The fibre proposed in this work was made of AST ($\text{As}_3\text{Se}_5\text{Te}_2$) chalcogenide glass for operation in mid-infrared. After the drawing process, the fibre was tapered

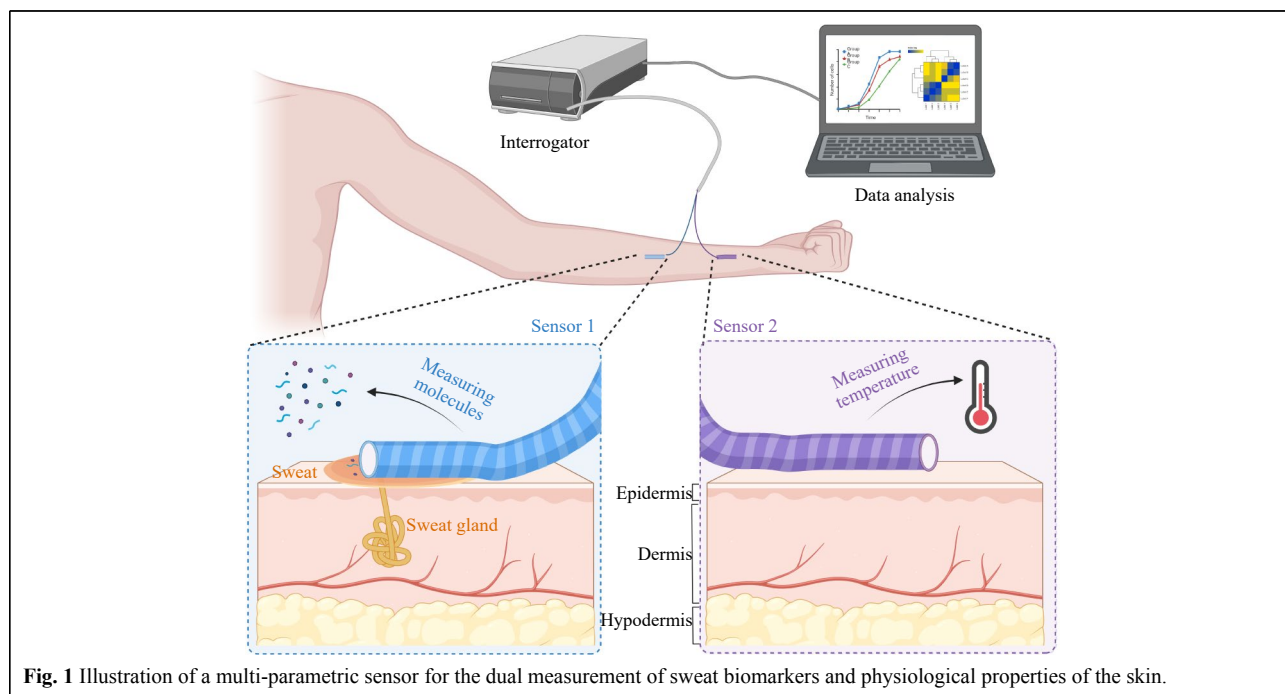


Fig. 1 Illustration of a multi-parametric sensor for the dual measurement of sweat biomarkers and physiological properties of the skin.

to increase the biomarker sensitivity. The sensing fibre was mounted on a wristband to monitor the evolution of sweat biomarkers (lactic acid, glucose, and urea) under static conditions and during physical exercise. The temperature change was measured using the wire resistance in the sensing zone, with a sensitivity of 5.84%/K.

Chalcogenide fibres can provide different perspectives for smart textiles and wearable devices. As described in a review by Lucas et al.²⁵, these fibres operate at mid-infrared wavelengths and can achieve a penetration depth of up to several hundreds of nanometres for wavelengths up to 8 μm . However, the high propagation losses and difficulties in handling miniaturised hardware have thus far limited these types of fibres to bulky bio-chemical setups²⁶, with the work of Fu et al. providing the first real case scenario of a wearable device operating at high speed.

While the measurement of body properties over the skin and related biomarkers has been dominated by electrode-based technologies to date, optical fibres now have the potential and maturity to provide substantial innovation in the field. Parallel opportunities offered by telecom-grade fibres (which are excellent for transmission and multiplexing), plastic fibres (which are highly stretchable and use the simplest hardware), and chalcogenide fibres (with high biological sensitivity) are likely to be exploited in the near future for next-generation photonic Internet-of-Things devices^{7,8,27}.

Author details

¹School of Engineering and Digital Sciences, Nazarbayev University, Astana 010000, Kazakhstan. ²Laboratory of Biosensors and Bioinstruments, National Laboratory Astana, Astana 010000, Kazakhstan. ³CICECO – Aveiro Institute of Materials, Physics Department, University of Aveiro, Aveiro 3810-193, Portugal. ⁴Department of Physics, Faculty of Electrical Engineering and Computer Science, VSB—Technical University of Ostrava, Ostrava 70800, Czech Republic. ⁵Federal University of Espírito Santo, Vitória 29075-910, Brazil. ⁶Department of Cybernetics and Biomedical Engineering, VSB-Technical University of Ostrava, Ostrava 70800, Czech Republic

Data availability

All data are available from the corresponding authors upon reasonable request.

Conflict of interest

All authors declare that they have no conflicts of interest.

Received: 12 May 2025 Revised: 20 June 2025 Accepted: 23 June 2025

Published online: 30 July 2025

References

- Lee, K. P., Yip, J., Yick, K. L., Lu, C., & Lo, C. K. Textile-based fiber optic sensors for health monitoring: A systematic and citation network analysis review. *Textile Research Journal* **92**, 2922–2934 (2022).

- Ye, C., Wang, M., Min, J., Tay, R. Y., Lukas, H., Sempionatto, J. R., & Gao, W. A wearable aptamer nanobiosensor for non-invasive female hormone monitoring. *Nature Nanotechnology* **19**, 330–337 (2024).
- He, H., Fasoula, N. A., Karlas, A., Omar, M., Aguirre, J., Lutz, J., & Ntziachristos, V. Opening a window to skin biomarkers for diabetes stage with optoacoustic mesoscopy. *Light: Science & Applications* **12**, 231 (2023).
- Quandt, B. M., Scherer, L. J., Boesel, L. F., Wolf, M., Bona, G. L., & Rossi, R. M. Body-Monitoring and health supervision by means of optical fiber-based sensing systems in medical textiles. *Advanced Healthcare materials* **4**, 330–355 (2015).
- Issatayeva, A., Beisenova, A., Tosi, D., & Molardi, C. Fiber-optic based smart textiles for real-time monitoring of breathing rate. *Sensors* **20**, 3408 (2020).
- Li, H., Yang, H., Li, E., Liu, Z., & Wei, K. Wearable sensors in intelligent clothing for measuring human body temperature based on optical fiber Bragg grating. *Optics Express* **20**, 11740–11752 (2012).
- Leal-Junior, A., Avellar, L., Frizera, A., & Marques, C. Smart textiles for multimodal wearable sensing using highly stretchable multiplexed optical fiber system. *Scientific Reports* **10**, 13867 (2020).
- Aitkulov, A., & Tosi, D. Optical fiber sensor based on plastic optical fiber and smartphone for measurement of the breathing rate. *IEEE Sensors Journal* **19**, 3282–3287 (2019).
- Koyama, Y., Nishiyama, M., & Watanabe, K. Smart textile using hetero-core optical fiber for heartbeat and respiration monitoring. *IEEE Sensors Journal* **18**, 6175–6180 (2018).
- He, C., Korposh, S., Hernandez, F. U., Liu, L., Correia, R., Hayes-Gill, B. R., & Morgan, S. P. Real-time humidity measurement during sports activity using optical fibre sensing. *Sensors* **20**, 1904 (2020).
- Avellar, L., Frizera, A., & Leal-Junior, A. POF Smart Pants: a fully portable optical fiber-integrated smart textile for remote monitoring of lower limb biomechanics. *Biomedical Optics Express* **14**, 3689–3704 (2023).
- Domingues, M. F., Alberto, N., Leitão, C. S. J., Tavares, C., De Lima, E. R., Radwan, A., & Antunes, P. F. Insole optical fiber sensor architecture for remote gait analysis—An e-health solution. *IEEE Internet of Things Journal* **6**, 207–214 (2017).
- Li, L., Li, Y., Yang, L., Fang, F., Yan, Z., & Sun, Q. Continuous and accurate blood pressure monitoring based on wearable optical fiber wristband. *IEEE Sensors Journal* **21**, 3049–3057 (2020).
- Massaroni, C., Zaltieri, M., Presti, D. L., Nicolò, A., Tosi, D., & Schena, E. Fiber Bragg grating sensors for cardiorespiratory monitoring: A review. *IEEE Sensors Journal* **21**, 14069–14080 (2020).
- Krehel, M., Schmid, M., Rossi, R. M., Boesel, L. F., Bona, G. L., & Scherer, L. J. An optical fibre-based sensor for respiratory monitoring. *Sensors* **14**, 13088–13101 (2014).
- Aitkulov, A., & Tosi, D. Design of an all-POF-fiber smartphone multichannel breathing sensor with camera-division multiplexing. *IEEE Sensors Letters* **3**, 1–4 (2019).
- Leal-Junior, A. G., Díaz, C. R., Leitão, C., Pontes, M. J., Marques, C., & Frizera, A. Polymer optical fiber-based sensor for simultaneous measurement of breath and heart rate under dynamic movements. *Optics & Laser Technology* **109**, 429–436 (2019).
- Li, J., Liu, J., Li, C., Zhang, H., & Li, Y. Wearable wrist movement monitoring using dual surface-treated plastic optical fibers. *Materials* **13**, 3291 (2020).
- Bariya, M., Nyein, H. Y. Y., & Javey, A. Wearable sweat sensors. *Nature Electronics* **1**, 160–171 (2018).
- Yang, D. S., Ghaffari, R., & Rogers, J. A. Sweat as a diagnostic biofluid. *Science* **379**, 760–761 (2023).
- Criscuolo, F., Hanitra, I. N., Aiassa, S., Taurino, I., Oliva, N., Carrara, S., & De Micheli, G. Wearable multifunctional sweat-sensing system for efficient healthcare monitoring. *Sensors and Actuators B: Chemical*

- 328**, 129017 (2021).
22. Karipbayeva, K., Blanc, W., & Tosi, D. Optical fiber semi-distributed interferometer assisted by an FBG for thermorefractometry and sweat sensing. *IEEE Sensors Journal* **23**, 14161-14166 (2023).
 23. Zhang, Z., Li, K., Li, Y., Zhang, Q., Wang, H., & Hou, C. Dual-function wearable hydrogel optical fiber for monitoring posture and sweat pH. *ACS Sensors* **9**, 3413-3422 (2024).
 24. Fu, Y., Kang, S., Zhou, G., Huang, X., Tan, L., Gao, C., & Lin, C. Unlocking body-surface physiological evolution via IR-temperature dual sensing with single chalcogenide fiber. *Light: Science & Applications* **14**, 173 (2025).
 25. Lucas, P., Riley, M. R., Boussard-Plédel, C., & Bureau, B. Advances in chalcogenide fiber evanescent wave biochemical sensing. *Analytical Biochemistry* **351**, 1-10 (2006).
 26. Lucas, P., Solis, M. A., Le Coq, D., Juncker, C., Riley, M. R., Collier, J., & Bureau, B. Infrared biosensors using hydrophobic chalcogenide fibers sensitized with live cells. *Sensors and Actuators B: Chemical* **119**, 355-362 (2006).
 27. Gomes, H. C., Liu, X., Fernandes, A., Moreirinha, C., Singh, R., Kumar, S., & Marques, C. Laser-Induced graphene-based Fabry-Pérot cavity label-free immunosensors for the quantification of cortisol. *Sensors and Actuators Reports* **7**, 100186 (2024).