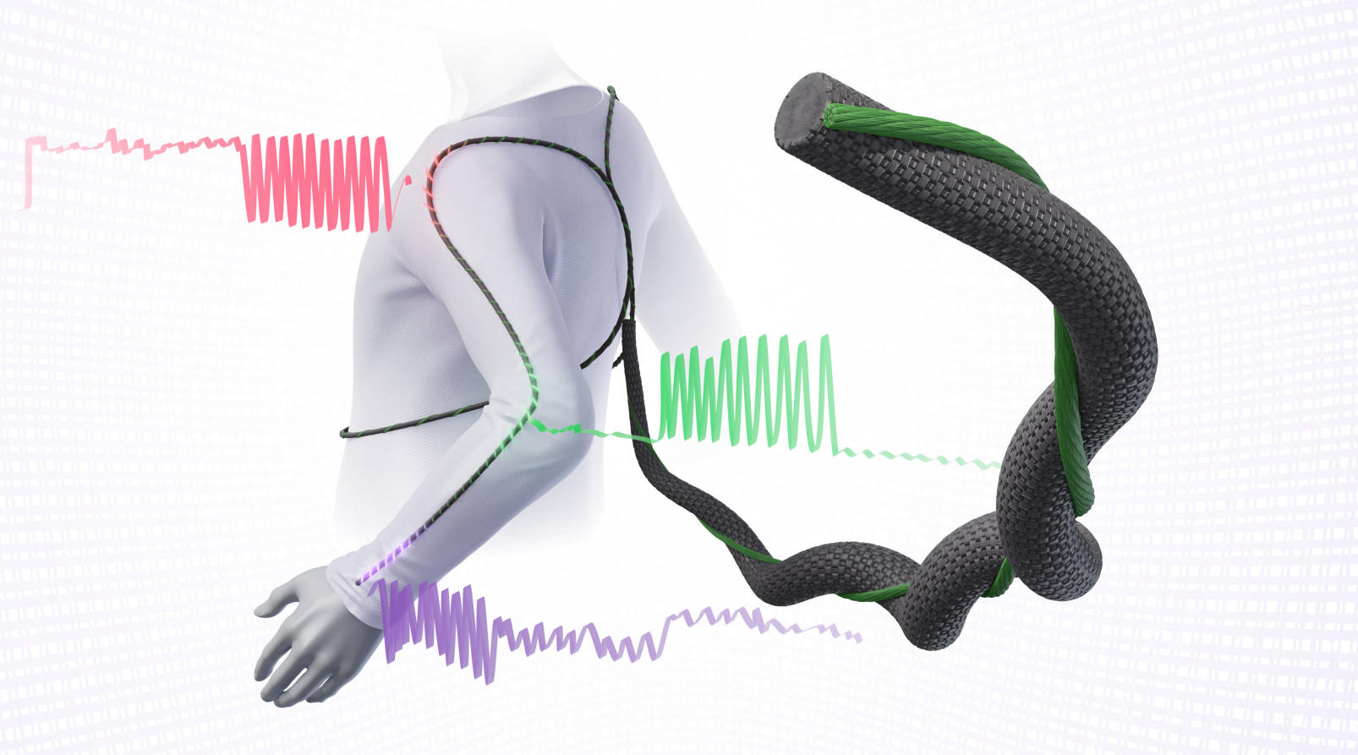
ETH zürich

DHEST
Departement Gesundheitswissenschaften
und Technologie

Strain Sensing Along Fibres for Smart Clothing[†]



Brett C. Hannigan, Tyler J. Cuthbert, Chakaveh Ahmadizadeh, and Carlo Menon
Biomedical and Mobile Health Technology Lab, Department of Health Sciences and Technology, ETH Zürich, CH

1 Introduction

Textile sensors transform our everyday clothing into a means to track movement in a completely unobtrusive way. One major hindrance to the adoption of "smart" clothing is that connections between rigid and textile elements are often unreliable and laborious to produce [1, 2]. Distributed sensing is a promising solution to this problem and has been demonstrated on the bench [3, 4]. We present a smart garment that can monitor three arm joint angles from a continuous fibre with a single connection point. We achieved around 5° error when compared to optical motion capture.

2 The Sensing Fibre

Our helical auxetic capacitive fibre strain sensor technology [5] has several attractive features for distributed sensing:

- Its auxetic behaviour unlocks a higher sensitivity (GF>1) than theoretically expected for capacitive strain sensors.
- This sensitivity can be tuned by manipulating the helical pitch, so that sensing regions near the joints have high sensitivity while strain occurring in other areas is rejected.
- The outer coil and conductive polymer core form an electrical transmission line.

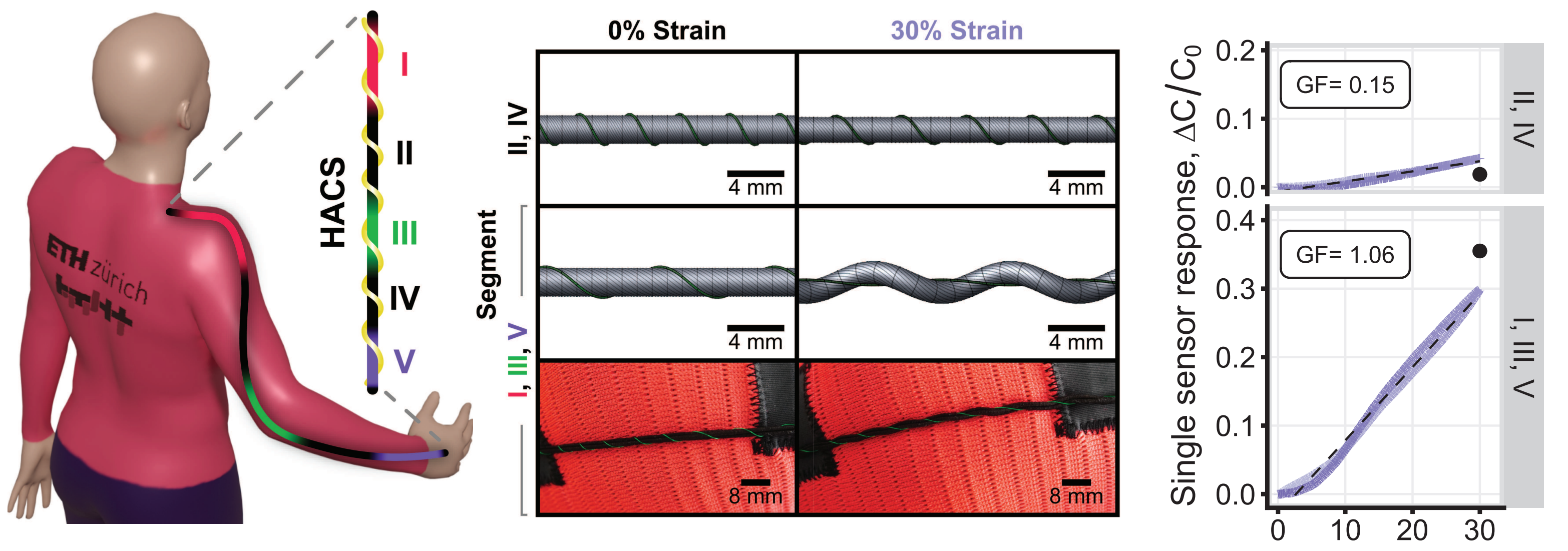


Figure 1: Prototype garment (left), sensing fibre geometric model and photographs (middle), strain response (right).

3 Distributed Sensing Method

- The sensor fibre is electrically similar to a cascade of infinitesimally small RC low-pass filters.
- By probing the impedance of the line at multiple frequencies, the spatial distribution of strain may be inferred.
- We developed a custom FPGA impedance analyzer and fixtures to validate the method with a tensile testing apparatus.

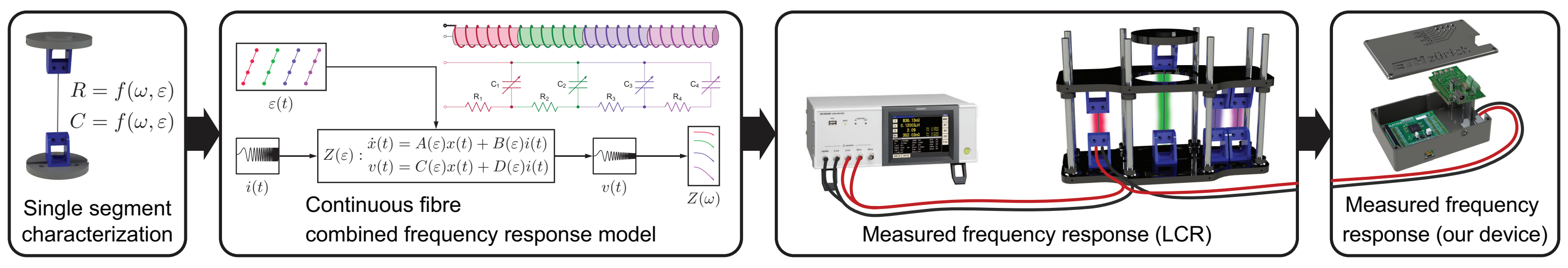


Figure 2: Procedure for device validation on the bench.

4 Results

- We embedded the sensing fibre along the arm of an athletic shirt.
- A test subject wore the shirt and performed a series of controlled arm movements with the reference shoulder, elbow, and wrist angles measured using optical motion capture.
- We trained a neural network regression model to predict these joint angles from the impedance signals at 4 frequencies.

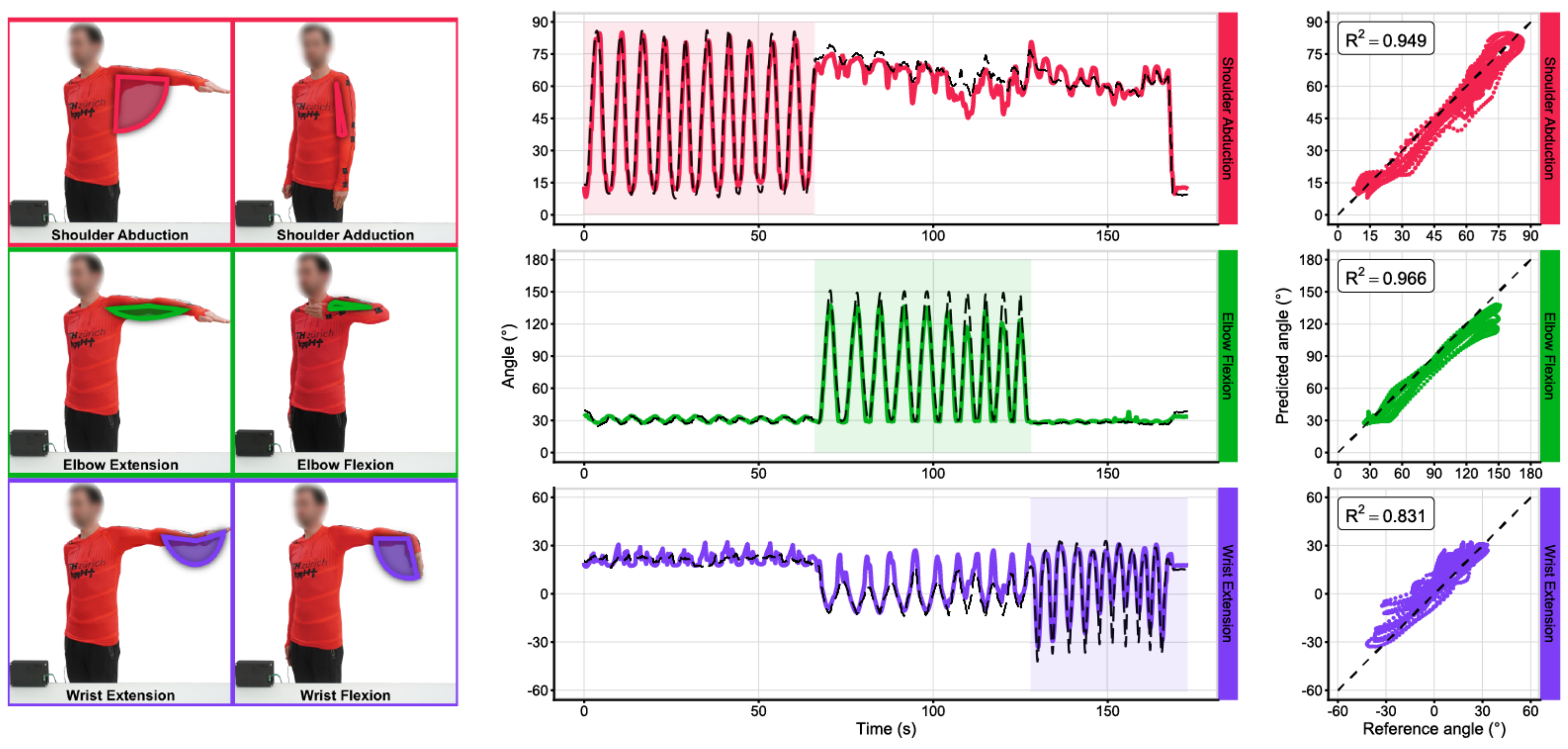


Figure 3: Arm movements (left) and corresponding reconstructed strain signals and reference trace (middle, right).

5 Conclusion

In this study, we have demonstrated distributed sensing in clothing to monitor multi-joint arm movement with a single fibre sensor:

- We achieve a test set root-mean-squared joint angle error of less than 5° compared to the gold standard optical motion capture.
- We apply our sensing fibre in a way that allows the sensitivity to be modulated along its length to reject unwanted strain signals.
- Our solution has a single pair of connections located at one end of the fibre in a proximal "hub" location, which allows better compatibility with textile production methods.

We hope to explore the limits of sensing region density in future work. We can envision using this technology to create multi-sensing fabrics capable of measuring strain maps across the body in real time.

References

[1] S. Niu, N. Matsuhisa, L. Beker, J. Li, S. Wang, J. Wang, Y. Jiang, X. Yan, Y. Yun, W. Burnett, A. S. Y. Poon, J. B. Tok, X. Chen, and Z. Bao, "A wireless body area sensor network based on stretchable passive tags," *Nature Electronics*, vol. 2, no. 8, pp. 361–368, 2019.

[2] L. M. Castano and A. B. Flatau, "Smart fabric sensors and e-textile technologies: A review," *Smart Materials and Structures*, vol. 23, no. 5, p. 053001, 2014.

[3] A. Tairych and I. A. Anderson, "A numerical method for measuring capacitive soft sensors through one channel," *Smart Materials and Structures*, vol. 27, no. 3, 2018.

[4] E. L. White, M. C. Yuen, and R. K. Kramer, "Distributed sensing in capacitive conductive composites," in *2017 IEEE Sensors*, (Glasgow), IEEE, 2017.

[5] T. J. Cuthbert, B. C. Hannigan, A. Shokurov, and C. Menon, "HACS: Helical Auxetic Yarn Capacitive Sensors that Go Beyond the Theoretical Sensitivity Limit," *Advanced Materials*, vol. 35, no. 10, 2023.

[†] Brett C. Hannigan, Tyler J. Cuthbert, Chakaveh Ahmadizadeh, and Carlo Menon. "Distributed Sensing Along Fibres for Smart Clothing." *Science Advances* (2023). (In Review)

IEEE SENSORS 2023

IEEE Sensors Conference: 30th November 2023