

Multimodal Textile-Based Wearable System for Upper-Limb Motion and Heart Rate Monitoring in Rehabilitation

C. Alglave¹, G. Jodin¹, A. Laarabi², J. Schoch¹, C. Depontailier¹, A. Marin³, J. Prioux⁴ and F. Razan¹

¹ Univ Rennes, ENS Rennes, CNRS, IETR - UMR 6164, Rennes, 35170, France,

² SII Ouest, 3b Av. de Belle Fontaine, Cesson-Sévigné, 35510, France

³ Inria, CNRS, ENS Rennes, Univ Rennes, IRISA, Bruz, France

⁴ Movement, Sport and Health Laboratory (EA 1274), UFR APS, Rennes 2, France

Corresponding author: florence.razan@ens-rennes.fr

Summary:

Continuous upper-limb monitoring is essential for rehabilitation outside clinical environments. This paper presents a textile wearable system for synchronized motion and heart rate monitoring. A piezoresistive textile sleeve combined with an LSTM-based network enables elbow angle estimation, with a normalized error of 8.43% against Kinovea reference angles. Heart rate is estimated using photoplethysmography and an electrocardiography sensor with errors below 10%. The system enables unobtrusive monitoring of both kinematic and physiological parameters for rehabilitation assessment outside clinical settings.

Keywords: wearable sensing, textile sensors, multimodal monitoring, heart rate, upper-limb motion

Background, Motivation and Objective

Human motion analysis is essential for rehabilitation and functional assessment [1], especially for upper-limb monitoring in daily life. Optical motion capture systems such as Qualisys provide high accuracy but require controlled environments [2]. Markerless vision-based methods are more flexible but remain sensitive to occlusions and lighting variations [3], while wearable inertial sensors suffer from drift and cumulative errors [4]. Textile-based sensors offer a flexible alternative for motion capture [5]; however, their nonlinear behavior and inter-subject variability complicate accurate estimation, motivating data-driven modeling approaches [6]. Heart rate is widely used to assess exercise intensity and physiological state [7]. Although multimodal wearable systems are emerging [8], motion and physiological data are still often analyzed separately, limiting the understanding of their interaction. This work proposes a wearable multimodal system for synchronized analysis of kinematic and physiological signals, with potential relevance for rehabilitation monitoring. Kayaking-like movements were chosen as a demanding case study because they combine repetitive arm motion and varying intensity.

Description of the System

The system enables synchronized acquisition of motion and physiological signals using a textile-based sensing device with embedded modules. The device consists of a wearable sleeve embedding piezoresistive sensors around the elbow joint to measure deformation through

resistance variations. Signals are acquired wirelessly via BLE. Experimental characterization reveals nonlinear behavior and inter-sensor variability due to non-uniform strain distribution, motivating data-driven modeling. Physiological data are collected using an electrocardiography (ECG) chest strap (Polar H9) and a photoplethysmography (PPG) module (WPSE340), the latter being processed for peak detection and heart rate estimation. Synchronization between camera and Arduino acquisitions enabled the extraction of Kinovea reference angles for model training and validation. Experiments were conducted on a SkiErg2 ergometer configured in kayak mode to reproduce kayaking posture and motion in a controlled environment (Fig.1).

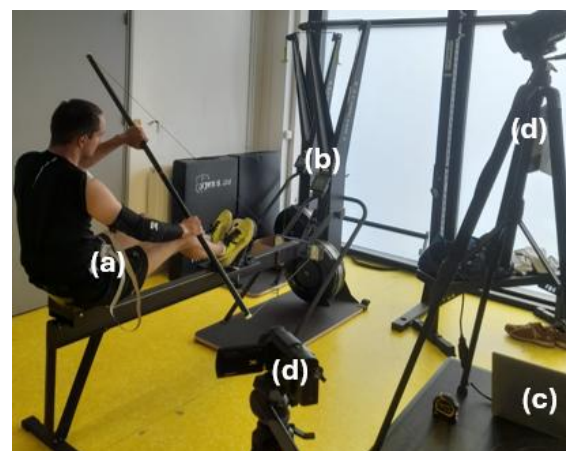


Fig. 1. Multimodal acquisition setup (M2S platform, Bruz, France): (a) textile sleeve and heart rate measurement, (b) ergometer, (c) acquisition system, (d) color (RGB) cameras.

Motion estimation was performed using an LSTM-based neural network, chosen because the textile sensor signals form temporal sequences and elbow angle evolution depends on previous time steps. The system combines textile sensing and physiological monitoring in a portable multimodal framework.

Results and Discussion

The system was evaluated on kayaking-like upper-limb movements under controlled dynamic conditions. The LSTM-based model enabled elbow angle estimation, with a normalized error of 8.43% against Kinovea reference angles. Model architecture and training details will be provided in the full presentation. The textile signals and predicted angle reflect movement dynamics across different phases (Fig. 2). Heart rate was estimated from PPG and ECG measurements, with errors below 10% during high-intensity activity.

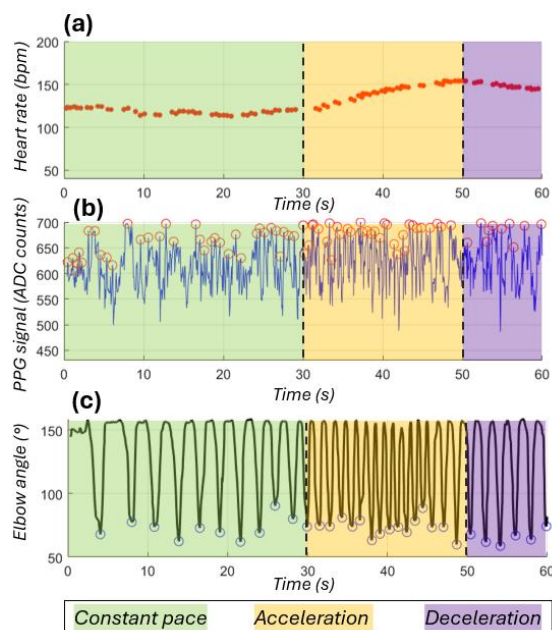


Fig. 2. Multimodal monitoring of upper-limb motion and physiological signals. (a) Heart rate measured using an ECG chest strap. (b) Raw PPG signal with detected peaks. (c) Predicted elbow angle. The shaded regions correspond to different movement phases (constant pace, acceleration, deceleration).

The synchronization of kinematic and physiological signals reveals a clear relationship between movement dynamics and cardiovascular response, illustrating the coupling between motion and physiological state. These results highlight the potential of combined motion and heart rate monitoring to assess exercise intensity during upper-limb activity, which is highly relevant for rehabilitation. Overall, the system enables robust multimodal monitoring in controlled

dynamic conditions, extending its applicability to performance analysis and health monitoring.

Conclusion

This work presents a portable multimodal wearable system combining motion tracking and physiological monitoring. By capturing both kinematic and cardiovascular responses, the system enables accurate motion estimation and highlights the relationship between movement dynamics and physiological response. This approach opens the way to continuous and unobtrusive assessment of motor performance and exercise intensity outside clinical settings.

Acknowledgments

This work was supported by the ANR through the PIA EUR DIGISPORT project (ANR-18-EURE-0022) and the France 2030 program, ESOS (ANR-23-CMAS-0007), as well as by SII group (Paris, France).

References

- [1] J. Strandberg, A. Pini, C. K. Häger, L. Schelin, *Analysis Choices Impact Movement Evaluation: A Multi-Aspect Inferential Method Applied to Kinematic Curves of Vertical Hops in Knee-Injured and Asymptomatic Persons*, *Front. Bioeng. Biotechnol.* 9 (2021) 645014. doi:10.3389/fbioe.2021.645014.
- [2] B. Baker, *Measuring walking: a handbook of clinical gait analysis*, Mac Keith Press (2013).
- [3] Z. Cao, G. Hidalgo, T. Simon, S. Wei, Y. Sheikh, *OpenPose: Realtime multi-person 2D pose estimation using part affinity fields*, *IEEE Trans. Pattern Anal. Mach. Intell.* 43, 172–186 (2021); doi: 10.1109/TPAMI.2019.2929257
- [4] A. M. Sabatini, *Inertial sensing in biomechanics: a survey of computational techniques bridging motion analysis and personal navigation*, *Sensors* 11, 639–672 (2011); doi: 10.4018/978-1-59140-836-9.ch002
- [5] L. Yin, X. Sun, *Textile-based sensors for human motion sensing: recent developments and future perspectives*, *Nanocomposites* 11, 79–98 (2025); doi: 10.1080/20550324.2025.2477392
- [6] S. Gong, W. Schwalb, Y. Wang, et al., *A wearable and highly sensitive pressure sensor with ultrathin gold nanowires*, *Nat. Commun.* 5, 3132 (2014); doi: 10.1038/ncomms4132
- [7] A. Achten, A. E. Jeukendrup, *Heart rate monitoring: applications and limitations*, *Sports Med.* 33, 517–538 (2003); doi: 10.2165/00007256-200333070-00004
- [8] S. Patel, H. Park, P. Bonato, L. Chan, M. Rodgers, *A review of wearable sensors and systems with application in rehabilitation*, *J. Neuroeng. Rehabil.* 9, 21 (2012); doi: 10.1186/1743-0003-9-21