Wearable Textile-based flexible sensors for motion analysis

Nicola Carbonaro

Assistant Professor in Bioengineering

Research Centre "E. Piaggio" & Information Engineering Department

nicola.carbonaro@unipi.it

Short Bio

- Nicola Carbonaro is an Assistant Professor of Bioengineering at the Information Engineering Department and at the Research Center “E. Piaggio”, University of Pisa.
- Nicola Carbonaro received the degree in Electronic Engineering from the University of Pisa, in 2004, and the Ph.D. degree in Information Engineering from University of Pisa, in 2010, where he worked on the development of wearable system for human activity classification.

- He was reference professor of the biosensor course of the degree course in biomedical engineering of the University of Cagliari (from 2014-2017). Since 2018 he is the reference professor of “Natural and artificial senses” course of the Degree course in Biomedical Engineering of the University of Pisa
- His research is mainly focused on hardware and software development for wearable sensing technology for physiological and behavioral human monitoring in biomedical applications.
- Dr. Carbonaro has collaborated on different research projects both at National and European levels. He has published many journal papers and has made contributions to International conferences and books’ chapters.

Wearable and Biosensing group

Wearables and Biosensing

- Prof. Alessandro Tognetti   Eng. Nicola Carbonaro
  - Eng. Lucia Arcarisi, Eng. Francesca Giannetti , Eng. Carlotta Marinai

- Work group Research Interest:
  - design and development of wearable multisensory technologies for measurement and analysis - outside the laboratory and during daily activities - of posture, human movement and physiological signals
    - development of soft sensors (flexible, e-textiles), non-invasive biomedical devices and sensory fusion

TOLIFE

LAID
SMART BED

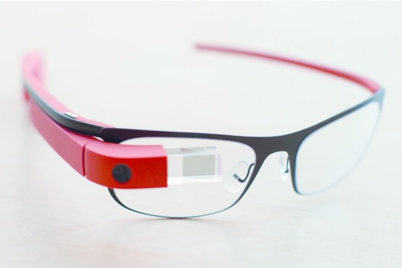
KIFOOT
Calzatura sensorizzata per l'analisi del cammino

Presentation Outline

- Wearable sensors: general idea and technological challenge
- Working principles and realization of textile sensors for pressure detection
- Examples of application scenarios and results obtained

Wearables and smart objects

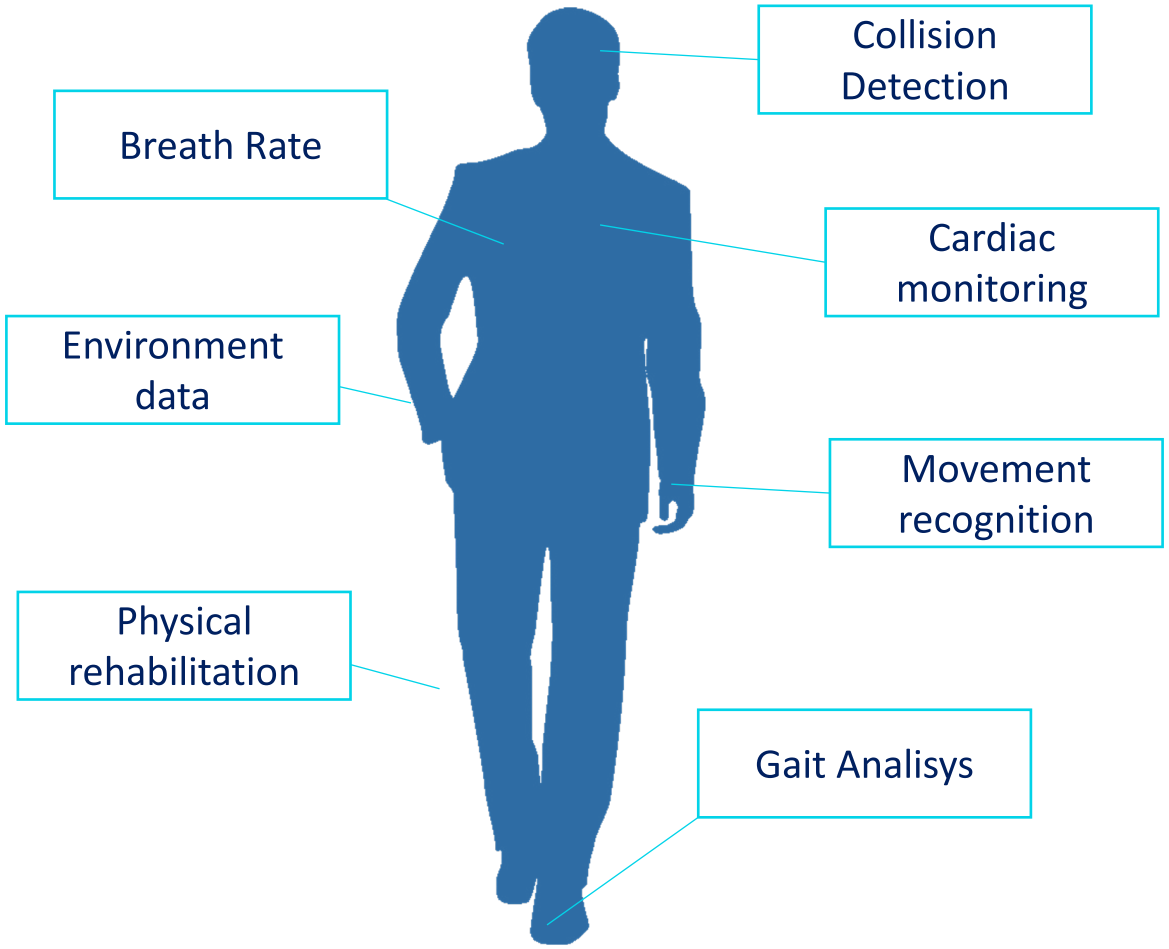
- Anything a person wears or interacts with can become a tool to extract body parameters







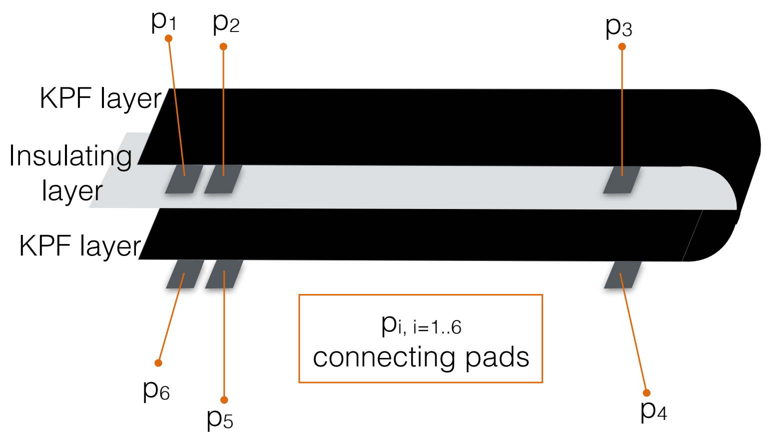
Textile sensors for wearables and smart objects

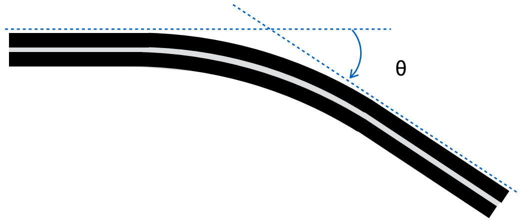


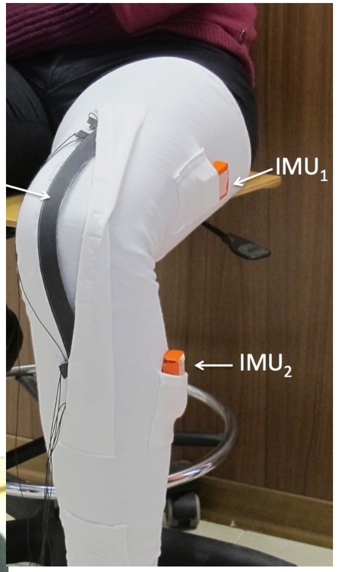
Our early research

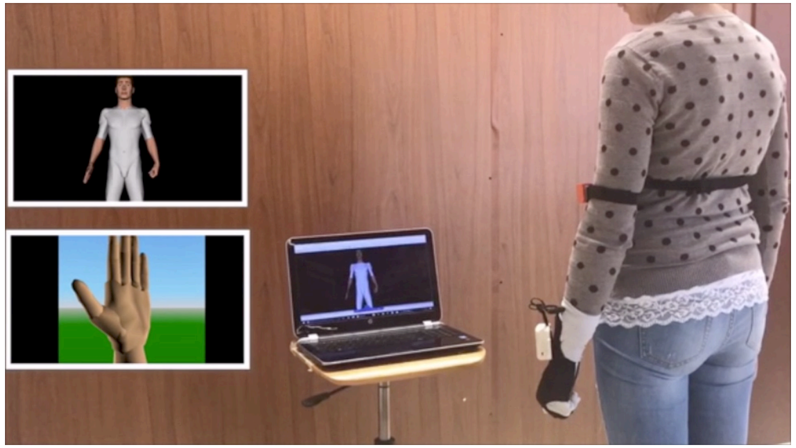
Sensing garments for motion analysis and rehabilitation

KPF goniometers: Two layers of knitted piezoresistive fabrics









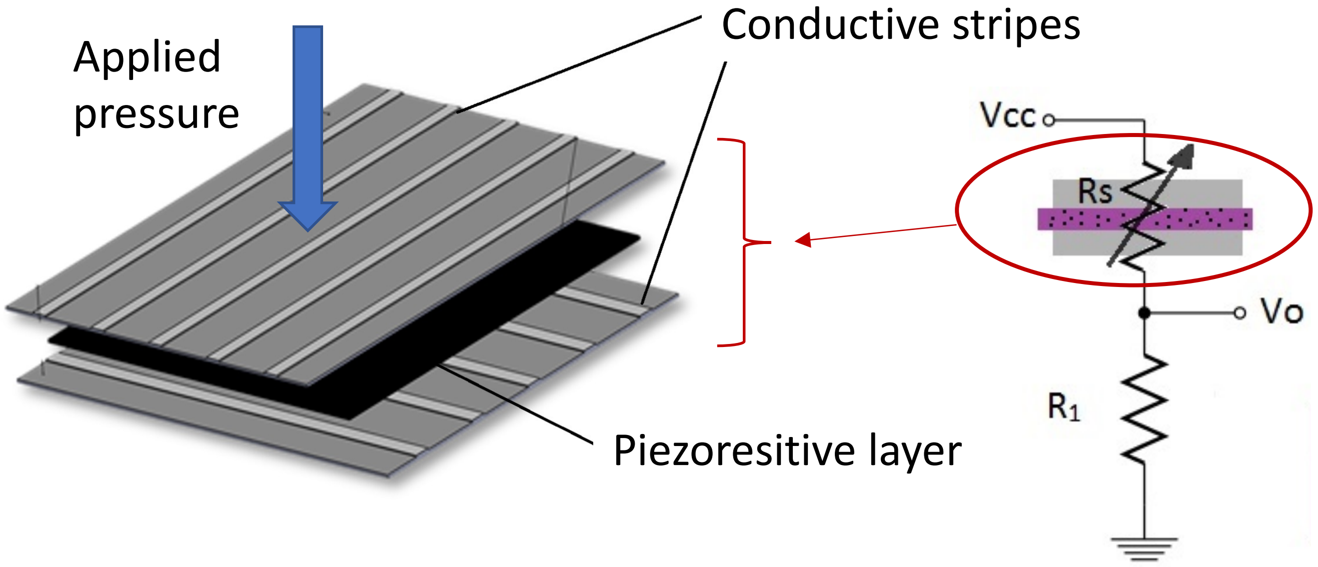
Textile-based bending Sensors

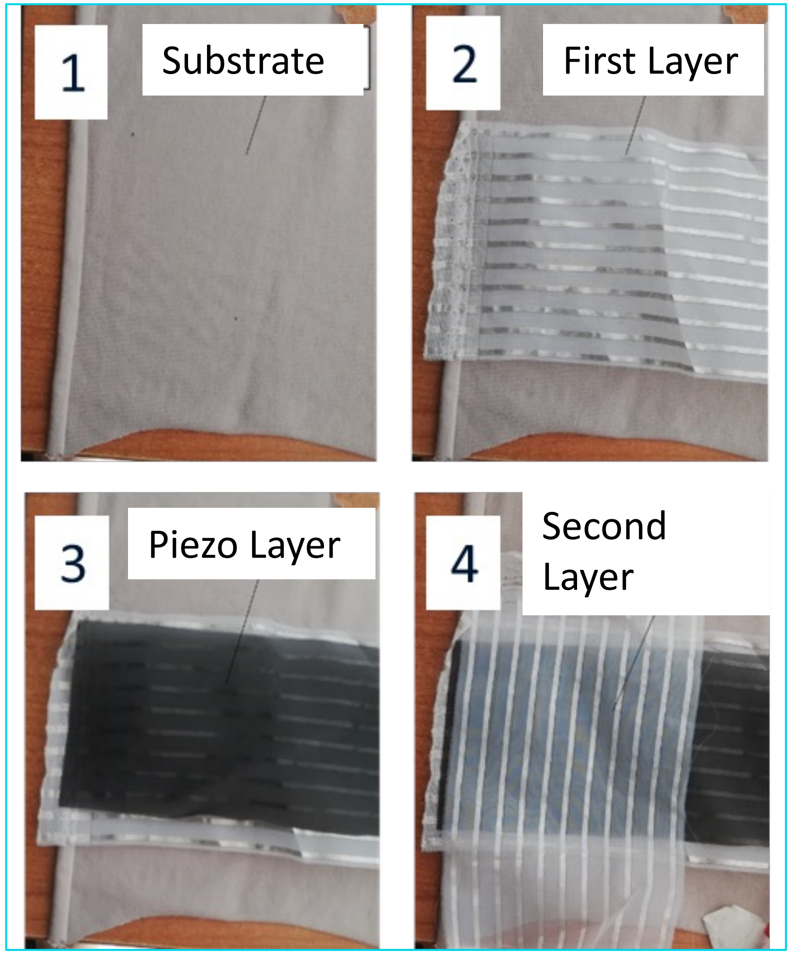
Joint angular movements

Current focus

Pressure sensing surfaces

Basic principle: resistive matrix method



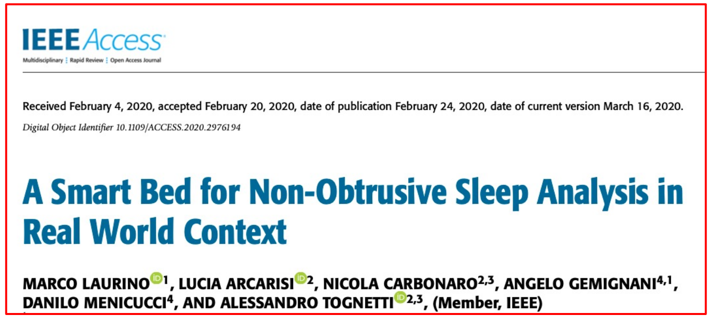


Pervasive and Mobile Computing 30 (2016) 97–112
Contents lists available at ScienceDirect
Pervasive and Mobile Computing
journal homepage: www.elsevier.com/locate/pmc
ELSEVIER

Smart-surface: Large scale textile pressure sensors arrays for activity recognition

Jingyuan Cheng *, Mathias Sundholm, Bo Zhou, Marco Hirsch, Paul Lukowicz

Sensing mattress for the Smart Bed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Digital Object Identifier 10.1109/ACCESS.2020.2976194

A Smart Bed for Non-Obtrusive Sleep Analysis in Real World Context

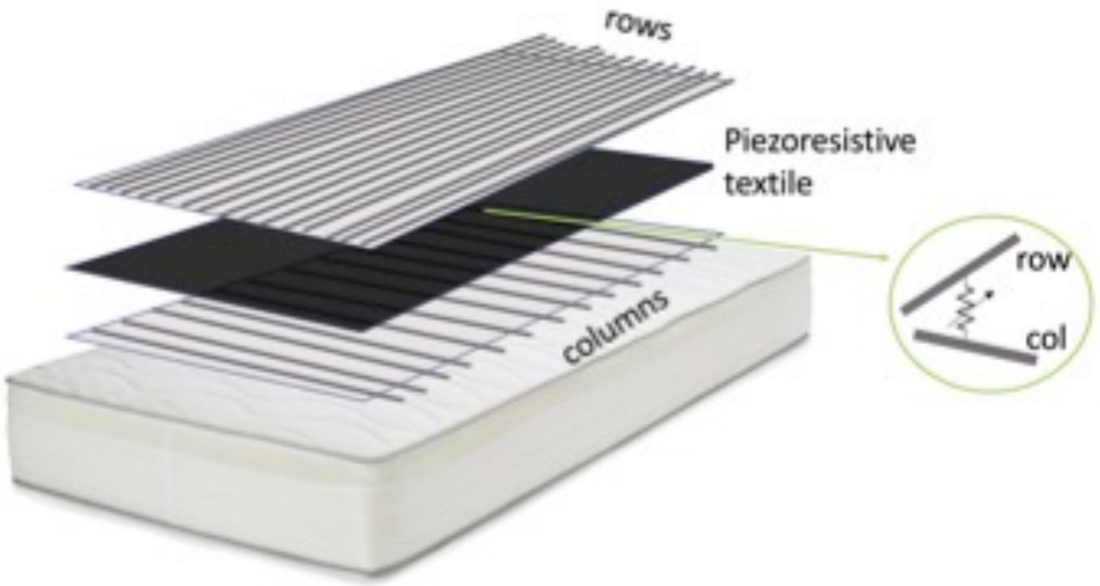
MARCO LAURINO[1], LUCIA ARCARISI[2], NICOLA CARBONARO[2,3], ANGELO GEMIGNANI[4,1], DANILO MENICUCCI[4], AND ALESSANDRO TOGNETTI[2,3], (Member, IEEE)

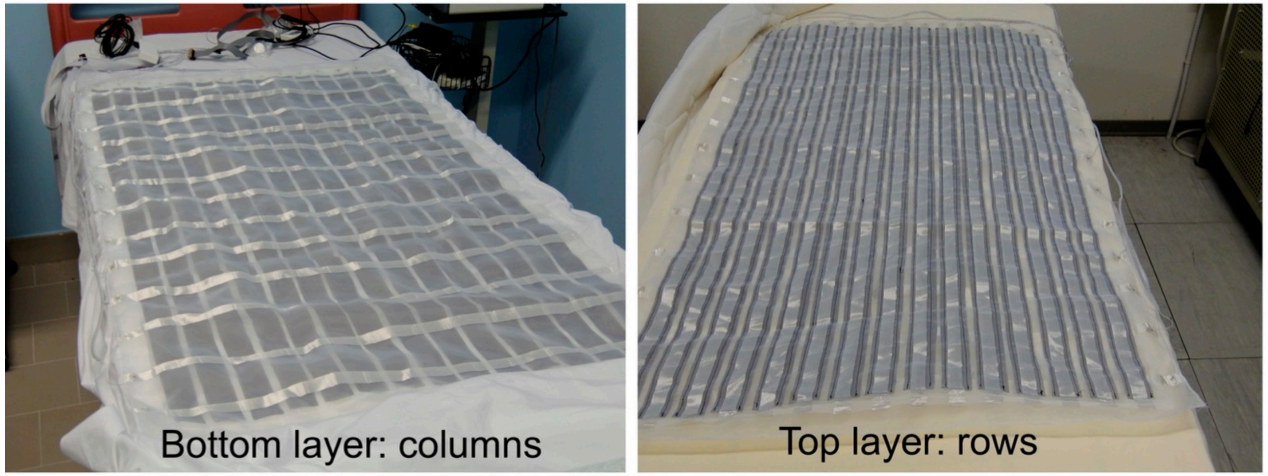
Array of **13 × 15 piezoresistive elements** spread over an **area of 125 × 75 cm**.

Slight modification of the classic resistive matrix method

Sleep posture
Subject movements
Respiratory activity

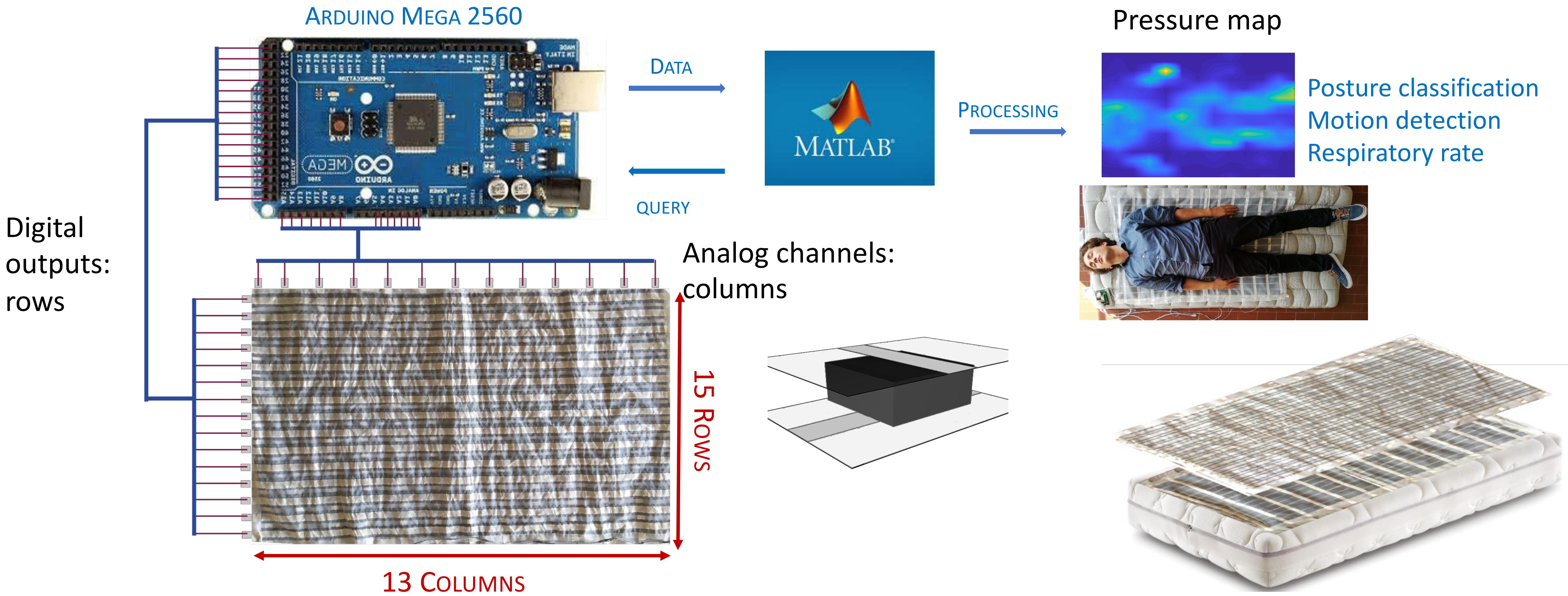
Flexible, non stretchable.





Piezoresistive fabric: CARBOTEX 03-82 by SEFAR AG (Heiden, Switzerland).
Top and bottom layers: PET fabric with integrated evenly-spaced metallic stripes (from SEFAR AG).

Sensing mattress architecture



Why a smart bed?

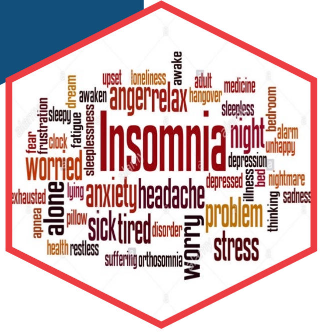
GENERAL AILMENTS AT NIGHT

MAIN PROBLEMS

PATHOLOGICAL DISORDERS

65% ITALIAN POPULATION

10% ITALIAN POPULATION



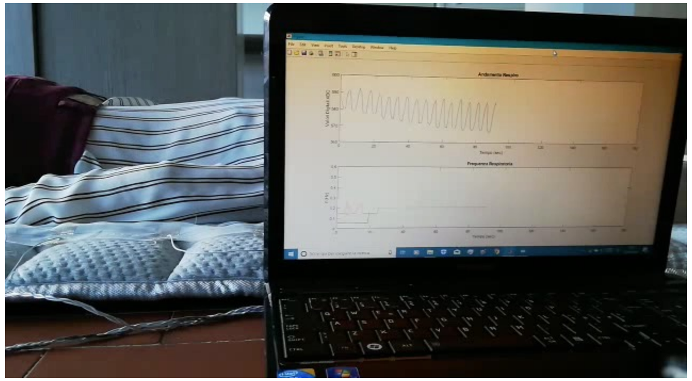
⬆ CAR ACCIDENTS

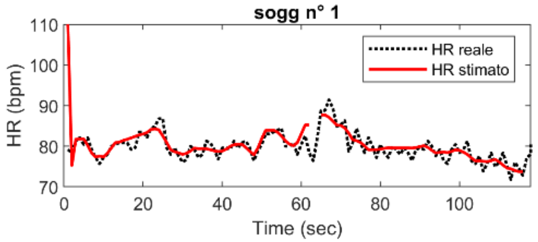
⬇ PERFORMANCE

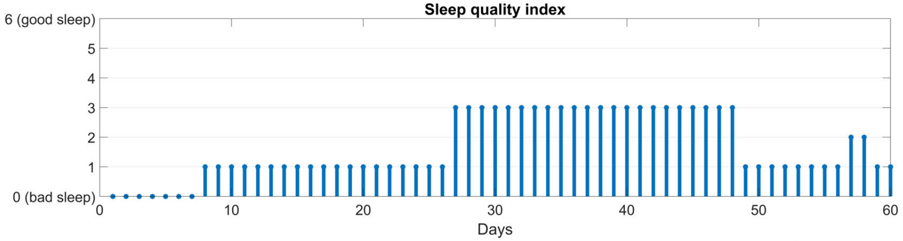
METABOLIC & CARDIOVASCULAR DISEASES

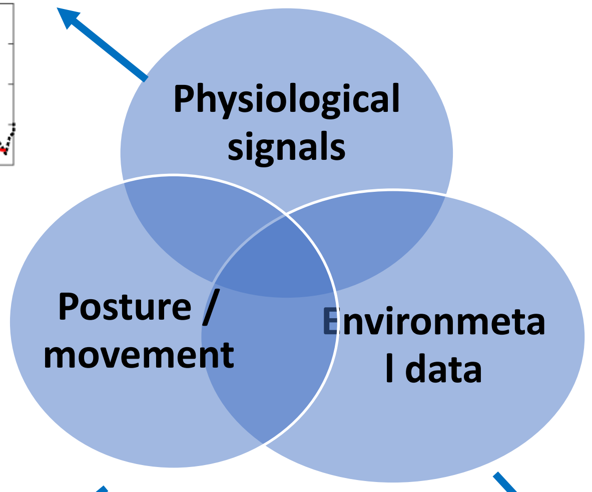
The **Gold standard** is the polysomnographic analysis: poor comfort and invasive

Sleep and physiological parameter monitoring

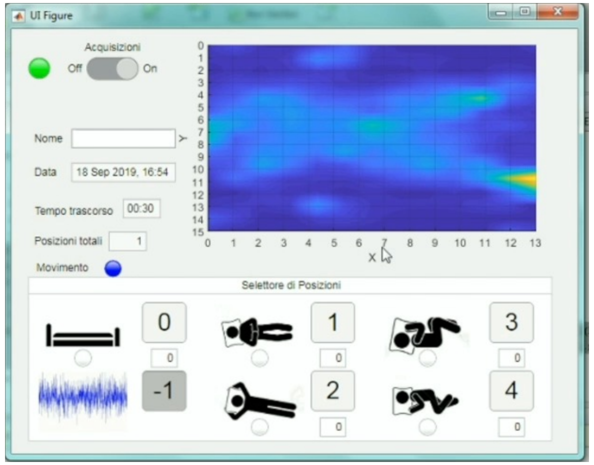


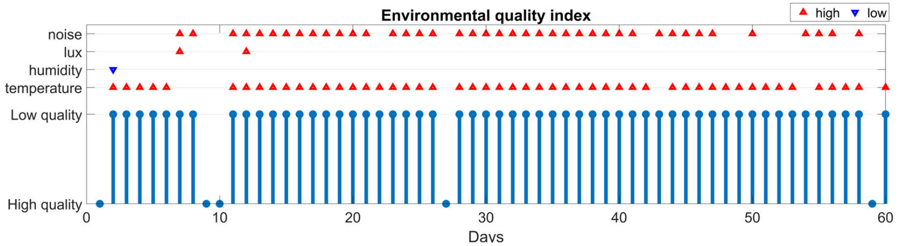






Validated Sleep quality index





Limitations of the resistive matrix method: the sensing sock case study

- Advantages
  - Easy fabrication
  - Low number of electrical contacts
  - Mechanical robustness
- Limitations
  - Complexity of signal routing
  - Cross talk between sensors
  - Non suitable for stretchable application
- Not suitable for personal wearable devices

Why a sensing sock?

Gait Analysis in daily life as gold standard for disease prediction

Normal gait speed is the “holy grail” for the assessment of loss of mobility

A reduction in normal gait speed is a reliable predictor of “hard” outcomes across several diseases

Journal of Evaluation in Clinical Practice
International Journal of Public Health Policy and Health Services Research
Journal of Evaluation in Clinical Practice ISSN 1365-2753

SYSTEMATIC REVIEW

Minimal clinically important difference for change in comfortable gait speed of adults with pathology: a systematic review

Richard W. Bohannon PT DPT EdD NCS[1] and Susan S. Glenney PT DPT GCS[2]

[1]Professor, [2]Clinical Assistant Professor, Program in Physical Therapy, Department of Kinesiology, Neag School of Education, University of Connecticut, Storrs, CT, USA

The Journal of Nutrition, Health & Aging©
Volume 13, Number 10, 2009

JNHA: CLINICAL NEUROSCIENCES

GAIT SPEED AT USUAL PACE AS A PREDICTOR OF ADVERSE OUTCOMES IN COMMUNITY-DWELLING OLDER PEOPLE AN INTERNATIONAL ACADEMY ON NUTRITION AND AGING (IANA) TASK FORCE

G. ABELLAN VAN KAN[1], Y. ROLLAND[1,2], S. ANDRIEU[2,3], J. BAUER[4], O. BEAUCHET[5], M. BONNEFOY[6], M. CESARI[7], L.M. DONINI[8], S. GILLETTE-GUYONNET[1,2], M. INZITARI[9], F. NOURHASHEMI[1,2], G. ONDER[10], P. RITZ[11], A. SALVA[9], M. VISSER[12], B. VELLAS[1,2]

Original Contribution

January 5, 2011

Gait Speed and Survival in Older Adults

Stephanie Studenski, MD, MPH; Subashan Perera, PhD; Kushang Patel, PhD; et al

Article Information

JAMA. 2011;305(1):50-58. doi:10.1001/jama.2010.1923

SCIENTIFIC REPORTS

OPEN

Gait Speed rather than Dynapenia Is a Simple Indicator for Complex Care Needs: A Cross-sectional Study Using Minimum Data Set

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Published online: 21 August 2017

Tzu-Ya Huang[1,2], Chih-Kuang Liang[1,3,4,6], Hsiu-Chu Shen[1,3], Hon-I Chen[2], Mei-Chen Liao[1], Ming-Yueh Chou[1,4], Yu-Te Lin[1,3] & Liang-Kung Chen[4,5]

THE GERONTOLOGICAL SOCIETY OF AMERICA®

Journals of Gerontology: Medical Sciences
cite as: J Gerontol A Biol Sci Med Sci, 2016, Vol. 71, No. 1, 63–71
doi:10.1093/gerona/glv126
Advance Access publication August 22, 2015

OXFORD

Research Article

Gait Speed Predicts Incident Disability: A Pooled Analysis

ELSEVIER

Journal of the American Medical Directors Association

Volume 15, Issue 3, March 2014, Pages 194-200

Original Study

Gait Speed in Ambulant Older People in Long Term Care: A Systematic Review and Meta-Analysis

Suzanne S. Kuys PhD [a, b], Nancye M. Peel PhD [c], Kerenaftali Klein PhD [d], Alexandra Slater [c], Ruth E. Hubbard MD [c]

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The American Journal of Geriatric Psychiatry

Volume 25, Issue 4, April 2017, Pages 374-385

Gait Speed and Processing Speed as Clinical Markers for Geriatric Health Outcomes

Joost B. Sanders M.D. [a, b], Marijke A. Bremmer M.D., Ph.D. [b, c], Hannie C. Comijs Ph.D. [c, e], Peter M. van de Ven Ph.D. [d], Dorly J.H. Deeg Ph.D. [b, d], Aartjan T.F. Beekman M.D., Ph.D. [b, c, e]

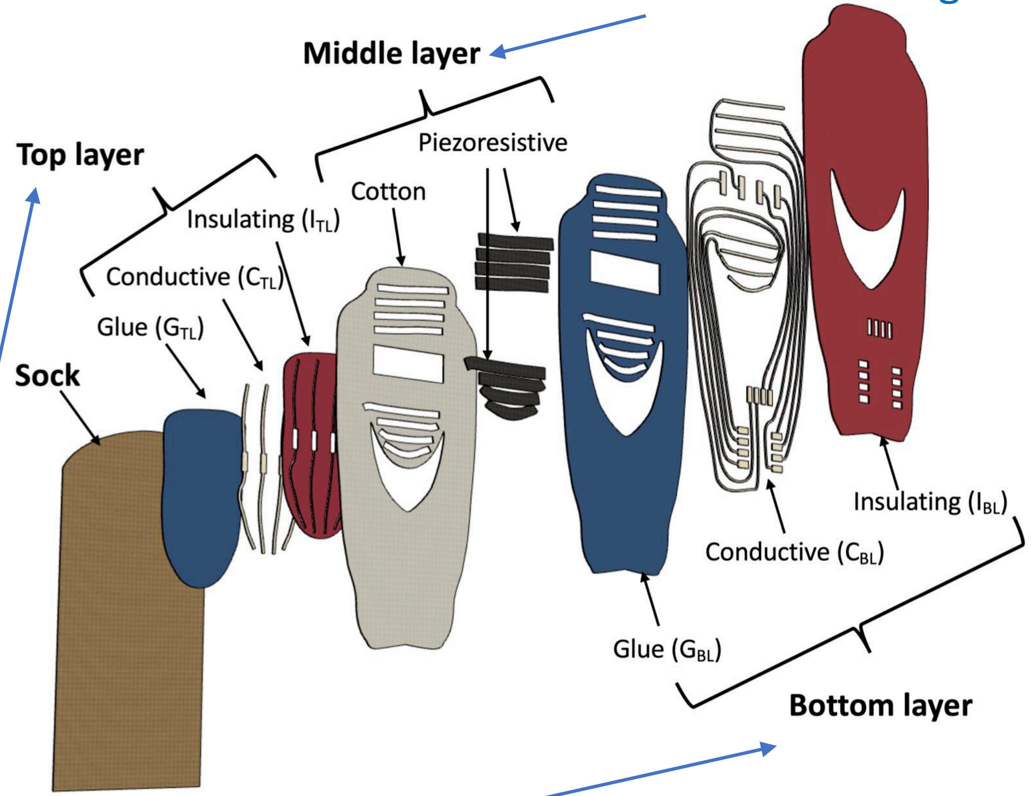
Frailty as Tested by Gait Speed is an Independent Risk Factor for Cirrhosis Complications that Require Hospitalization

Michael A Dunn MD, Deborah A Josbeno PT, PhD, Amit D Tevar MD, Vikrant Rachakonda MD, Swaytha R Ganesh MD, Amy R Schmotzer RN, BSN, Elizabeth A Kallenborn RN, CCTC, MS, Jaideep Behari MD, PhD, Douglas P Landsittel PhD, Andrea F DiMartini MD & Anthony Delitto PT, PhD

The American Journal of Gastroenterology **111**, 1768–1775 (2016) | Download Citation

Modified resistive matrix method: the sensing sock case study

Laser cutter and gluing



Screen printed stretchable circuit + heat print transfer

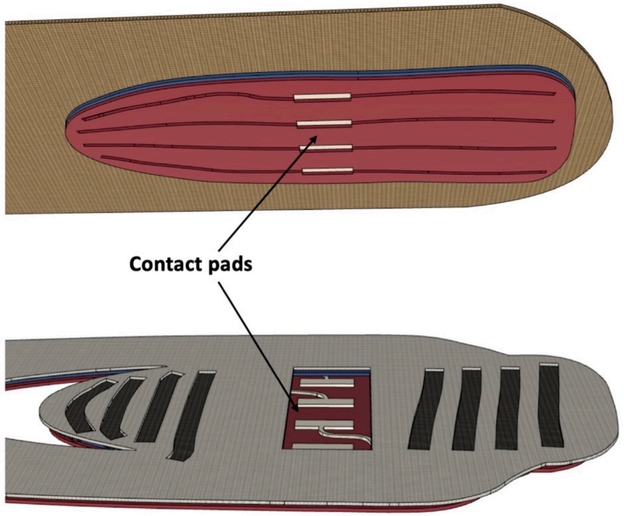

sensors MDPI

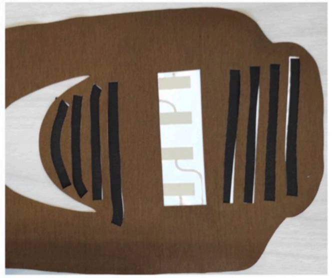
Article

Exploiting Resistive Matrix Technology to Build a Stretchable Sensorised Sock for Gait Analysis in Daily Life

Nicola Carbonaro [1,2,*], Lucia Arcarisi [1], Carlotta Marinai [1], Marco Laurino [3], Francesco Di Rienzo [1], Carlo Vallati [1] and Alessandro Tognetti [1,2]

Top layer transferred on the sock





Bottom layer transferred on the middle layer and then sewn on the sock

Patent pending: PROCESS FOR MAKING A FLEXIBLE SENSOR MEMBRANE, n° EP22157410.6

Modified resistive matrix method: <u>the sensing sock case study</u>

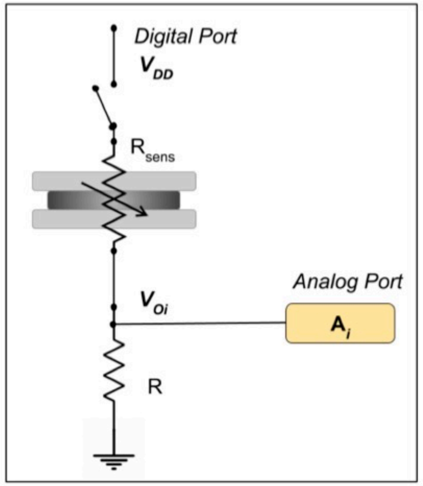
Stretchable

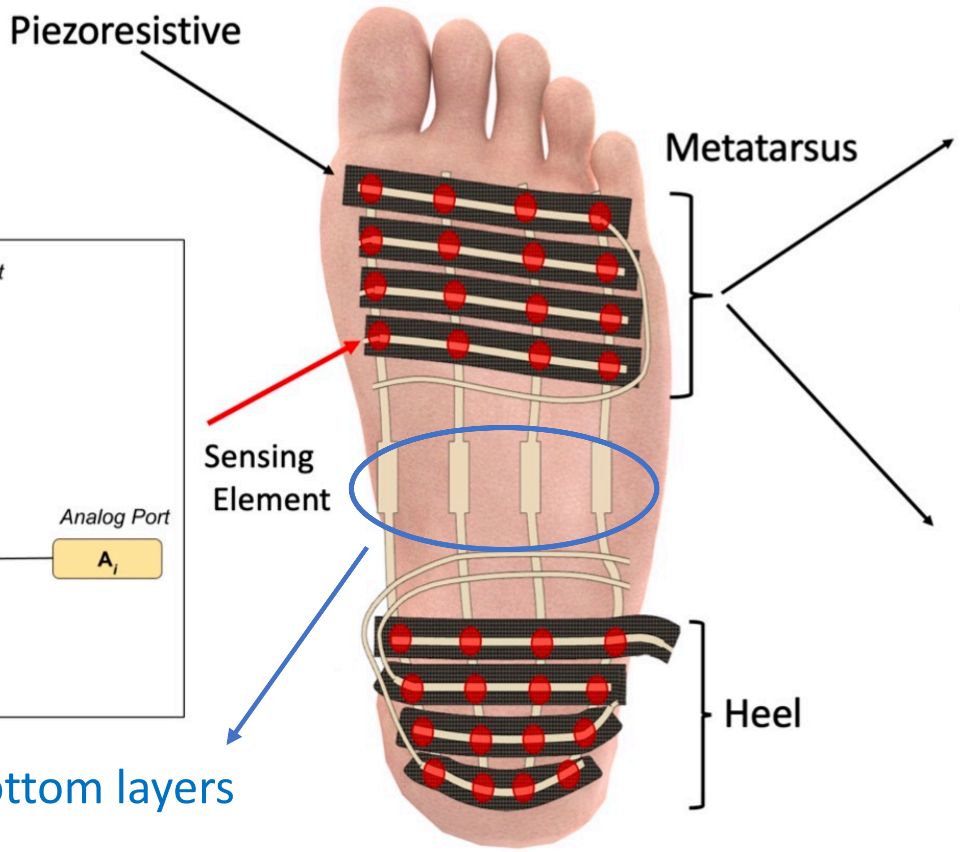
Easy to wear

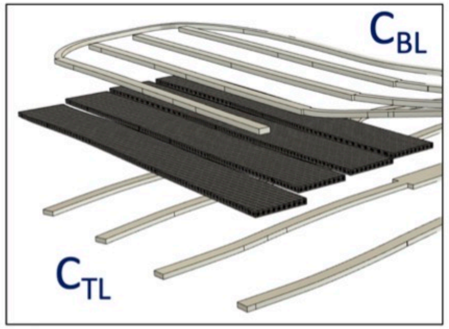
Can fit different sizes

Reduced crosstalk

The resistive matrix structure







Connection between top and bottom layers

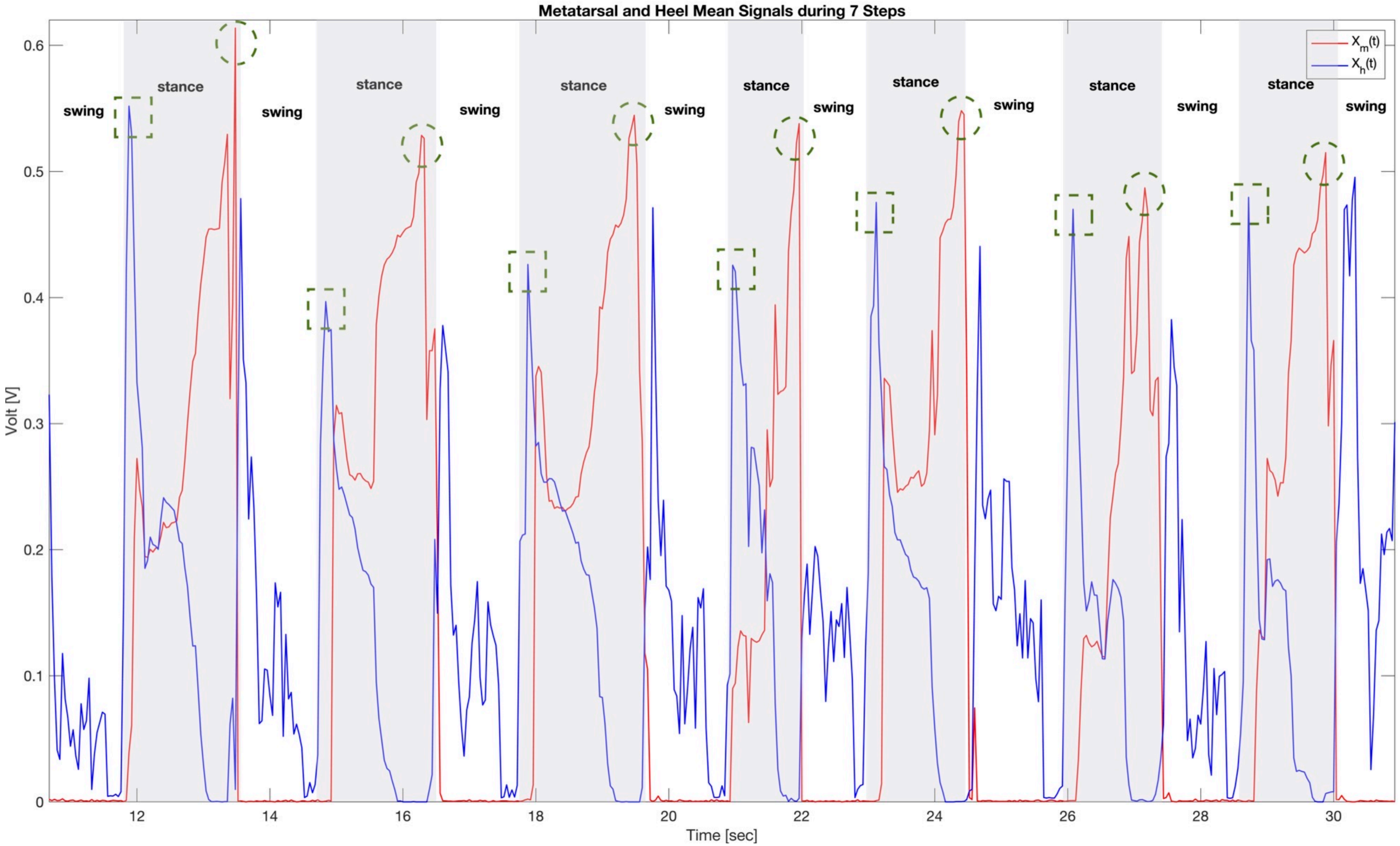
⬇

All electrical contacts are on the bottom layer

32 sensing elements concentrated in metatarsal and heel regions ➡ Each sensing element **decreases its electrical resistance** once the applied **pressure increases**

Main Parameter Extraction

Typical trend of mean signals acquired during 7 steps. Dotted square indicates **HS events,** dashed circle **TO events**.

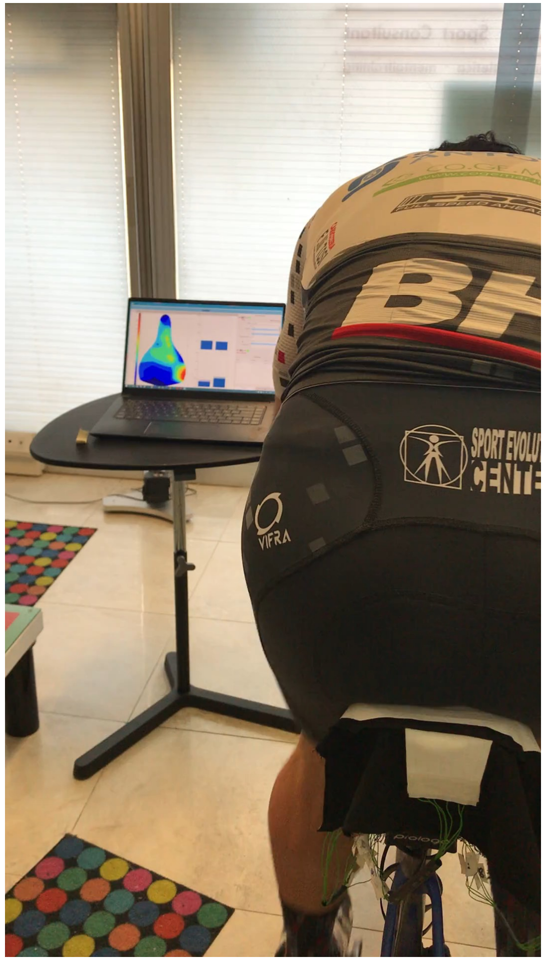


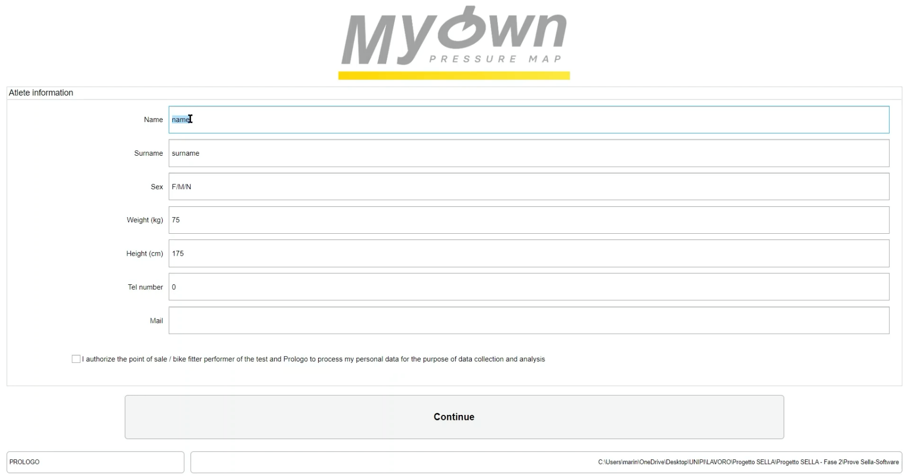
Proof of concept

Temporal Parameters of gait

Balance

Modified resistive matrix method: the sensing seat for cyclists





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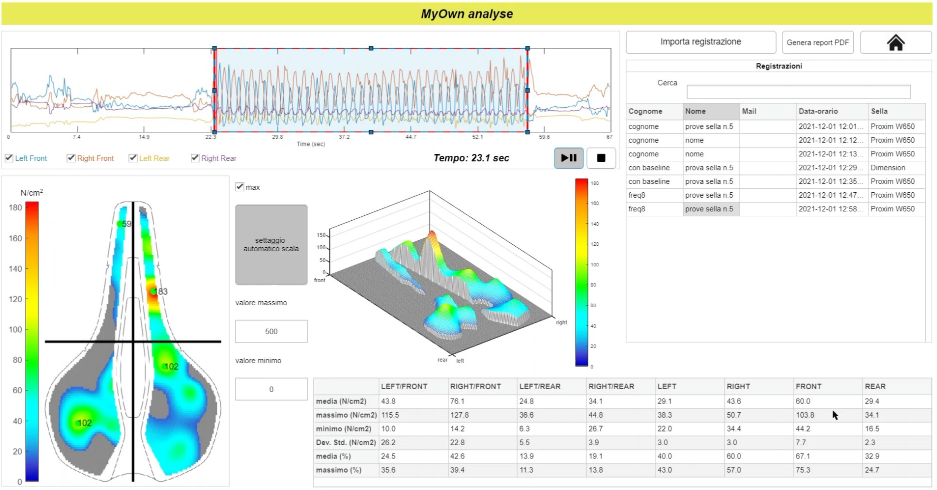
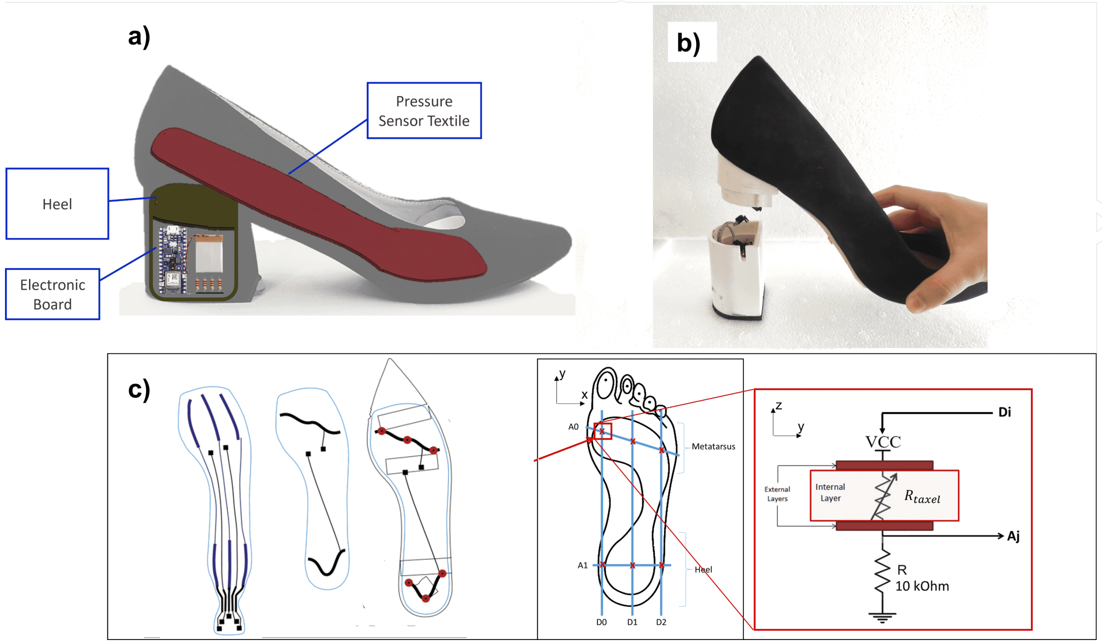
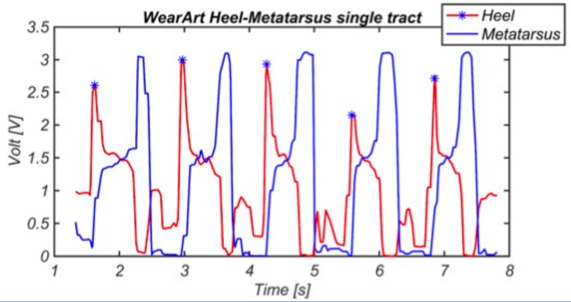


[redacted]

Modified resistive matrix method: the high-heel sensing shoe

- WearArt project funded by Regione Toscana and leaded by the shoe manufacturer Simone Martini srl
- Technological added value to a high quality high-heel shoe
- Pressure sensors "hidden" in the insole layer, without modifying the shoe look

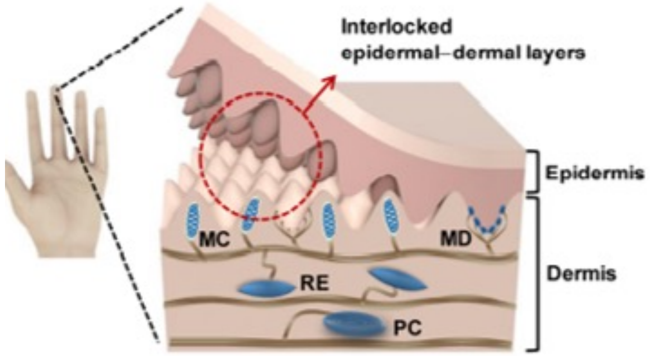


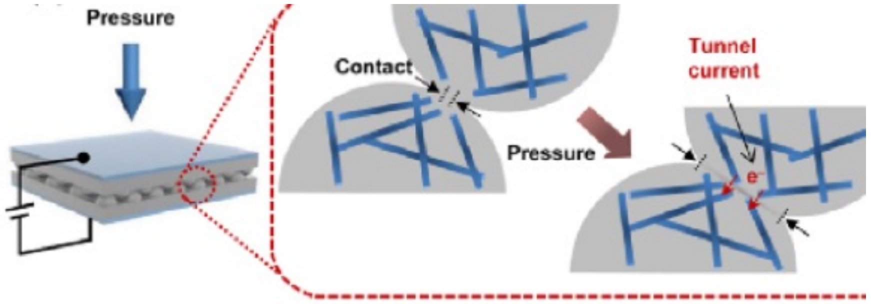


Future directions

Bio-inspiration to improve the sensing layer

Intermediate ridges at the epidermal-dermal junction → **Transduction** and **magnification** of the mechanical stimuli

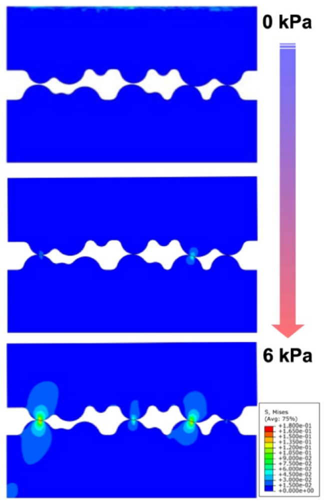




Increase sensitivity

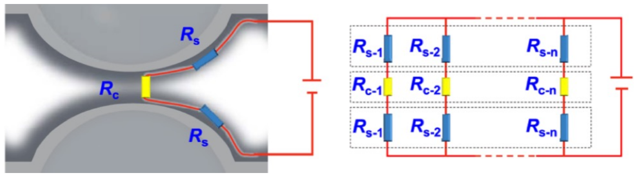
Better time response

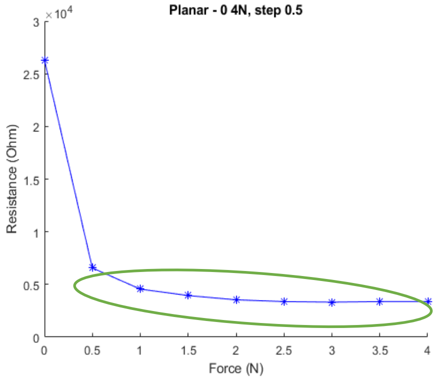
Two layers **pressure sensor** with **conductive interlocked micro-structures**

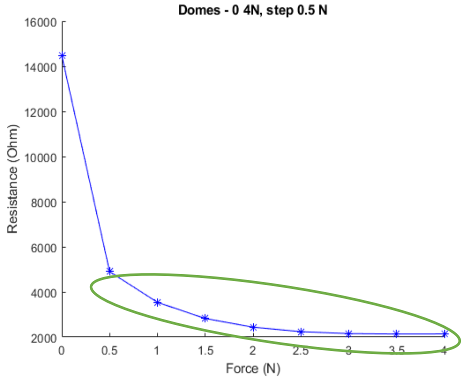


Global piezoresistive effect → gradual decrease in resistance depending on the external pressure

Onset of different contact areas between the conductive domes generate paths for the current flow.







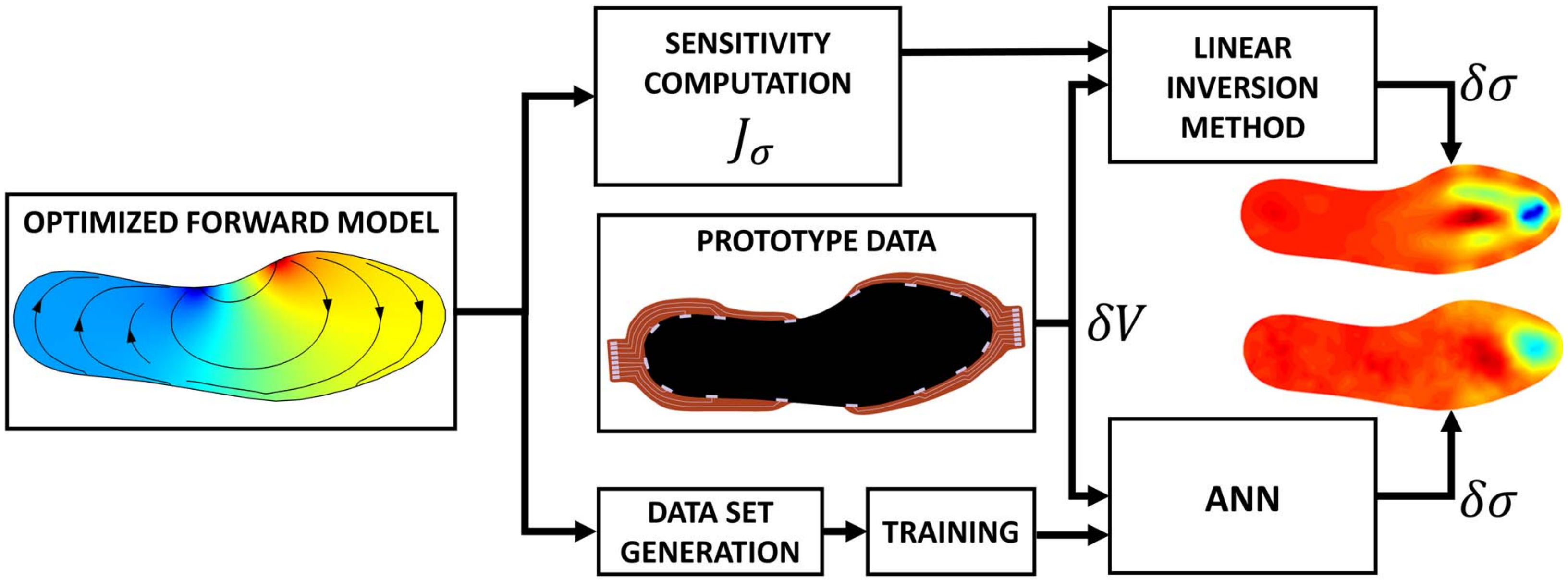
Electrical impedance tomography

- One-layer pressure sensing surface
- Conductivity distribution estimation

4186 IEEE SENSORS JOURNAL, VOL. 22, NO. 5, MARCH 1, 2022 IEEE Sensors Council

Physics-Based Simulation and Machine Learning for the Practical Implementation of EIT-Based Tactile Sensors

Niccolò Biasi, Andrea Gargano, Lucia Arcarisi, Nicola Carbonaro, *Member, IEEE*, and Alessandro Tognetti, *Member, IEEE*



Simple structure

Complex inverse-problem-based processing

Clinical applications

TOLIFE

Combining Artificial Intelligence and smart sensing TOward better management and improved quality of LIFE in chronic obstructive pulmonary disease

Combining smart surfaces and AI for optimizing patients' management

Smart bed

Sleep quality
Heart rate
Breath rate
Environment
patient sounds

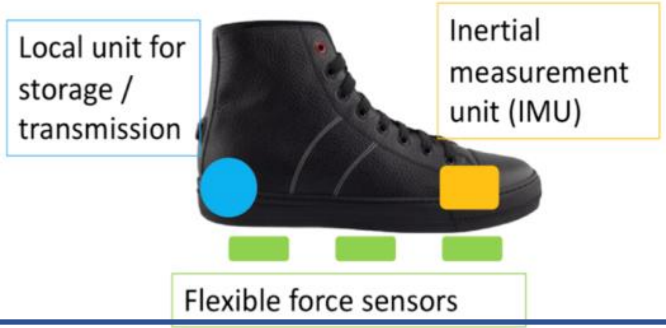
Smartphone

Mobility
Patient sounds
Social interaction
Light exposure

Smartwatch

HR / HRV
SpO2
Patient sounds
Mobility
Light exposure

Smart shoes



Walking patterns
Mobility
Gait speed