Textile Sensing Platforms to support a Healthier Life Style

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Beauty and Seduction

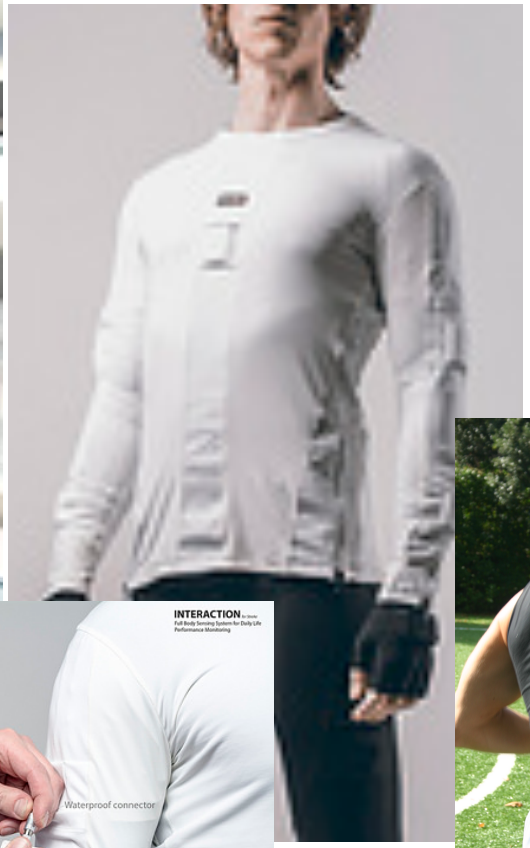
The Wingsuit

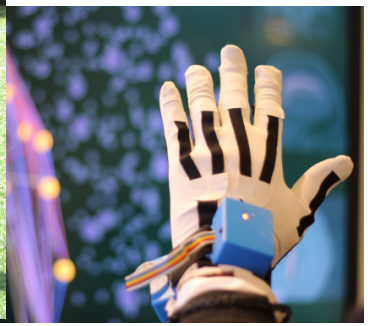
Nylon coated with Teflon

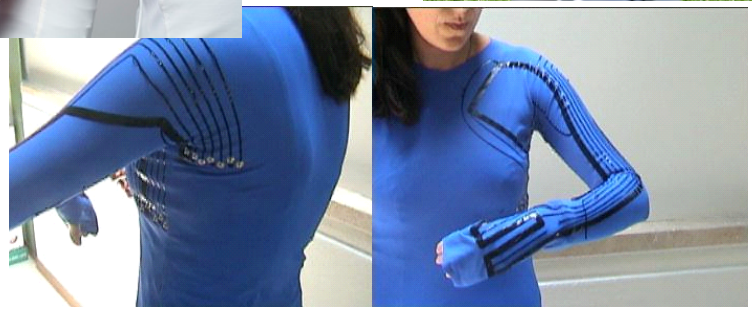
The Birdman Skyflyer S.5

Source: Superhuman Performance (Edizioni Museo del Tessuto)

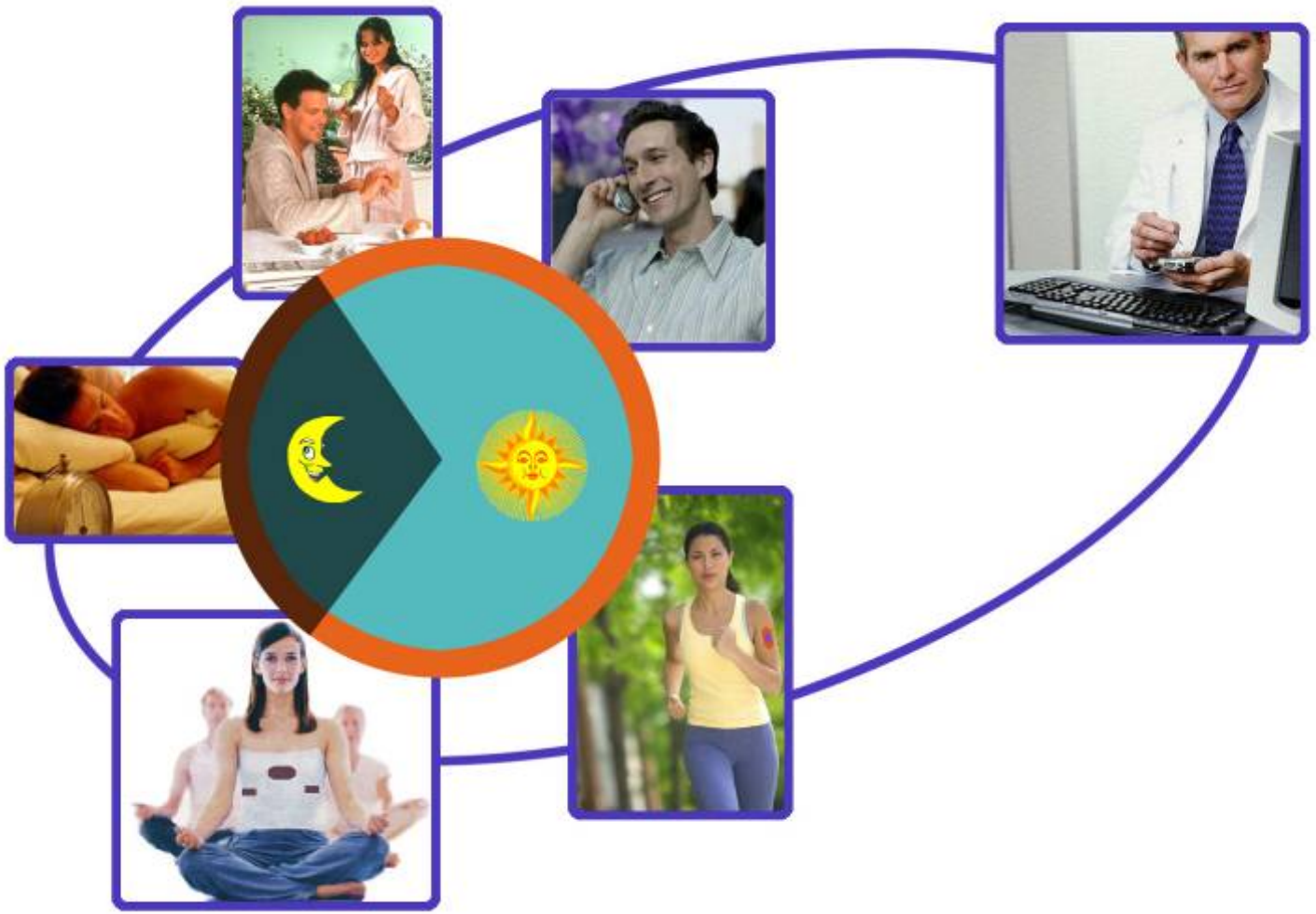
MONITORING SYSTEMS







CONTINUOUS , IMPERCEPTIBLE, UNOBTRUSIVE SENSING



DAY

wherever you are

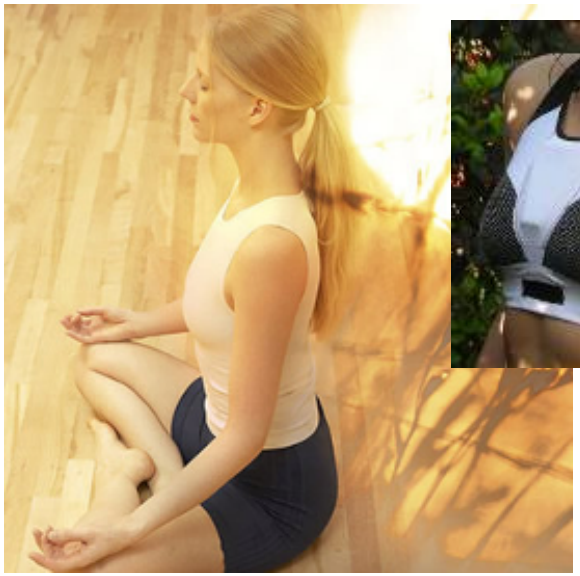
Taking care of you

Cardio-Respiratory Monitoring
ECG
Respiratory signal
Heart Rate
Breathing Rate
HR Variability
Stress Monitoring
Activity level classification
Posture

@ DAY

Cardio-Respiratory Monitoring
5-lead ECG
Impedance measurement (respiration)
Piezo-resistive bands (movement)
Skin temperature
Standard SpO2
Posture

1 ECG lead, Respiratory signals through Pletismography, HR, HRV, BR
Activity level classification, Energy activity, steps counter



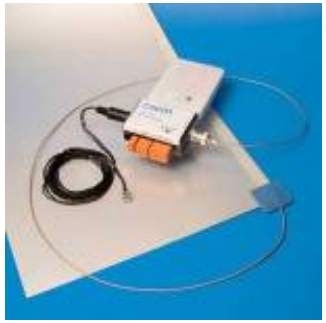
NIGHT

whatever you're dreaming

Watching your sleep

Smart Bed System
Sleep Quality Monitoring
Apnea detection
Cardio-Respiratory Monitoring@night

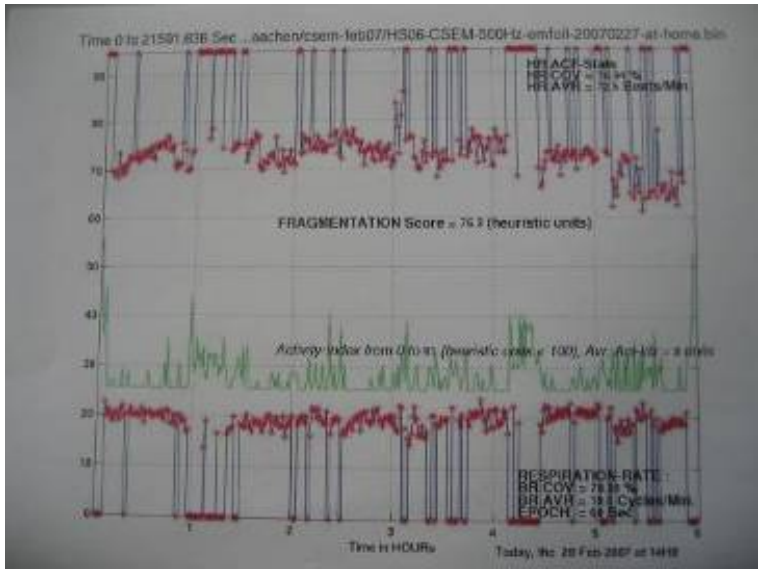
@ NIGHT



Smart bed system

PIEZO ELECTRICS FOIL→ HR, breathing, HRV

BED SHEET→HR, HRV



ECG, RESPIRATORY SIGNAL, ACTIVITY

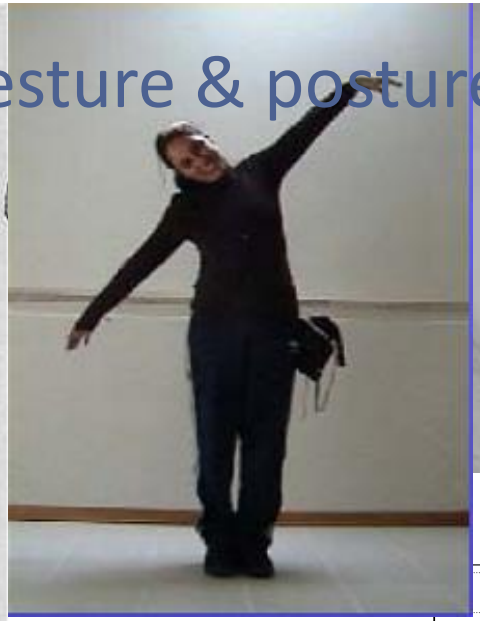
HR, HRV, POSTURE

whatever you're doing

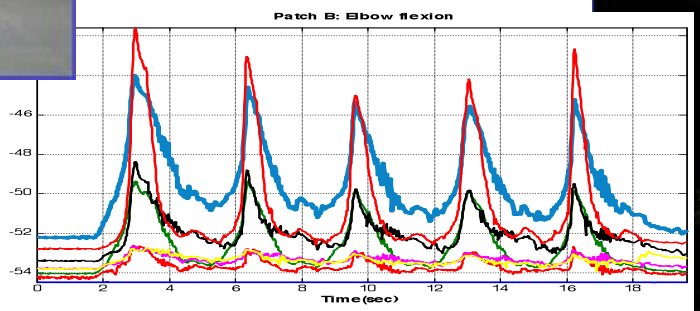
Non verbal language

- Gesture & Movement detection
- Posture Recognition
- Joints articulation
- Muscles activity

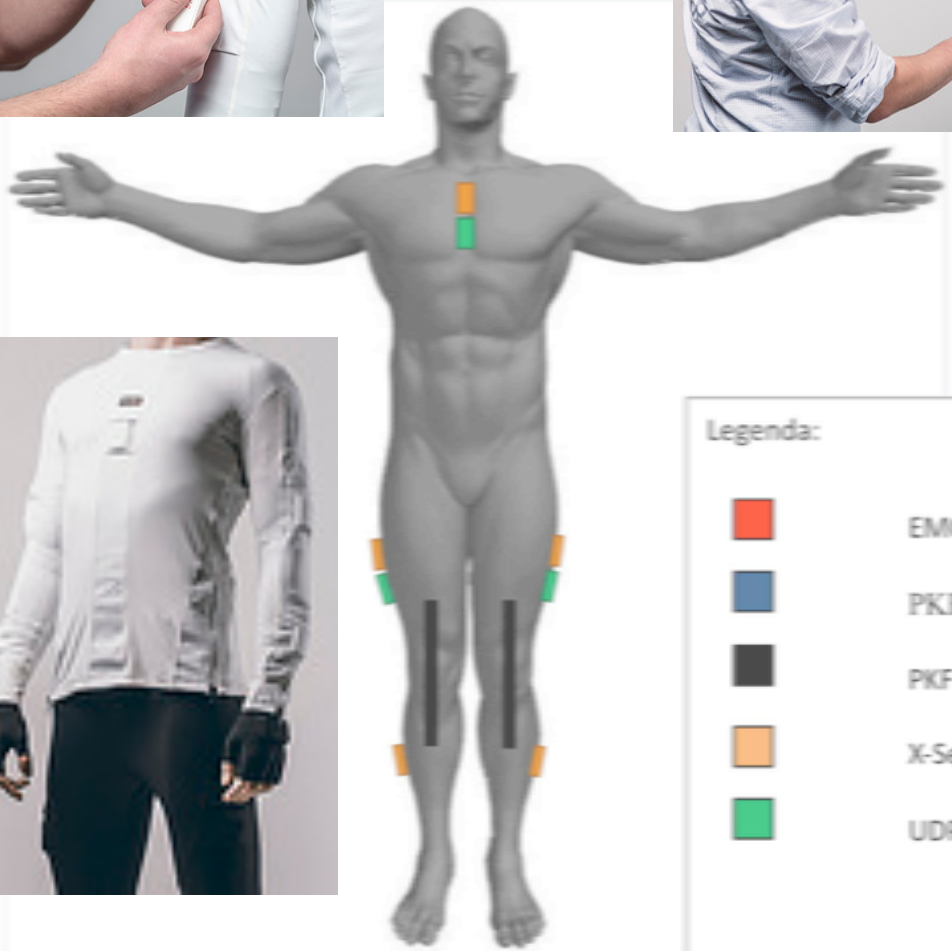
@ ANY TIME-NON VERBAL LANGUAGE



Gesture & posture monitoring



@ ANY TIME DAILY-LIFE PHYSICAL INTERACTION WITH THE ENVIRONMENT



Legenda:

- EMG sensor
- PKF strain
- PKF Goniometer
- X-Sens
- UDP Interface

WORK

whatever you're facing

Behavioral & Attitude sensors

Cardio-Respiratory Monitoring@Work
Stress Monitoring
Activity level classification
Posture
Temperature
Multivariable approach to track the instinctual side of human behavior
Alarms Management System

@ WORK

Behavioral & attitudinal sensors combined with stress indicators

eSPONDER

PROETEX

@ Work: e Sponder Field Test

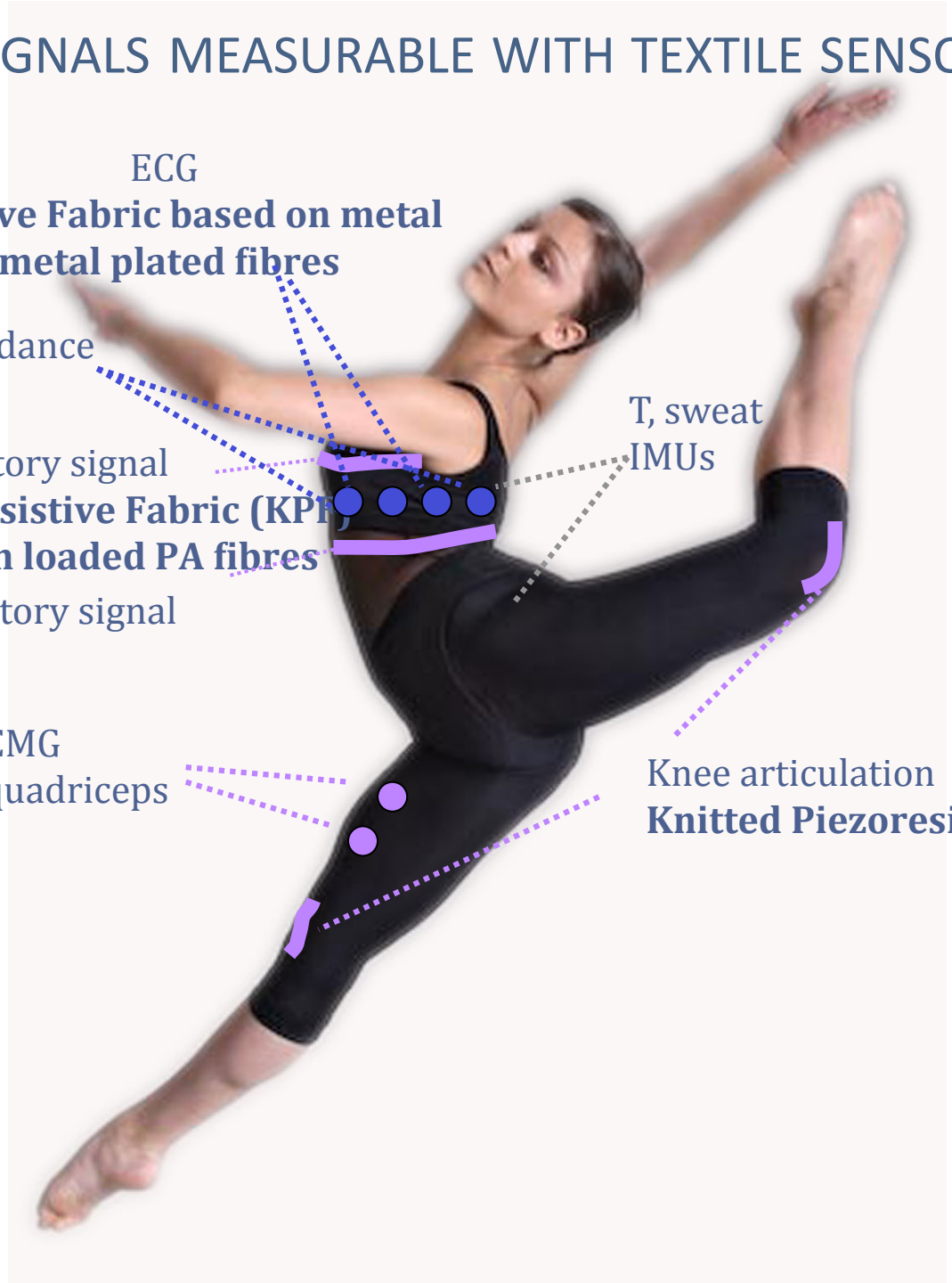
TEXTILE SENSORS

TABLE II

BODY SIGNALS OR VARIABLES UNDER MONITORING IN E-TEXTILES AND THEIR FABRIC IMPLEMENTATION

Body signals or variables	Sensing devices/component	Device implementation
Electrocardiogram(ECG)	Bioelectrodes	Woven or Knitted fabric based on metal fibers/wires
Electromiogram(EMG)	Bioelectrodes	Woven or Knitted fabric based on metal fibers/wires
Carotide pulse and radial artery pulse	Piezoelectric sensors	Small-size film strips or textile fibers based on electroactive polymers (under development)
Heart apex pulse (ballistocardiogram)	Piezoelectric sensors	Small-size film strips or textile fibers based on electroactive polymers (under development)
Respiratory activity	Bioelectrodes Piezoresistive sensors Piezoelectric sensors	Woven or Knitted fabric based on metal Knitted fabrics based on carbon loaded PA yarns Fabric coated with carbon loaded silicone Small-size film strips
Articulation segment position and movements	Piezoresistive sensors	Knitted fabrics based on carbon loaded PA yarns Fabric coated with carbon loaded silicone
Skin electrical impedance	Bioelectrodes	Woven or Knitted fabric based on metal fibers/wires
Blood oxygenation(pulse oximetry)	Optical fibers	Optical fibers

SIGNALS MEASURABLE WITH TEXTILE SENSORS



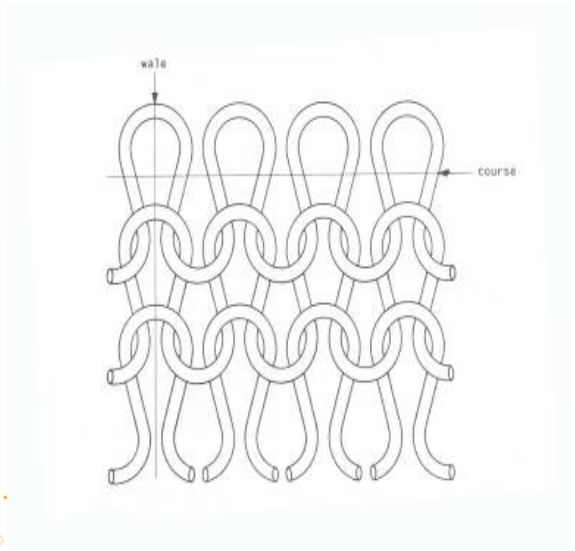
Textile Electrodes & bio mechanical sensors: Elasticity & Conductivity

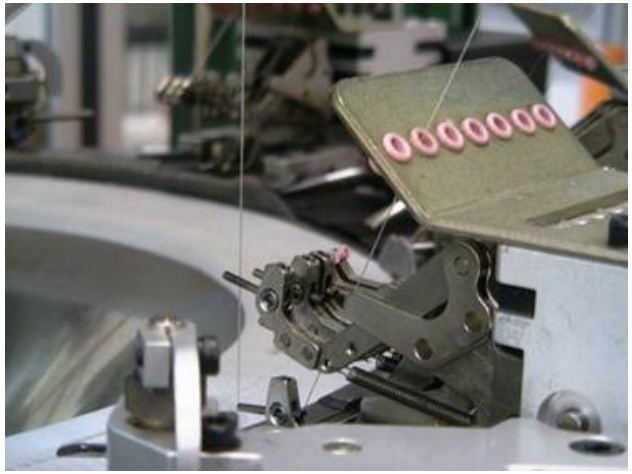
Seamless technology provides:

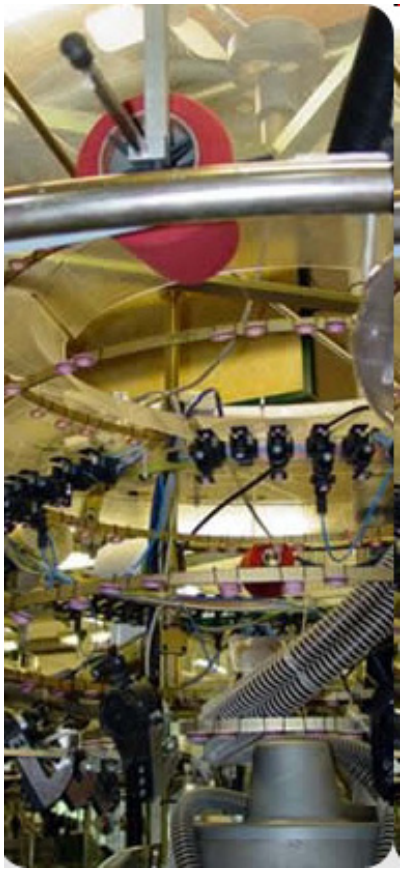
Inlaid knit-work

Pocket knitted in the same production step

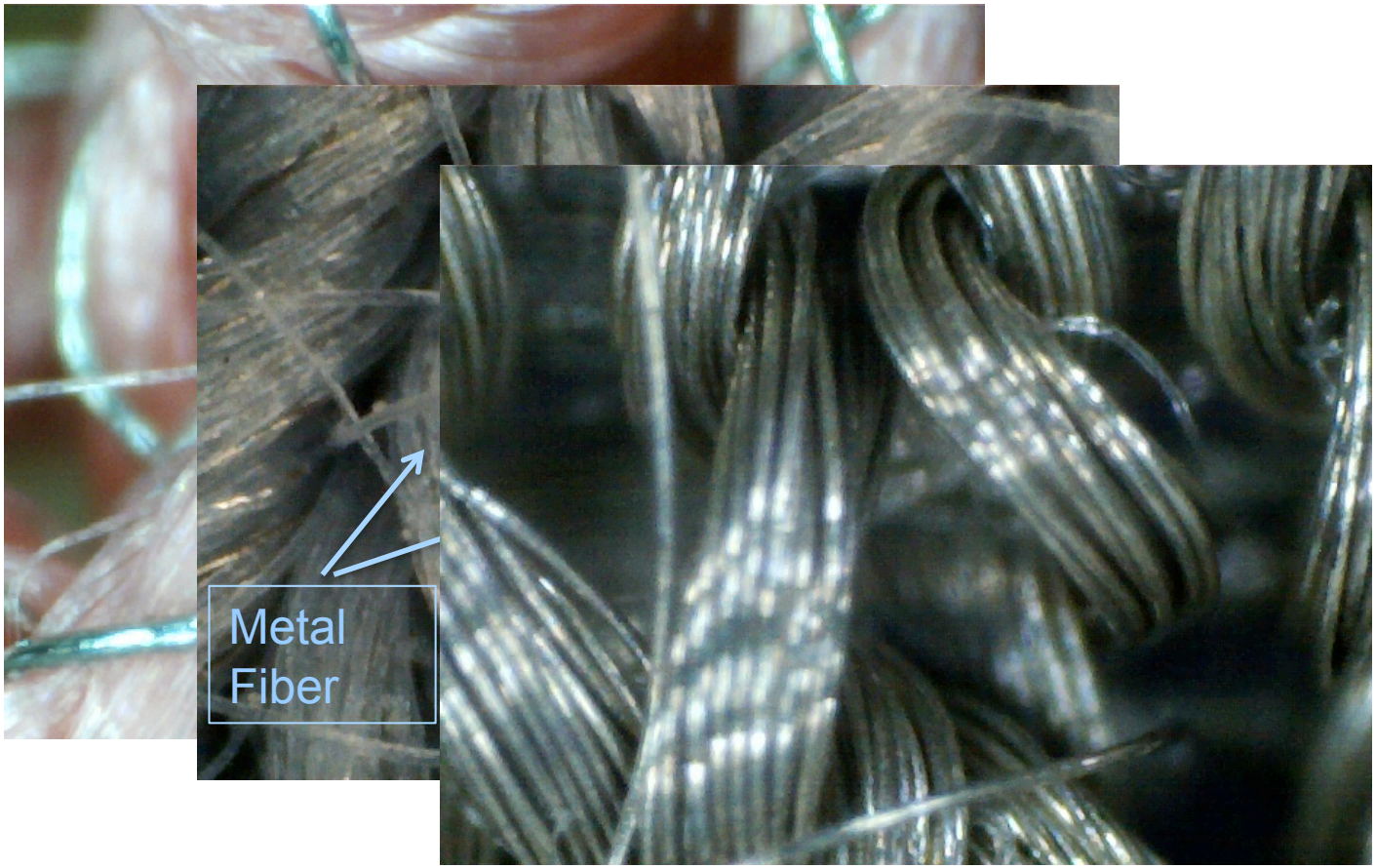
Shaped zones by using intarsia technology and different elasticity



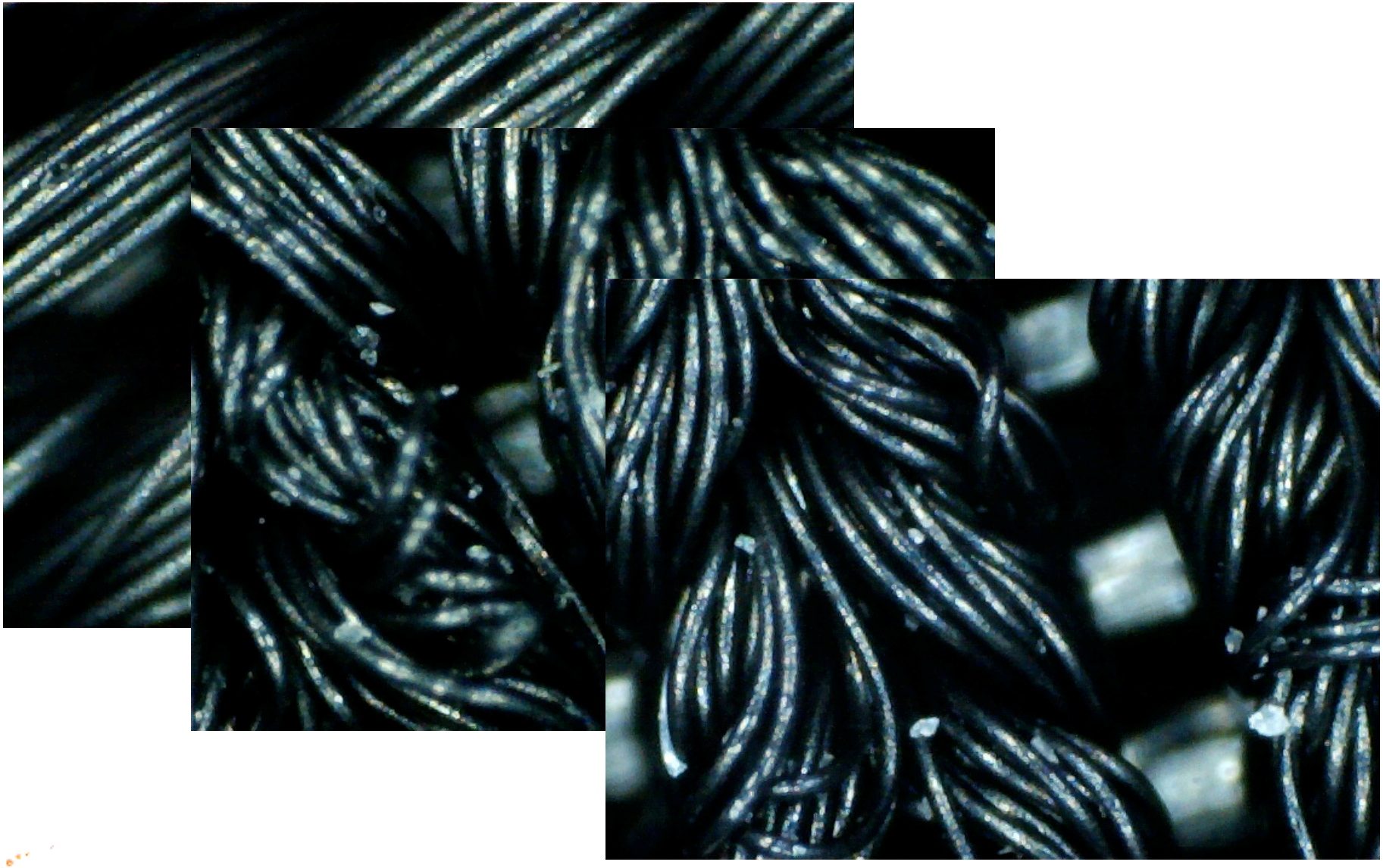




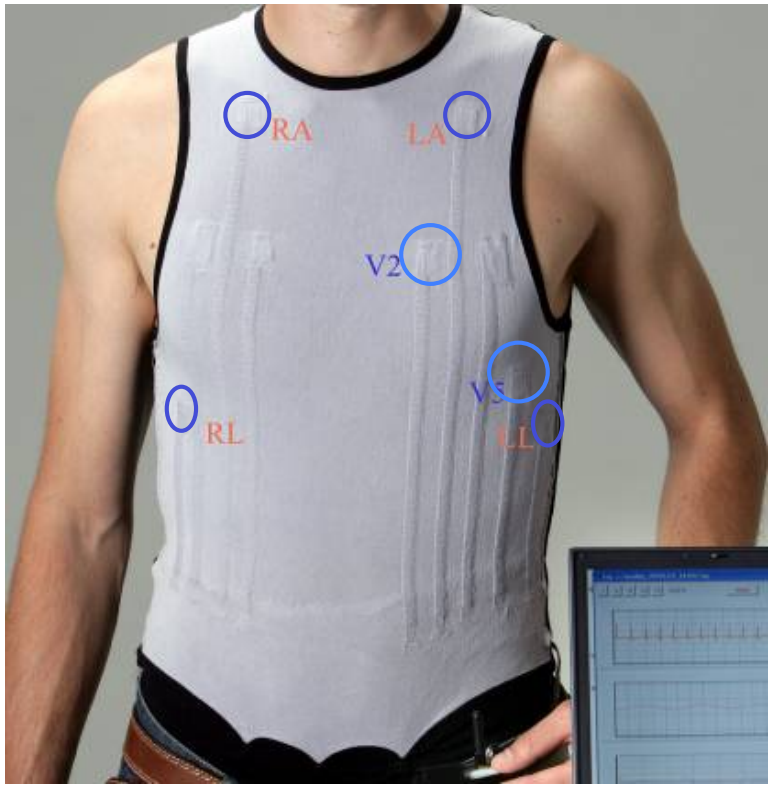
Textile Electrodes: From Monofilament to Fiber and Coating

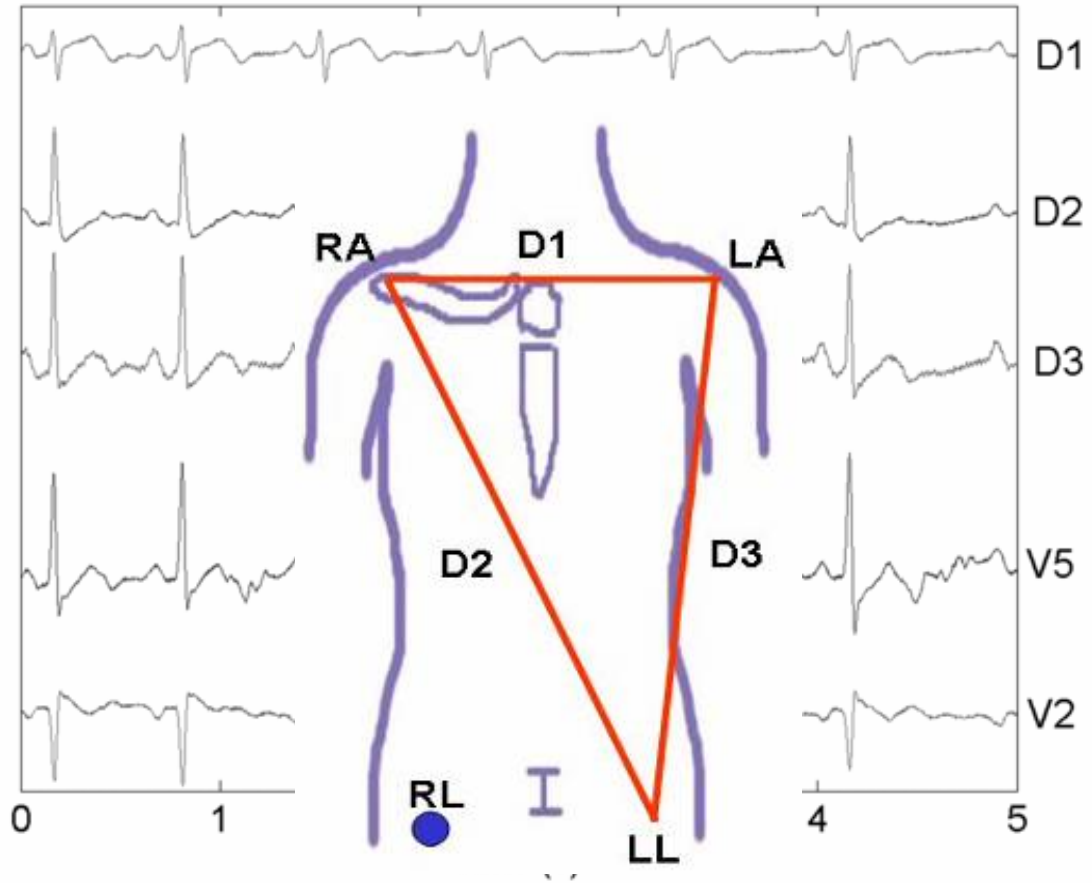


Piezoresistive fabric sensor: elasticity and conductivity



TEXTILE ELECTRODES: ECG ACQUISITION





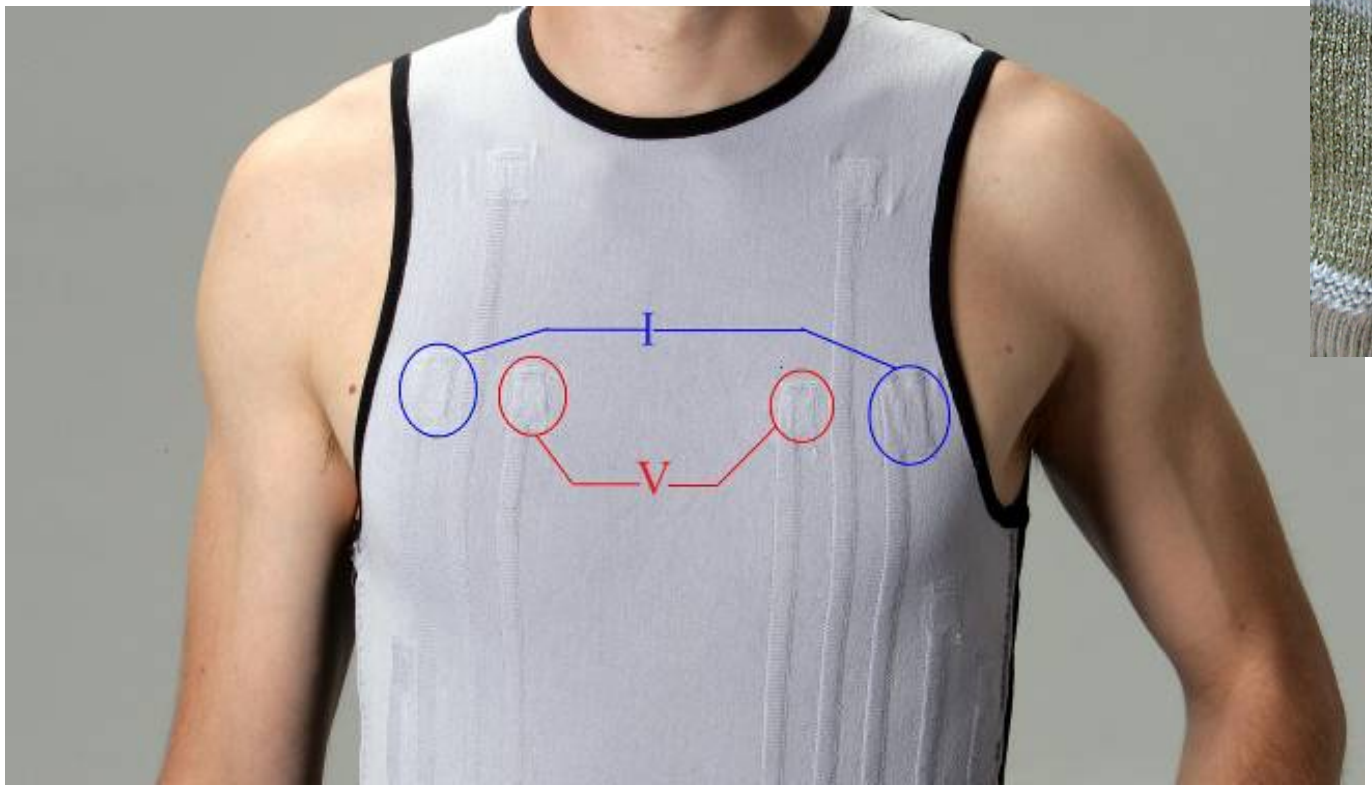
Simultaneous acquisition of 5 leads:

- Einthoven Leads: D1, D2, D3
- Precordial Leads: V2, V5

WEALTHY IST-2001-37778

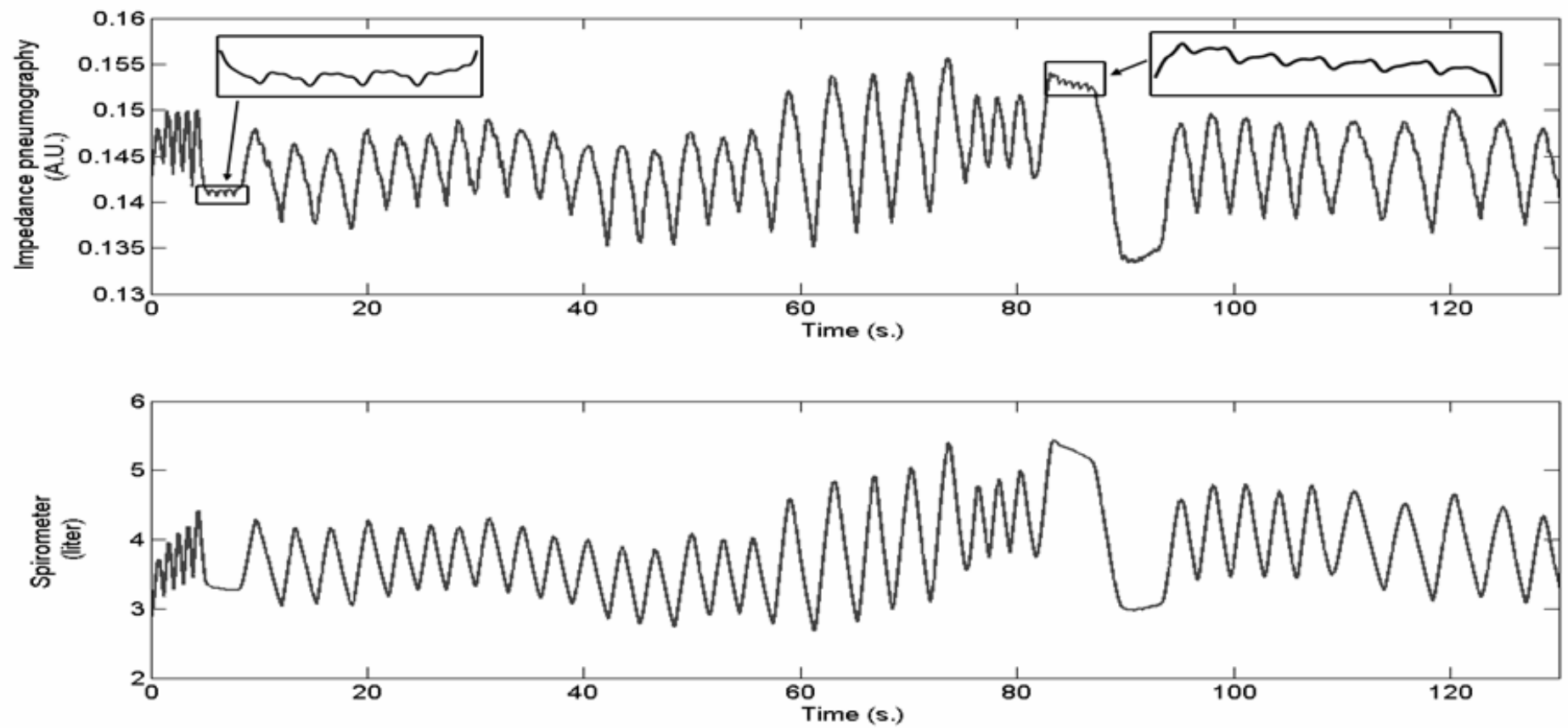
Paradiso R**,** Loriga G, Taccini N, "A Wearable Health Care System based on Knitted Integrated Sensors", IEEE Transaction Technology in Biomedicine, vol 9 (3), pp.337-345, 2005

TEXTILE ELECTRODES: IMPEDANCE PNEUMOGRAPHY ACQUISITION



Impedance pneumography methodology is used to monitor respiratory activity. Four textile electrodes are placed on thoracic position: the outer ones are used to inject a high frequency current (50 kHz) and the inner ones to capture the voltage variation caused by thoracic impedance change.

IMPEDANCE PNEUMOGRAPHY CHARACTERISATION

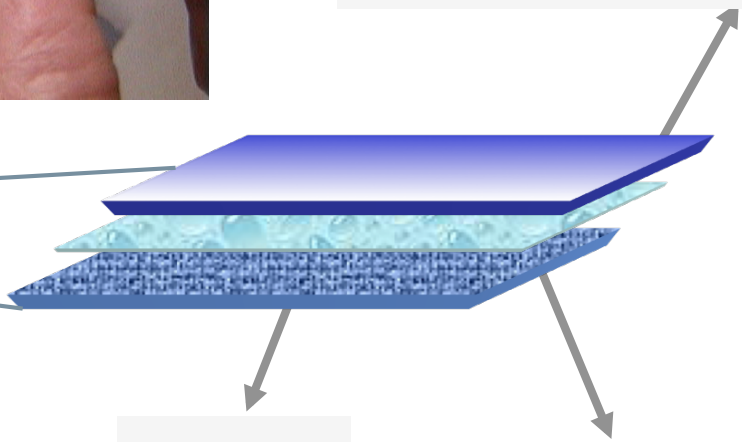


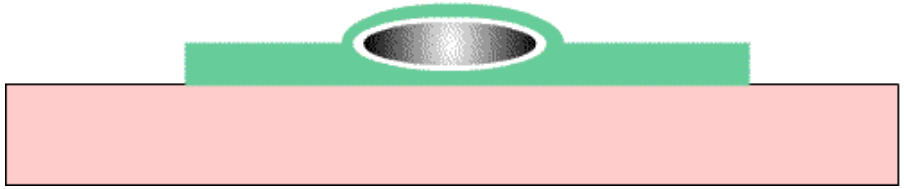
Signal comparison between IP through textile electrodes and Biopac[1] systems in terms of rhythm and amplitude of breathing.

[1]Biopac® MP30 with SS11LA airflow transducer

Paradiso R, Loriga G, Taccini N,, Gemignani, A.,Ghelarducci, WEALTHY, A Wearable Health Care System: New frontier on E-Textile, Journal of Telecommunications and Information technology, vol. 4, pp. 105-113, 2005

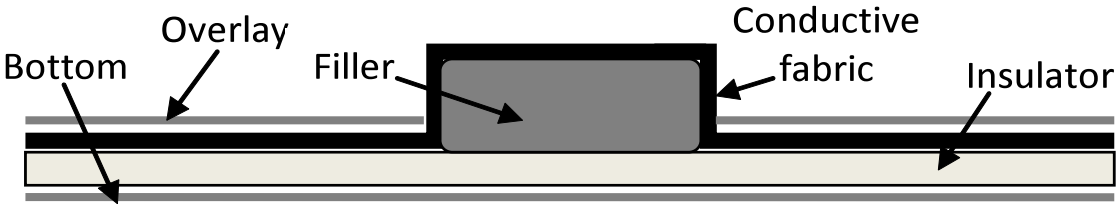
Textile Electrodes: Skin Contact





TEXTILE ELECTRODES: EMG ACQUISITION

Internal structure of electrodes

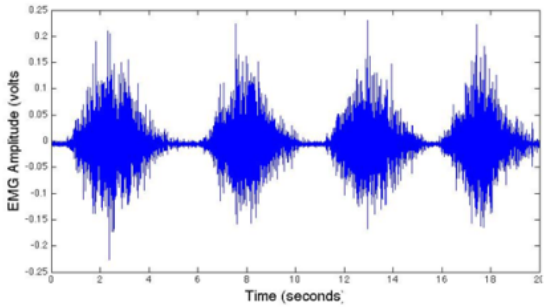


Example of the patch with the sensors.

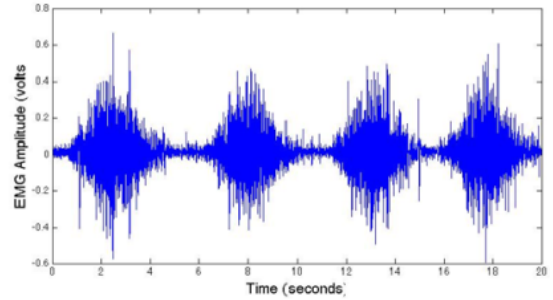
Particular of electrode padding to increase the skin contact, electrodes are integrated in a garment

FUNCTIONAL VALIDATION EMG ELECTRODES

Raw signals from the systems

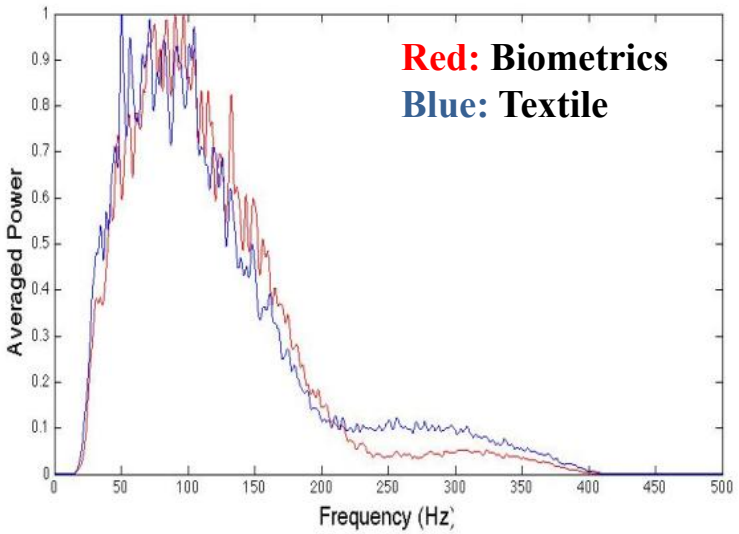


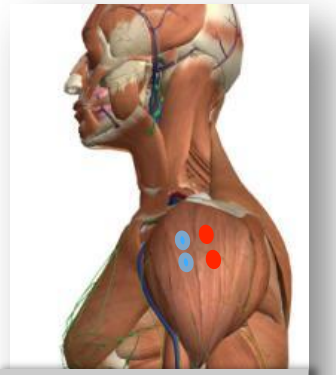
Biometrics electrodes



Smartex electrodes

Averaged power spectrum of 0 kg. trials from subject 5.





Placement of the electrodes on deltoids muscle: Red: Biometrics Blue: Textile

No significant difference was observed in the median frequency and standard deviation between the two electrodes

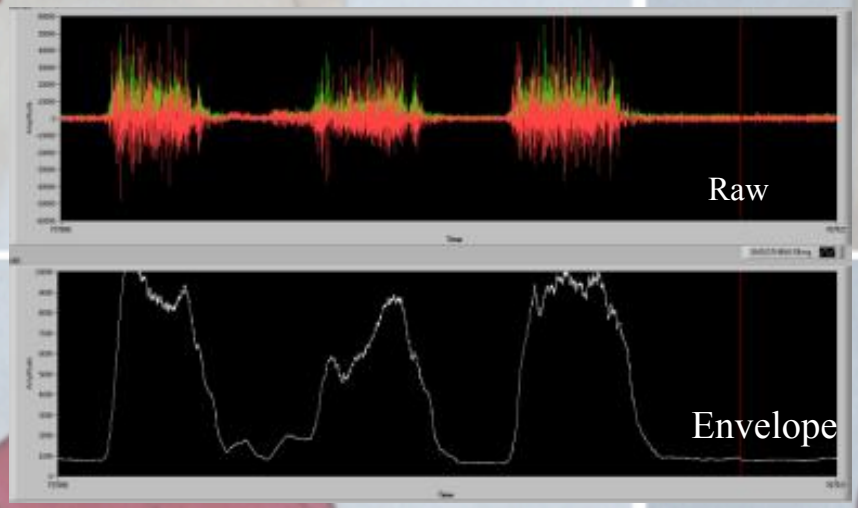
The variability of SNR values, in terms of subject and system, is due to the physiological diversity of muscle subjects and relative positioning of the electrodes

Electrode	*Test done with 0 Kg*		*Test done with 2 Kg*	
	Amplitude SD	*Median Frequency*	*Amplitude SD*	*Median Frequency*
Biometrics	12.60%	96.2 Hz	13.00%	94.6 Hz
Smartex	10.70%	102.5 Hz	21%	98.6 Hz

SNR [dB]	*Number of Subject*						*Mean* ± SD
	1	*2*	*3*	*4*	*5*	*6*	
Biometrics	9.931	16.129	6.571	13.100	15.883	15.256	12.81±1.68
Smartex	13.285	11.600	9.580	9.480	11.828	15.590	11.89±2.33

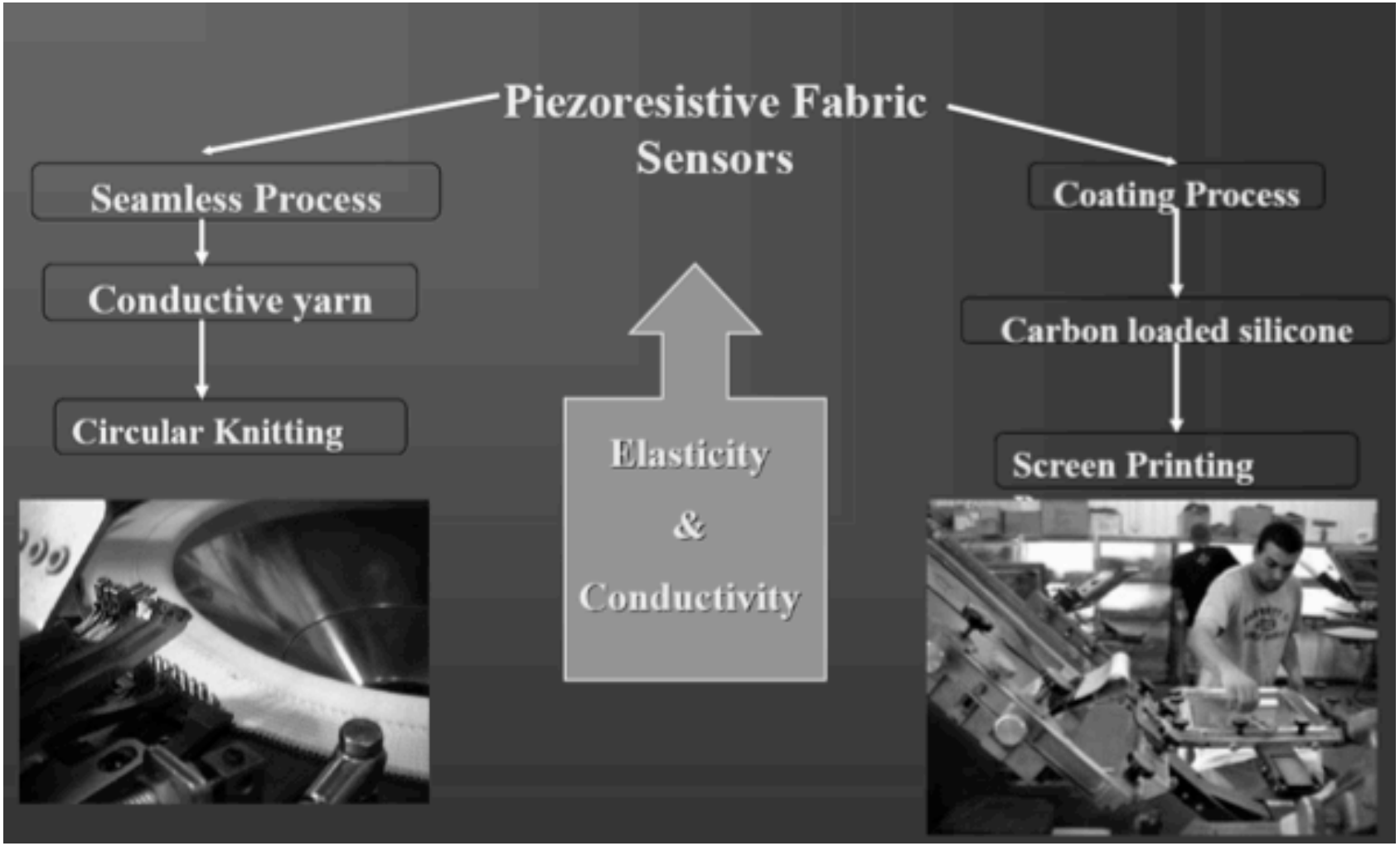
B. Sumner, C. Mancuso, and R. Paradiso, “Performances evaluation of textile electrodes for EMG remote measurements” Proceedings of the 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society: 6510-6513, 2013.

EMG ELECTRODES: PLACEMENT AND FUNCTIONALITY TEST



EMG activity during daily life

Textile Process for Piezoresistive Fabric



Piezoresistive Sensors Characterization

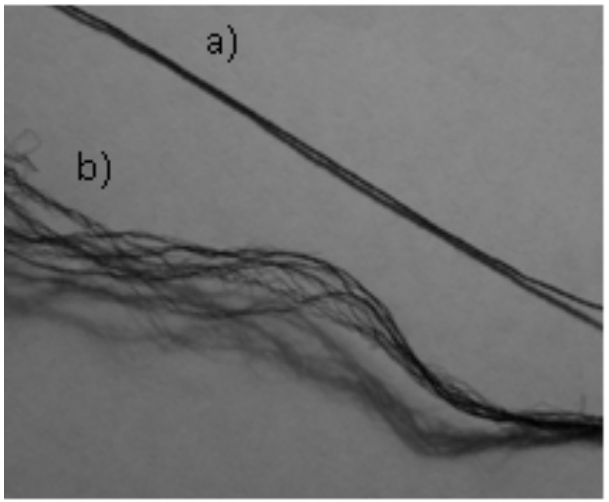
•Magnetic Encoder for the detection of the sensor elongation

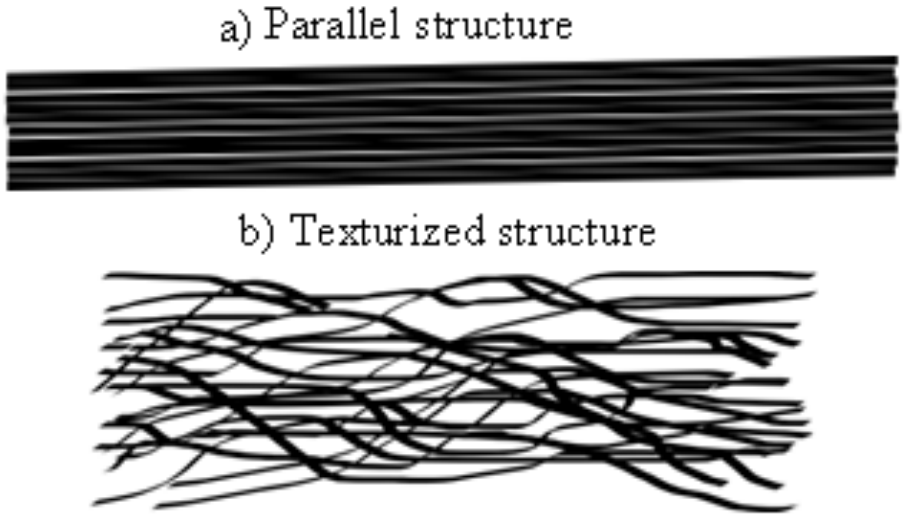
• Load Cell for the measurement of the force applied to stretch the samples

• Voltage Divider to detect the electrical resistance variations

To characterize the piezoresistive sensors an electro-dynamic system has been used. The apparatus is able to apply prefigured strains with controlled amplitude, by using a PLC that controls a linear motor. The system measures the electrical resistance of the samples and the applied strains in synchronous, by sampling at 334Hz.

Piezoresistive Fabric Sensors: Effect of the Yarns Structure





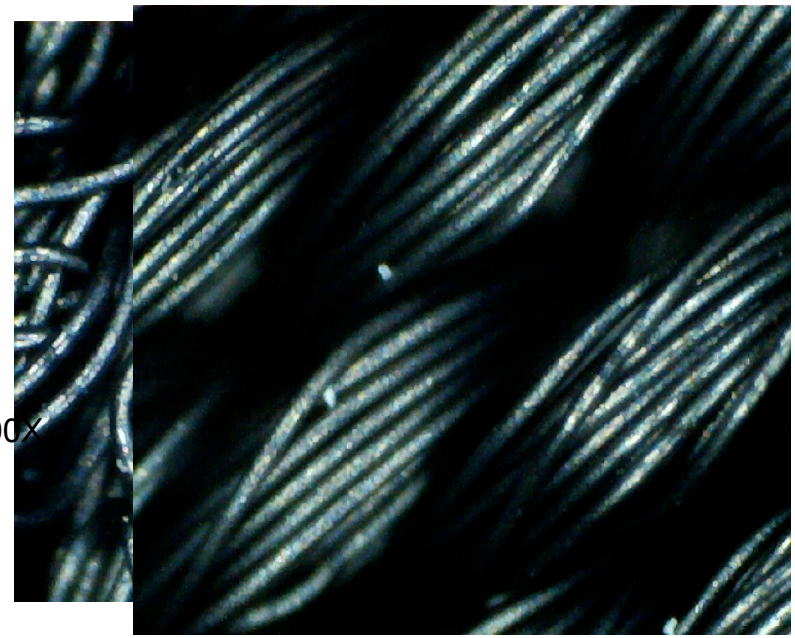
P-KPF

T-KPF

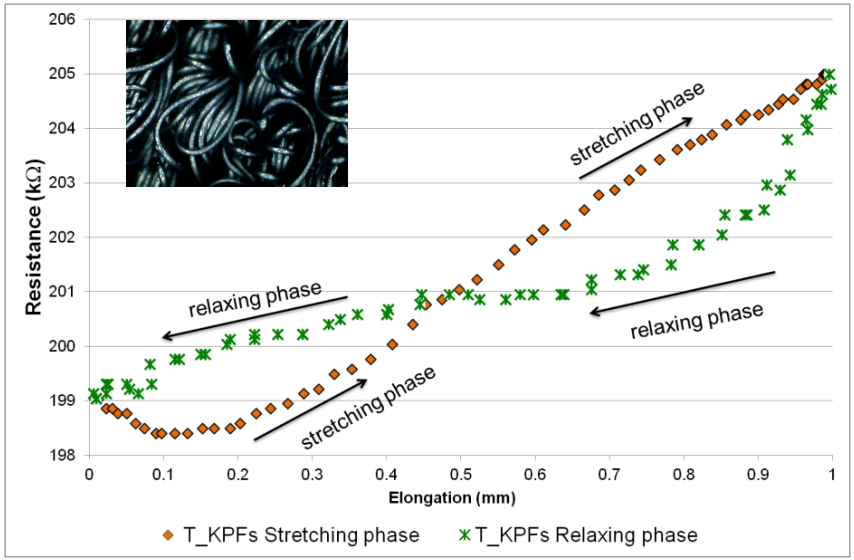
Fabric sensor:
Same number of resistive filaments.
Same selection of stitches.
Same composition: 75% electro-conductive yarn and 25% Elastan

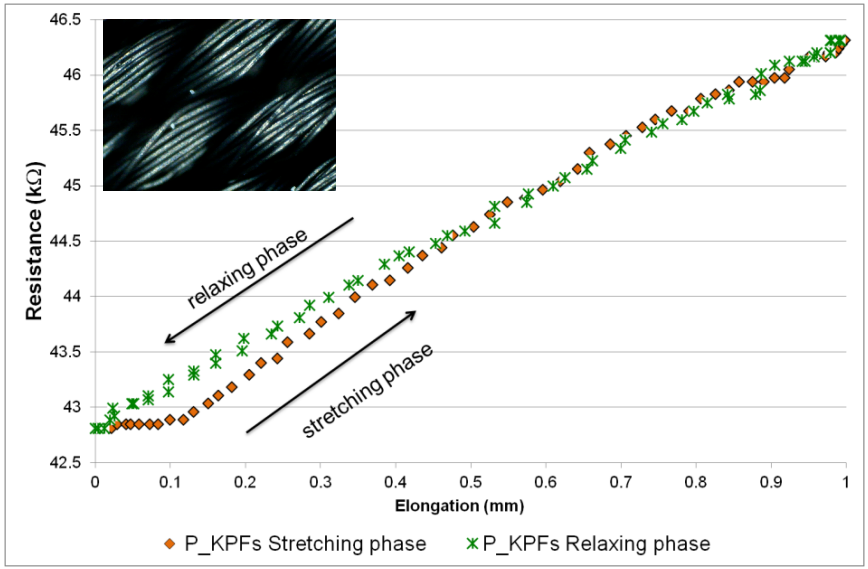
400X

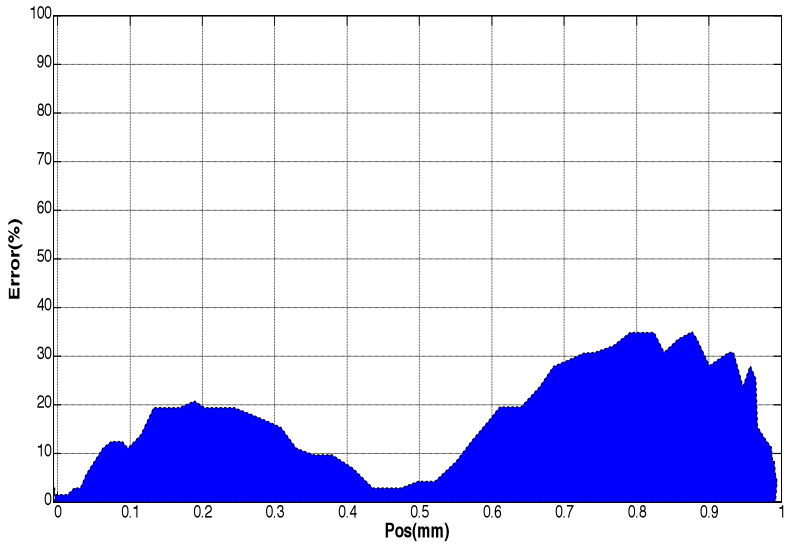
400X

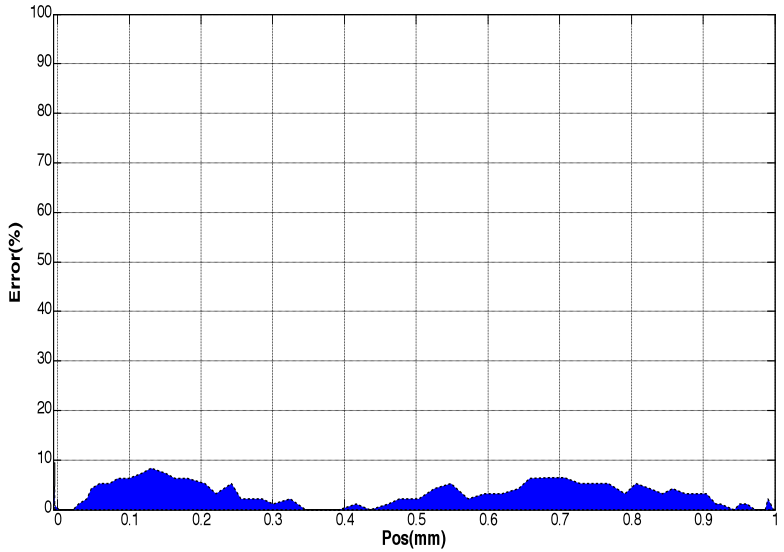


HYSTERESIS



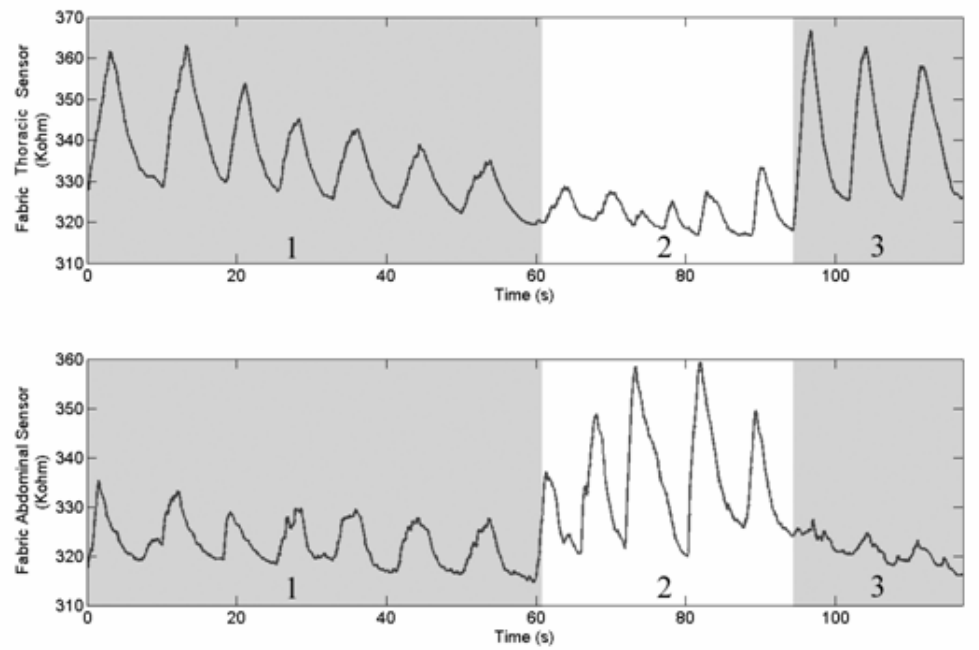






M. Pacelli, L. Caldani and R. Paradiso, Performances of piezoresistive fabric sensors as function of yarn structure, 35th Annual International Conference of the IEEE EMBS Osaka, Japan, 3 - 7 July, 2013, 6502-6505

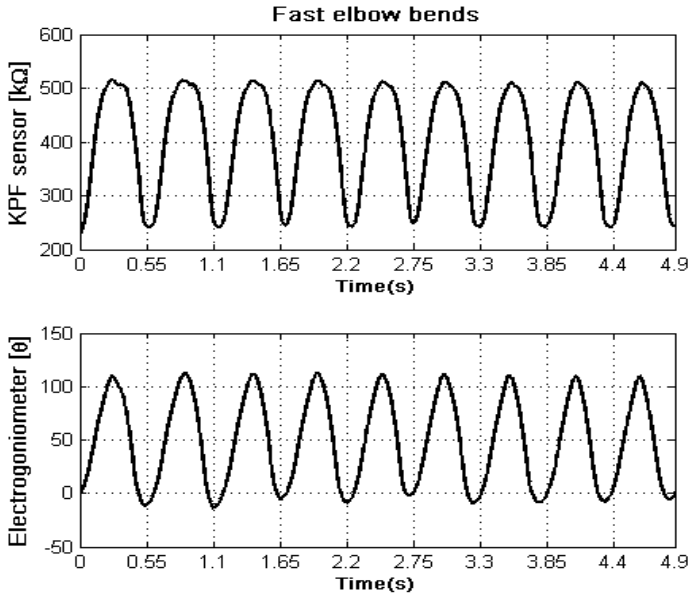
PLETHYSMOGRAPHY
BY PIEZORESISTIVE FABRIC



Two piezoresistive fabric sensors integrated in a seamless shirt provide information about thoracic and abdominal respiration

Taccini N, Loriga G, Pacelli M and Paradiso R, Wearable Monitoring System for Chronic Cardio-Respiratory Diseases, pp. 3690-3693, Proceedings of the30th Annual Conference of the IEEE Engineering in Medicine and Biology Society, August 20-24, 2008 Vancouver, BC Canada

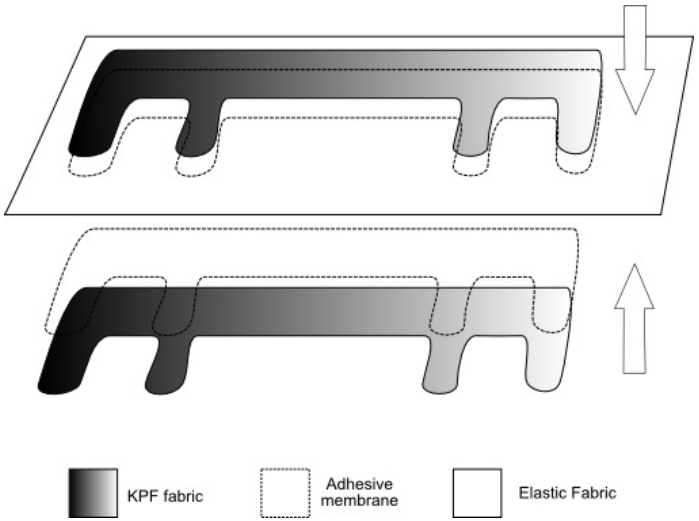
MOVEMENT OF THE JOINTS



- The Piezoresistive Fabric sensor signal during elbow bends compared with the response obtained through an electrogoniometer, both the signals have been acquired simultaneously.

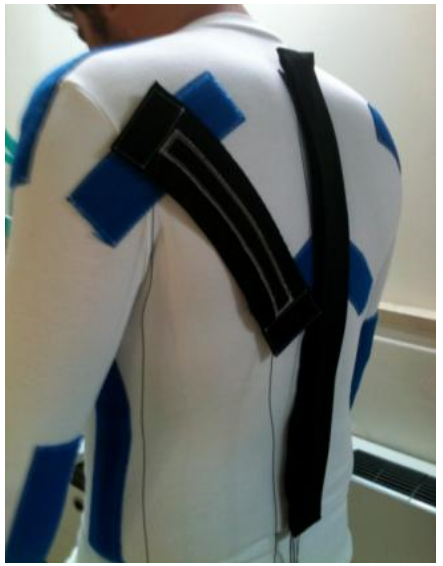
Scilingo EP, Gemignani A, Paradiso R, Taccini N, Ghelarducci B and De Rossi DPerformance Evaluation of Sensing Fabrics for Monitoring Physiological and Biomechanical Variables, IEEE Transaction on Information Technology in Biomedicine, num. 3, vol. 9, pp. 345-352, 2005

TEXTILE GONIOMETERS



Based on knitted piezoresistive fabric

- **Strain sensor**: single layer, integrated on the fabric substrate by sewing
- **Goniometer**: multi-layer structure, 2 conductive layers insulated by an adhesive membrane (designed in close collaboration with UNIPI)
- Connections realized with stainless steel fabric and wire.

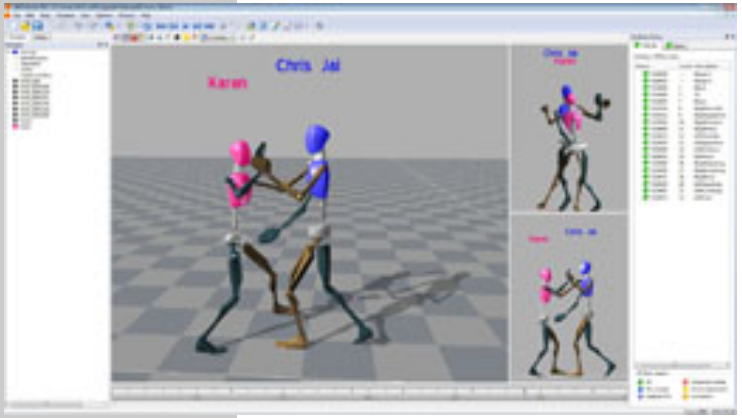


Tognetti et al., New generation of wearable goniometers for motion capture systems, Journal of NeuroEngineering and Rehabilitation 2014, 11:56http://www.jneuroengrehab.com/content/11/16

PHYSICAL INTERACTION WITH THE ENVIRONMENT
A BODY AREA NETWORK APPROACH

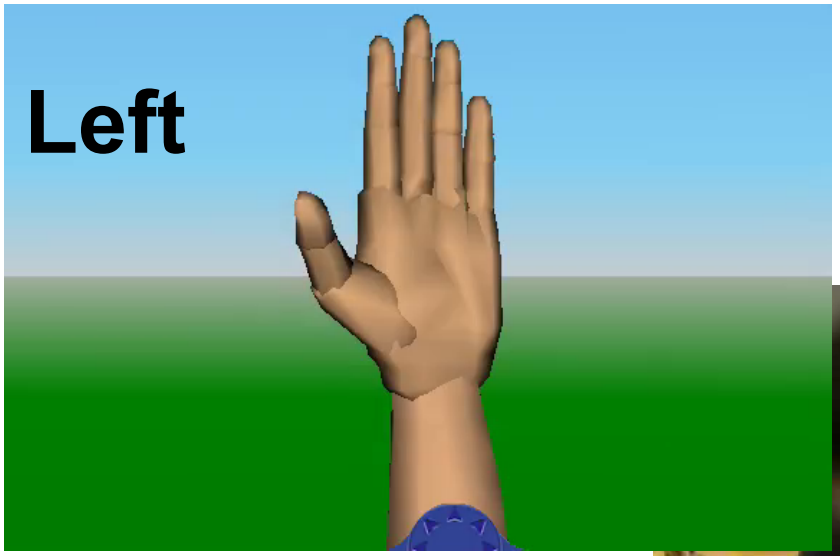
- On-body sensing platform including:
  - instrumented patches
  - sensor modules
  - real-time algorithms
  - portable devices

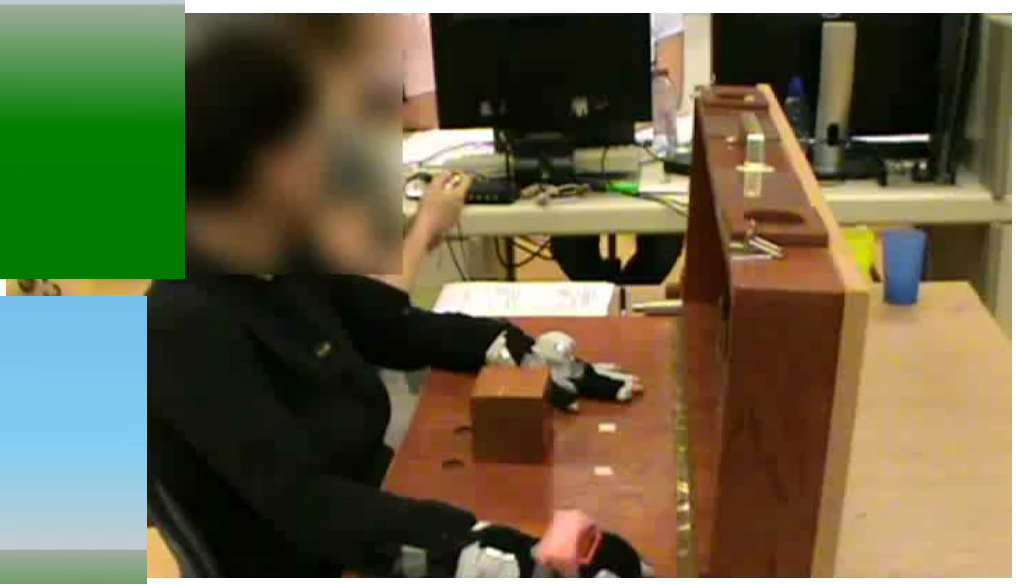
- Gathering parameters correlated to:
  - movement
  - gesture
  - force interaction with the environment
  - muscular activity

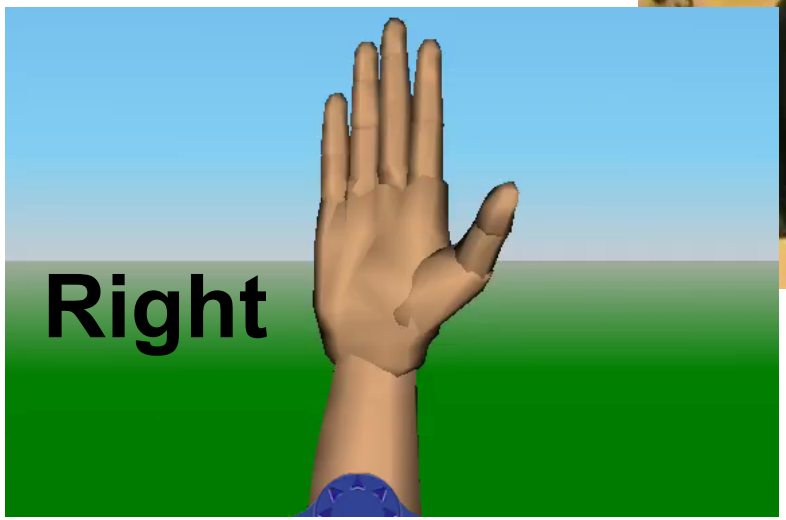


- Monitoring patient recovery
  - in clinical conditions
  - in daily life conditions

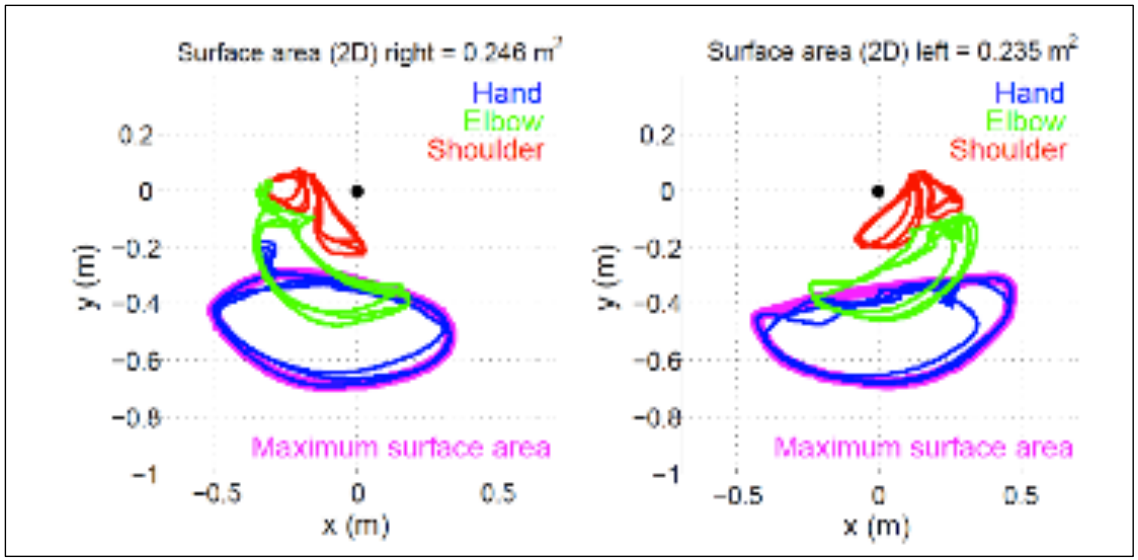
GESTURES RECOGNITION


Left

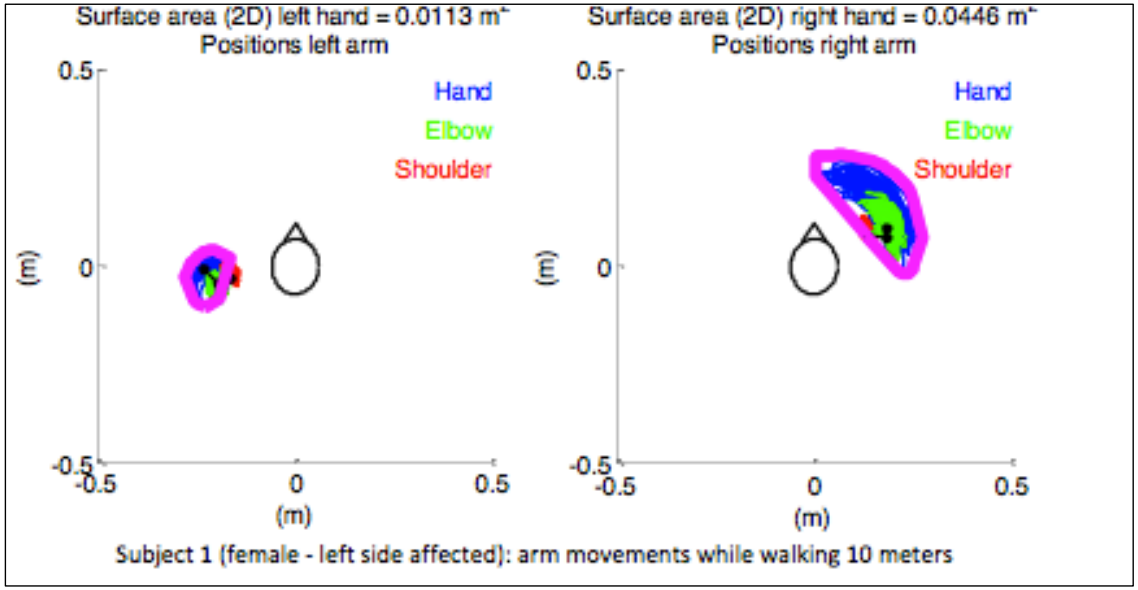



Right

ARM MOVEMENTS PERFORMING THE TASK



Hand, elbow and shoulder position relative to the position of the pelvis, of subject 1 (female, left side affected) while performing circular arm movements. Top down view – left graph: positions of the right arm, right graph: positions of the left arm.



Arm movements relative to pelvis position and orientation, while walking 10 meters then turn around and next walk 10 meters back. The pink line represents the maximum reached area of the hand

Roessingh Research and Development

UNIVERSITY OF TWENTE.

STRESS INDICATORS

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Every stressor recalls neuropsychological, emotional, locomotor, hormonal and immunological regolative reactions.

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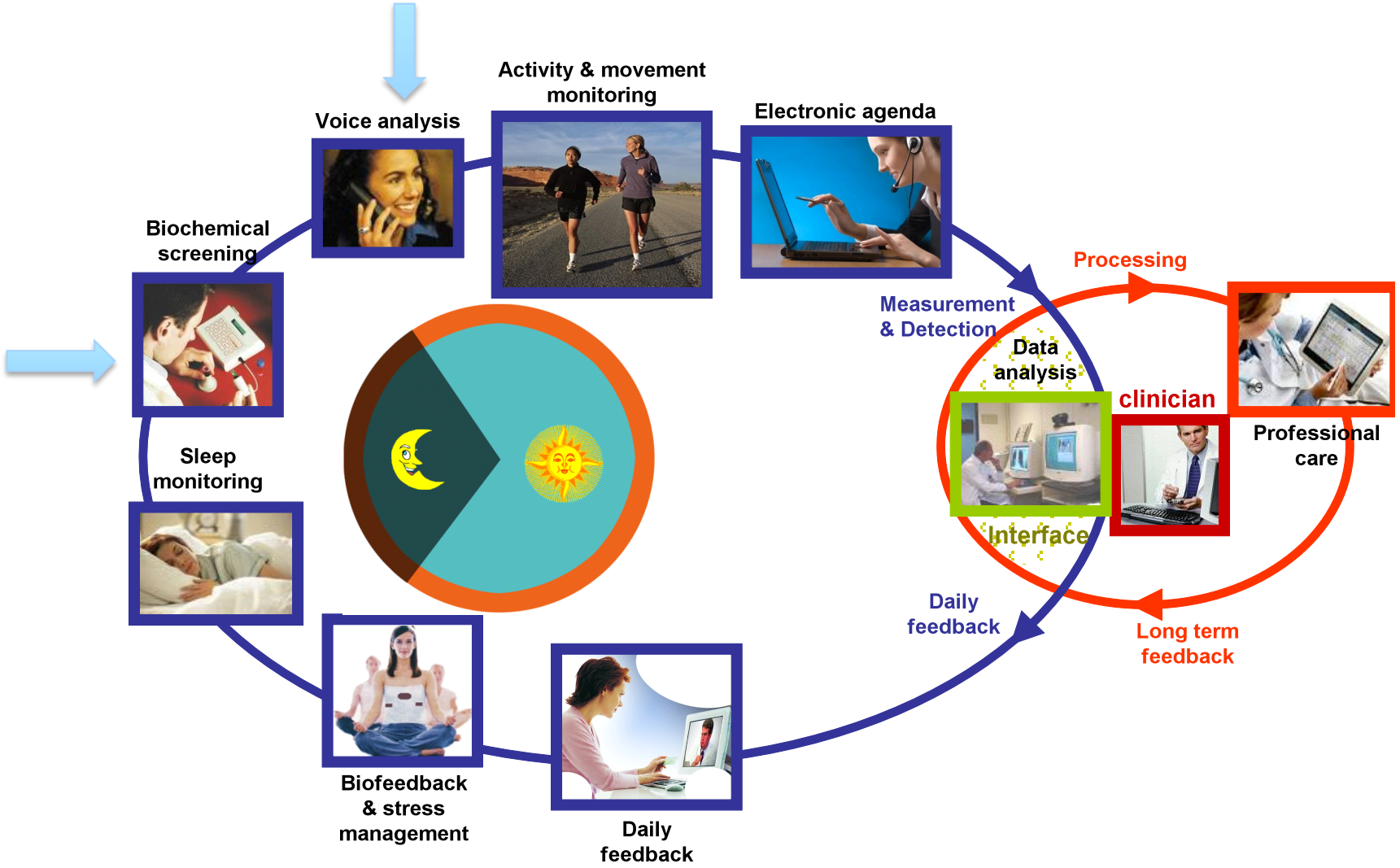
- *Exhaustion*, if stressors continue to act, the subject can be overwhelmed and it might cause permanent adverse effects in the psychic and/or somatic structure.

The stress can be instrumentally quantified as the variation of three factors:

- Electrodermal Response EDR (reliable under rest condition)
- Blood pressure pattern (reliable under rest condition)
- HRV Heart Rate Variability

PSYCHE VISION: A MULTIVARIABLE APPROACH TO MENTAL DISEASE MANAGEMENT



THE MULTIVARIABLE APPROACH

- Most of the studies about physiological signs and behavioural monitoring are based on just one or two physiological signs: a multi variables approach would probably result in higher sensitivity or specificity of the prediction.

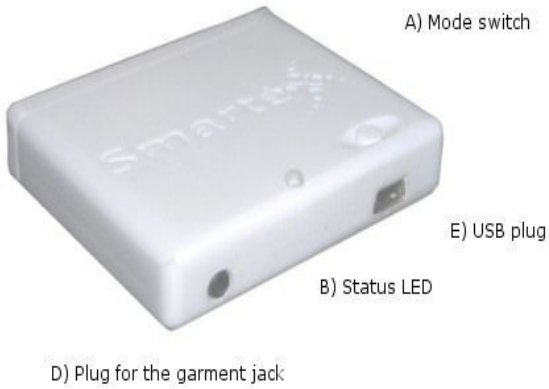
- Sensors can track the unconscious and instinctual side of human behavior.

WEARABLE WELLNESS SYSTEM (WWS)

Signal Sampling Frequency
ECG: sampled **and** transmitted at 250 Hz
Respiration-Piezoresistive: 25 Hz
3 axis Accelerometers: 25 Hz
RR parameters: one sample each event

two textile electrodes
one textile piezoresistive sensor
one connector to plug the garment to the electronic device

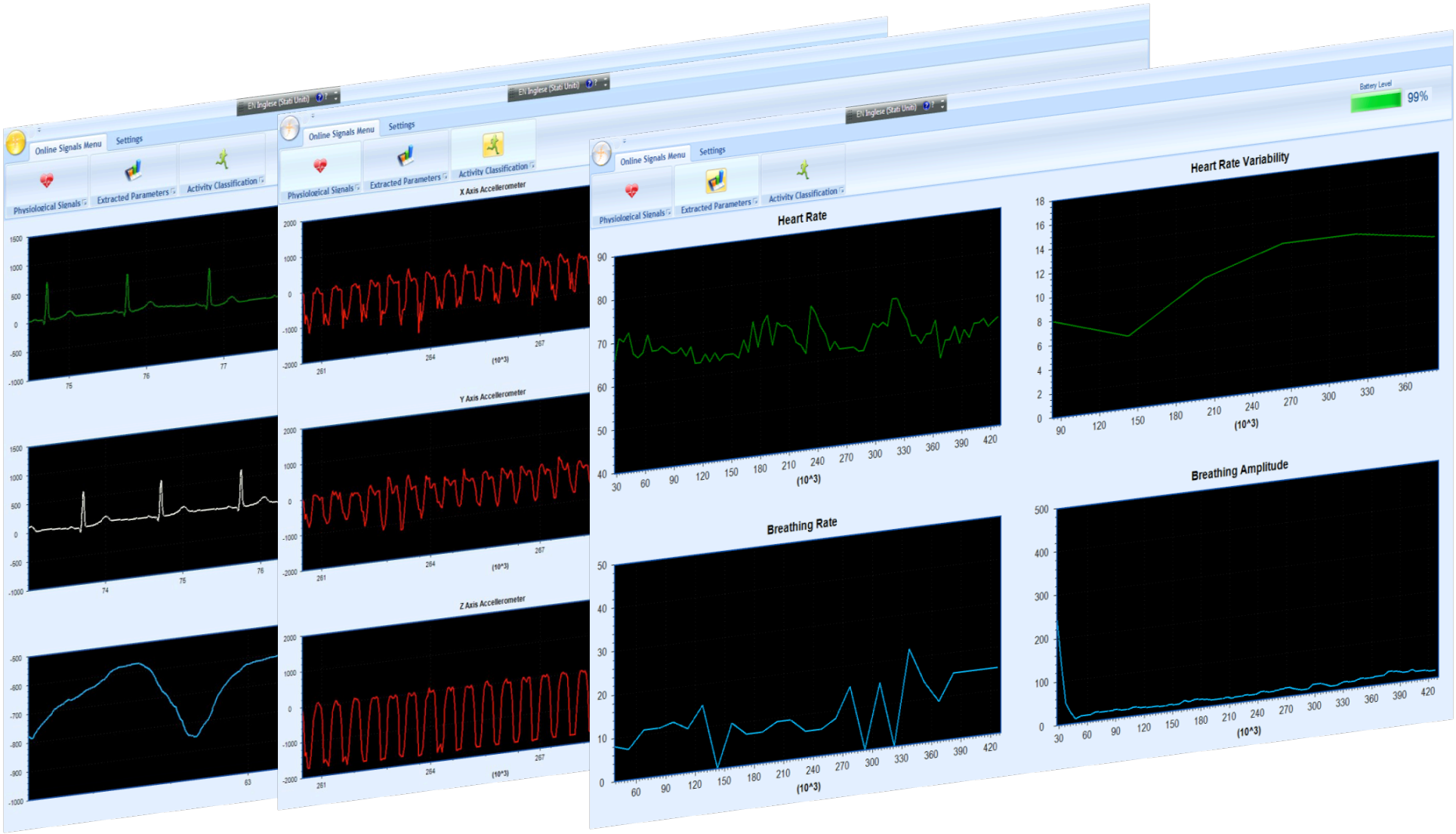
PORTABLE ELECTRONICS



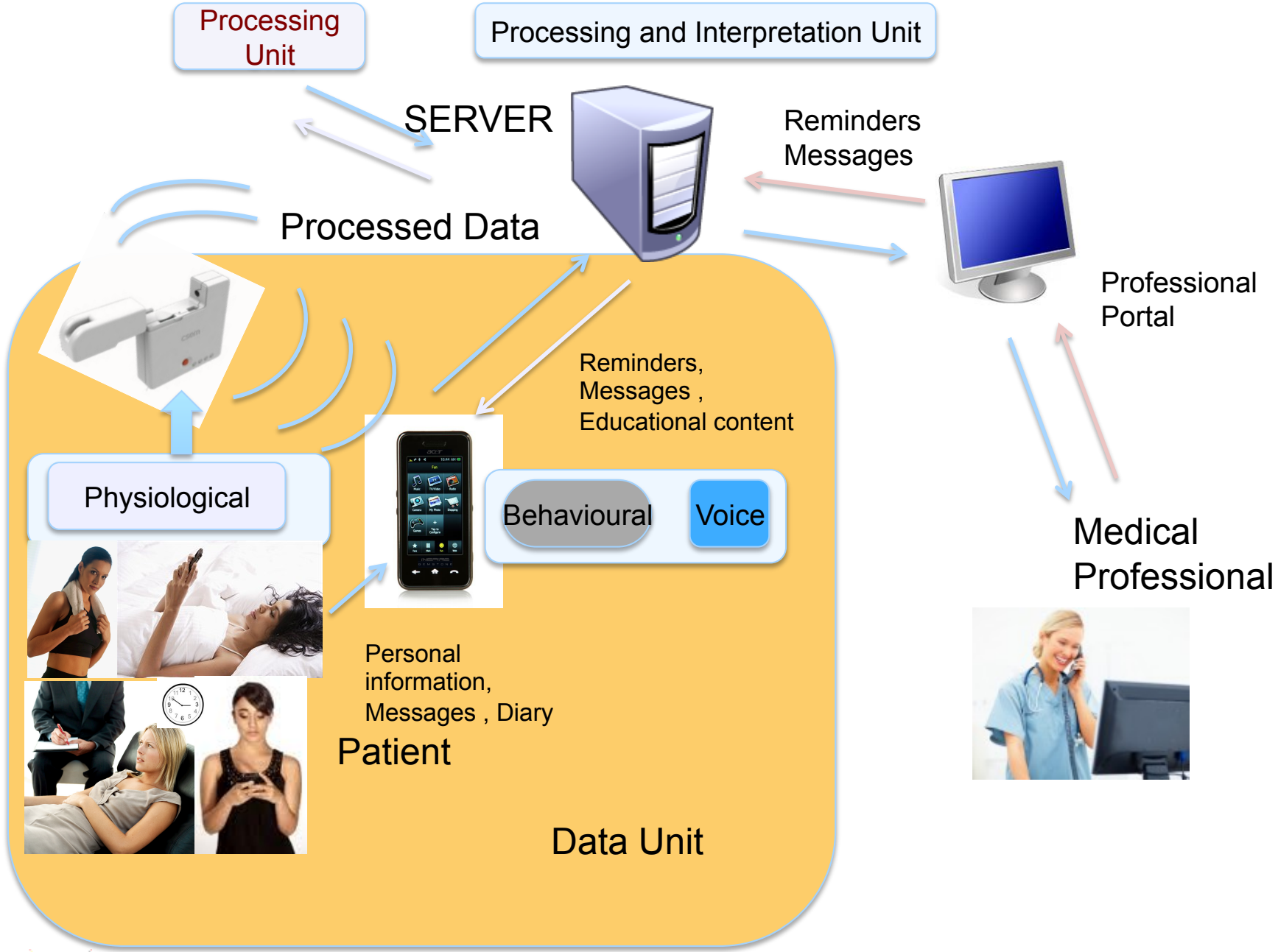
Characteristics	
Power management	
Battery	Lithium-polymer, 580 mAh
Battery charging	Through USB
Storage capability	
Memory	Micro-SD card, 2 GB
Autonomy*	
Autonomy while recording	Up to 30 hours
Autonomy while streaming	More than 12 hours
Stand-by time	More than 40 days
Memory capacity (with 1GB)	More than 400 hours
Temperature	
Operating	0 to 50°C
Storage	-20 to 50°C
Humidity	Operational up to 95% non-condensing
Device	
Dimensions	63 x 52 x 16 mm^3
Weight	45 g

* The autonomy was measured with a device running firmware v.0.33. Newer revisions may exhibit different autonomies due to new features. Data are indicative and refer to a new battery.

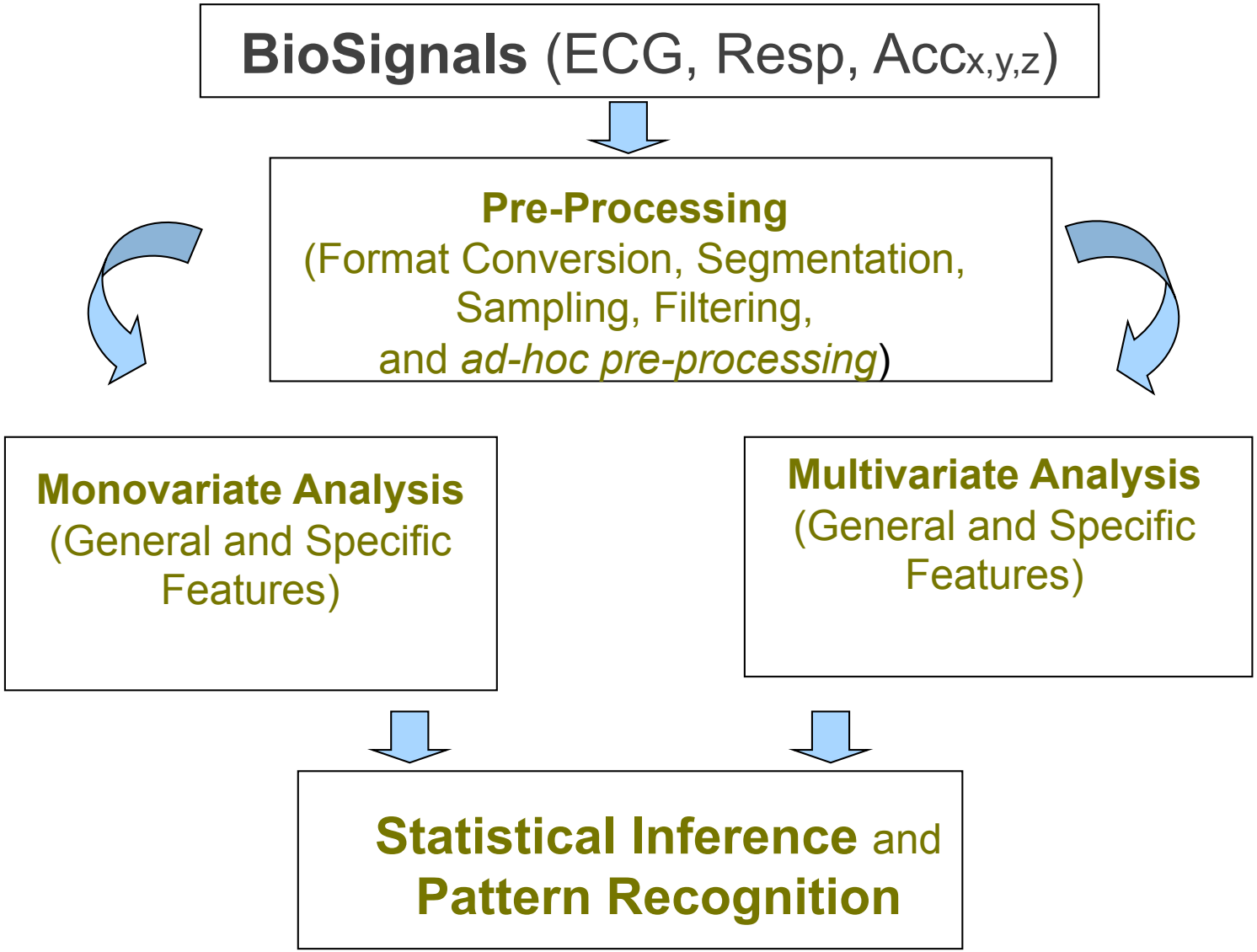
Signals and Parameters on board



The system is completed by a software suite that runs under windows OS and .NET framework 3.5 or above. The software can be used for seeing acquired data and features in real time (useful during the setup phase) or to download and convert the recorded data session over USB connection.

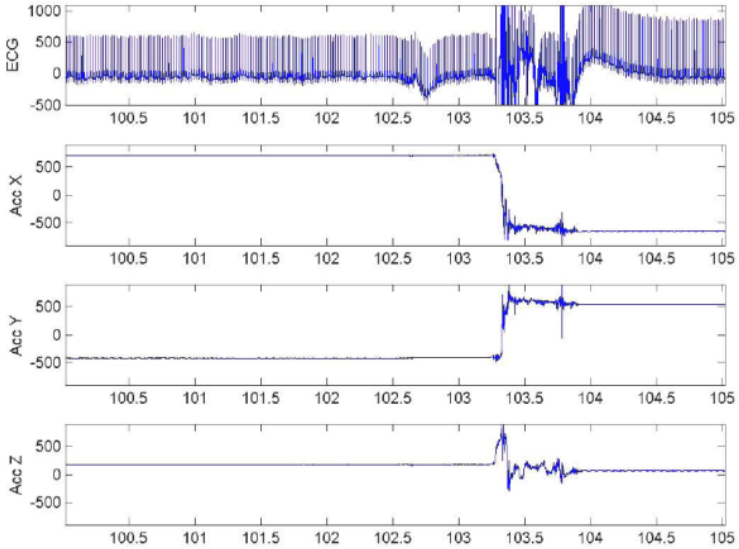

Processing Unit
Processing and Interpretation Unit
SERVER
Reminders
Messages
Processed Data
Professional
Portal
Reminders,
Messages ,
Educational content
Physiological
Behavioural
Voice
Medical
Professional
Personal
information,
Messages , Diary
Patient
Data Unit

EXTRACTION OF FEATURES

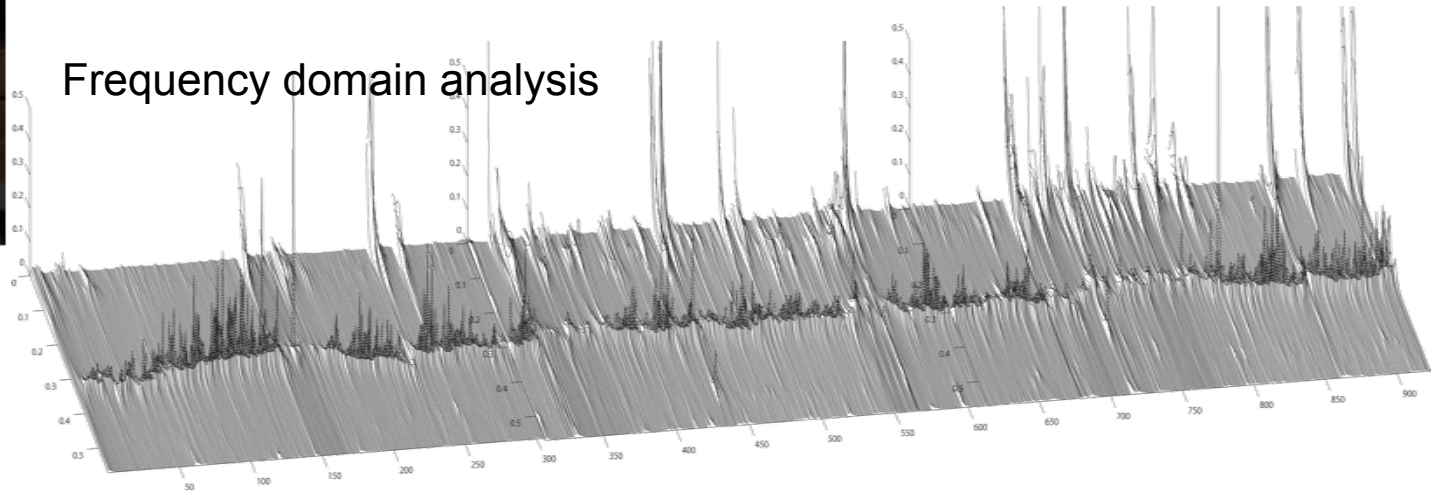


psyche

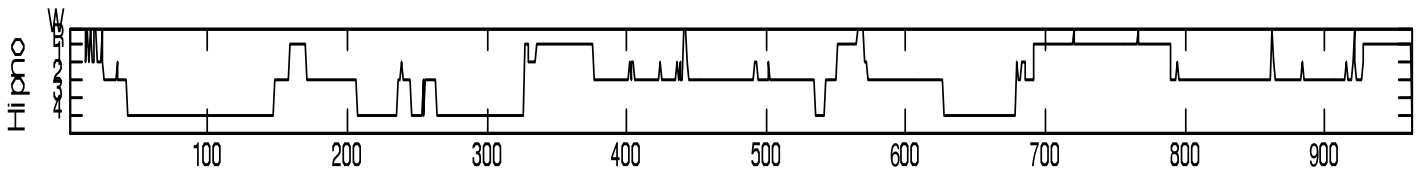
PHYSIOLOGICAL FEATURES FOR SLEEP MONITORING



Frequency domain analysis



Hypnogram



EXTRACTION OF FEATURES

Sleep parameters

Hypnogram	[sleep stages (W, REM, NREM, 1 int / 30 s)
Sleep disorder	[boolean (yes/no)],
sleep quality	[3/4 levels (good/mid/poor)],
Total sleep time	[integer (min)],
sleep efficiency	[integer (%)],
REM latency	[integer (min)],
REM %	[integer (%)]

....

Other parameters useful for autonomic control assessment

HRV parameters (LF, HF, etc.)	[set of float]
Entropy (ApEn, SamEn),	[float]
DFA,	[float]
1/f	[float]

psyche

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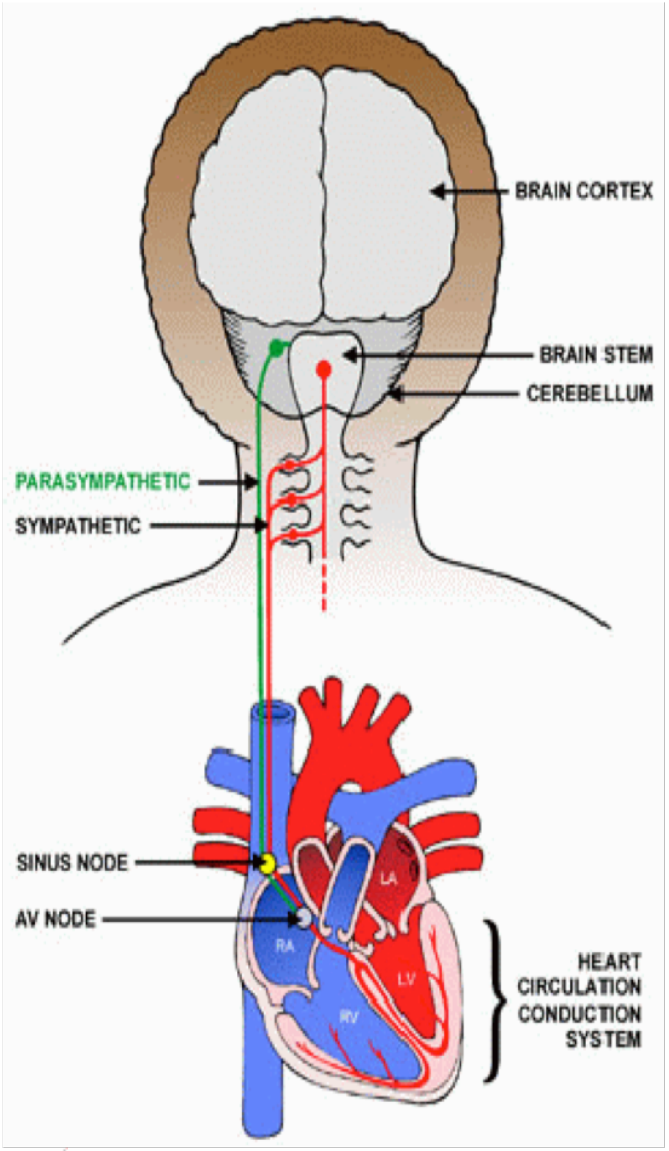
HEART RATE VARIABILITY



HRV is the heart rate natural variability in response to such factors as the rate of breathing, emotional states, the state of anxiety, stress, anger, relax, thoughts, etc.

The HRV is related to the interaction between the sympathetic and parasympathetic nervous system.

- ***Sympathetic Nervous system***, when activated, produces a range of effects such as: increased heart rate, dilation of bronchus, increased blood pressure, peripheral vasoconstriction, pupil dilation, increased sweating.

- ***Parasympathetic Nervous system*** (also called ***vagal activity***), when activated, produces a slowdown of the heart rate, an increase in bronchial muscle tone, dilation of blood vessels, decreased blood pressure, slowed breathing, muscle relaxation, breathing becomes more calm and deep, genitals, hands and feet become hotter.

SYMPATHO-VAGAL BALANCE

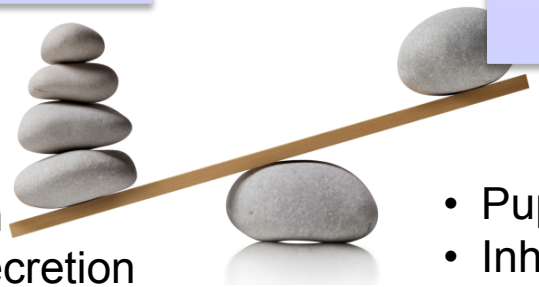
INPUT

Supine state
Relaxation
Sleep

Orthostatic state
Mental activity
Physical activity
Fear

Parasympathetic Nervous system

Sympathetic Nervous system



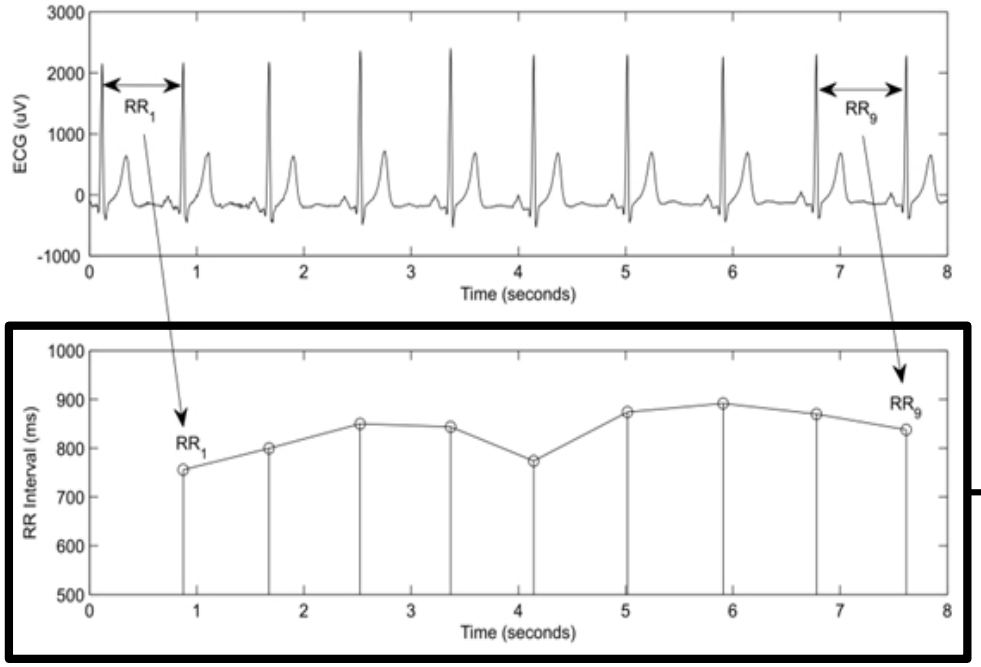
OUTPUT

- Pupillary constriction
- Stimulate salivary secretion
- Reduction in heart activity
- bronchial constriction
- Stimulation of gastric and pancreatic secretion
- Stimulation of bile release

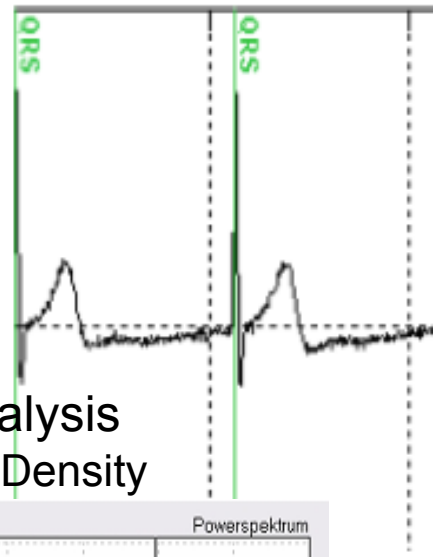
- Pupillary dilation
- Inhibit secretion of saliva
- Increased heart activity
- Bronchial dilation
- Inhibit gastric secretion and pancreatic
- Stimulation of the adrenaline and noradrenaline secretion

METHODOLOGY WITHIN FREQUENCY DOMAIN

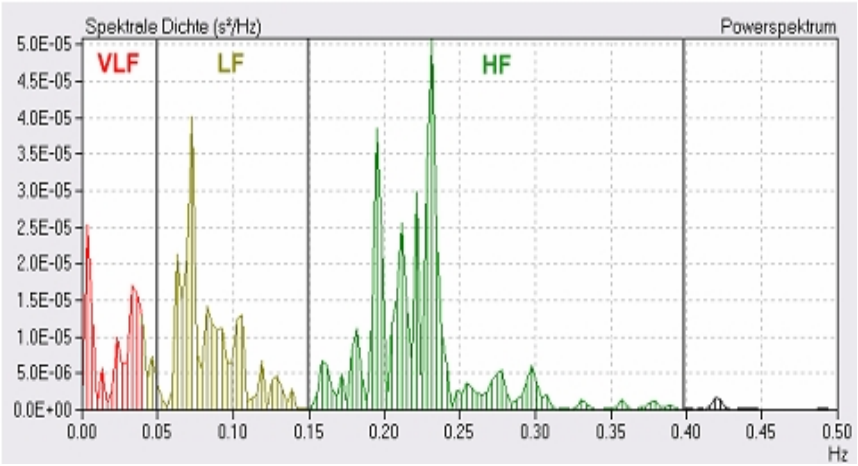
To quantify the HRV it is used an ECG recording that allows to obtain a good QRS complex amplitude and a electrocardiographic baseline stable which yields the tachogram.
The components of the heart rhythm can be obtained using methods in the time domain or in the frequency domain.



RR versus time obtained from a QRS complex recognition algorithm



Frequency Analysis
Power Spectral Density

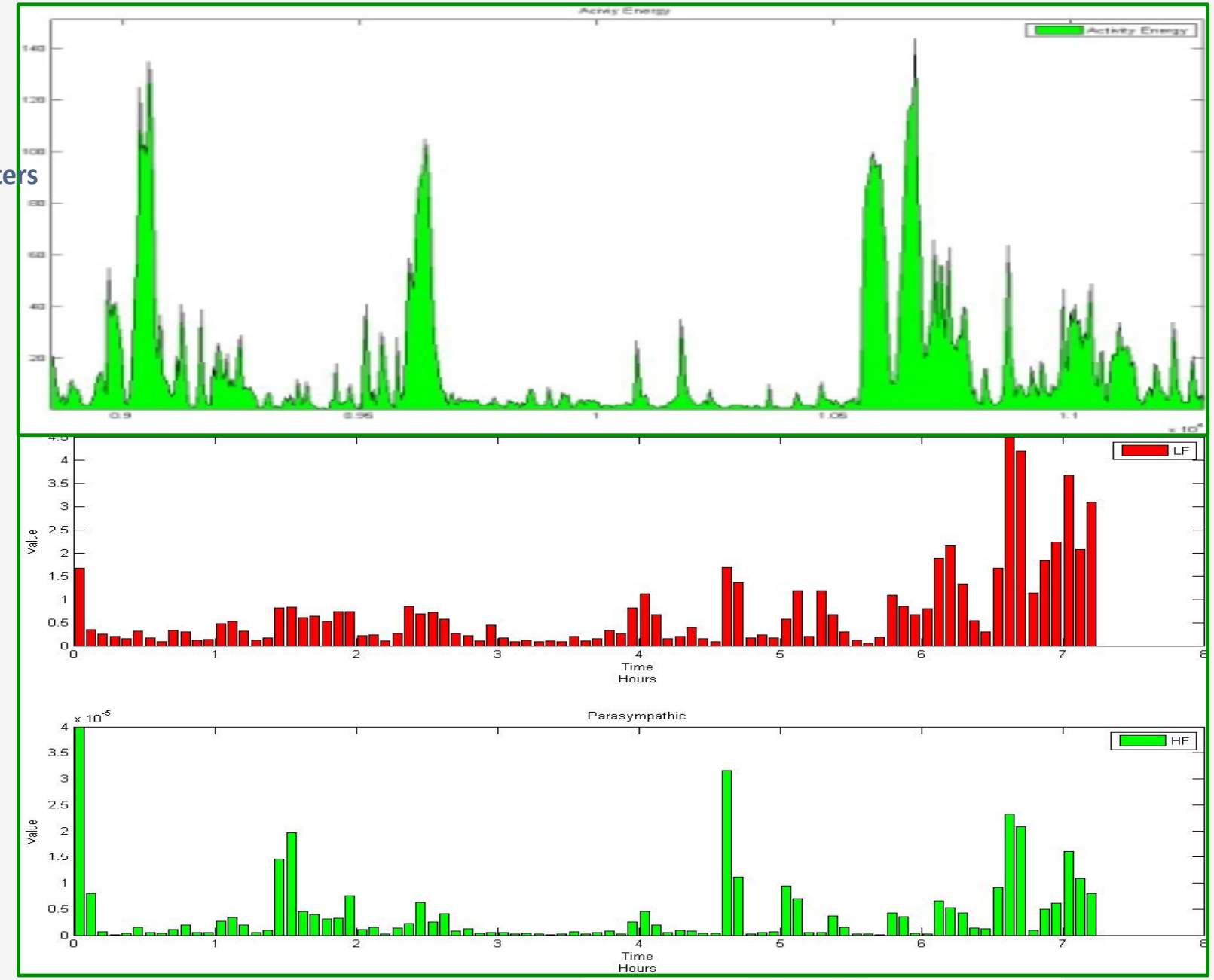


- **LF** (0.04-0.15 Hz) expression of both sympathetic and parasympathetic activity

- **HF**(0.15-0.45 Hz) expression of parasympathetic nervous system

STRESS INDICATORS

3D Accelerometers



ECG: QRS

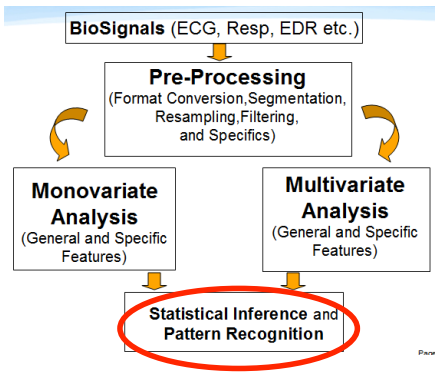
Statistical inference and Pattern Recognition

Feature Dataset: Input Matrix for Data Mining

Features from ALL SIGNALS and TEST must be included as column. **Subject's data (ID, age etc.) is also included**

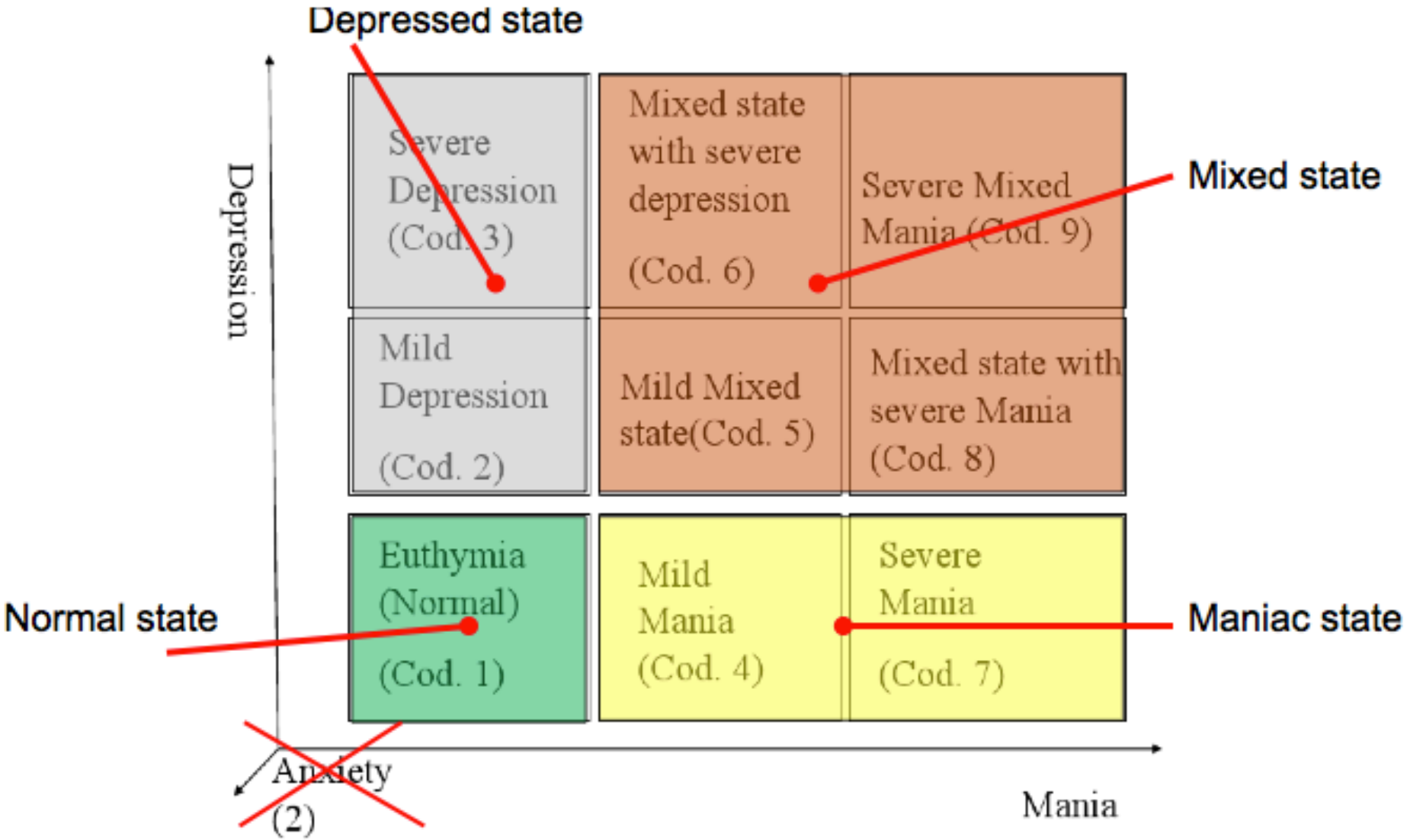
Subjects from ALL DATASETS must be included and assotiated to similar Classes (according to PSYCHE model)

Examples from ALL ACQUISITIONS must be included as row according to the time window (e.g. 30 sec.)



	Feature 1	Feature 2	Feature 3	...	Feature N	Label (i.e. Class)
Subj. 1	Example 1.1					
	Example 2.1					
	⋮					
	Example K.1					
Subj. 2	Example 1.2					
	Example 2.2					
	⋮					
	Example K.2					
	⋮					
Subj. N	Example 1.N					
	Example 2.N					
	⋮					
	Example K.N					

Reduced reference indicator

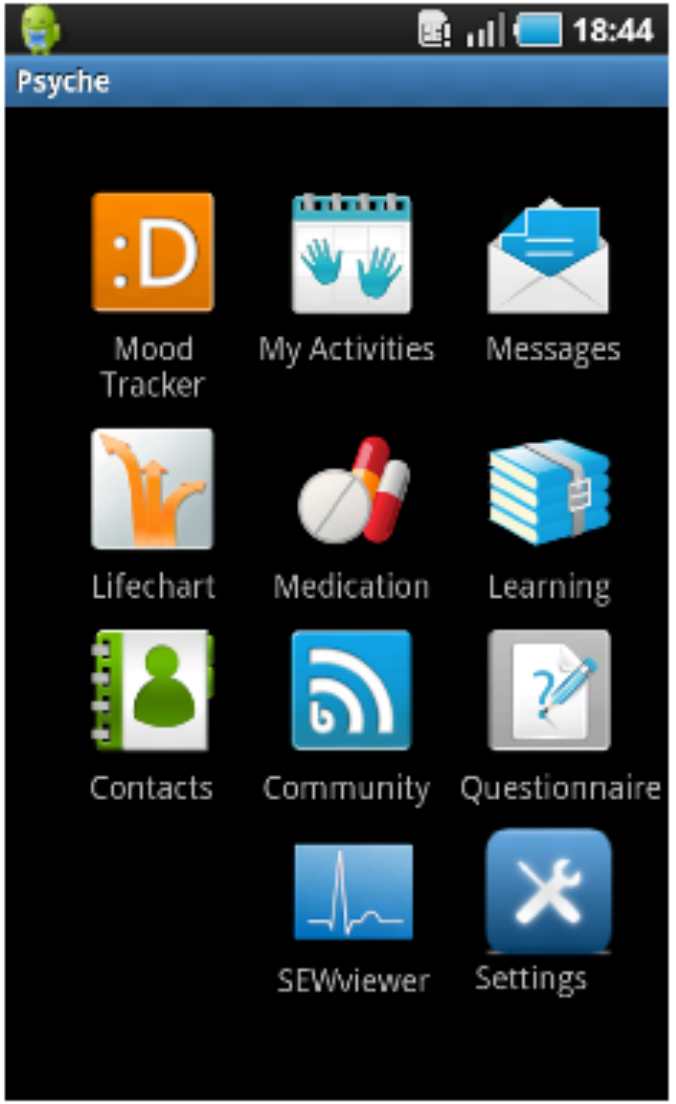


Mobile Platform Functionalities

Subjective data
•Mood Agenda
•Diary of Activities
•Questionnaires
•Sleep agenda

Objective data gathering
• Night Monitoring
•Morning SEW acquisition modalities
Voice acquisition
•Reading a text
•Describing an image

Improvement of communication
• Message system
Self management
•Life chart to see evolution of reported variables
•Medication map with reminder
Learning modules
• Direct access to the Psyche community
Setting area, used by technician to configure the Smartphone



MEDICAL WEB PORTAL

psyche | Personalised monitoring SYstems for Ca in mental H

Username: STR01
Password: Access denied
Gender: Male

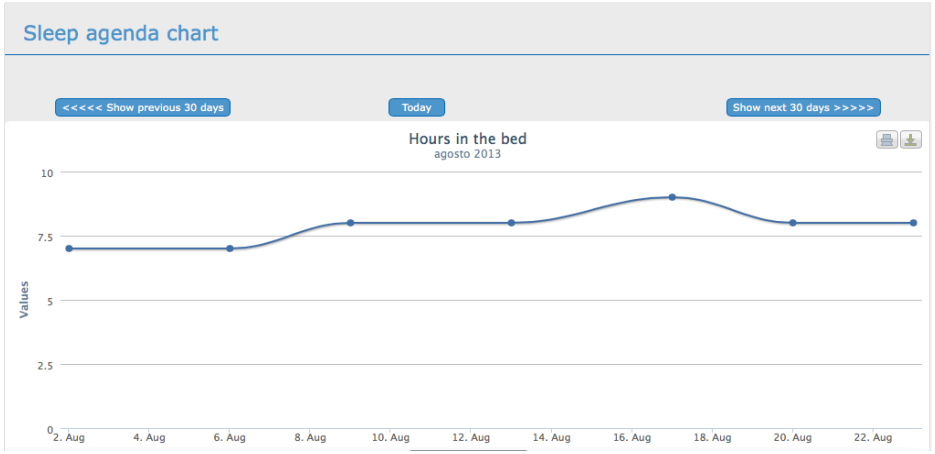
The patient's account is disabled
Logout

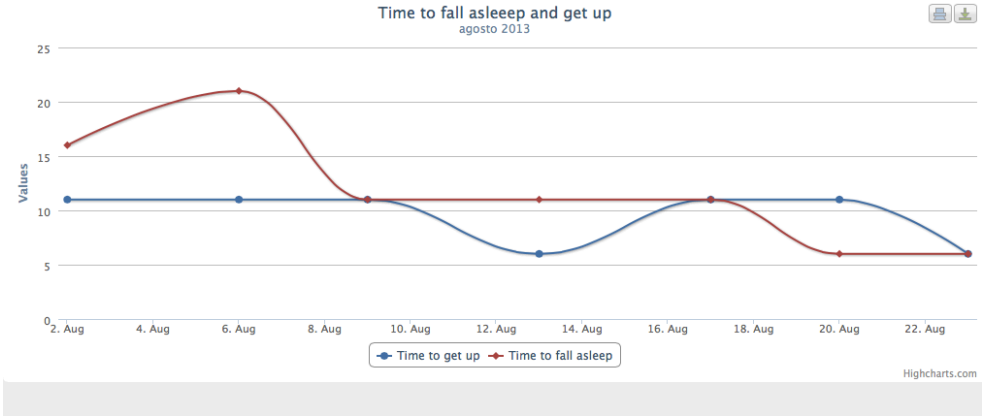
Home | Patient Info | Subjective Data | Objective Data | Medication | Mood Assessment | Alerts

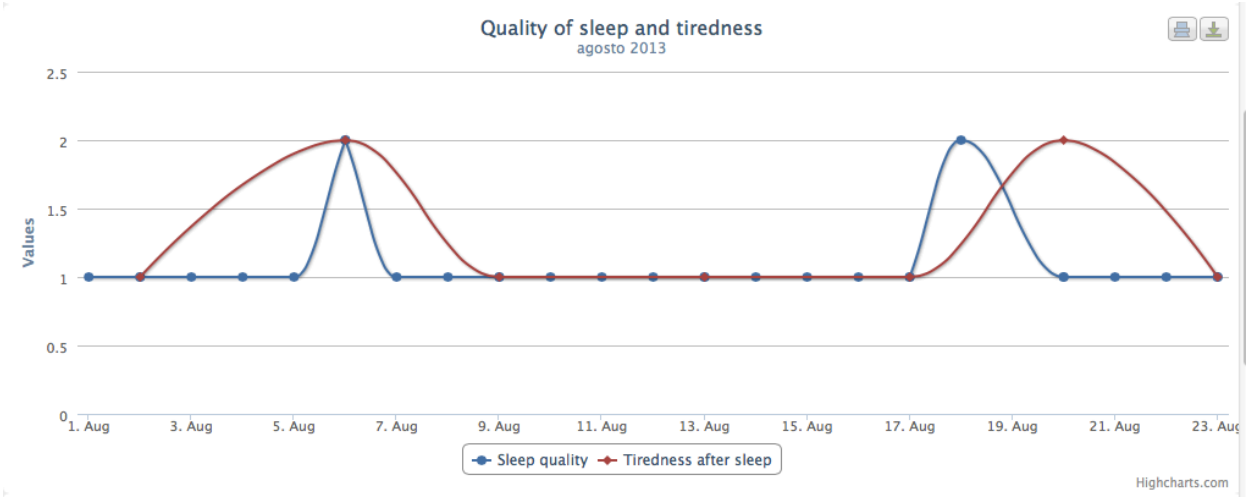
Current telemonitoring configuration

Activity	Description	Reminder
Mood Agenda	Mania scale: none (23-08-2013) Depression scale: none (23-08-2013) Irritability scale: none (23-08-2013) Anxiety scale: none (23-08-2013) Sleep quality scale: none (23-08-2013)	Daily (Early Morning)
Questionnaire	Bauer: 22-08-2013	Twice a week (Evening)
Wearable system monitoring	Last session was: 23-08-2013	Twice a week (Evening)
Sleep Agenda	Hours in the bed: 7 hours (23-08-2013) Time to fall asleep: 5 minutes (23-08-2013) Time to get up: 5 minutes (23-08-2013) Wake up during night: 1 times (06-08-2013) Sleep quality scale: none (23-08-2013) Tiredness after sleep scale: none (23-08-2013)	Twice a week (Early Morning) Twice a week (Early Morning) Twice a week (Early Morning) Twice a week (Early Morning) Twice a week (Early Morning) Twice a week (Early Morning)
Voice recording	Answer a question () [Never performed] Describe random images [Last session:23-08-2013]	None Twice a week (Evening)
Down and Up	Lay down (300 sec) and stand up (300 sec) using SEW	(Early Morning)

MEDICAL WEB PORTAL







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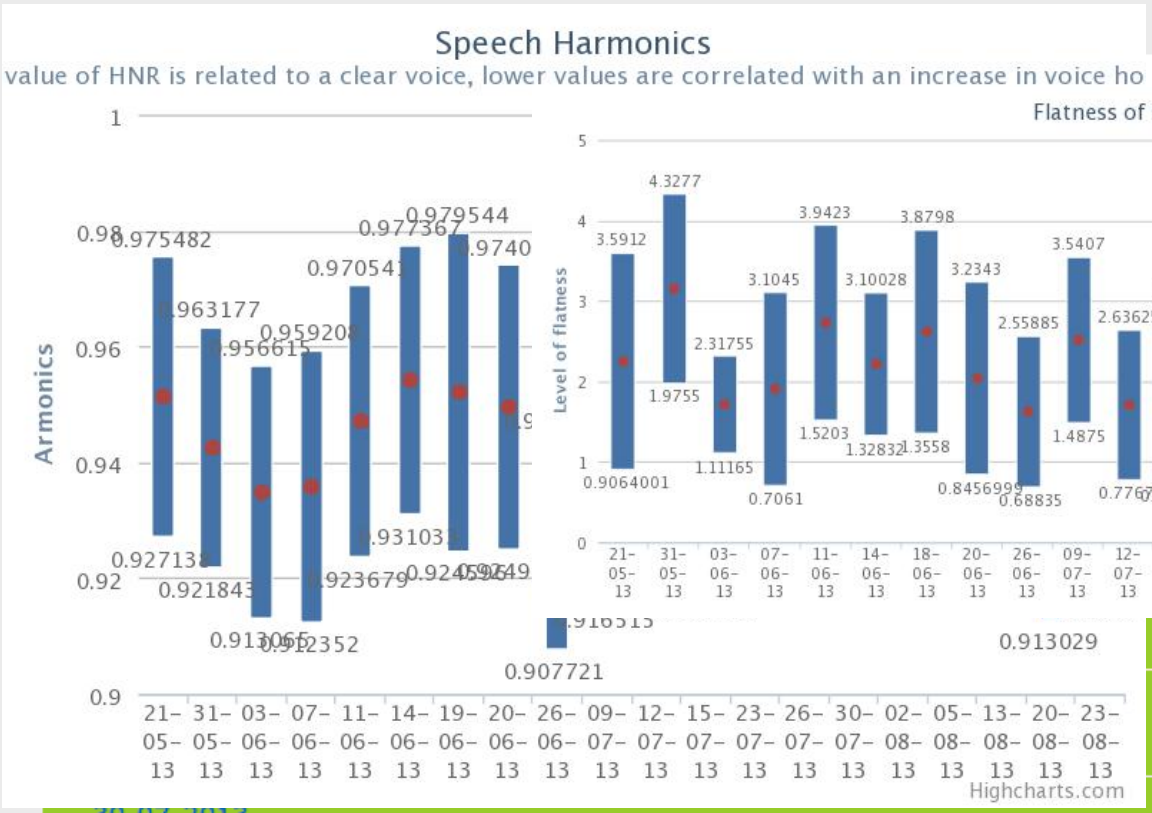
Voice acquisitions and algorithms results

Show trends of pitch | Show trend of speech Harmonics | Show trend of flatness of speech

Speech Harmonics

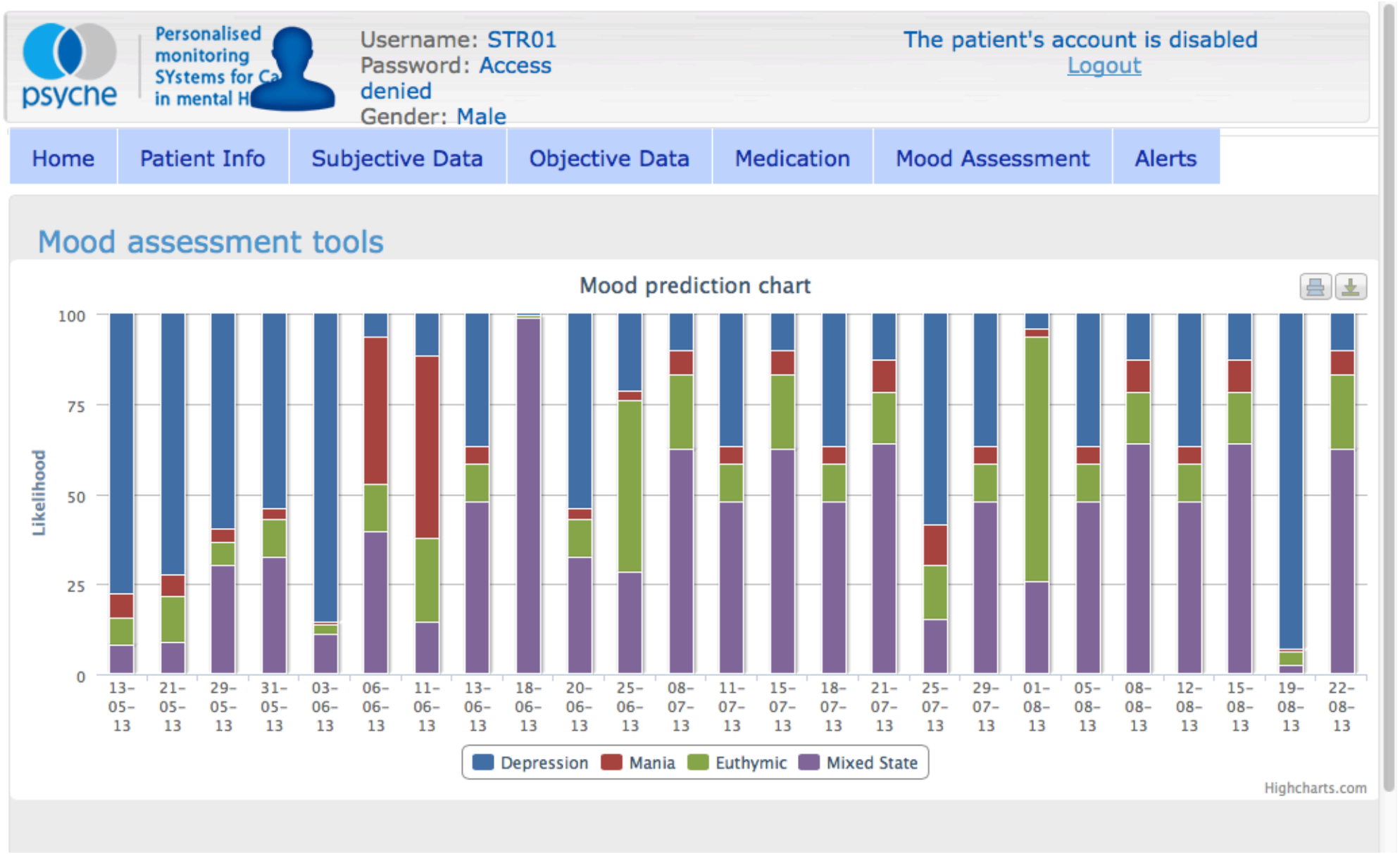
value of HNR is related to a clear voice, lower values are correlated with an increase in voice ho



Flatness of speech

					1	ANALYZED	Fake data
					1	ANALYZED	Real data Fake data
30-07-2013	31s	17 KB	74 KB	Image description	1	ANALYZED	Real data

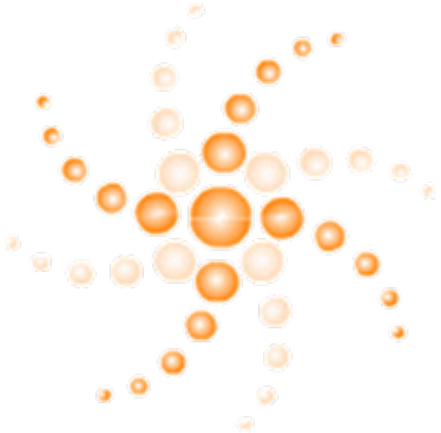
MEDICAL WEB PORTAL



Conclusions

- Textile is the more natural interface with the skin; the use of textile sensors and hybrid sensors allows to realize sensing platform that can be used in a naturalistic environment, number of sensors and the location con move toward a redundant configuration.
- Sensors fusion, multivariable approach, big data are the new keywords.
- The extraction of reliable features and parameters on the data acquired remotely through wearable platforms has shown to be feasible.
- Smart data management, data security and use of information based on ethics principle is mandatory

Thank you



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