August 10, 2017, IEEE Seminar, IEEE Circuits and Systems Society Joint Chapter of the Vancouver/Victoria, Simon Fraser University and University of British of Columbia, Canada

Unobtrusive Smart Sensing and Pervasive Computing for HealthCare

Cardio-Respiratory and Motor Activity Assessment

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– **Kristen Donnell**

AdCom (2016-2019);

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- http://ieee-ims.org/education/distinguished-lecturers-program

Outline

- Population ageing phenomena: Facts and Motivation

- Assistive Environments for Healthcare
    - Daily used object with sensing and computation capabilities
    - Modular wearable smart sensing solutions
    - Objective Physical Rehabilitation based on Kinect Sensor and Thermography
- Conclusions

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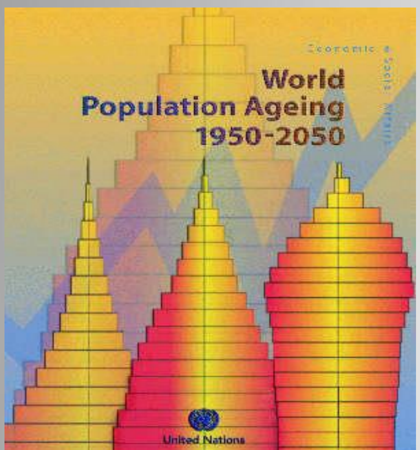
Ageing

Facts



- Elderly people are the fastest growing segment of the population;
- According with UN the population over 60 years old will increase worldwide from11% now to 22% in 2050;

The healthcare system is under pressure

Ageing

Motivation

Develop new assistive environments for healthcare for higher:

- QoS
- Efficiency

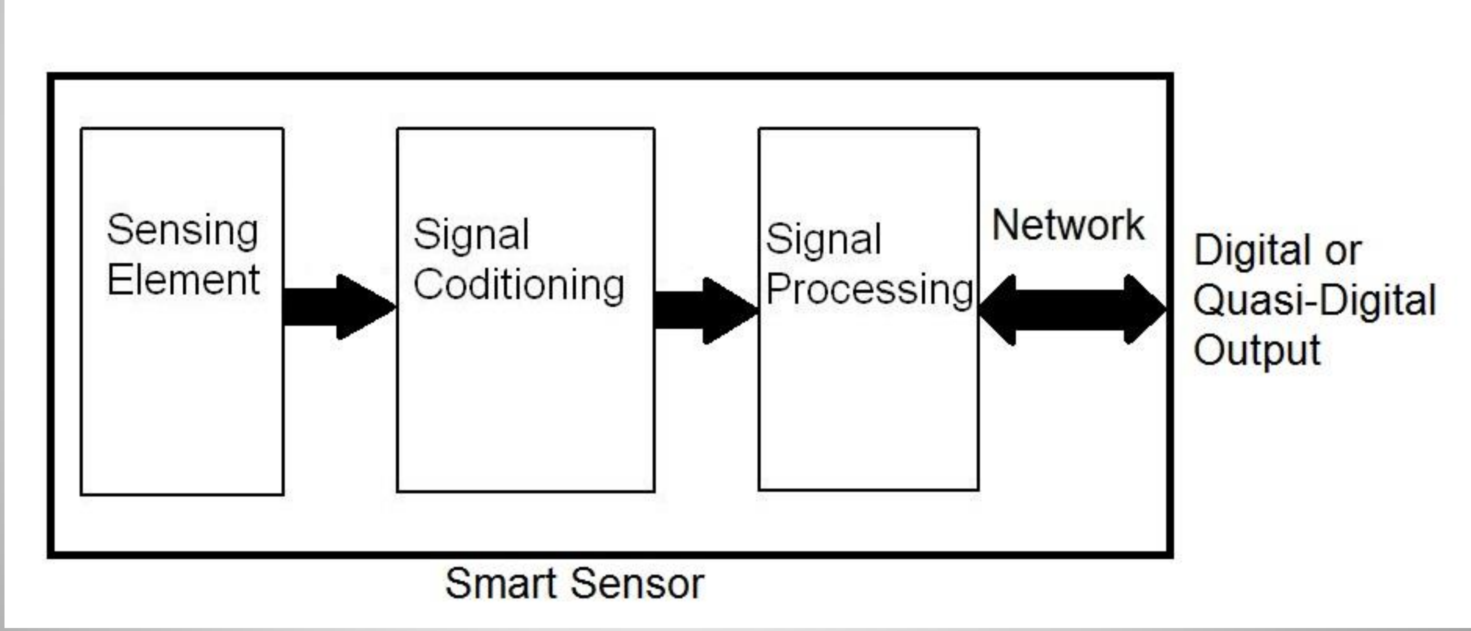
Increase the usability and the acceptance by Elderly of new healthcare devices

Assistive Environments for Healthcare

Smart Sensing

smart sensors → combination of **sensor, signal conditioning**, **embedded algorithms** and **communication interface**

Standards: IEEE 21451.X



E. Song. K. Lee, et al, ICEMI 2011,
R. Morelo , O. Postolache , Guest Editor, Advanced, IEEE Sensors Journal, 2015

Assistive Environments for Healthcare

Pervasive Computing

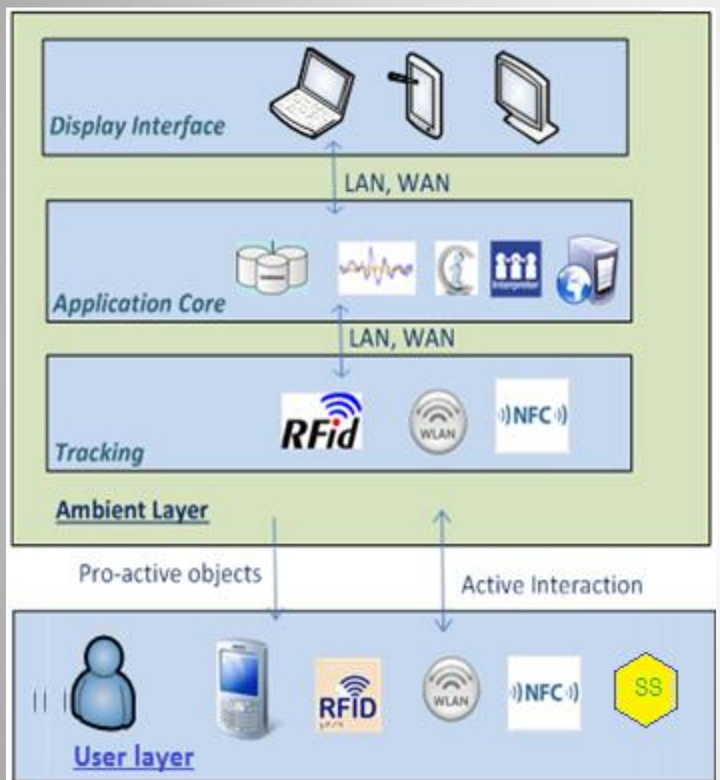
Pervasive (ubiquitous) computing → embedding microprocessors in everyday used objects so they can communicate information

… *Healthcare Beyond ..*
pervasive sensing & computing?

***Mark Weiser**, "The Computer for the 21st Century", Scientific American. 1991*
Mark Weiser- - father of ubiquitous computing, PARC Xerox company

Assistive Environment for Healthcare

Healthcare Ecosystem for elderly



Sensing and Computing

Implemented
Healthcare ecosystem- Ecosystem

O.Postolache ,"Pervasive Sensing and M-Health", Springer 2012

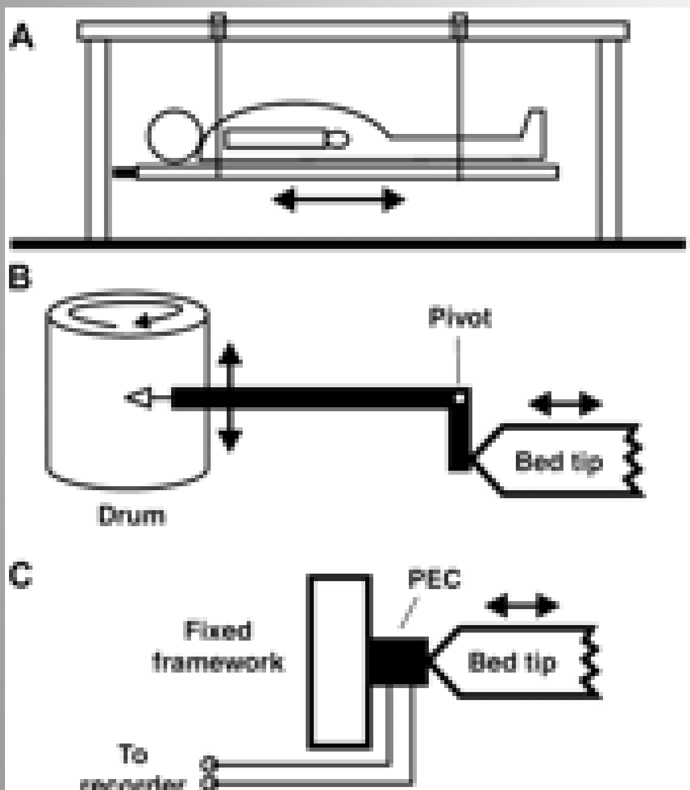
Assistive Environments for Healthcare

Objectives

- To perform vital signs and motor activity assessment in non-intrusive way;
- To provide accuracy and reliability based on unobtrusive smart sensing and pervasive computing associated with daily used objects;
- Real-time processing and multi-user monitoring.
- *smart wheelchair,*
- *smart walker;*
- *smart clothes and accessories.*

Smart Wheelchair
BCG sensing system

BCG yesterday



- *Isaac Starr – 50' cardiac monitoring fashion*

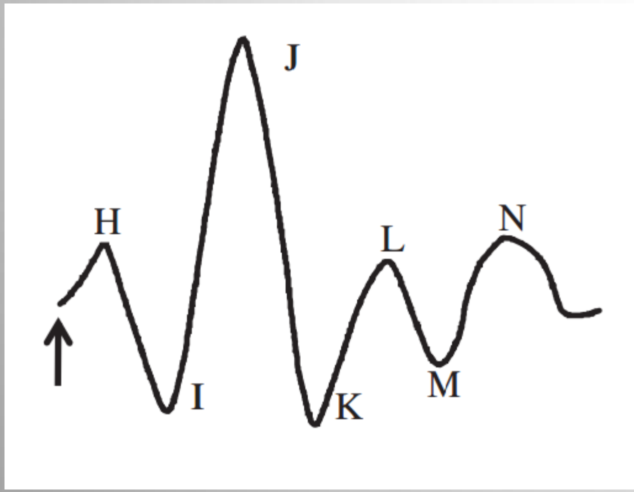
BCG today

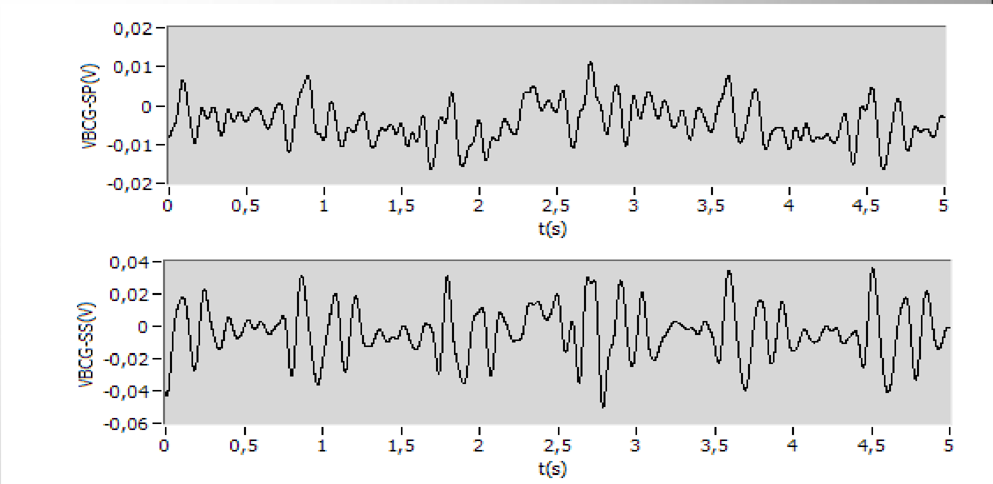
- *Cardio-respiratory monitor based on EMFIT and MEMS accelerometer*

Smart Wheelchair
BCG Sensing and Signals

- BCG captures pressure oscillations due to heart activity
- Cardiac output through HR, HRV is assessed

BCG wheelchair seat





BCG wheelchair backrest

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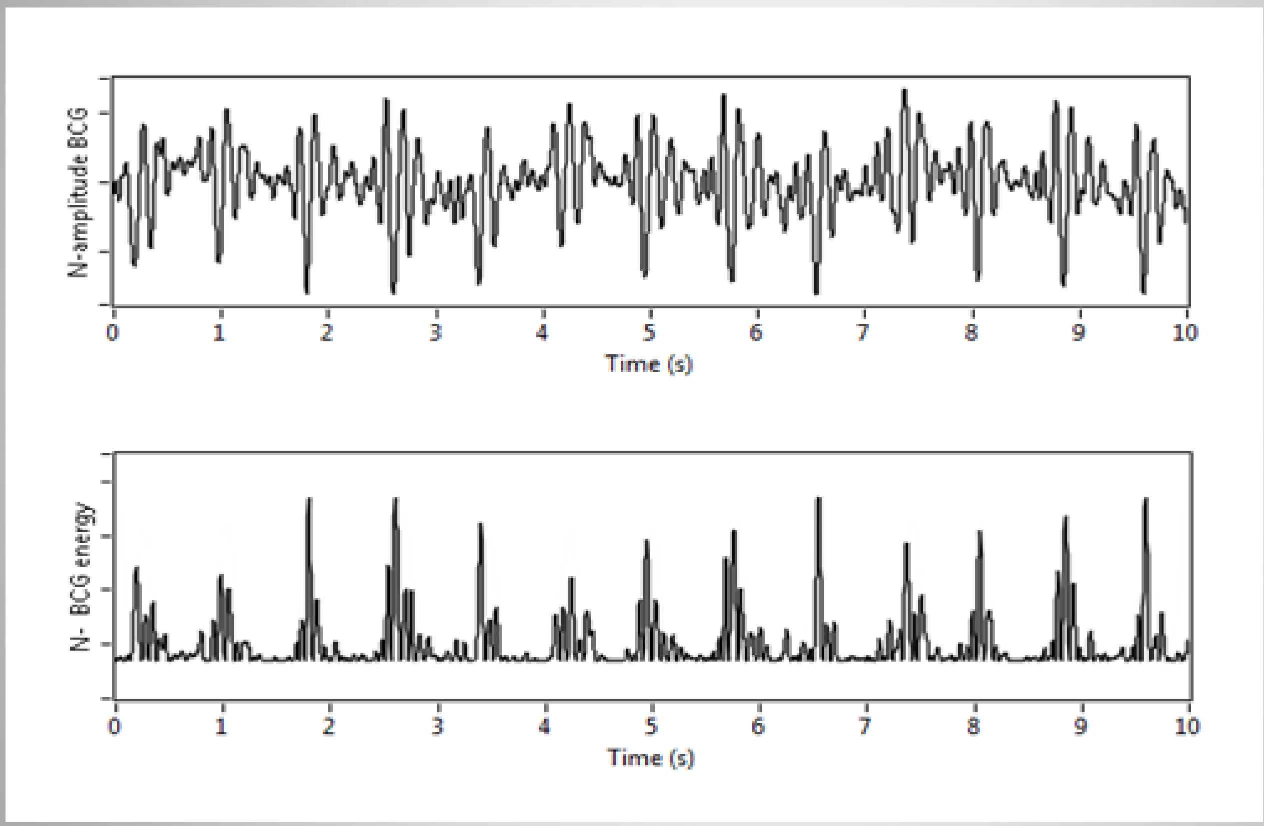
Smart Wheelchair
HR through BCG



$X_{BCG}(t)$

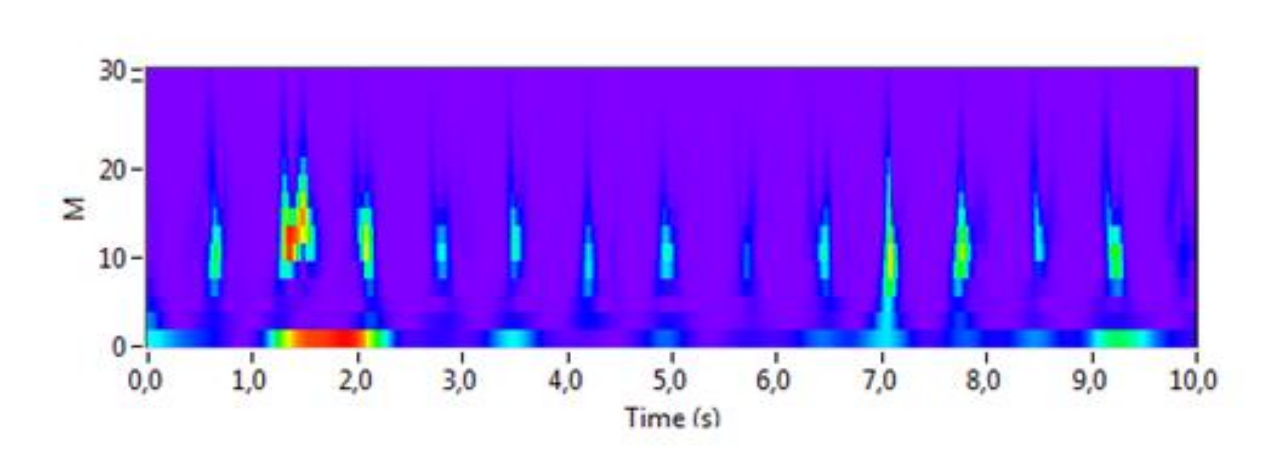
↓

$X_{BCG}^2(t)$

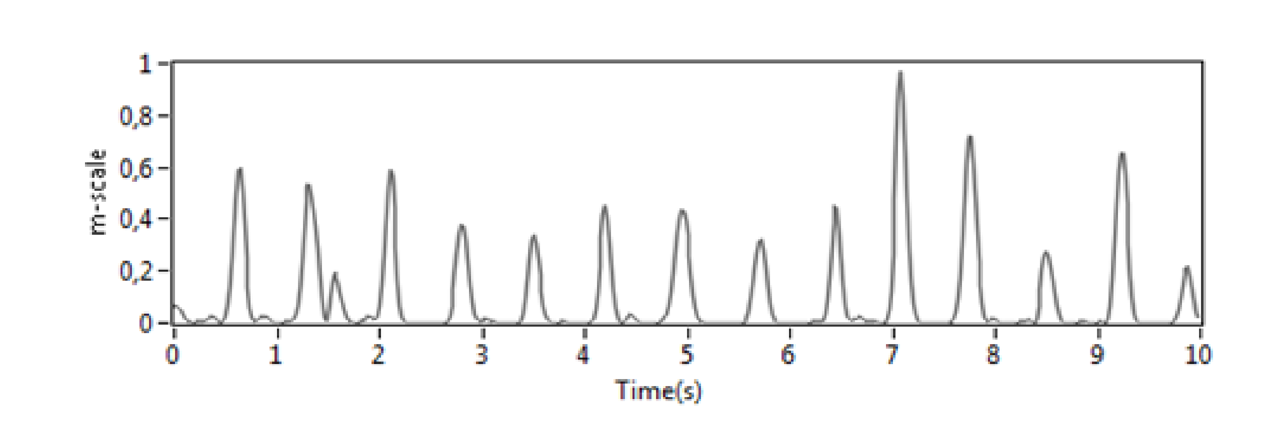
IEEE EMBC 2013, Osaka, Japan

Smart Wheelchair
BCG processing

Cardiac output through CWT Scallogram of BCG energy

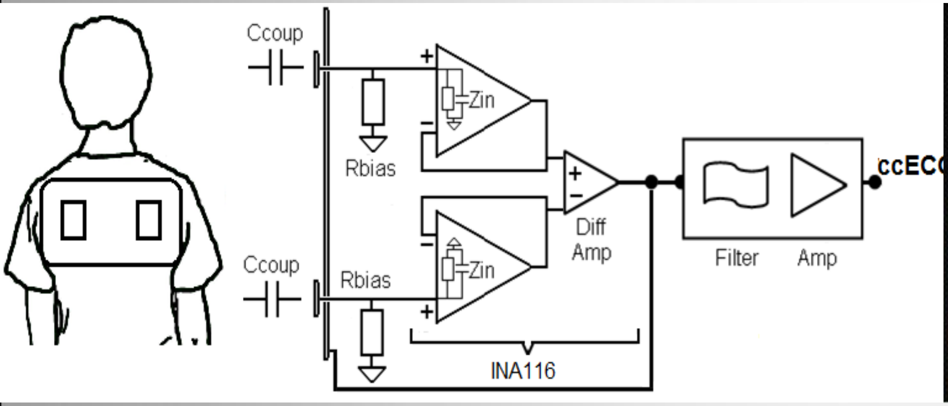


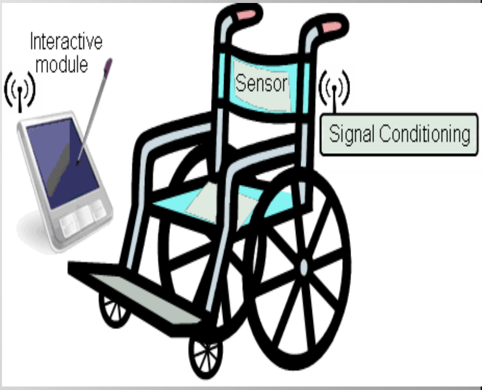
HR extraction based on peak detection of a selected scale and *threshold=0*).



IEEE EMBC 2013, Osaka, Japan

Capacitive Coupled Electrocardiogram (ccECG)





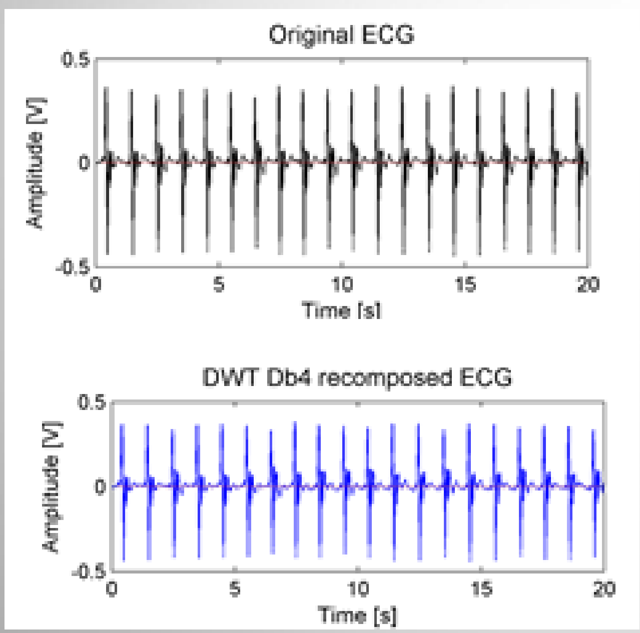
2 copper electrodes (33.75 cm^2) at 20 cm distance , embedded within the wheelchair backseat cover., 1 cooper plane of 550 cm^2

IIEEE 2MTC 2013, Mineapolis, USA

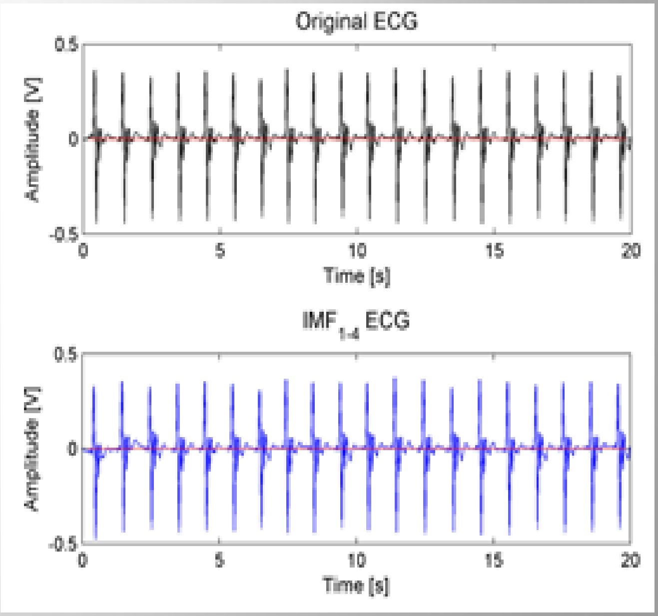
Smart Wheelchair
ccECG processing

- Artifact removal and denoising
- DWT and SWT (Doubechies mw)
- Empirical Mode Decomposition (with PCA-EMD optimization)

DWT



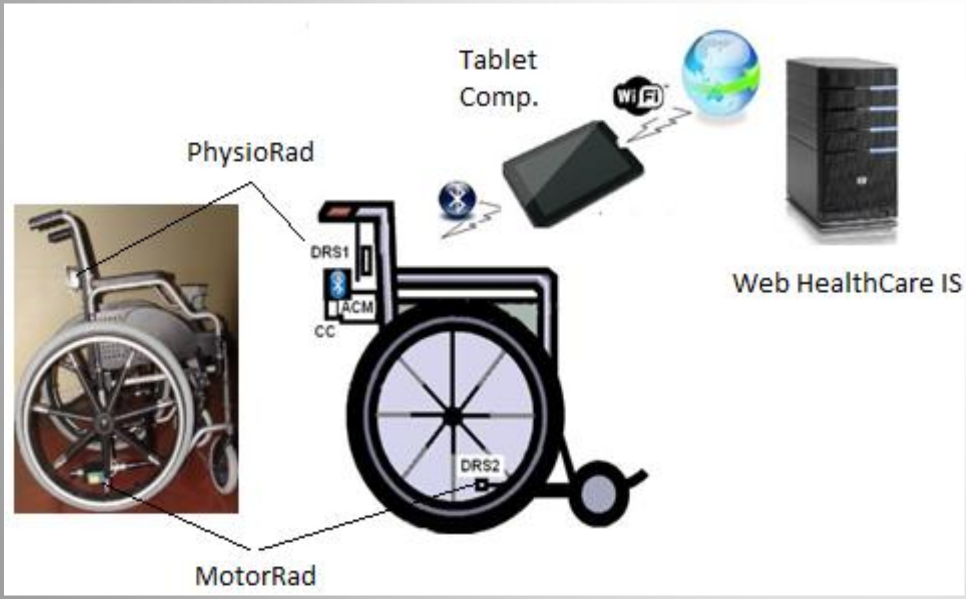
EMD

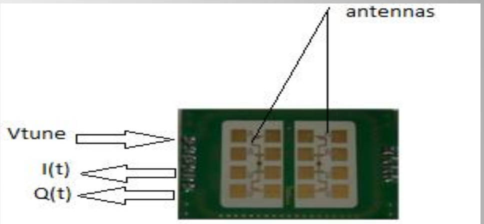


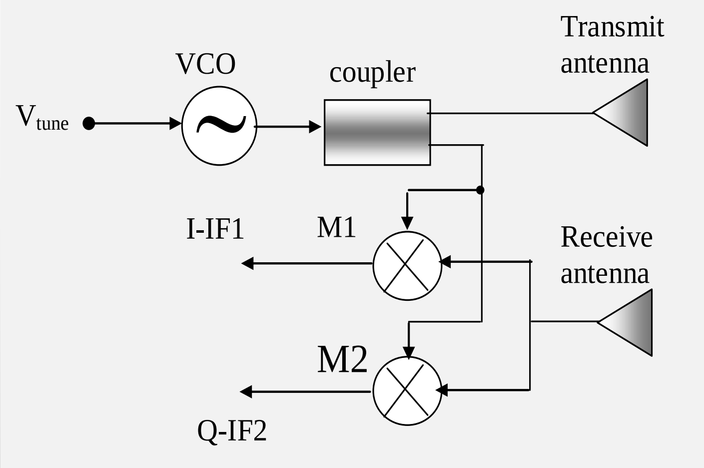
Pinheiro, E.C.; Postolache, et al, Measurement, Vol. 45, No. 2, pp. 175 - 181, February, 2012

Smart Wheelchair
rBCG

Ballistocardiography-seismography monitoring system based on 24GHz FMCW Doppler radar





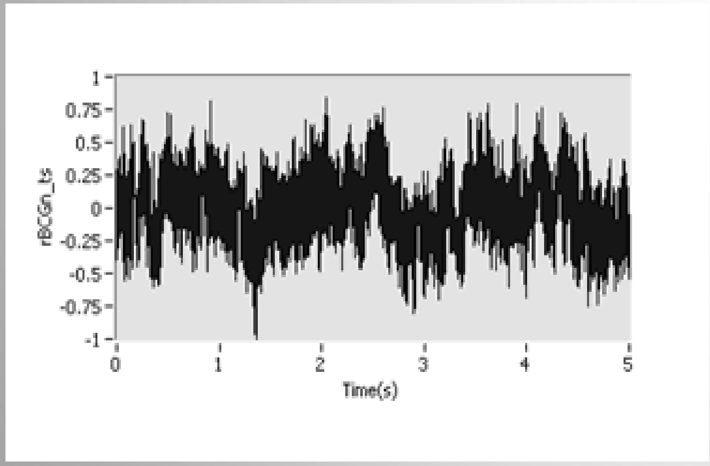


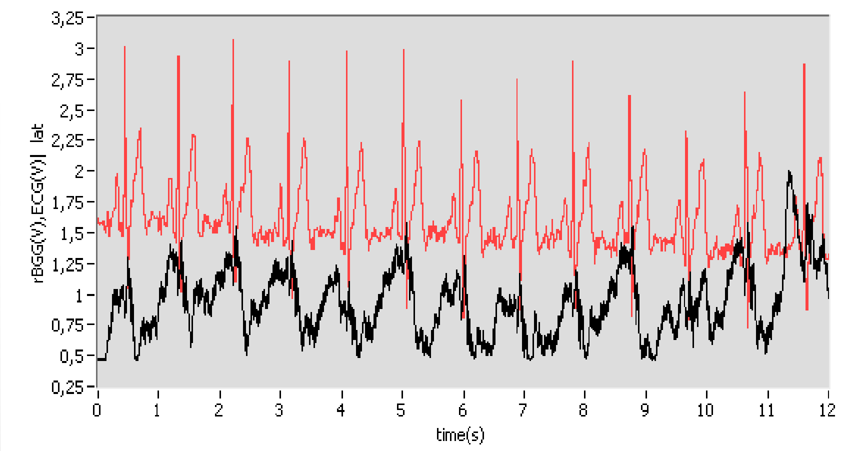
IEEE EMBC2011, Boston, USA

Smart Wheelchair

RadarSignal - CardioResp

- FMCW Doppler radar output signals - balistocardiography (BCG) signals include information about cardiac and respiration activity,

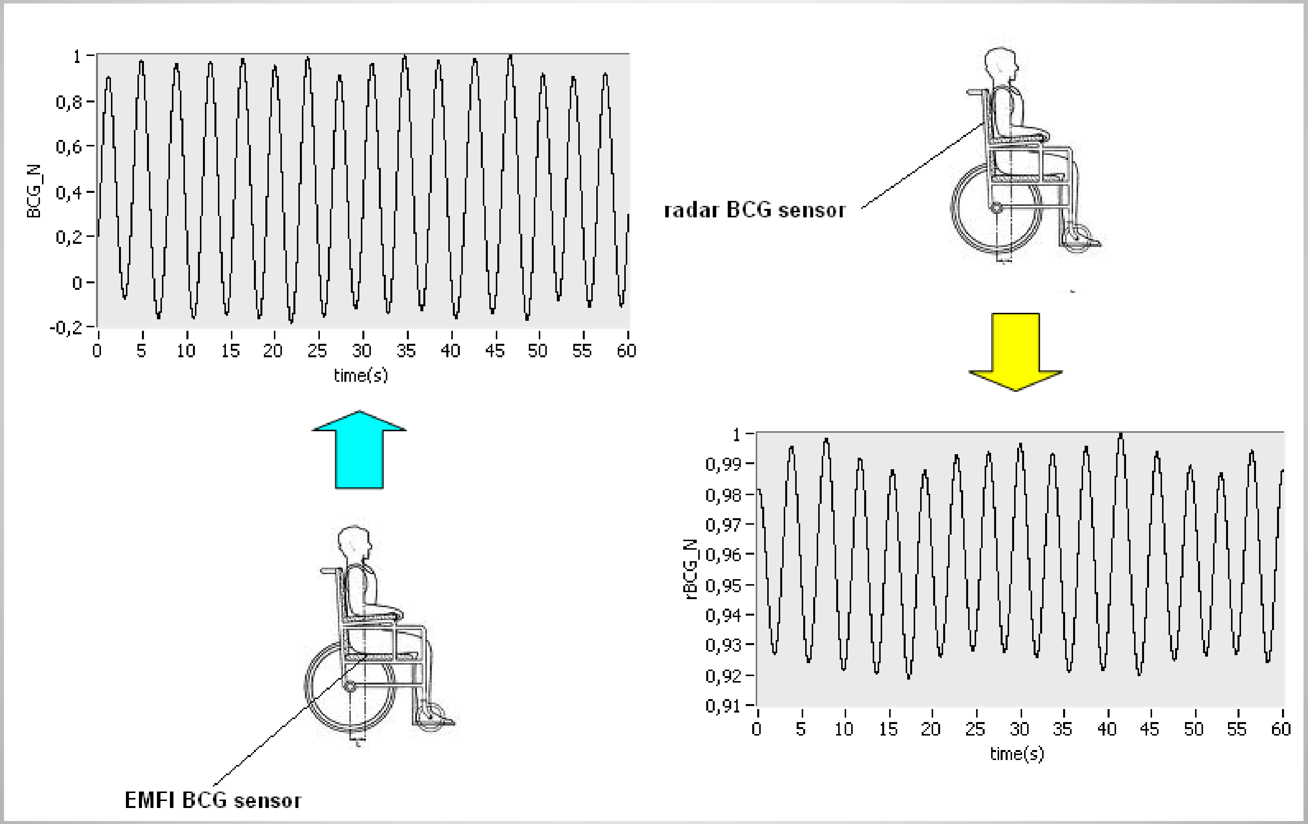


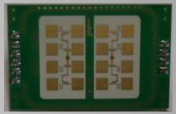


IEEE EMBC2011, Boston, USA

Smart Wheelchair

Respiration signals obtained from EMFIT BCG and Radar BCG signals





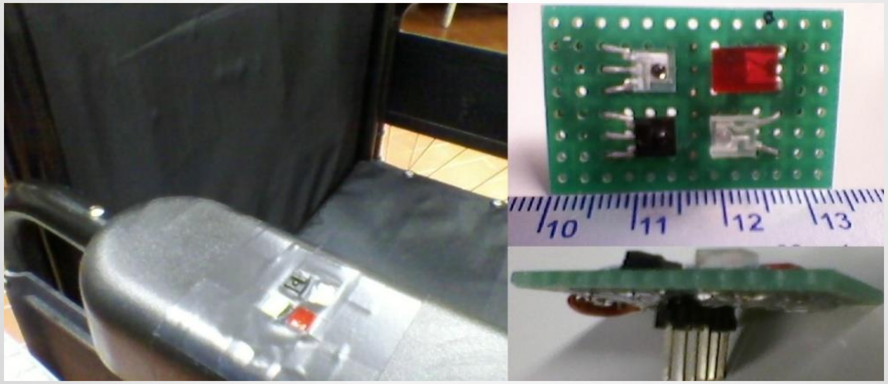
3rd order DWT decomposition db4 mother wavelet respS= approx.

MeMeA 2011, Bari, Italy

Smart Wheelchair

PPG

Reflective photo - plethysmography embedded in the wheelchair arms Electrocardiogram (rPPG)



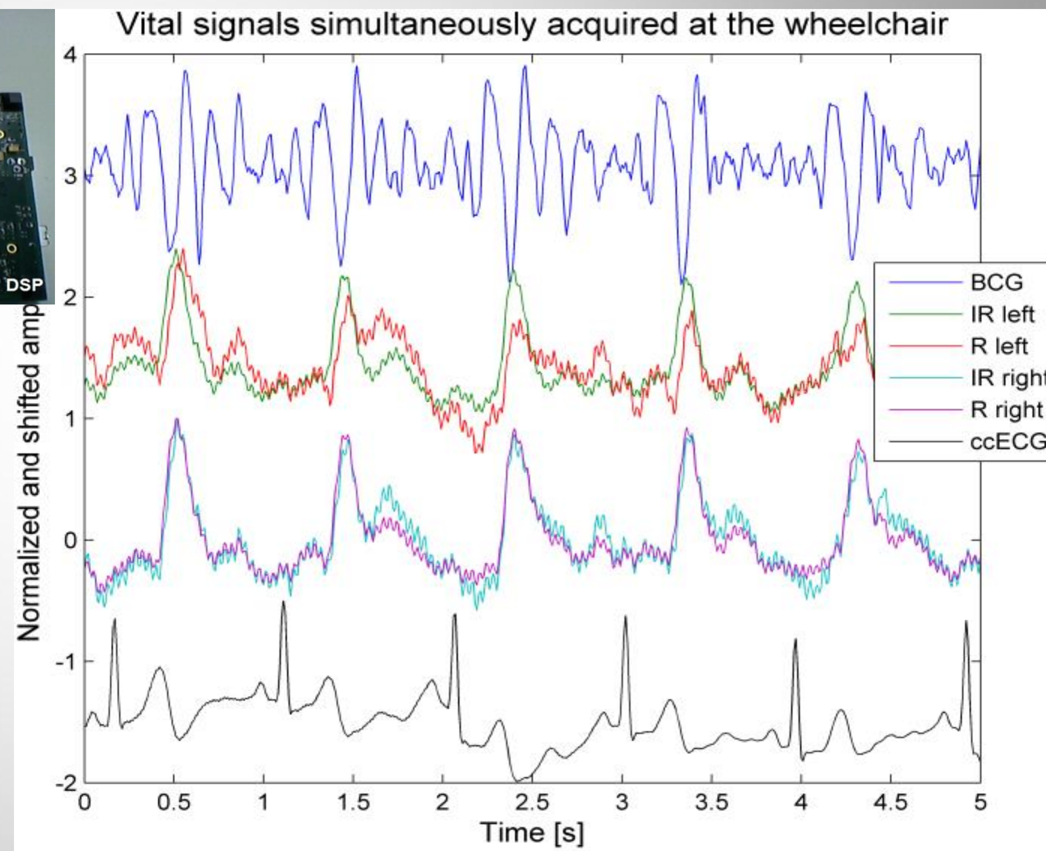
Robust measurement on arm/hand/wrist HR and SpO2 was obtained

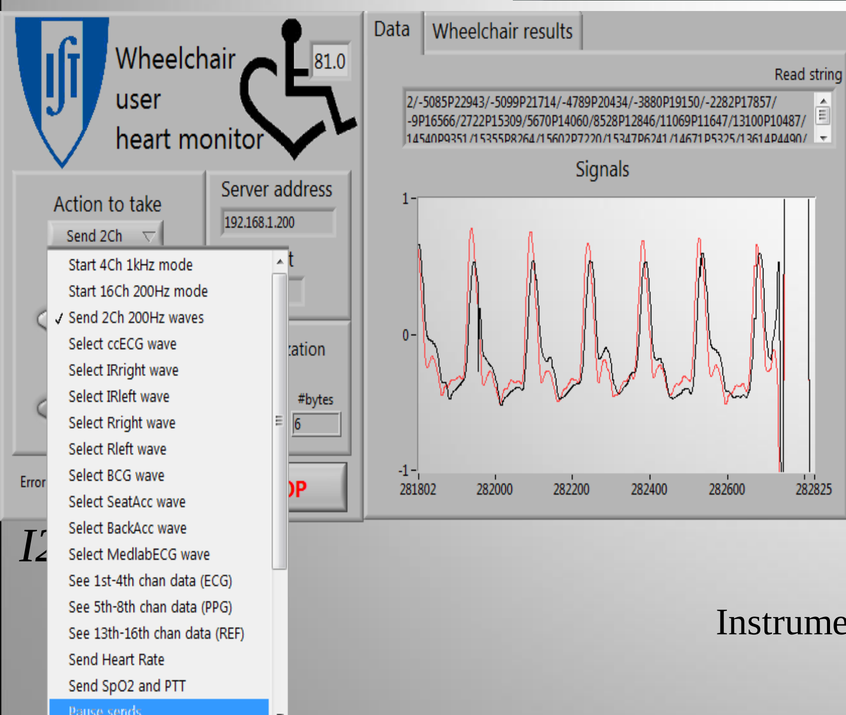
I2MTC 2013

Smart Wheelchair

Processing BCG, PPG and ccECG in DSP platform

Simultaneously acquired signals based on DSP platform



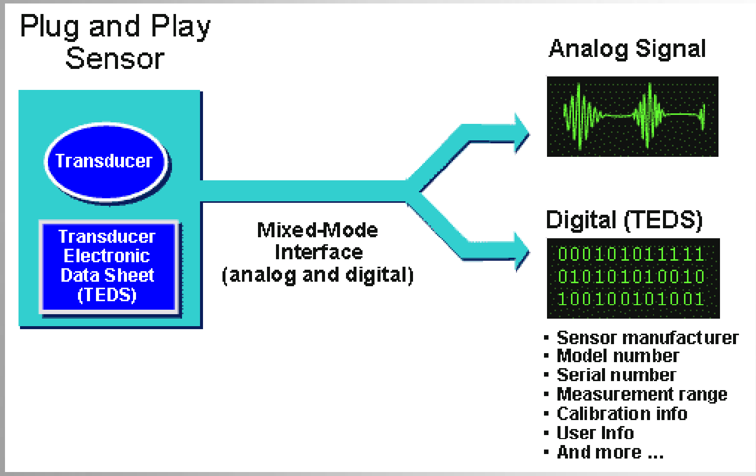


I2

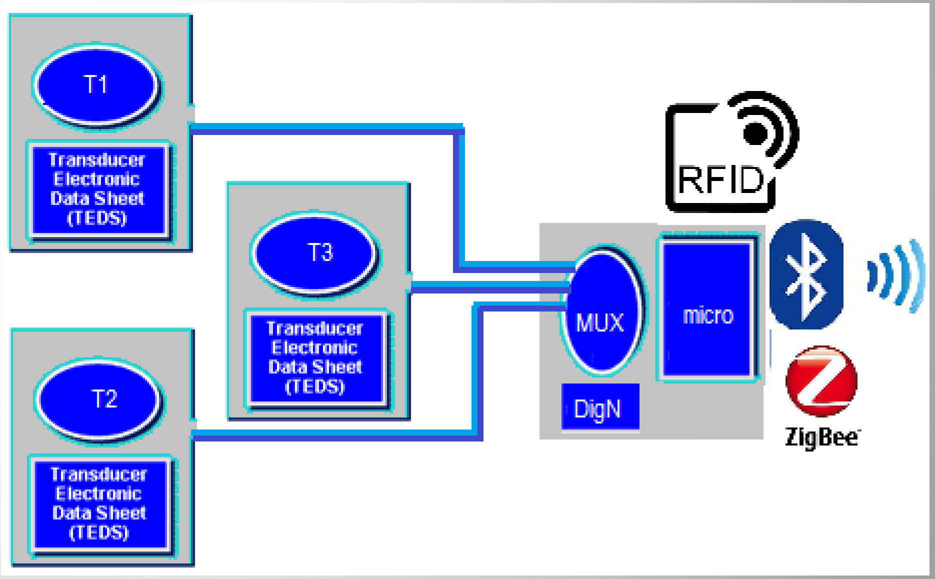
Smart Wheelchair

Interoperability & Standards

increase interoperability of the smart objects through the IEEE21451.4 implementation



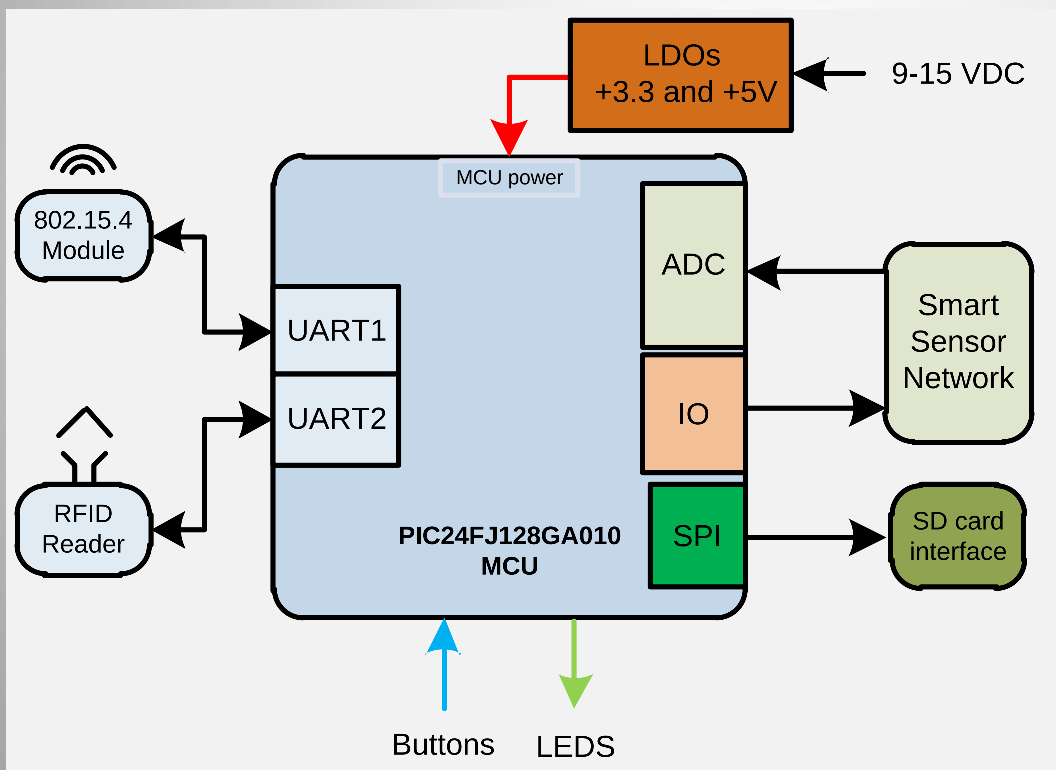
NI - IEEE 21451.4 Standard Overview

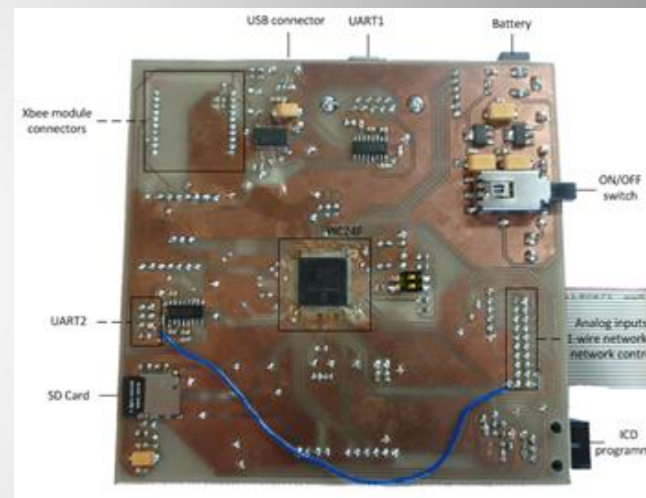


Implemented architecture

Smart Wheelchair

IEEE1451.4 Smart Gatteway

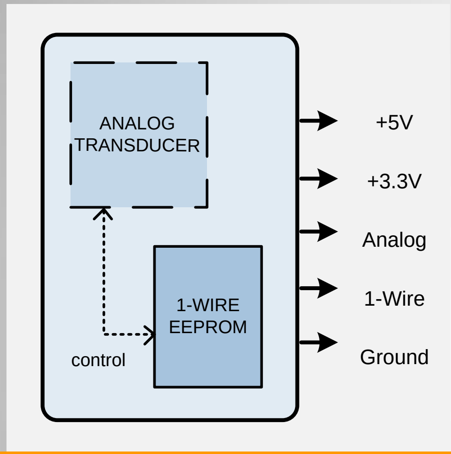


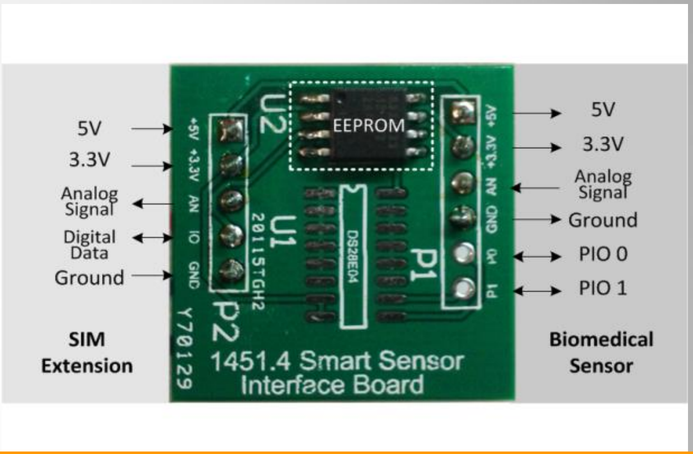


Smart Wheelchair

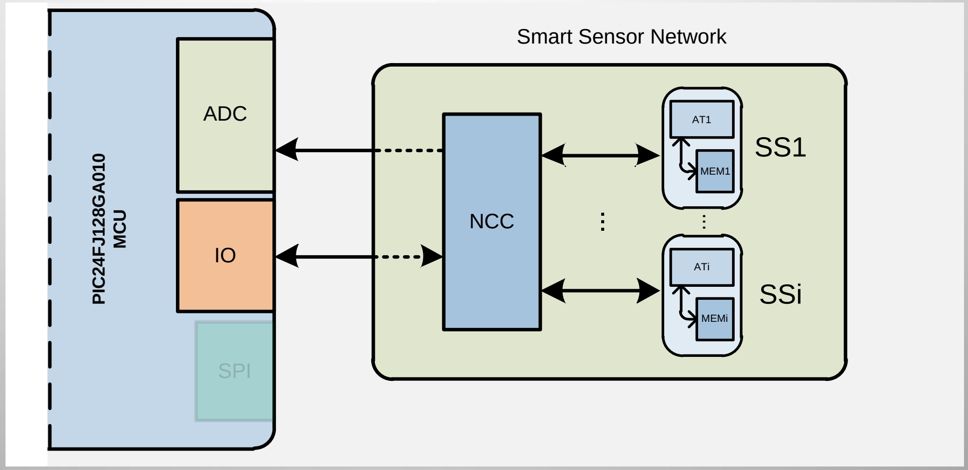
IEEE21451.4 nodes and interfacing

Smart sensor node





Smart sensor network



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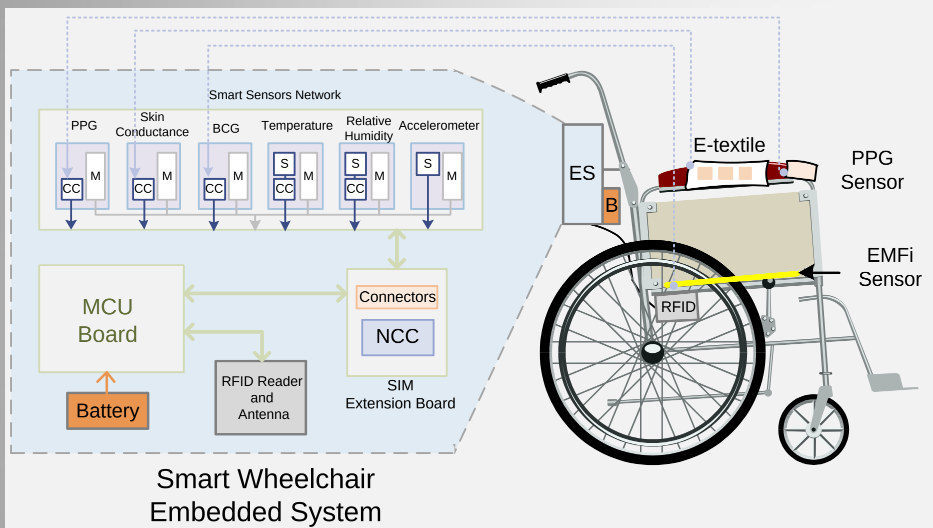
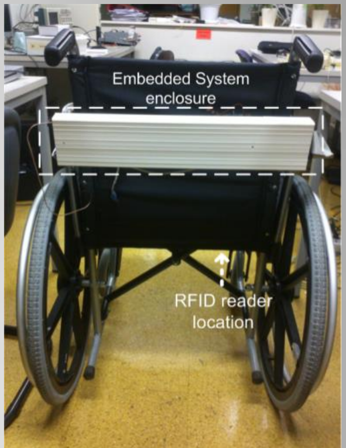
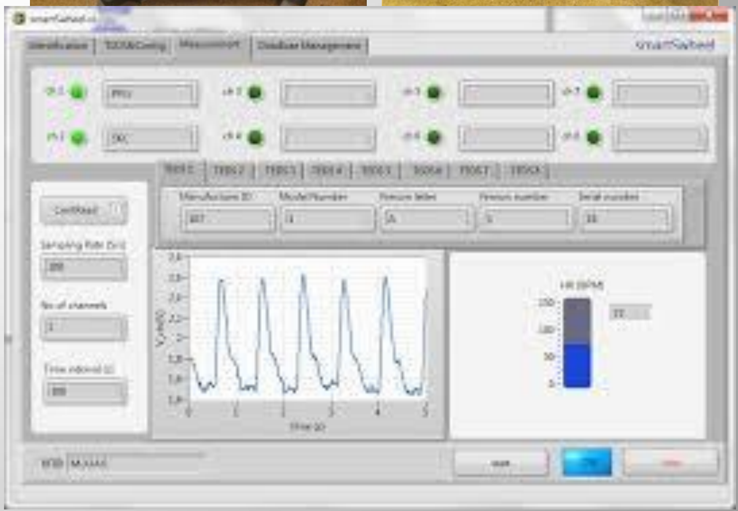
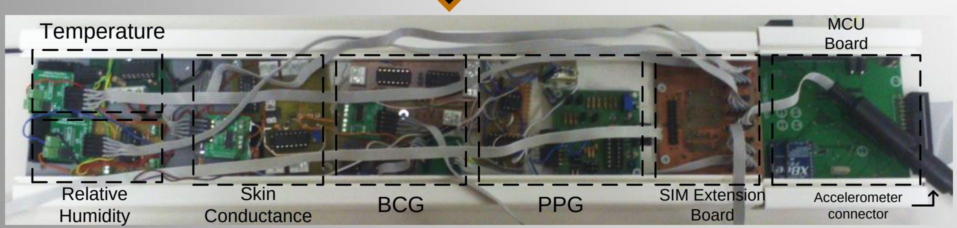
Smart Wheelchair

IEEE21451.4 implemented prototype

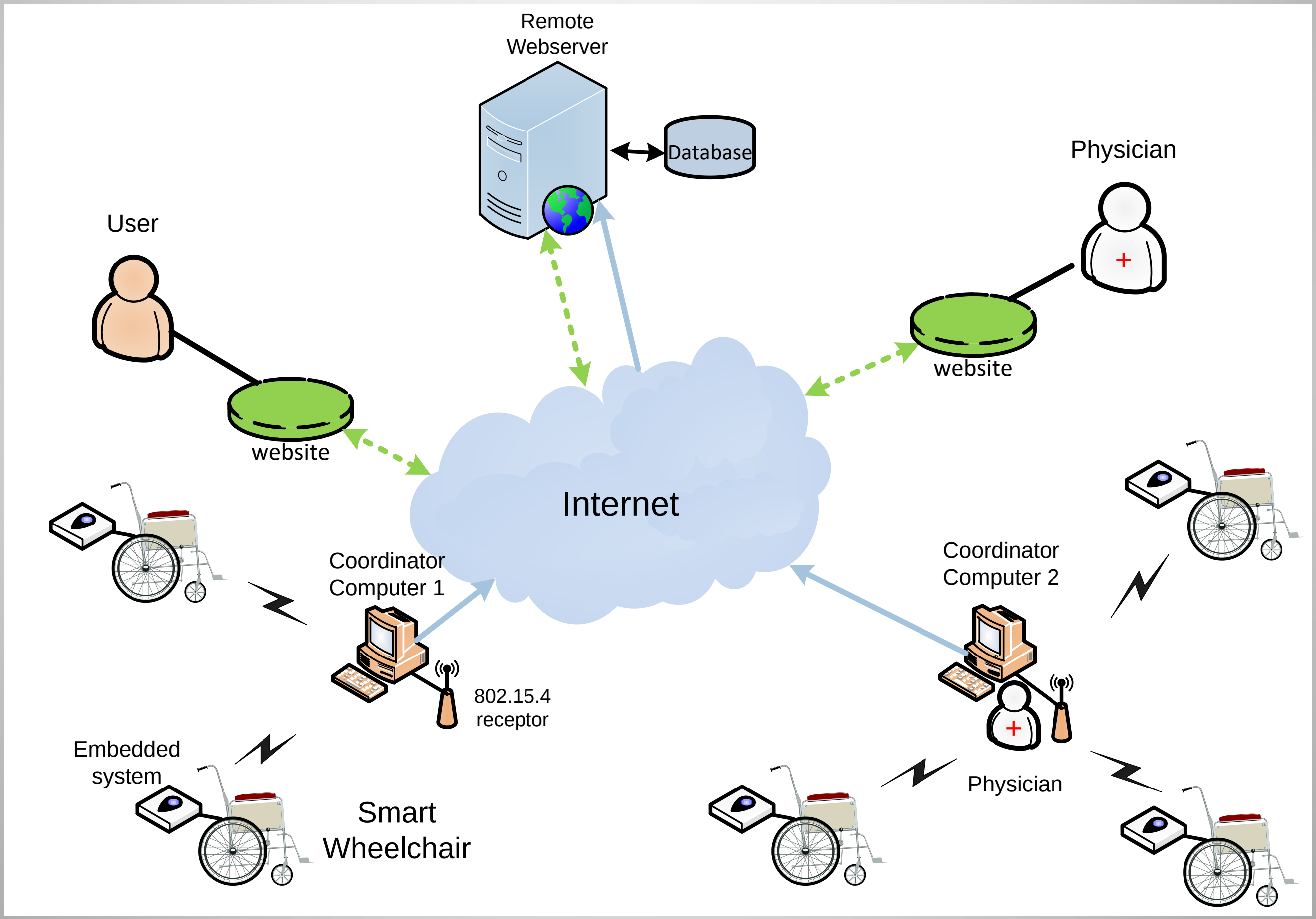








Smart Wheelchair
multiuser net



Postolache, IEEE ICST 2012, Kolkata, India

Physiotherapy Assessment

Smart Walkers Prototypes

standardW

2wheelsW

4wheelsW

O.Postolache et. al., IEEE, ICST 2011, NZ, O. Postolache et. Al., IEEE MeMeA 2015, Turin, Italy
O. Postolache IEEE EHB 2015, Iasi, Romania

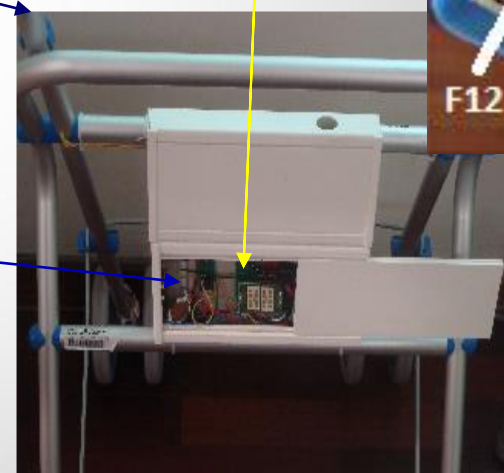
Smart Walker

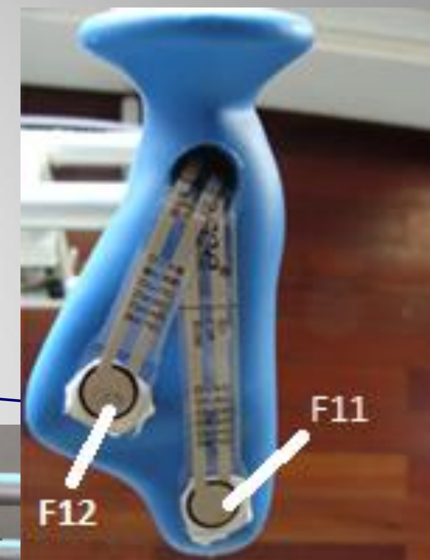
2W*Prototype*

Force sensor

3D accelerometer

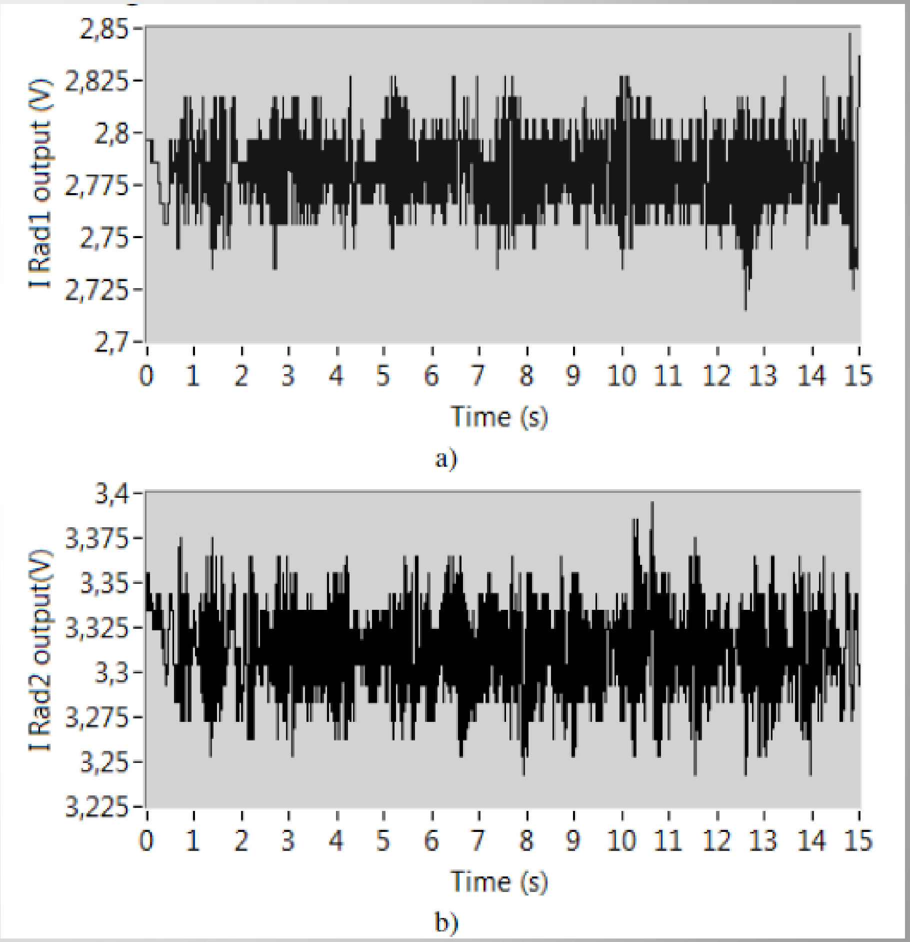
Single Doppler Radar





Smart Walker

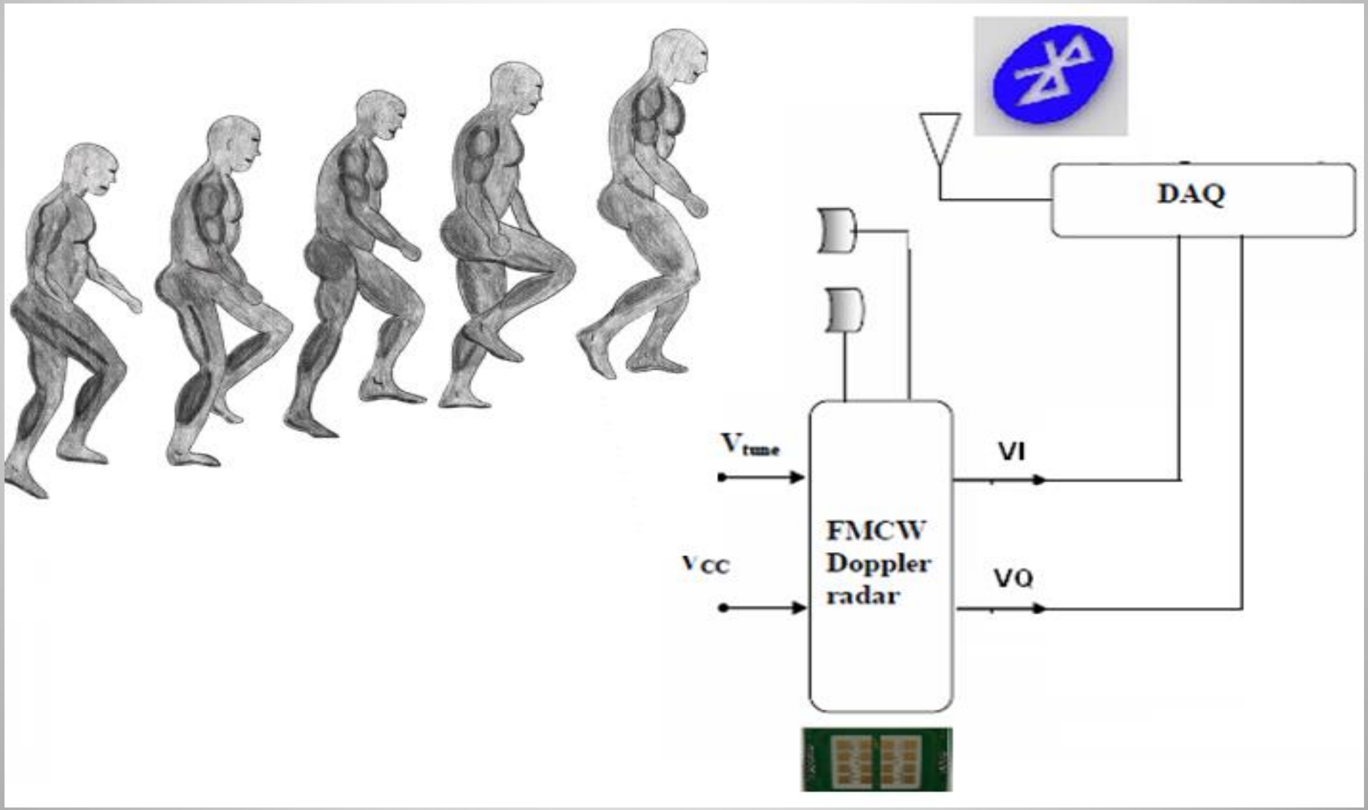
Gait assessment by Doppler radar sensor array



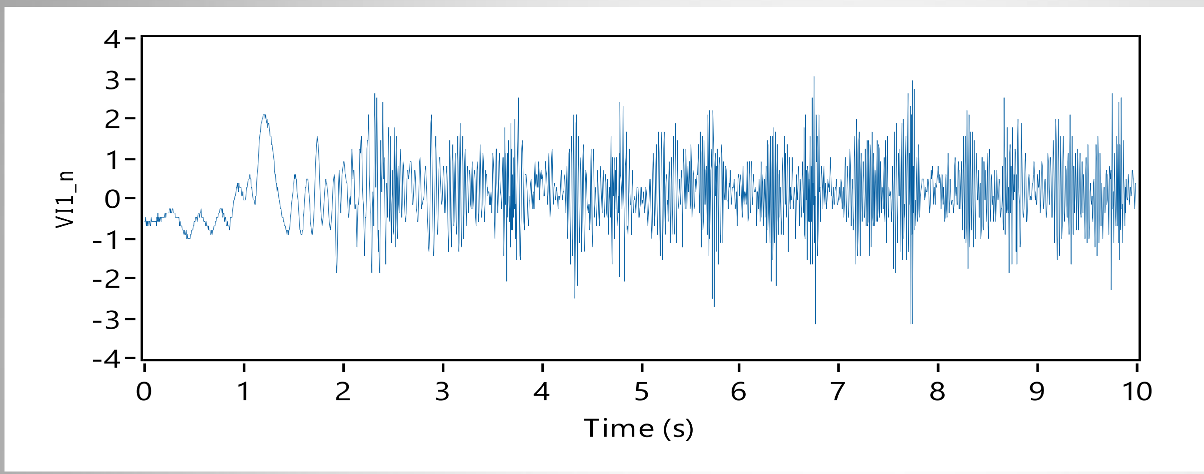
O. Postolache, et. al. IEEE, MeMeA, 2015, Torino, Italy

Smart Walker

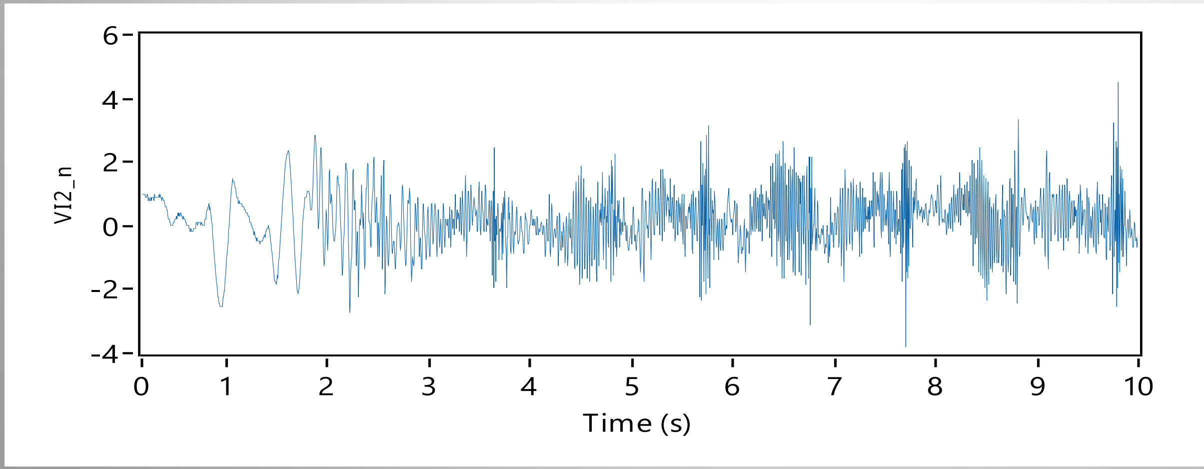
Gait Pattern Sensing and embedded processing



Smart Walker – *Gait Doppler radar Signals*



- Regular Gait

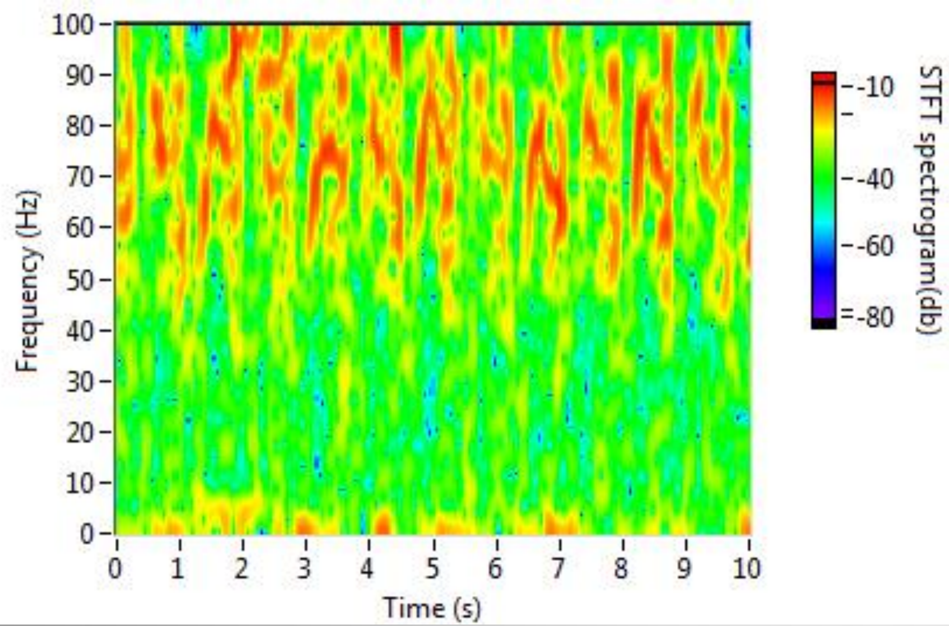


- Hemiparetic Gait

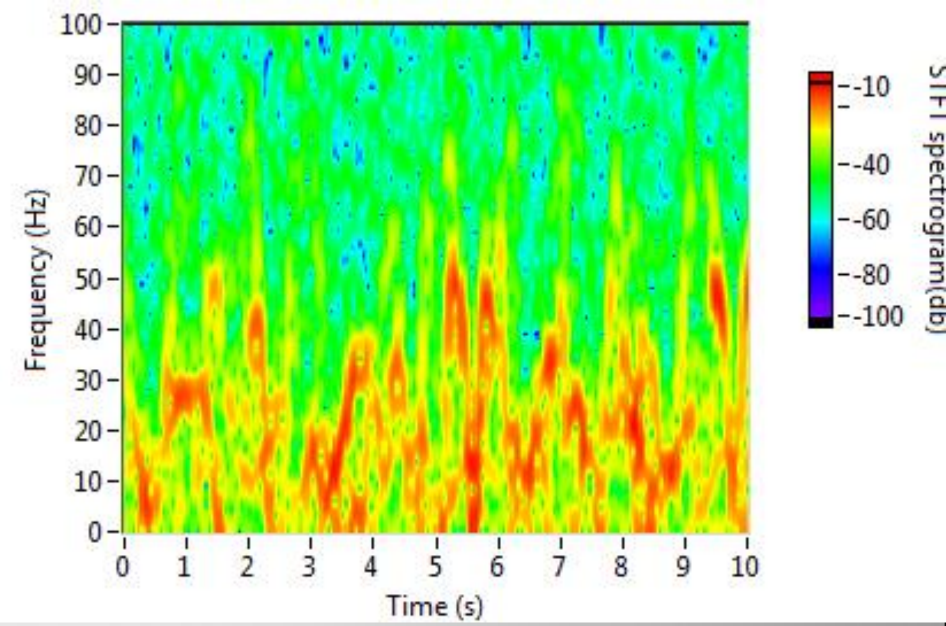
Smart Walker

Gait STFT Spectral Signatures

Regular Gait

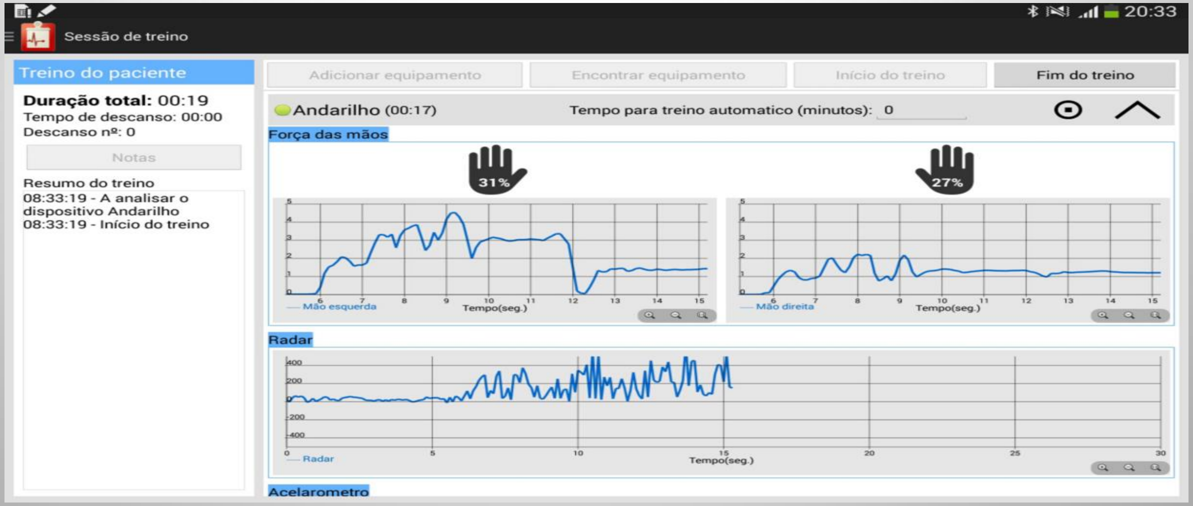


Hemi paretic Gait



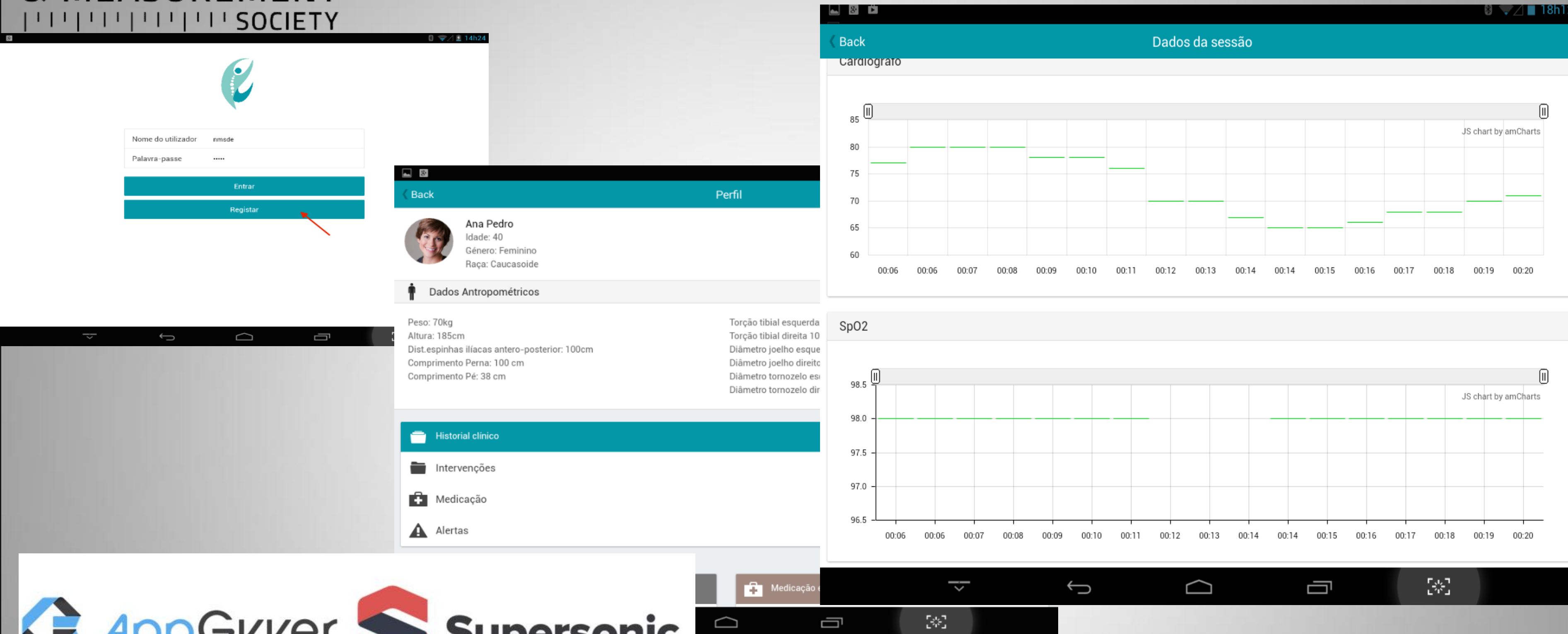
Smart Walker

Ubiquitous Computing APPs – V2.0



EHR & Smart Walker

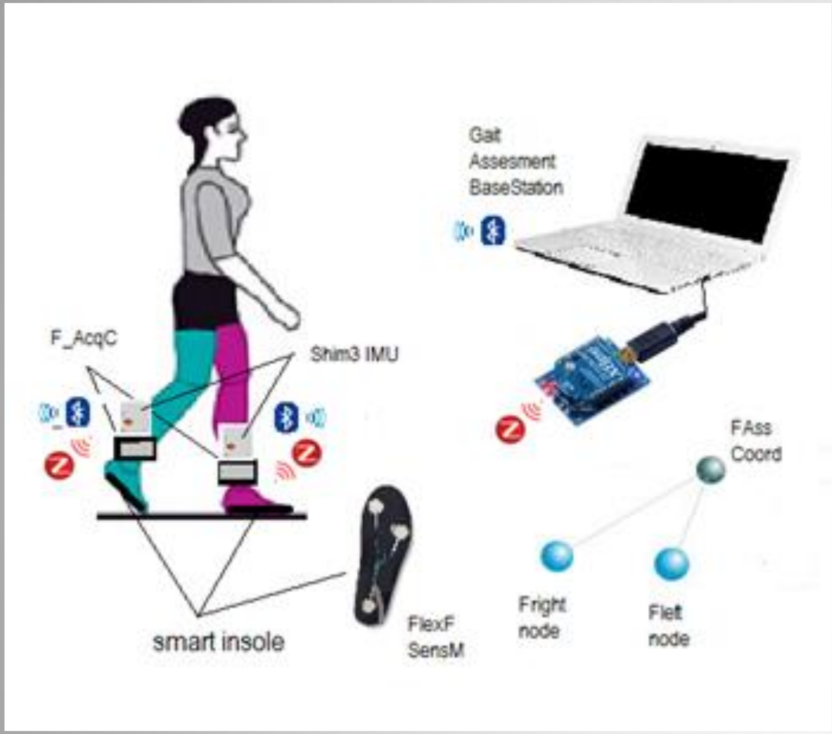
Cardiac and Motor Activity Monitoring

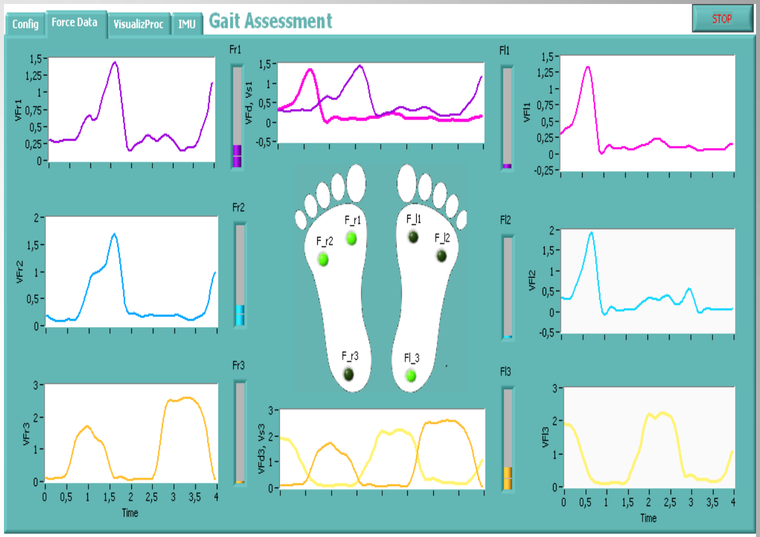


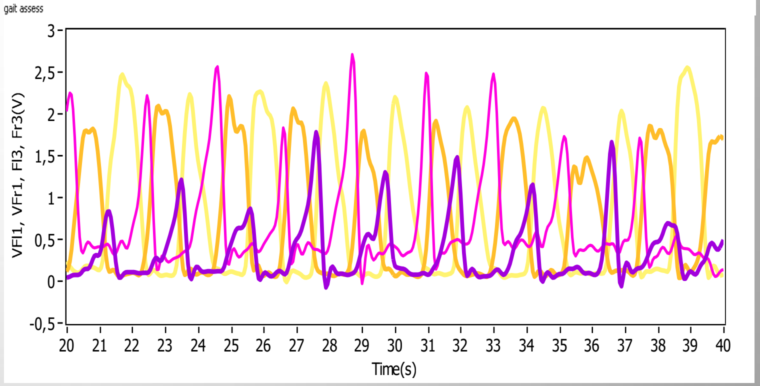
Login; Patient registration interface; cardiac information

Wearable Smart Insole

Architecture, Signals & Software







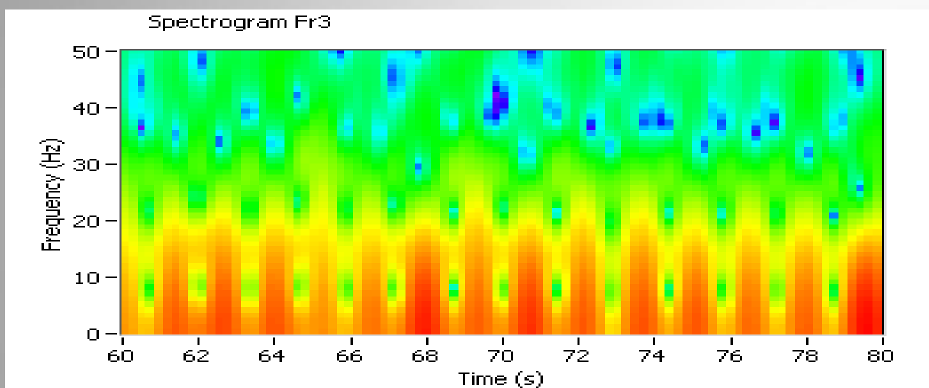
voltage signals normal gait from metatarsal calcaneus area

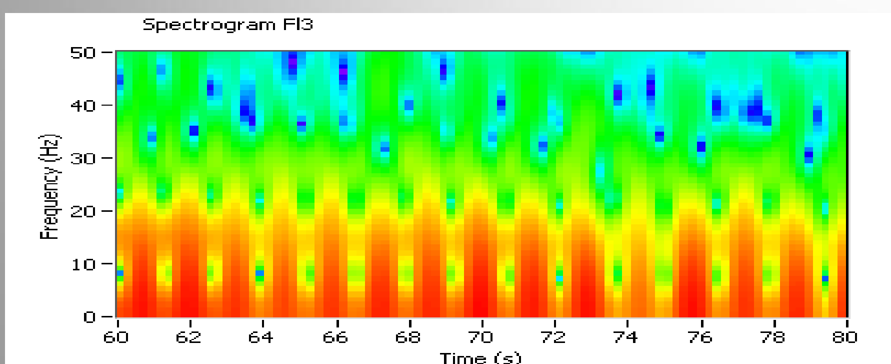
ATEE 2015, Bucharest, Romania

Wearable Smart Insole

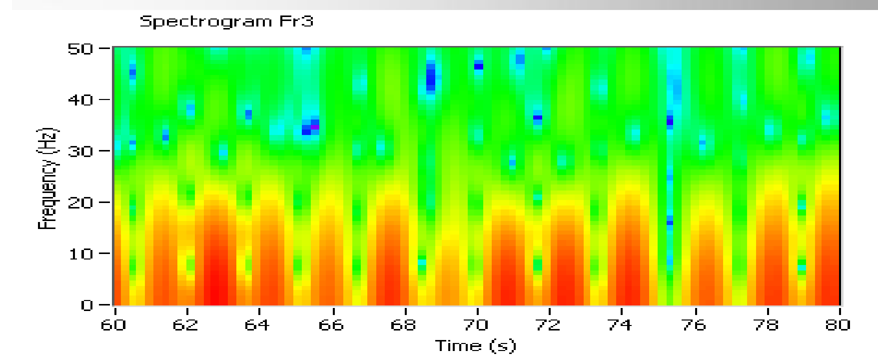
Spectrogram signature for normal and abnormal gait

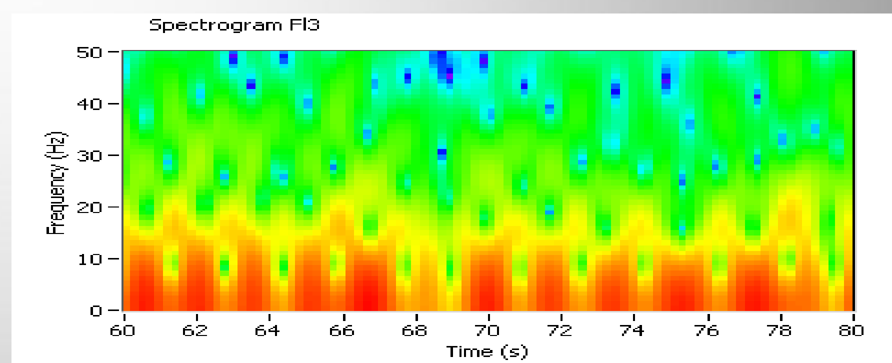
Normal gait





Abnormal gait

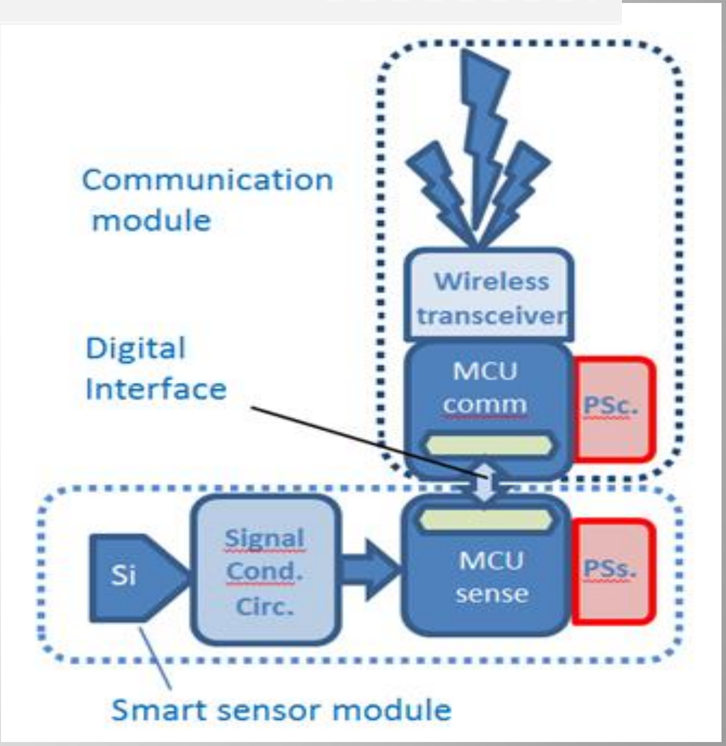




Wearable fast prototyping
qk platform

- Fully modular and interoperable;
- Distributed computation

- One module one task:
  - SSM: Sensing, auto-calibration, data fusion,
  - CM: data communication, data storage.



M.R Ribeiro; Postolache, Chapter, Springer , 2014

Qk platform

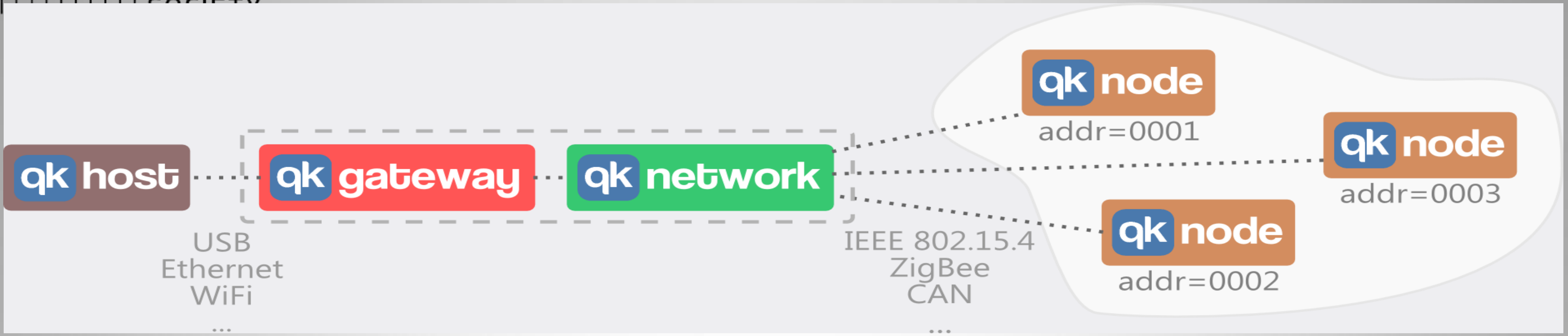
qk *node*

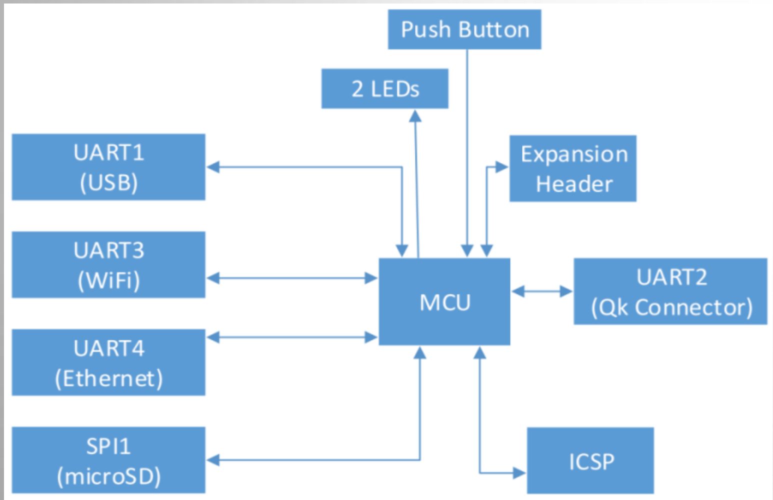
- qk node board includes: configurable smart sensing (qk device) communication (qk module) boards
- On-board non-volatile memory allows to store configuration data between power cycles

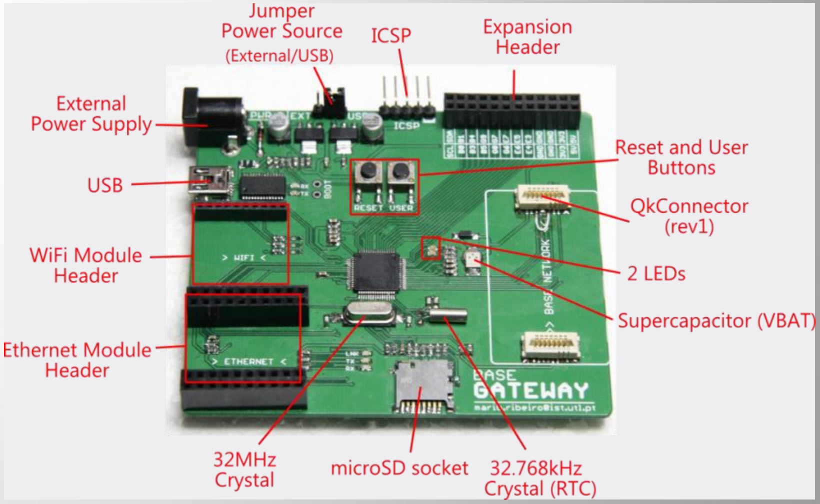
Advantages: *Remote access, Plug-and-play Capability, Interoperability*

qk platform

qk network - gateway







qk platform

qk node and qk network

qk gateway implementation

smart sensor module (qk device) : GPurpose IMU, PPG

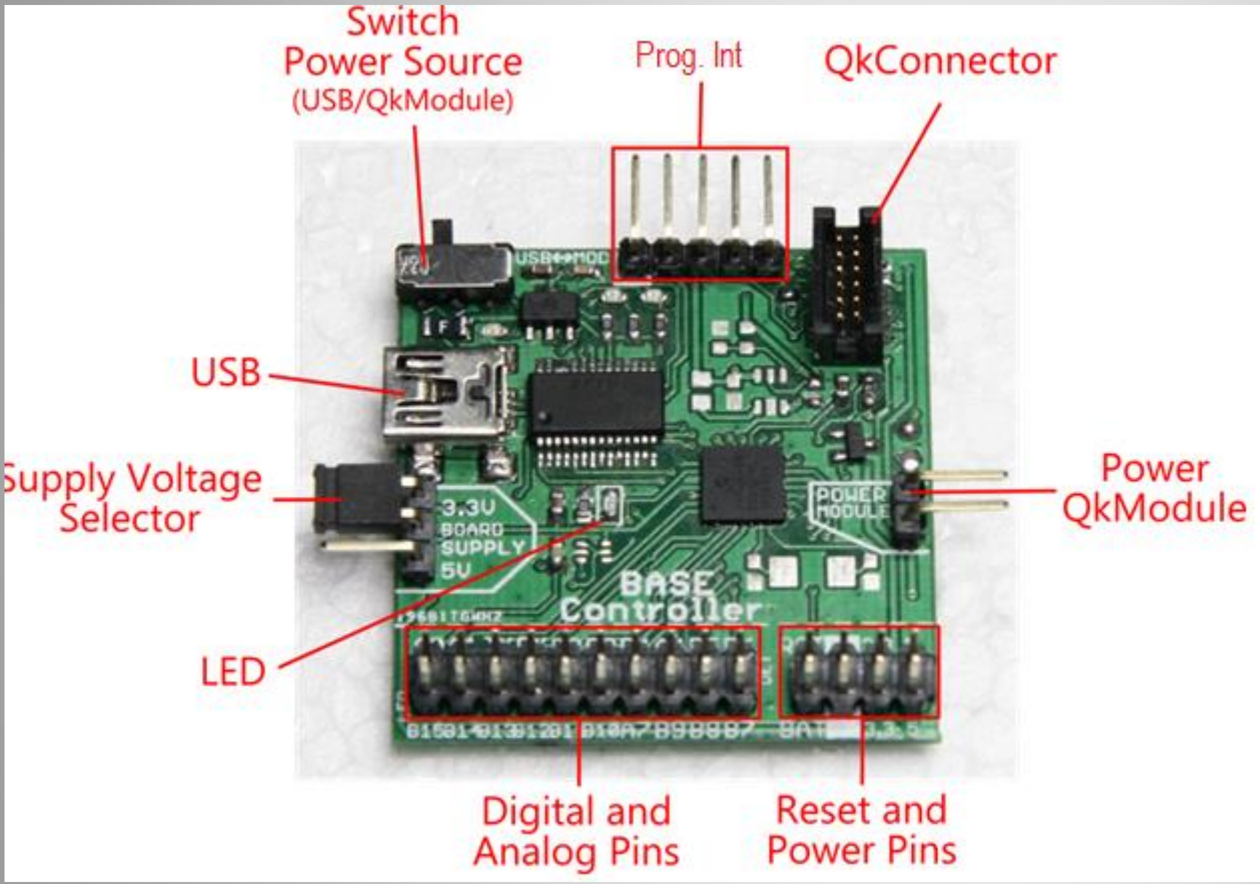
communication module (qk module): Bluetooth, ZigBee

- Wireless network communication:

- ZigBee
- Bluetooth

qk platform

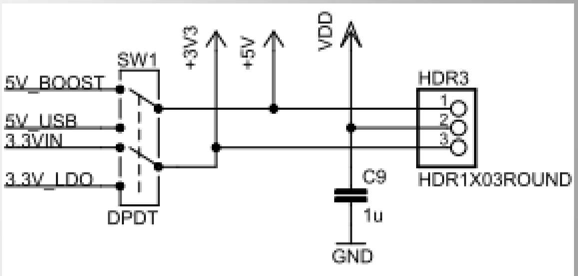
qk device: general purpose



QkConnector:

UART2

Power source selector:

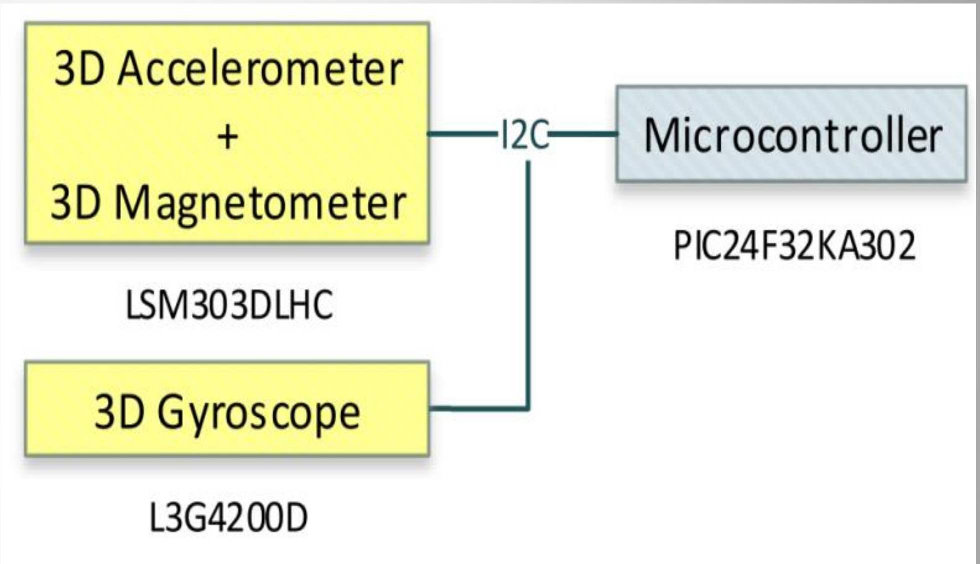


qk platform

qk device - IMU case

Applications: gait analysis

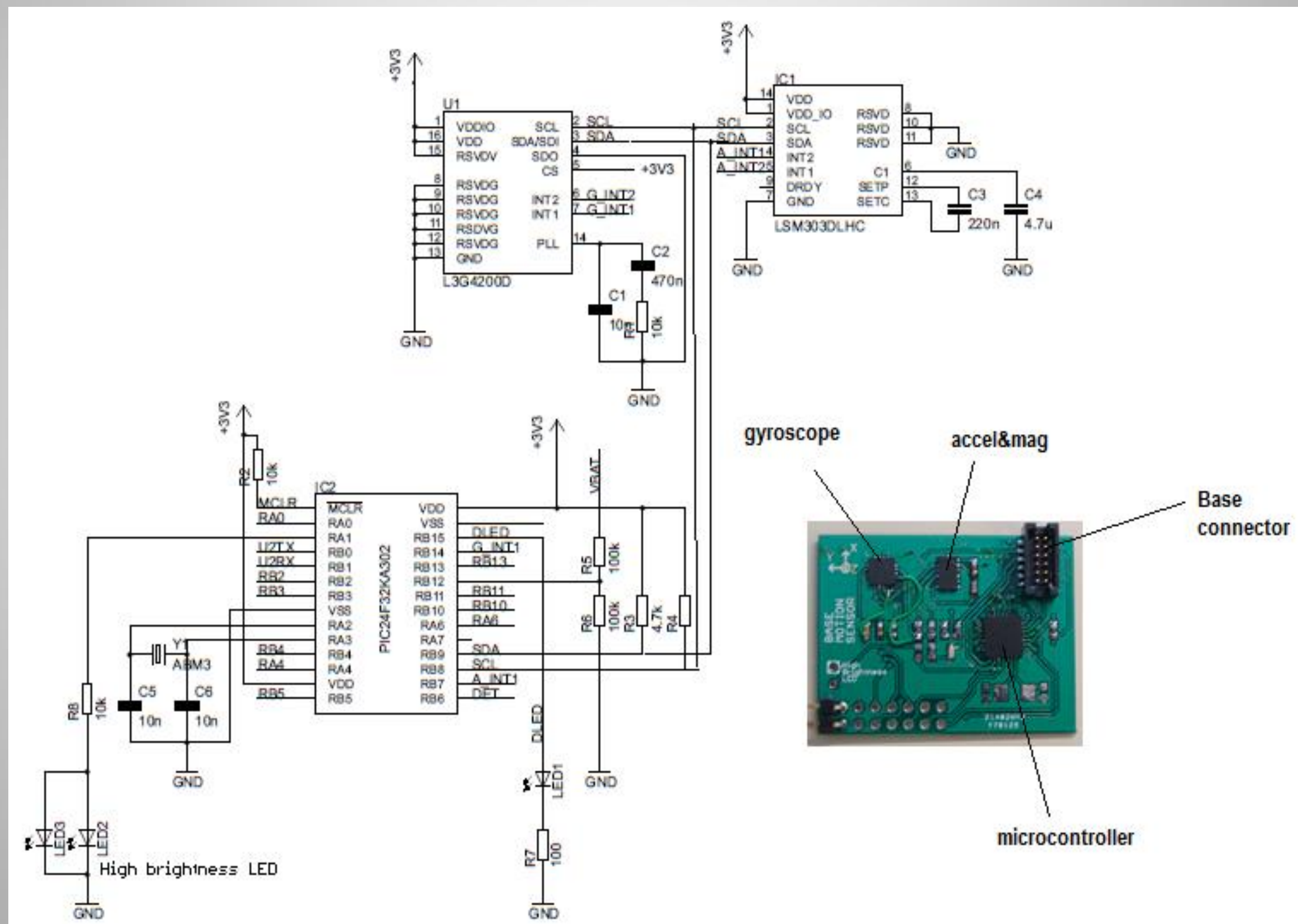
Gait test



9 Degree of Freedom (DOF) Inertial Measurement Unit (IMU)

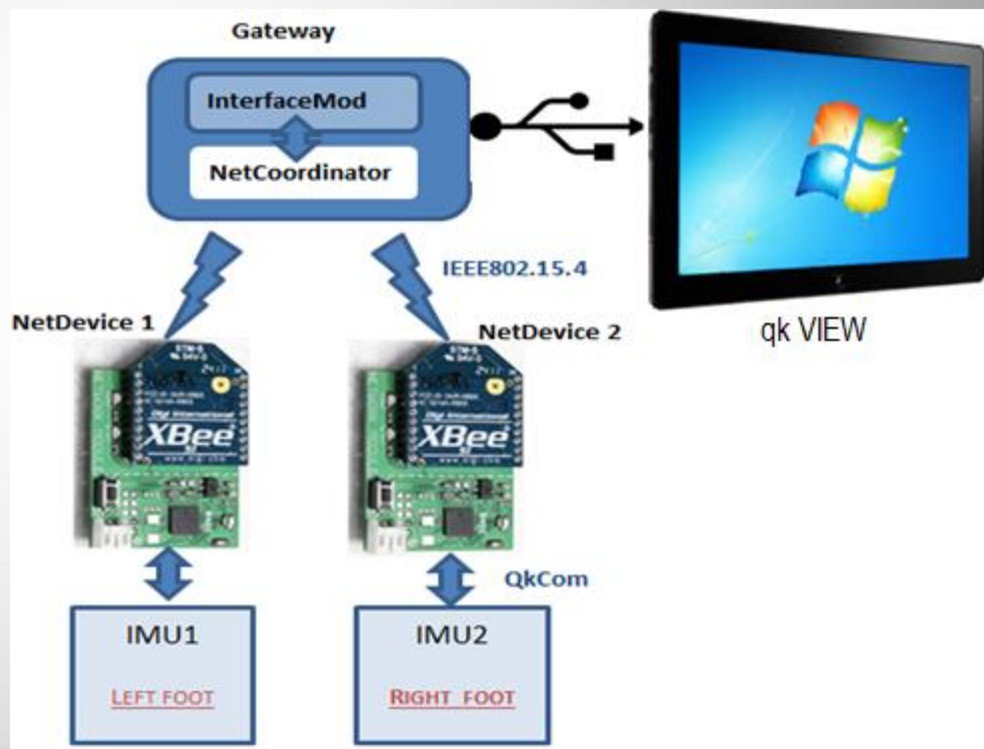
qk platform

qk device IMU for physiotherapy



Wearable Prototype

qk device IMU NET for physiotherapy



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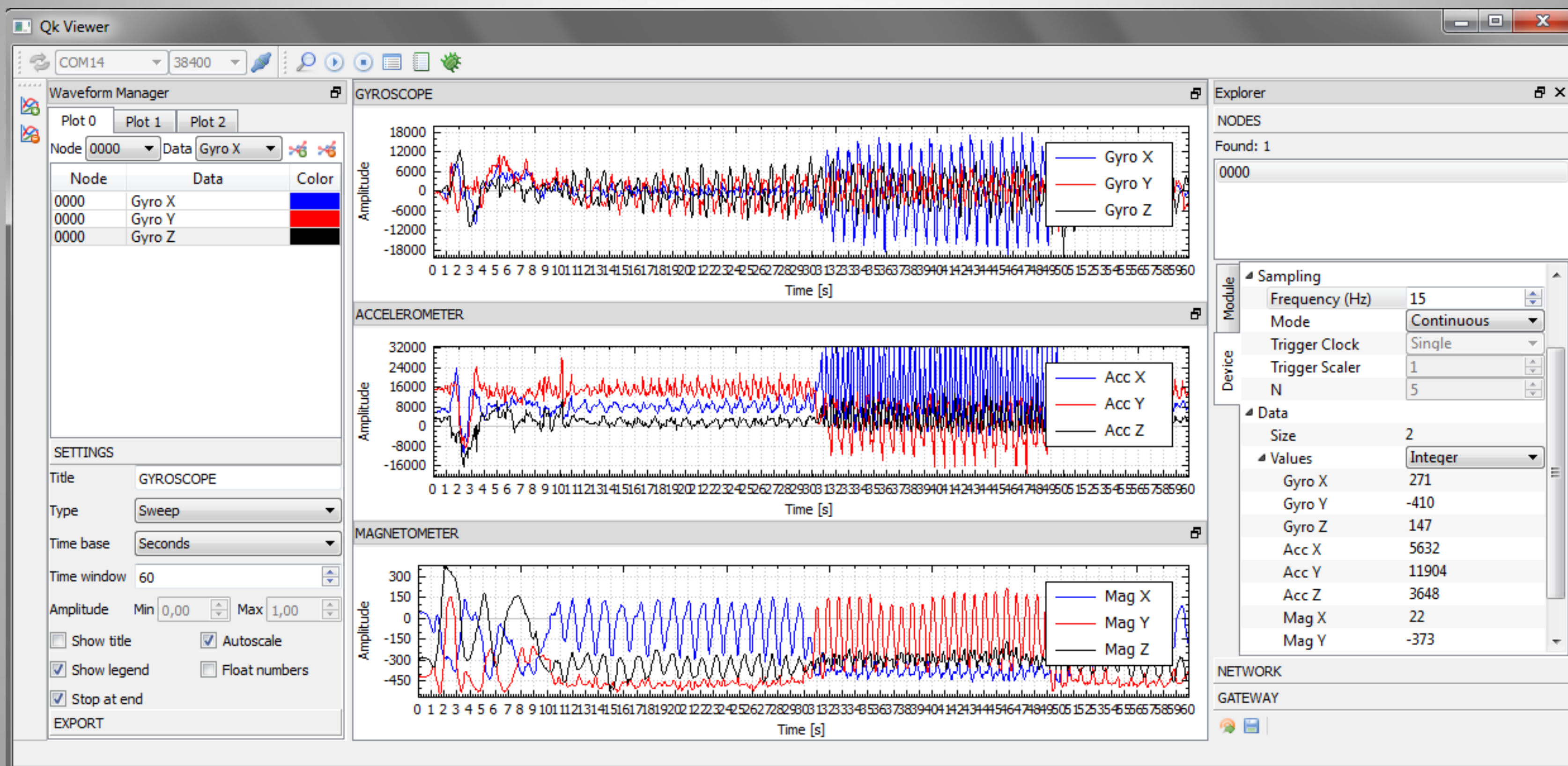
Wearable Prototyping

qk view



Unobtrusive sensing of physical rehabilitation

Kinect Sensing Technology

- Provide natural user interface - the body is the control;
- Measures range, angle and velocities during the physiotherapy sessions;
- Kinect Serious Games increase the motivation of the patient reducing the rehabilitation period.

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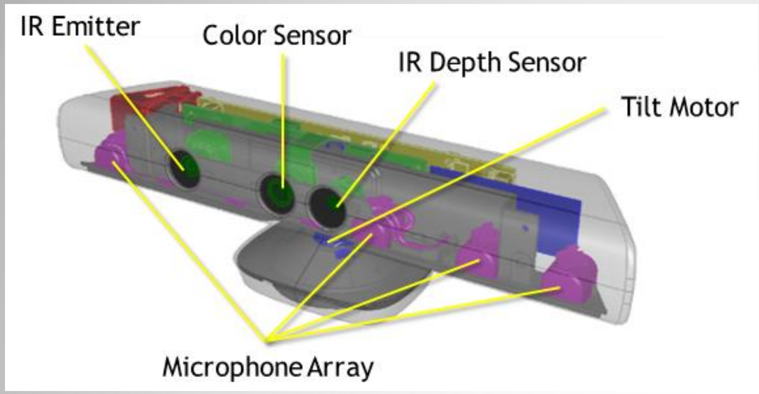
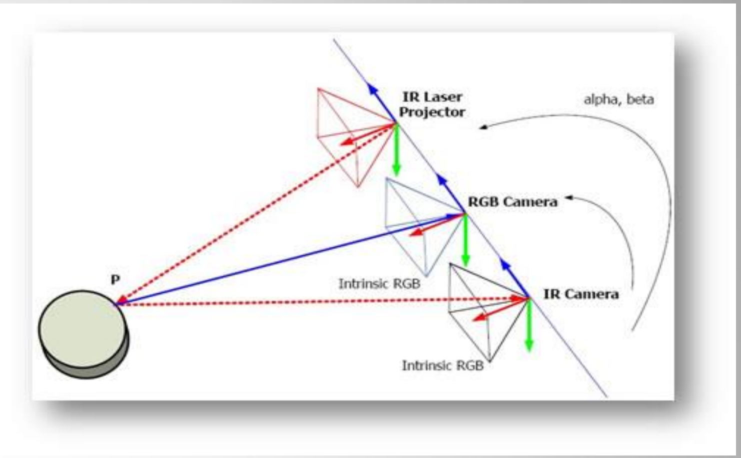
Unobtrusive sensing of physical rehabilitation

Kinect sensor





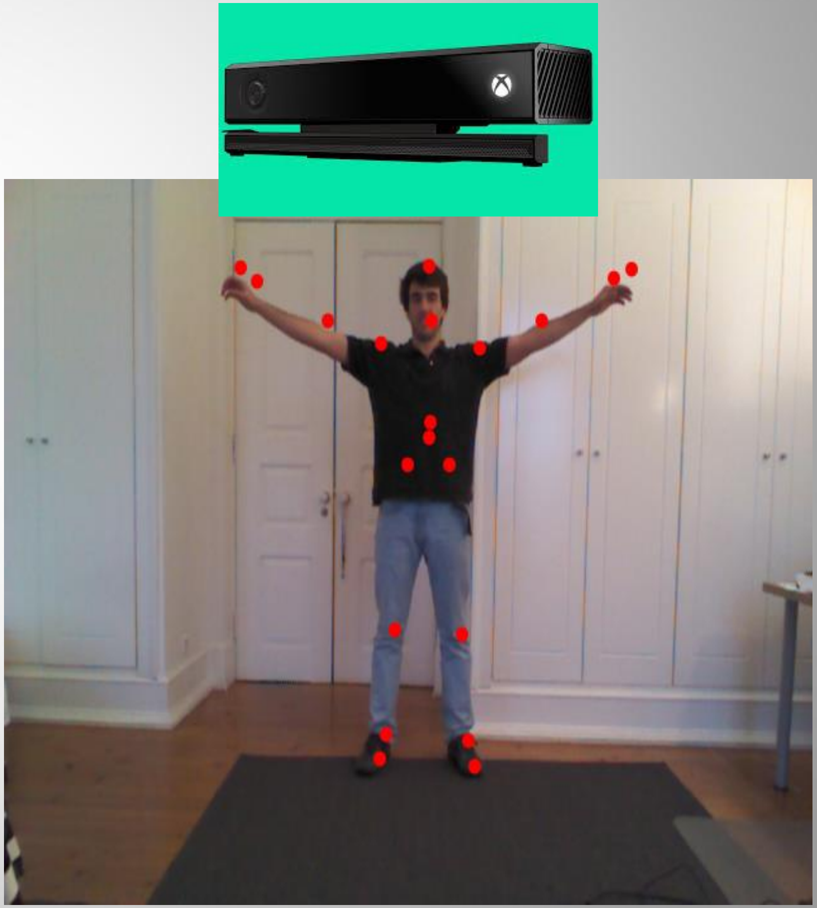
IR speckle pattern

Depth estimation

Unobtrusive sensing of physical rehabilitation

Kinect sensor and Microsoft SDK

- Materializes a natural user interface - the body is the control
- Provide 3D coordinates for the 20 joints
- Unobtrusive monitoring for 3D rehab serious game is provided



Body sensing for objective evaluation of physical rehabilitation

Kinect Serious games

- Serious Games concept refers to the use of computer games without the main purpose of providing pure entertainment,

- Physical Therapy based serious games (TheraGames) a solution for fast physical rehabilitation process with high acceptance by healthcare community.

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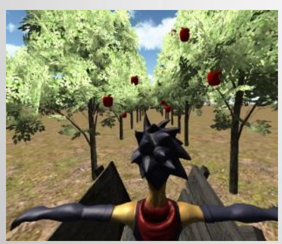
Unobtrusive sensing for objective evaluation of physical rehabilitation

Kinect Serious Games

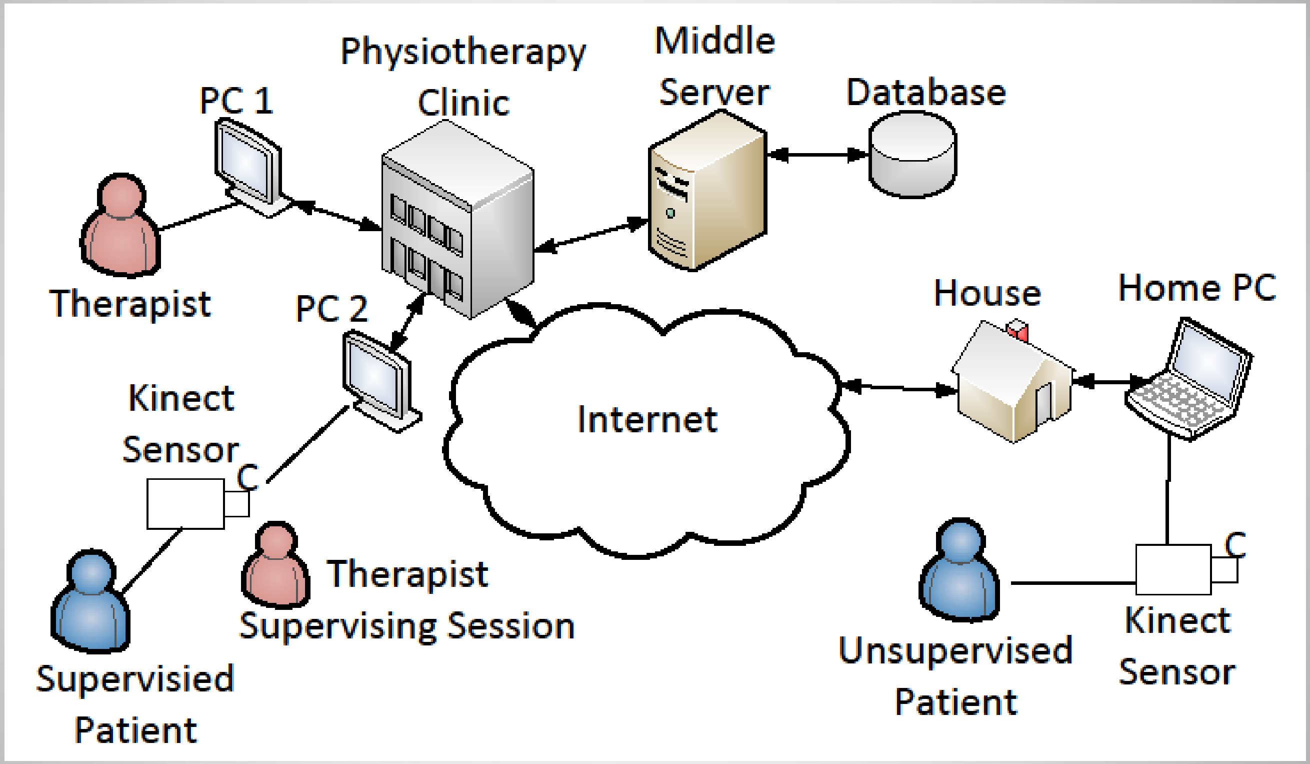
- Therasoup,



- AppleHarvesting

Unobtrusive sensing of physical rehabilitation

Kinect Computation Architecture



Kinect Serious Games on the client side are *GRANTED*

Kinect Serious Games For Rehabilitation

Therasoup v2.0

Unity 3D and C# technologies were used to develop the game

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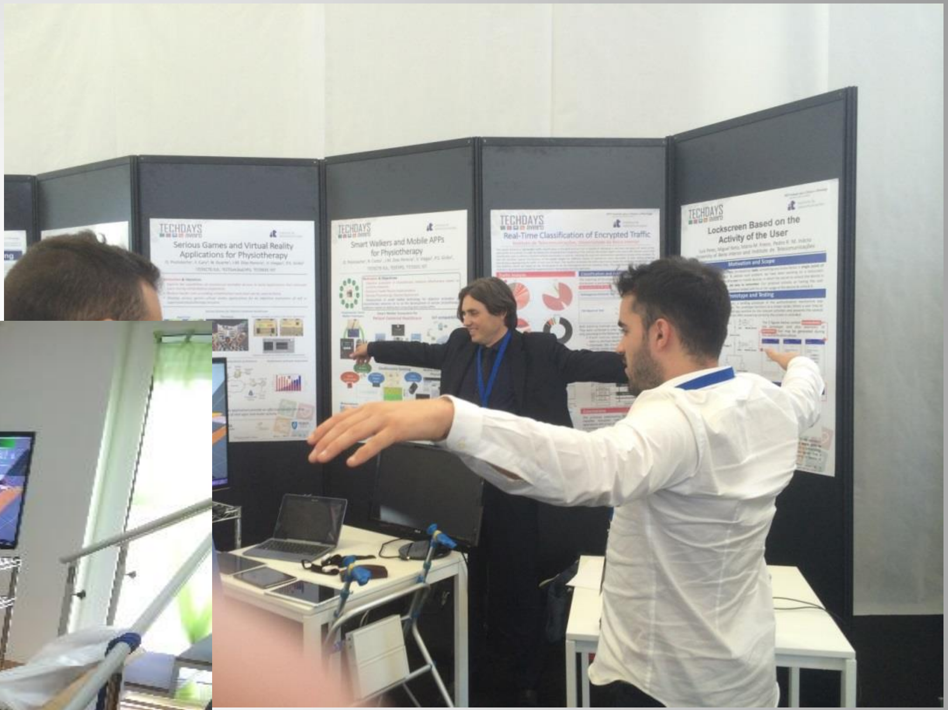
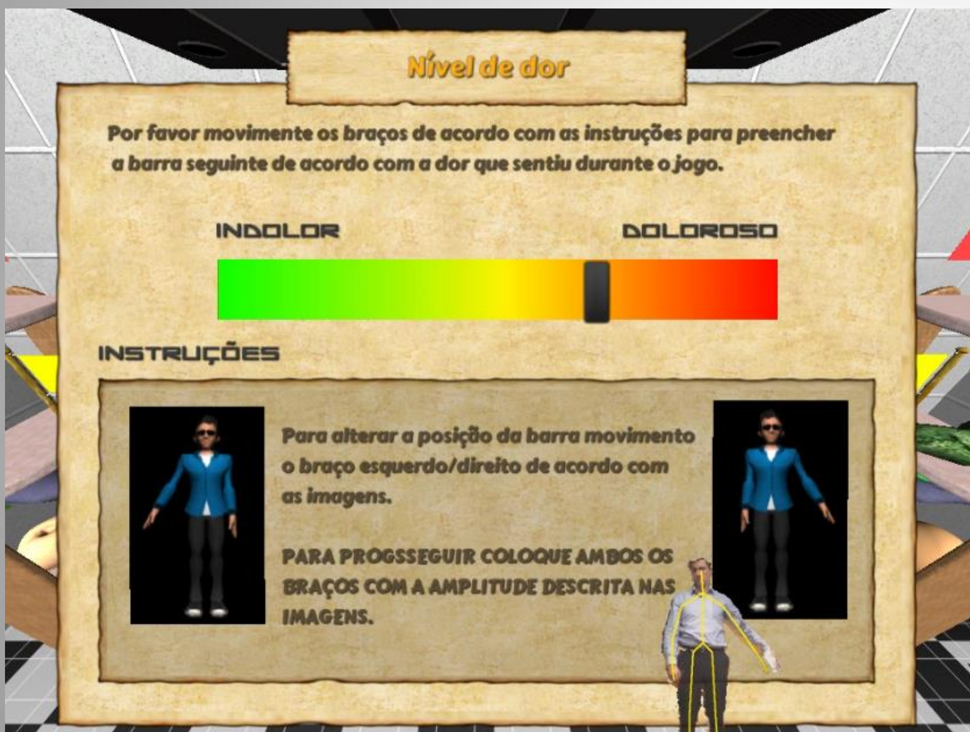
Kinect Serious Games For Rehabilitation



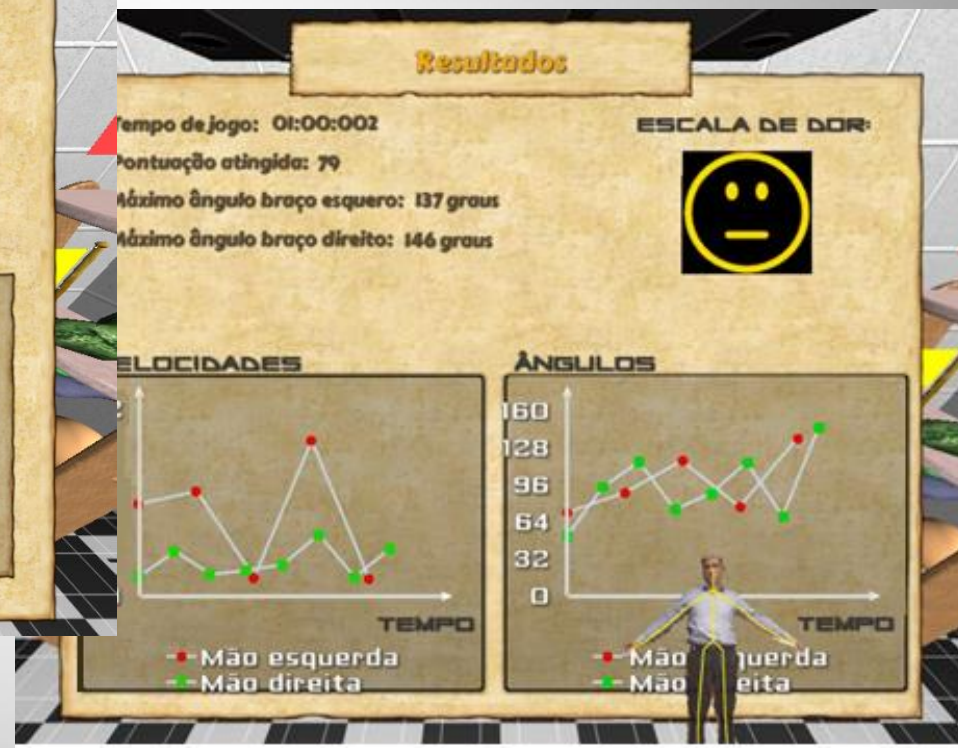
“Therasoup” under test in Beja Rehab Center and TechDays, Aveiro, September, 2015

“Therasoup“ Kinect Serious Games
training metrics and pain scale

Pain scale game GUI



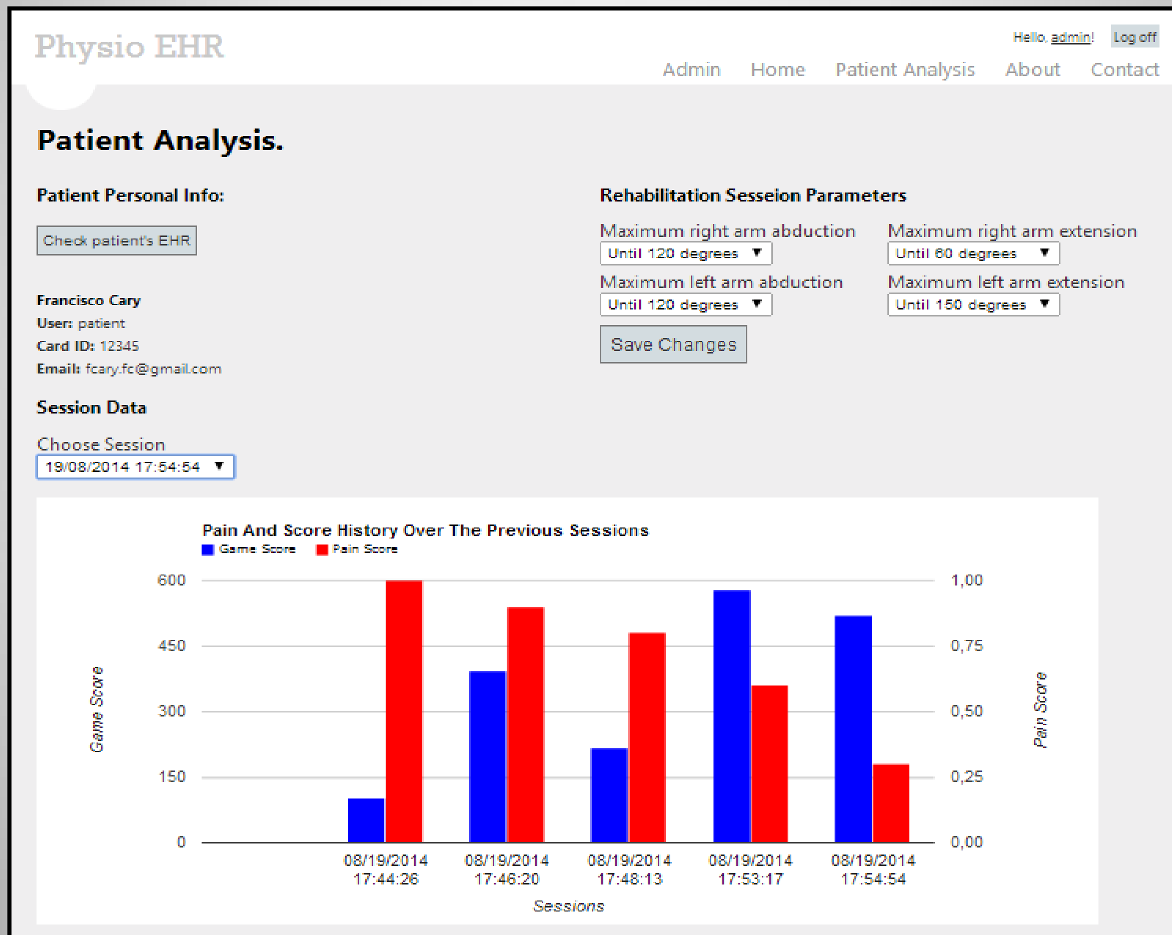
Training outputs



“*Therasoup* “ Kinect Serious Games

web based: game configurator

game score and pain assessment

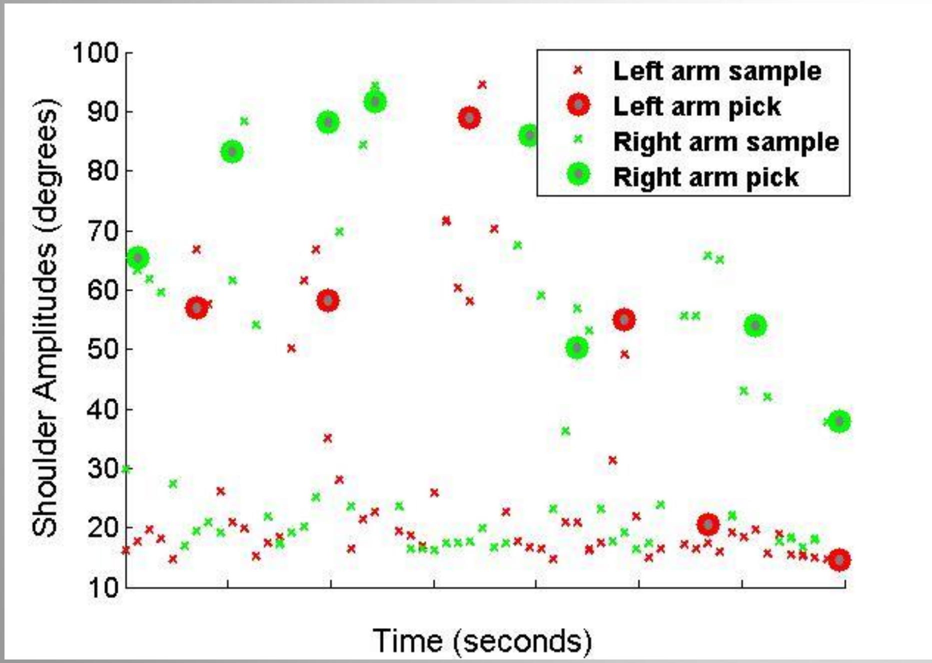


Kinect Serious Games For Rehabilitation

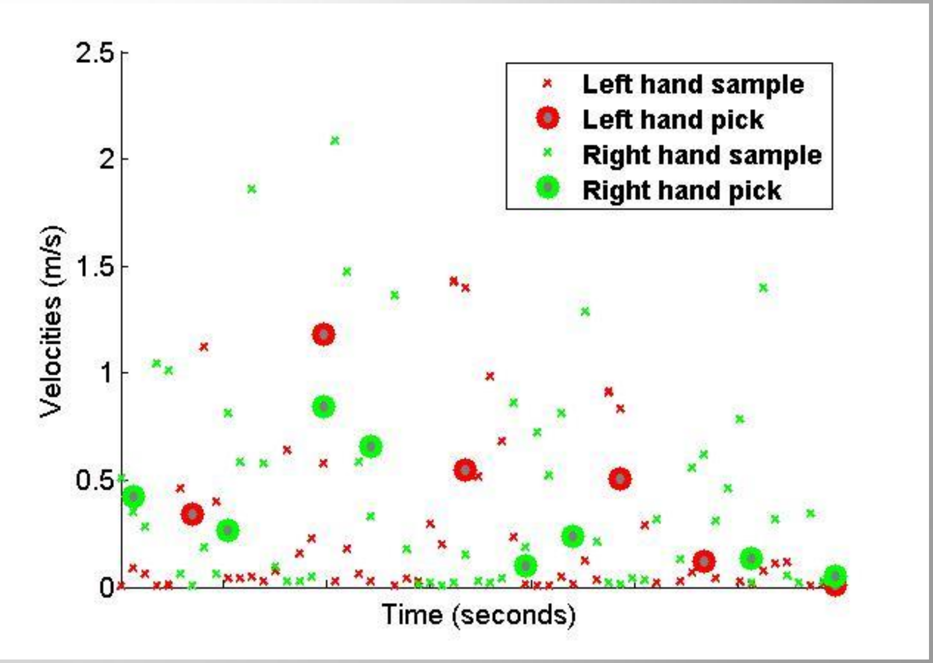
Therasoup v2.0

Measurements on arm rehabilitation

Shoulder amplitudes

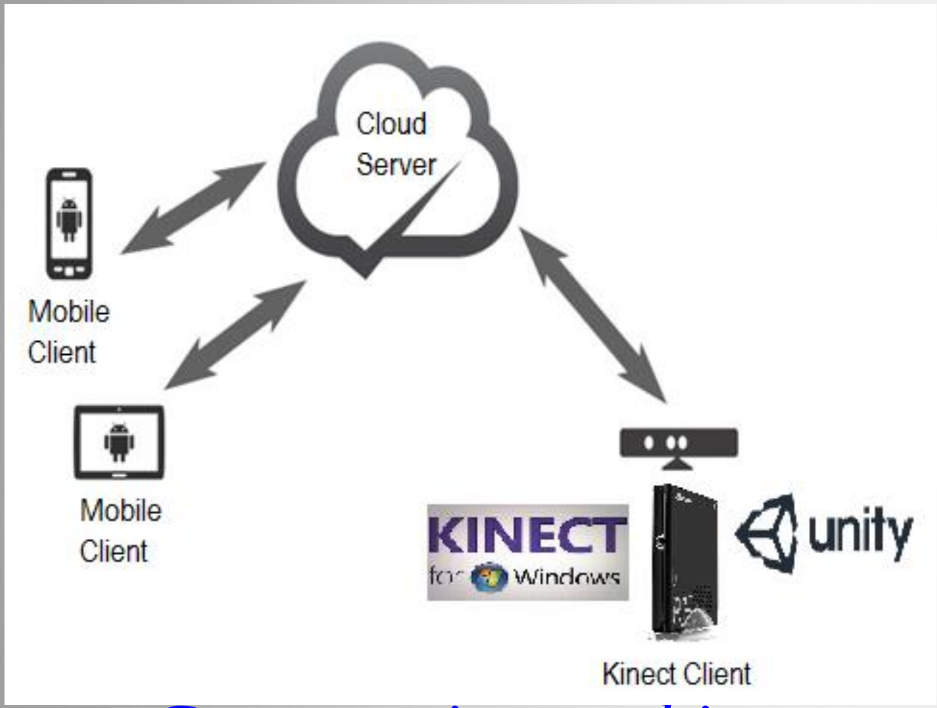


Arm velocities



"Apple Harvesting" Kinect Serious Game

Upper limb rehabilitation

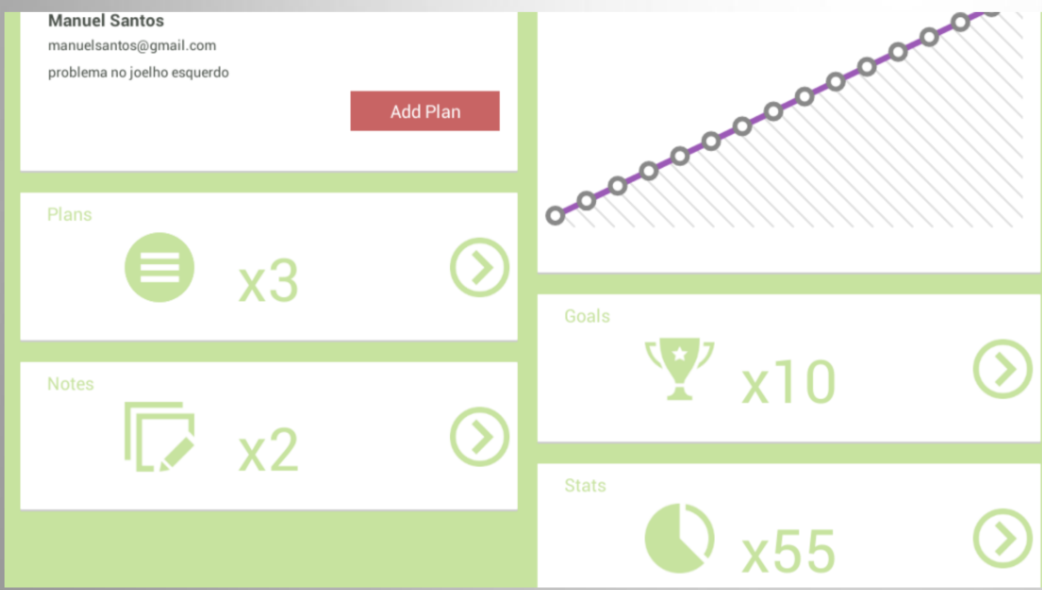


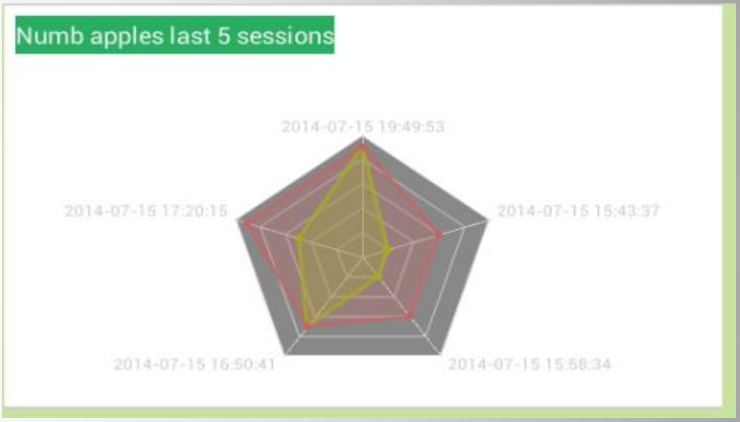
Computation architecture
Based on API

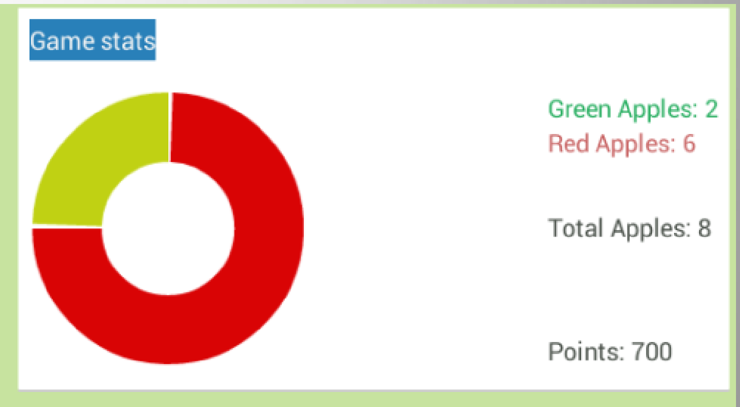
Implemented VR game
scenario

Kinect Serious Games For Rehabilitation

Pervasive computing on Apple Harvesting





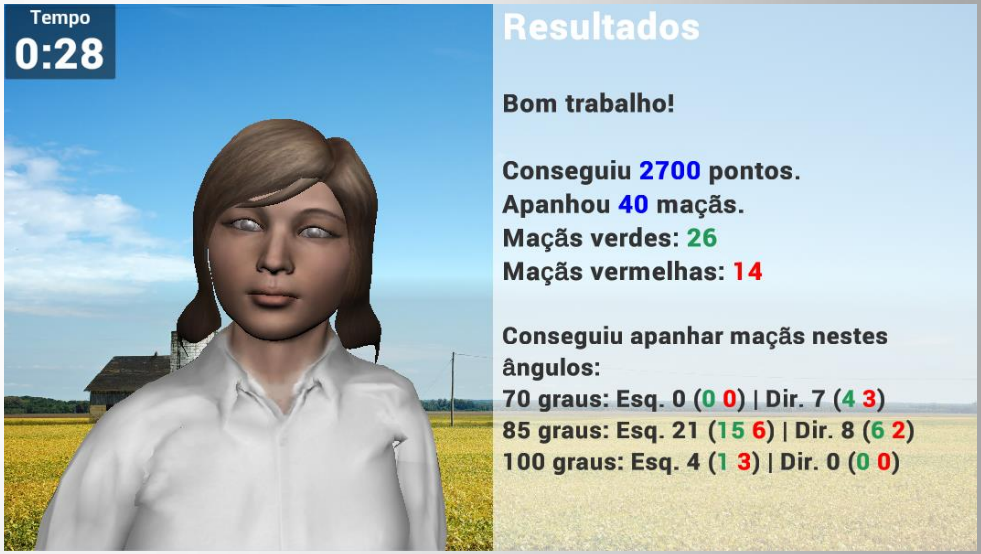


“Apple Harvesting” Kinect Serious Game

Tailoring for Increased Motivation

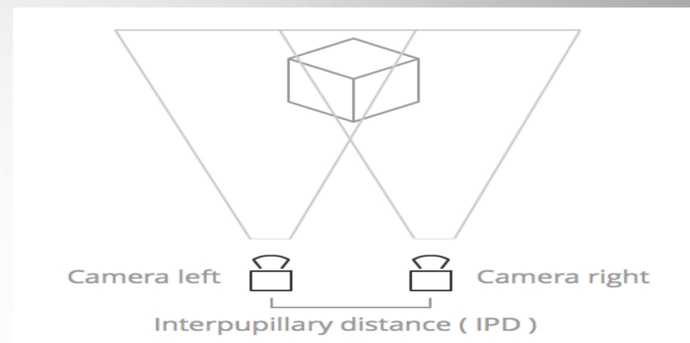
"Apple Harvesting" Kinect Serious Game

Objective evaluation



Unobtrusive sensing of physical rehabilitation

Leap Motion Controller

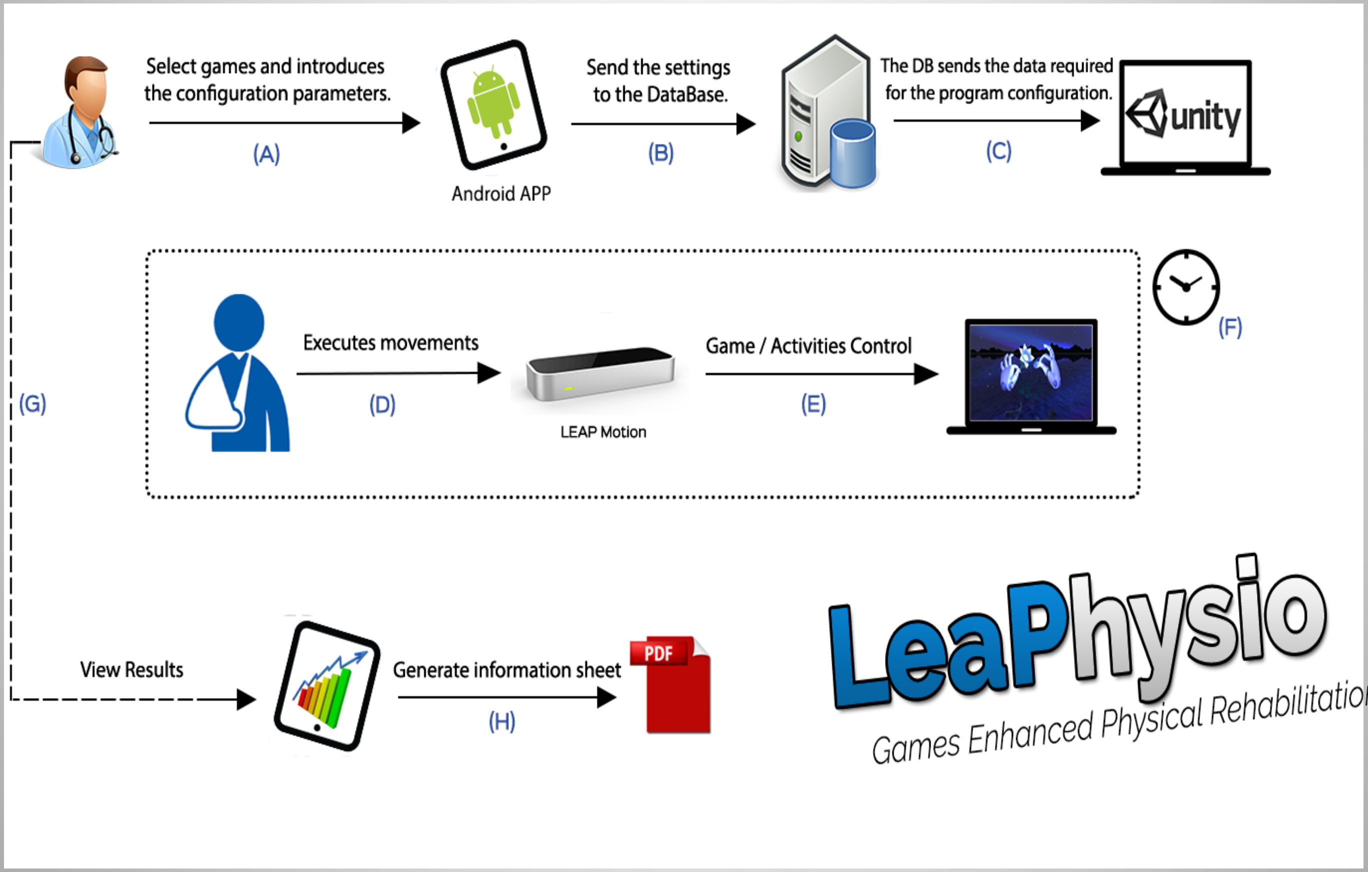


- two cameras track infrared light produced by three infrared LEDs→ 3D stereoscopic image

→Gesture and position tracking with sub-millimeter accuracy are provided

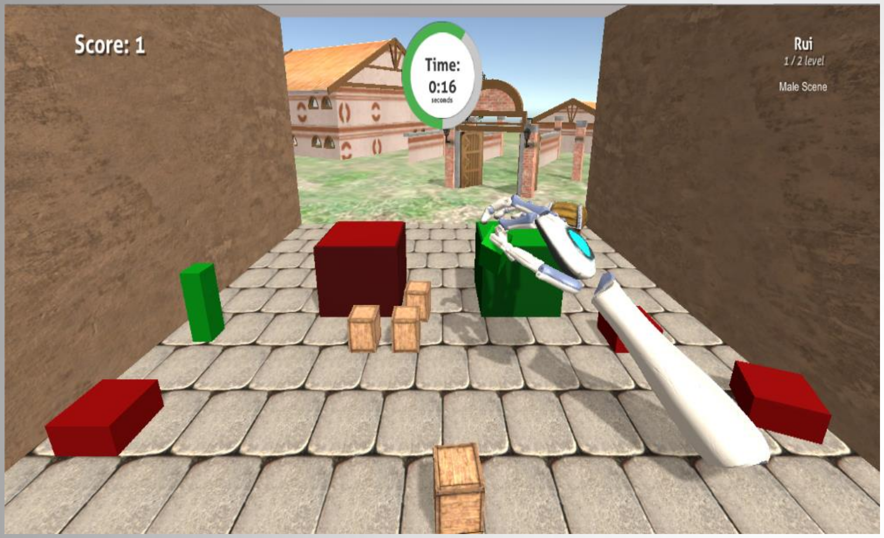
Unobtrusive sensing of physical rehabilitation

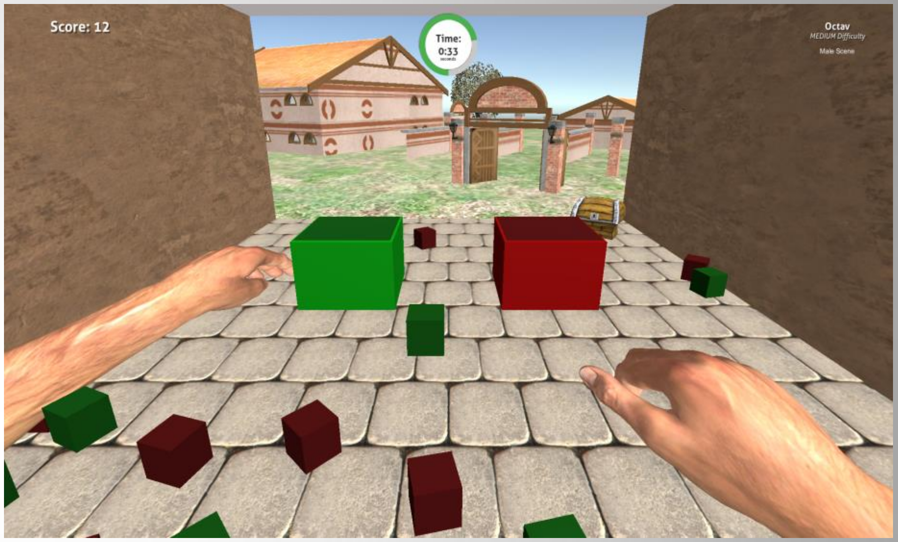
Leap Physio Serious Game Platform

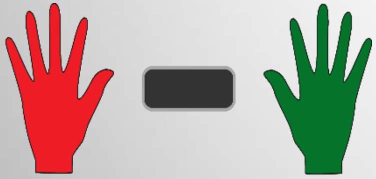


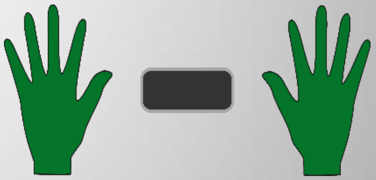
Leap Motion Serious Game

Collect CUBES









- The physiotherapist can configure which level of difficulty of the game – *(EASY, MEDIUM, HARD).*
- *Personalized for user in order to increase the motivation*

Physical Rehabilitation evaluation

Applied Thermography

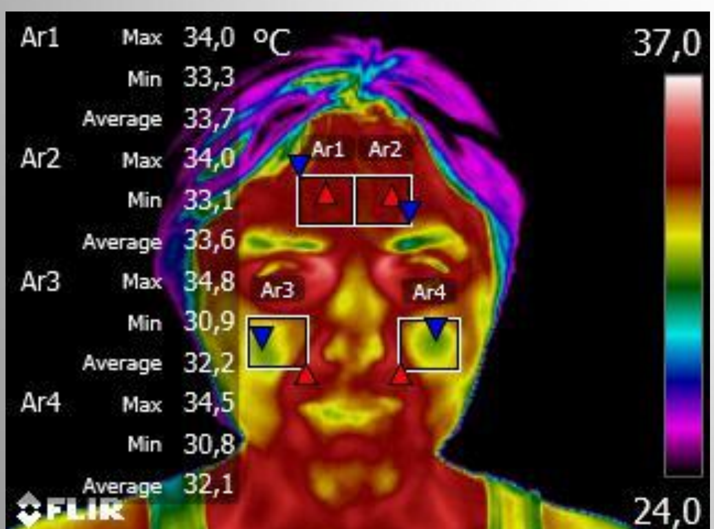
Infrared Thermography Principles: Every object whose surface temperature is above absolute zero (-273 °C) radiates energy at a wavelength (short wave 3-5um and long wave 7-9um) corresponding to its surface temperature.

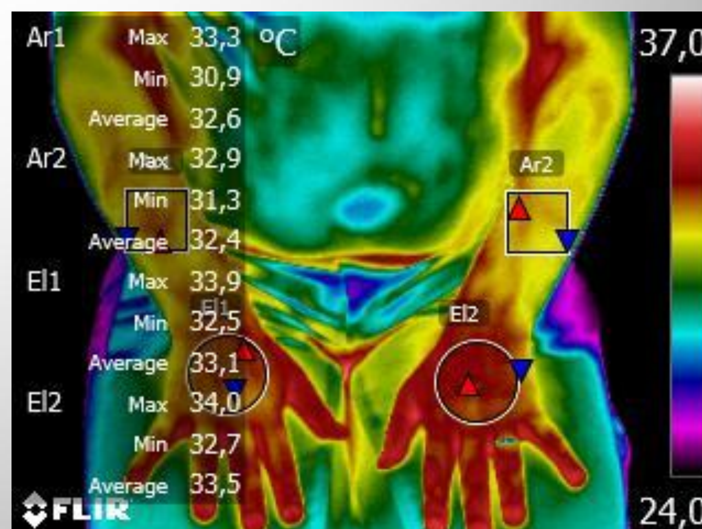
Highly sensitive infrared cameras capture this radiated energy in a thermal image of the object being surveyed. Thermal images are processed using FLIR Tools+ and Thermonitor™ software to extract appropriate metrics.

Physical Rehabilitation Evaluation

Applied Thermography

- Thermography camera provides unobtrusive procedure to measure the temperature without physical contact with the patient.
- Temperature increase caused by increased blood flow before and after physical therapy sessions are carried out.





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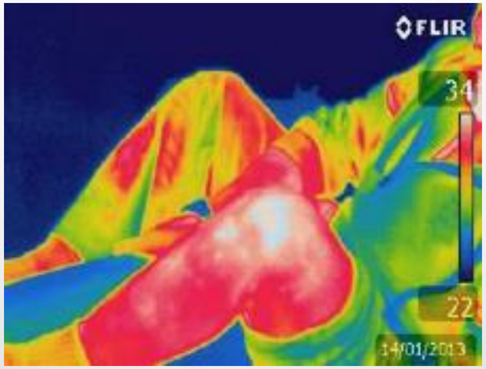
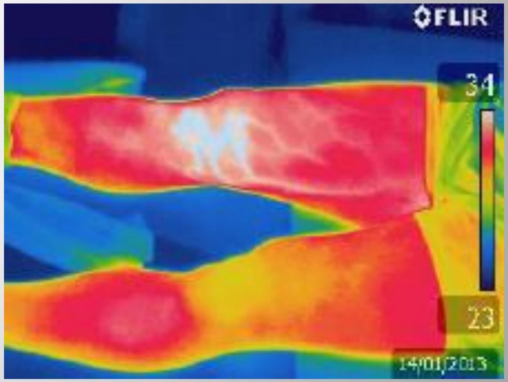
Physical Rehabilitation Evaluation

Knee Recovery Assessment

FLIR E60

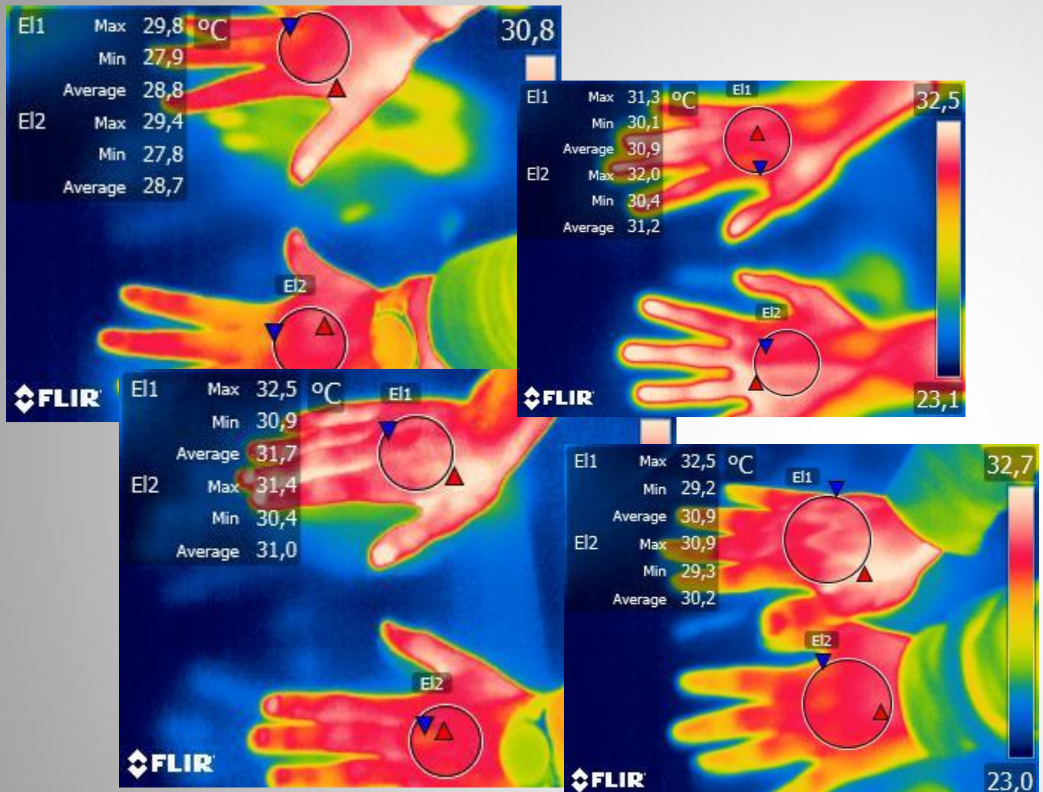


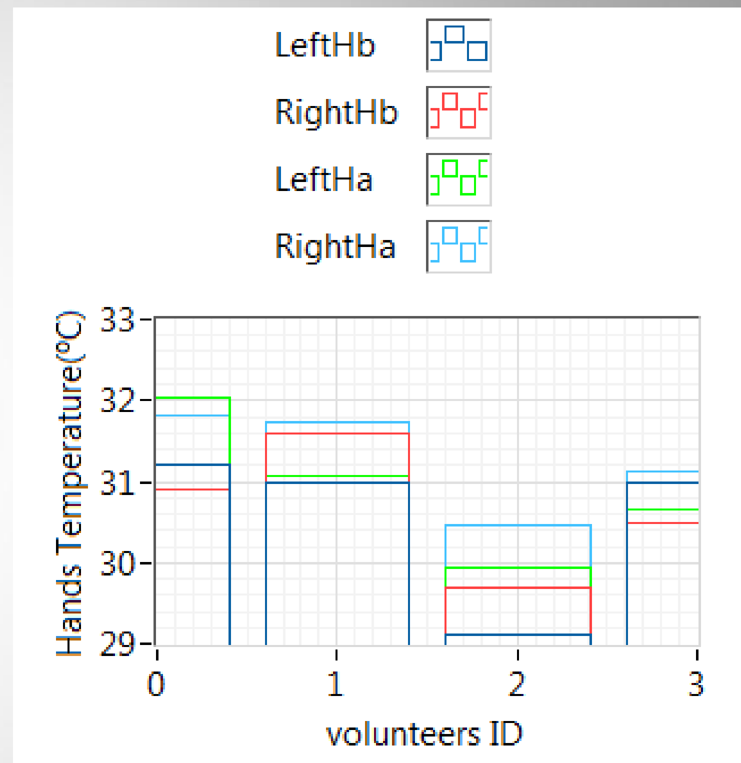


Thermal images provided by the FLIR E60 clearly indicate inflammation of the knee.

Physical Rehabilitation Evaluation

LeapMotion &Thermography

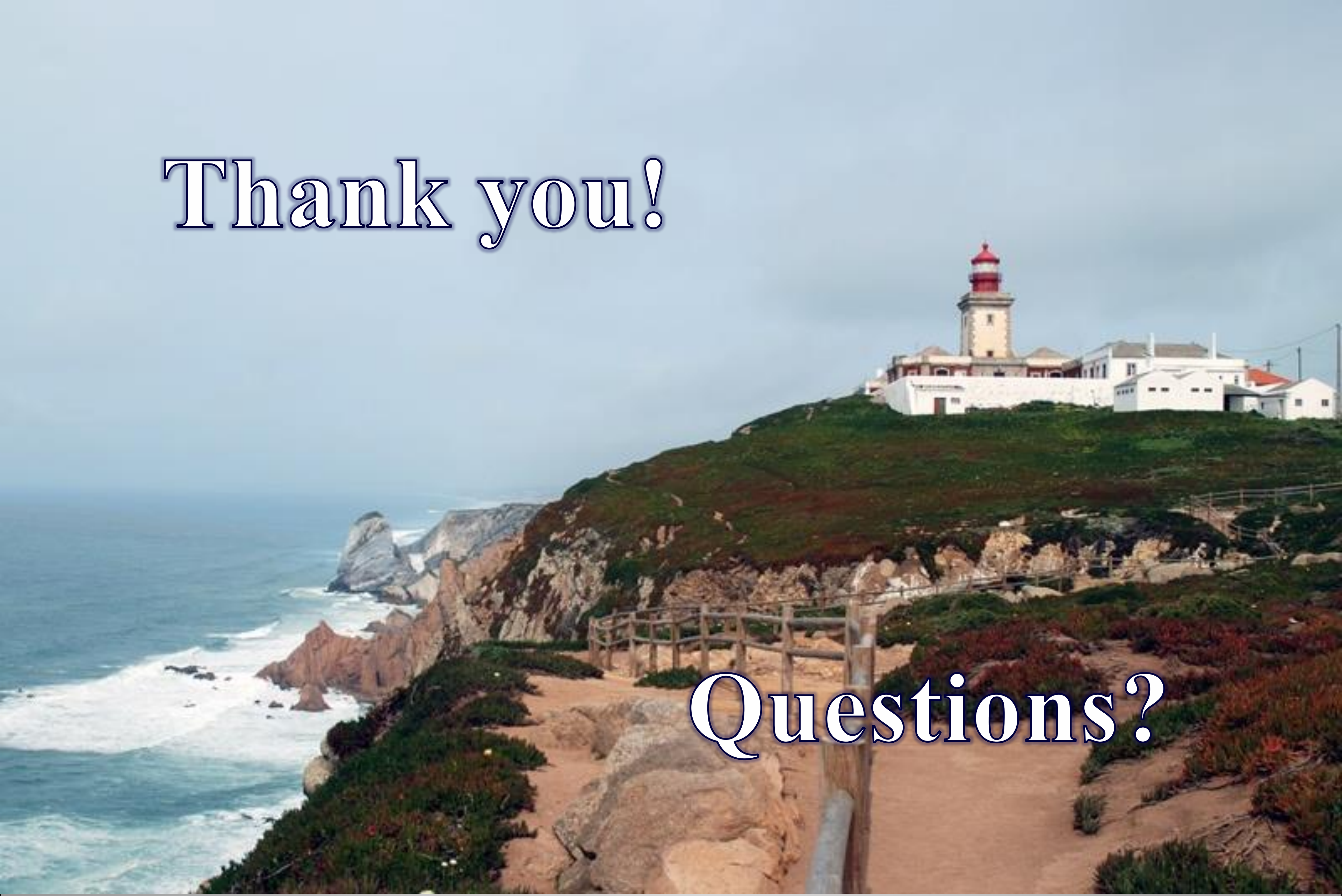




Thermal images provided by the FLIR E60 indicates the temperature of the hand cutaneous tissue → *training session efficiency indication*

Conclusions

- Development of assistive environments based on non-intrusive smart sensors and pervasive computing designed for vital signs and physical therapy interventions supports:
- *Preventive medicine;*
- *Personalized medicine;*
- *Participative medicine;*
- Smart environments → useful solutions for in-home and remote rehabilitation services.
- NUI Serious Games and Thermography new challenge regarding usability and acceptance


Thank you!
Questions?