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Unobtrusive Smart Sensing and Pervasive Computing for HealthCare

*Cardio-Respiratory and Motor Activity Assessment*

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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
– Elderly people are the fastest growing segment of the population;
– According with UN the population over 60 years old will increase worldwide from 11% now to 22% in 2050;

*The healthcare system is under pressure*
Develop new assistive environments for healthcare for higher:
- QoS
- Efficiency

Increase the usability and the acceptance by Elderly of new healthcare devices
smart sensors → combination of sensor, signal conditioning, embedded algorithms and communication interface

Standards: IEEE 21451.X

E. Song, K. Lee, et al, ICEMI 2011,
Pervasive (ubiquitous) computing → embedding microprocessors in everyday used objects so they can communicate information.

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**
- **BCG today**

Isaac Starr – 50’ cardiac monitoring fashion

Cardio-respiratory monitor based on EMFIT and MEMS accelerometer
- BCG captures pressure oscillations due to heart activity
- Cardiac output through HR, HRV is assessed

**BCG Sensing and Signals**

**BCG wheelchair seat**

**BCG wheelchair backrest**
Smart Wheelchair

HR through BCG

IEEE EMBC 2013, Osaka, Japan
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 cm²) at 20 cm distance, embedded within the wheelchair backseat cover, 1 copper plane of 550 cm²

IEEE 2MTC 2013, Minneapolis, USA
Smart Wheelchair

**ccECG processing**

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

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Ballistocardiography-seismography monitoring system based on 24GHz FMCW Doppler radar
FMCW Doppler radar output signals - balistocardiography (BCG) signals include information about cardiac and respiration activity,
Smart Wheelchair

Respiration signals obtained from
EMFIT BCG and Radar BCG signals

MeMeA 2011, Bari, Italy
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

Vital signals simultaneously acquired at the wheelchair
increase interoperability of the smart objects through the IEEE21451.4 implementation
Smart Wheelchair

IEEE1451.4 Smart Gateway

- UART1
- UART2
- ADC
- IO
- SPI
- PIC24FJ128GA010 MCU
- LDOs +3.3 and +5V
- 9-15 VDC
- Buttons
- LEDS
- RFID Reader
- 802.15.4 Module
- SD card interface
- Smart Sensor Network
- MCU power

Instrumentation & Measurement Society
8/17/2017 7:52 AM www.ieee-ims.org
Smart Wheelchair

IEEE21451.4 nodes and interfacing

Smart sensor node

Smart sensor network
Smart Wheelchair

IEEE21451.4 implemented prototype
Smart Wheelchair

multiuser net

Postolache, IEEE ICST 2012, Kolkata, India
Physiotherapy Assessment

Smart Walkers Prototypes

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

Single Doppler Radar

3D accelerometer
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

Instrumentation & Measurement Society
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Smart Walker –

Gait Doppler radar Signals

- Regular Gait
- Hemiparetic Gait
Smart Walker

Gait STFT Spectral Signatures

Regular Gait

Hemiparetic 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 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 host

qk gateway

qk network

qk node (addr=0001)

qk node (addr=0002)

qk node (addr=0003)

USB
Ethernet
WiFi

IEEE 802.15.4
ZigBee
CAN

Push Button

2 LEDs

Expansion Header

UART1 (USB)

UART3 (WiFi)

UART4 (Ethernet)

SPI1 (microSD)

MCU

UART2 (Qk Connector)

ICSP

Expansion Header

External Power Supply
(External/USB)

USB

WiFi Module Header

Ethernet Module Header

32MHz Crystal

microSD socket

32.768kHz Crystal (RTC)

Jumper Power Source

QkConnector (rev1)

Reset and User Buttons

Supercapacitor (VBAT)

2 LEDs
qk platform

qk node and qk network

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

communication module (qk module): Bluetooth, ZigBee

qk gateway implementation
Wireless network communication:

- ZigBee
- Bluetooth
qk platform

qk device: general purpose

QkConnector:
UART2

Power source selector:
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
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.
Unobtrusive sensing of physical rehabilitation

*Kinect sensor*

- IR emitter
- Color sensor
- IR depth sensor
- Tilt motor
- Microphone array

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

![Graph showing measurements on arm rehabilitation](image-url)
“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

**Resultados**

Bom trabalho!

Conseguiu **2700** pontos.
Apanhou **40** maçãs.
Maçãs verdes: **26**
Maçãs vermelhas: **14**

Conseguiu apanhar maçãs nestes ângulos:
70 graus: Esq. 0 (0 0) | Dir. 7 (4 3)
85 graus: Esq. 21 (15 6) | Dir. 8 (6 2)
100 graus: Esq. 4 (1 3) | Dir. 0 (0 0)
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**

1. **Select games and introduces the configuration parameters.**
2. **Send the settings to the Database.**
3. **The DB sends the data required for the program configuration.**
4. **Executes movements**
5. **Game / Activities Control**
6. **View Results**
7. **Generate Information Sheet**
8. **Unity**

**LeaPhysio**
Games Enhanced Physical Rehabilitation
The physiotherapist can configure which level of difficulty of the game – (EASY, MEDIUM, HARD).

Personalized for user in order to increase the motivation.
Infrared Thermography Principles: Every object whose surface temperature is above absolute zero (-273 °C) radiates energy at a wavelength (short wave 3-5μm and long wave 7-9μm) 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.
Thermal images provided by the FLIR E60 clearly indicate inflammation of the knee.
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 $\rightarrow$ useful solutions for in-home and remote rehabilitation services.
- NUI Serious Games and *Thermography* new challenge regarding usability and acceptance
Thank you!

Questions?