Human Motion Quantification:
Applications to Neurologic Diseases

João Paulo Cunha, PhD

- NeuroEngineering is defined as the interdisciplinary field of engineering and computational approaches applied to problems in basic and clinical neuroscience.
- First international conference – IEEE 2003
- It is a sub-area of Biomedical Engineering

- At FEUP, we have offering three degrees in this area:
  - MIB, MEB and ProDEB.

- We are setting up
  - a new lab – The NeuroEngineering Lab.
  - A new lecture course in NeuroEngineering (Approved, A3ES & Euro-ACE certified, starts next year)

- Mission: explore opportunities to innovate in Neurosciences
- Crossing Areas: Physics; Engineering (Electronics; Computation; etc.); Neurology; Neurosurgery; Neurophysiology; Neuroradiology; Neuroscience;

- Carried out with our partners:

- Movement quantification in Neurological diseases (NeuroQmove)

- Wearable technology

Human Motion Quantification:
Applications to Neurologic Diseases

João Paulo Cunha, PhD

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

INESCTEC TECHNOLOGY & SCIENCE ASSOCIATE LABORATORY

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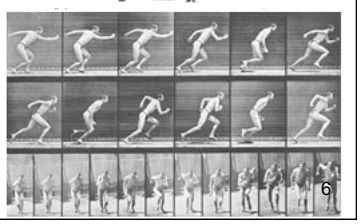
RNIFC

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

- Aristoteles (384-322 AC)
  - "De Motu Animalium"
- Leonardo da Vinci (1452-1519)
- Galileu (1564-1643)
  - Mathematical model
- Borelli (1608-1679)
  - Equilibrium and center of gravity
- Newton (1642-1727), Bernoulli (1700-1782), Euler (1707-1783), Poiseuille (1799-1869), Young (1773-1829)
  - All of them studied human motion
- Muybridge (1830-1904)
  - The first to use photography



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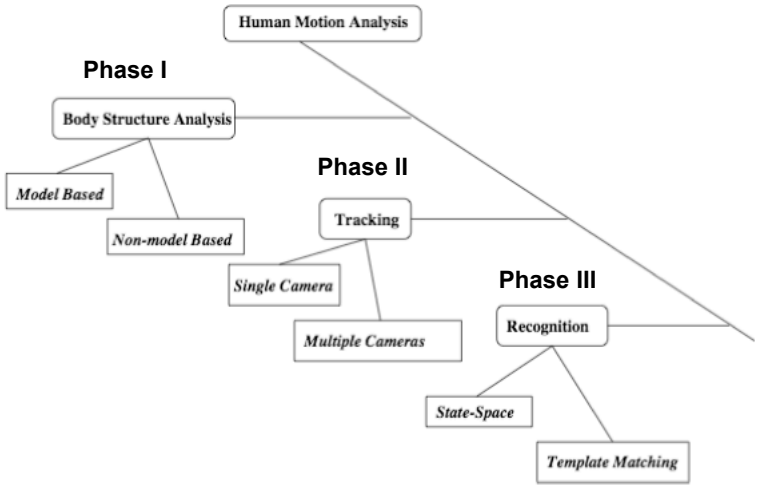
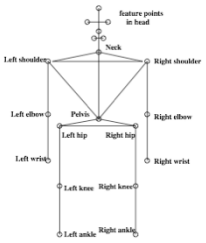
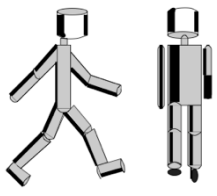
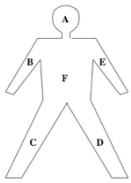


[12] Aggarwal & Cai, Computer Vision and Image Understanding, vol.73, 1999

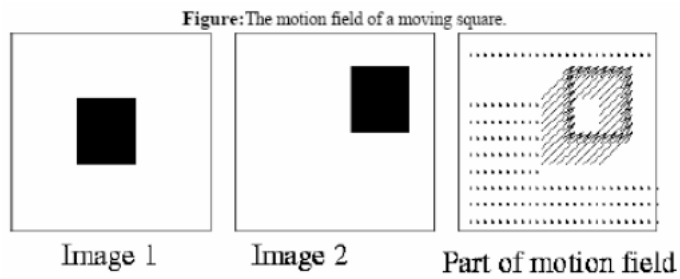
- Model based using
  - "Stick figures"[13]
  - Cylinders[14]
  - Contours[15]

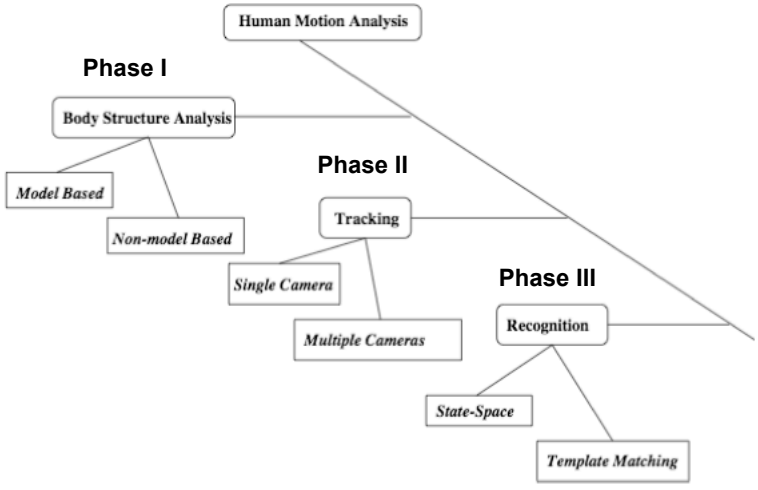






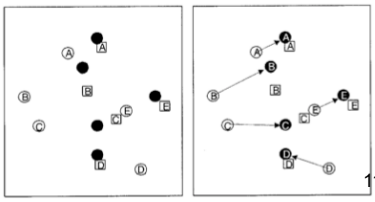
- Non-model based
  - Points correlation[18]
  - “joint iterative search”[19]
  - Optical flow (motion fields)[21]
  - Others…

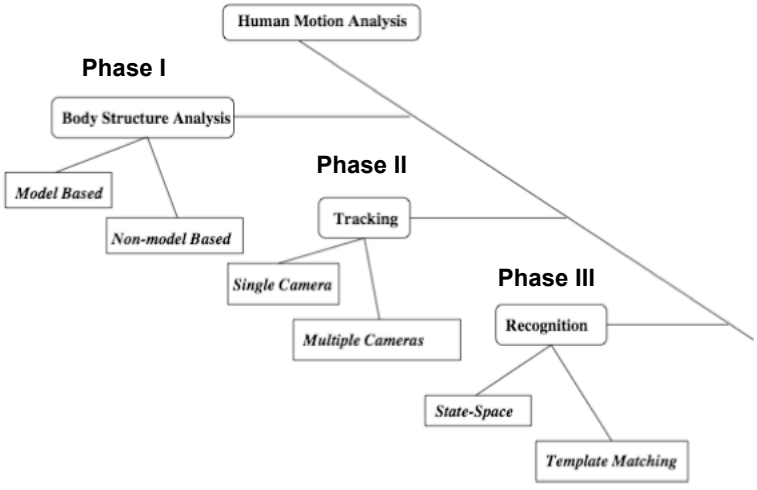




[12] Aggarwal & Cai, Computer Vision and Image Understanding, vol.73, 1999

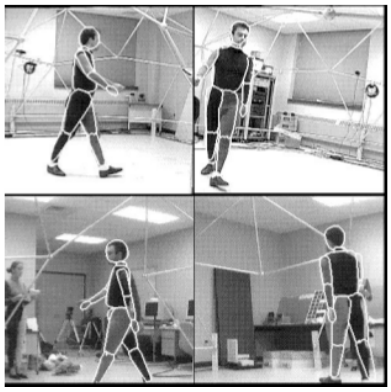
- Tracking body structure characteristics
  - Contours, bright spots, colour or texture
  - Centers of mass [24]
  - Multi-landmark (eg. Joints) [26,27]
- Different algorithms
  - Ballistic trajectories and Kalman filters [52]
  - "Mean-Shift" (circa 1975) and its evolutions (ex:CAMSHIFT) [Fukunava et al., IEEE TIT, 1975, 17(8): 790-799]



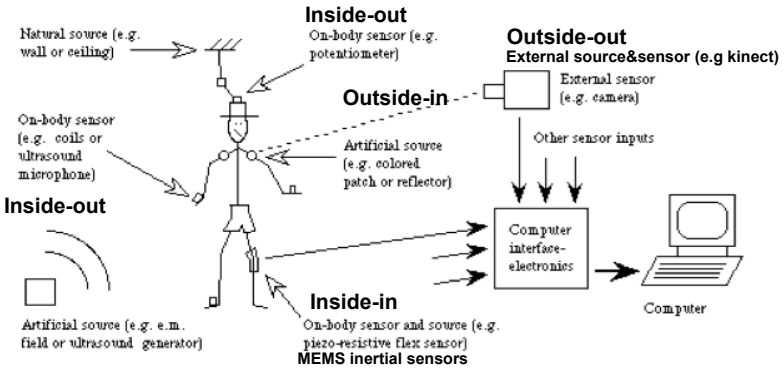


[12] Aggarwal & Cai, Computer Vision and Image Understanding, vol.73, 1999

- Pattern recognition approaches [24,31]
  - Template matching, among others
- Phase space theory [28]
- Others



[12] Aggarwal & Cai, Computer Vision and Image Understanding, vol.73, 1999



Technology classes:

Outside-in
(External sensors detect on body sources)

Inside-out
(Sensors on body detect external sources)

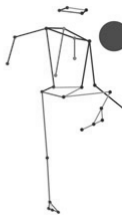
Inside-in
(sensors&sources on body)

Outside-out
(External sensors and sources detect body movements)

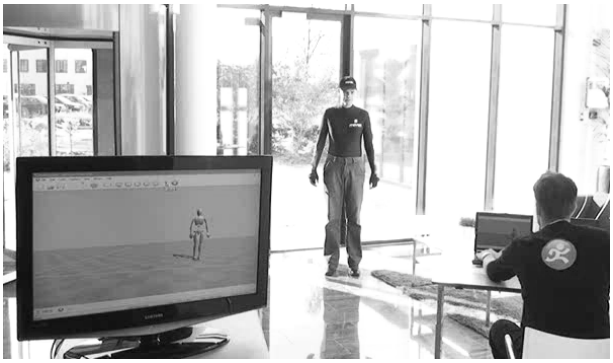
[32] Mulder, Human Movement tracking Technology, Simon Frazer University, 1994 / Cunha JPS, extended








motion capture session



- *There are many methods and technologies... …so,... what is the BEST ?*

Motion Tracking: No Silver Bullet, but a Respectable Arsenal

Greg Welch
University of North Carolina at Chapel Hill

Eric Foxlin
InterSense

If you read the surveys of motion tracking systems,[1-5] one thing that will immediately strike you is the number of technologies and approaches—a bewildering array of systems operating on entirely different physical principles, exhibiting different performance characteristics, and designed for different purposes. So why does the world need so many different tracking products and

(HMD) or on a projection screen. In immersive systems, head trackers provide view control to make the computer graphics scenery simulate a first-person viewpoint, but animations or other nonimmersive applications might use handheld trackers.

- *Navigation.* Tracked devices help a user navigate through a computer graphics virtual world. The user might point a tracked wand to fly in a particular direc-

[33] Welch & Foxlin, IEEE Comp. Graph. App., Vol.22, pp 24-38, 2002

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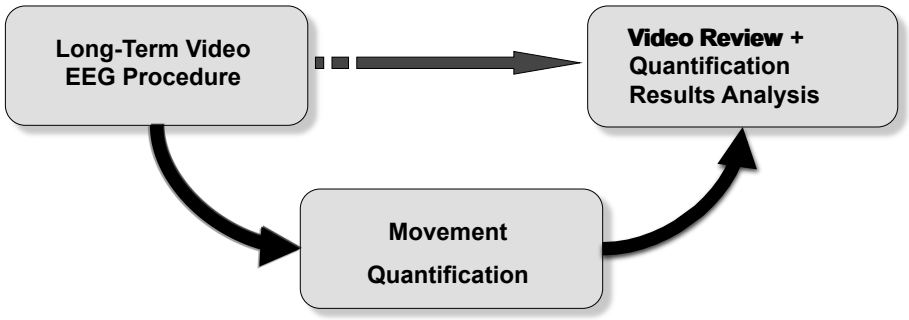
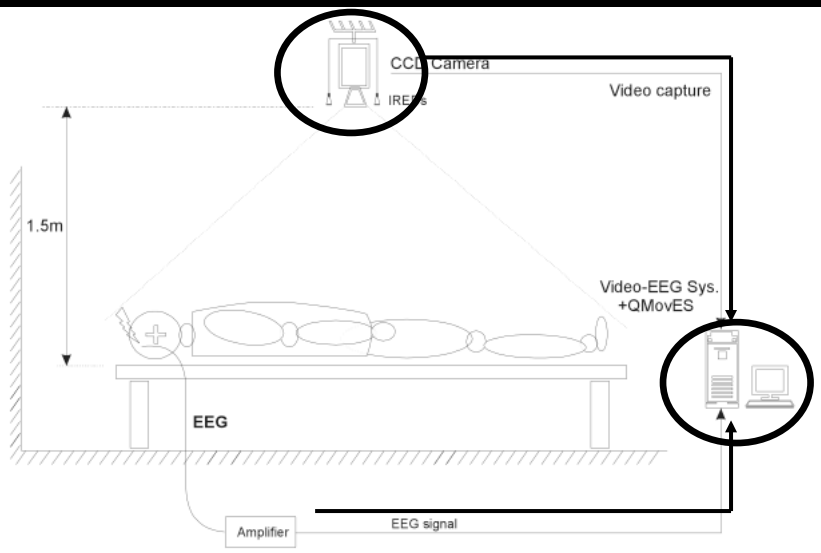
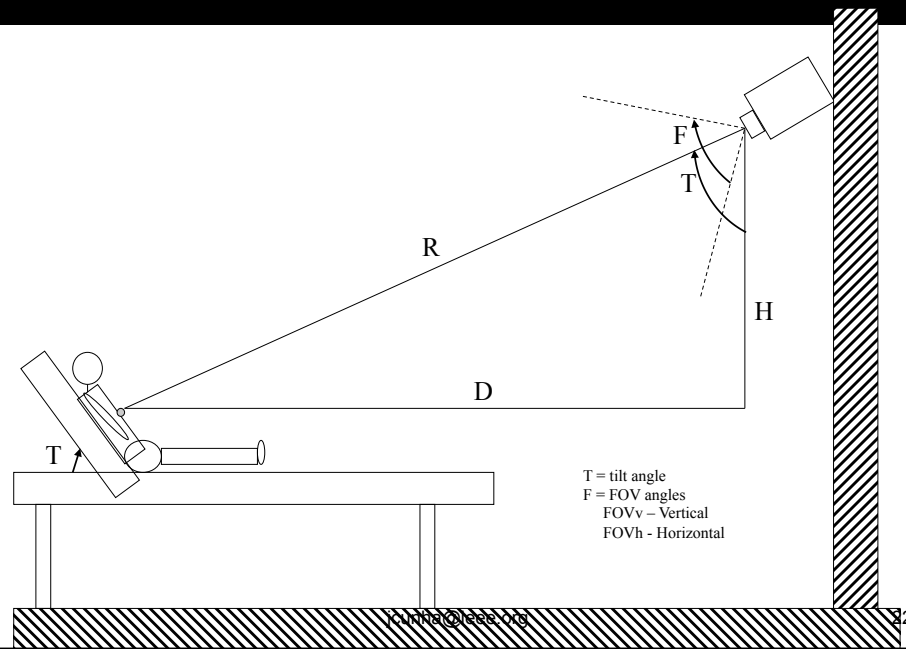
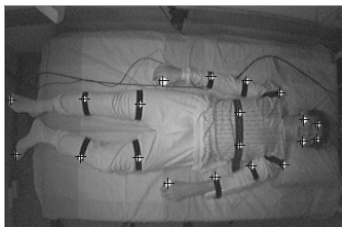
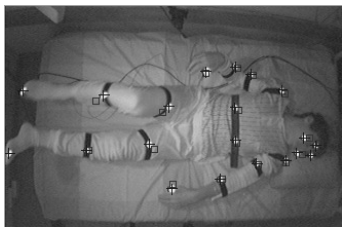



CCD Camera
IREDs
Video capture
1.5m
Video-EEG Sys.
+QMovES
EEG
Amplifier
EEG signal


F
T
R
H
D
T
T = tilt angle
F = FOV angles
FOVv – Vertical
FOVh - Horizontal





- Original video frame
- Thresholding video frame
- Clustering pixels and labeling markers to body structure components

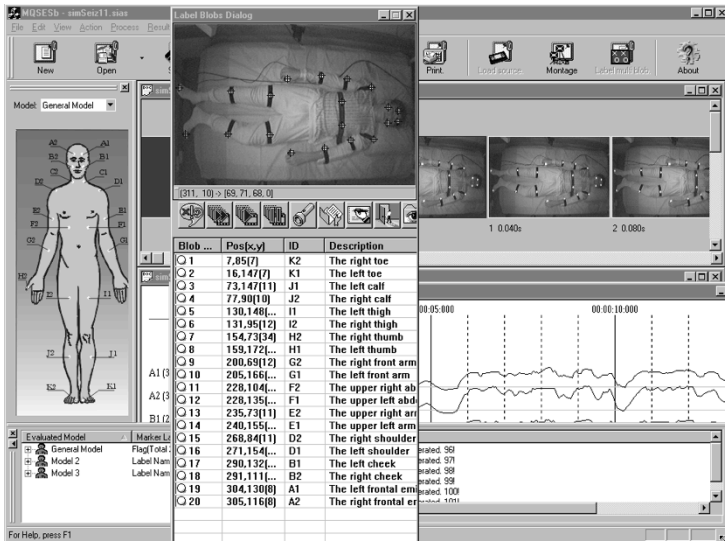
- Marker position prediction & tracking

Li et al., IEEE Trans. Biomed Eng, 2002

IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 49, NO. 6, JUNE 2002 565

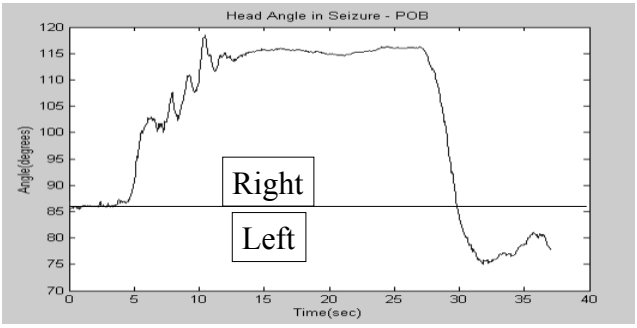
Movement Quantification in Epileptic Seizures: A New Approach to Video-EEG Analysis

Zhanjian Li*, António Martins da Silva, and João Paulo Silva Cunha, *Member, IEEE*

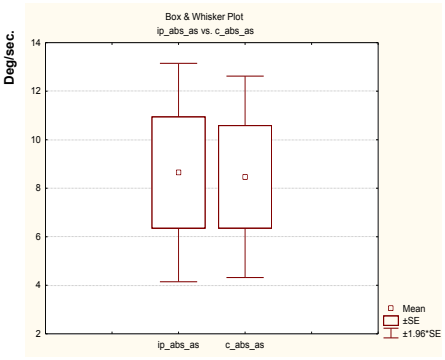


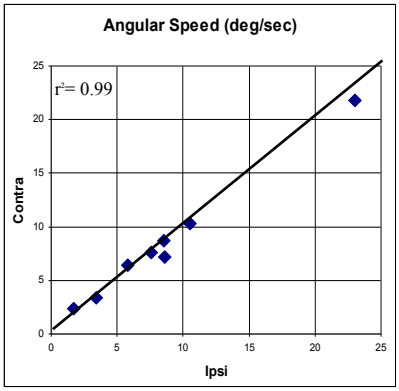

500 mm
d=3524.1
a=81.6

FIG. 1. Measurement of the head version of a patient in a typical EMU setting as defined by two-dimensional geometry. The head movement was tracked at the left nostril in relation to a reference point on the patient's shirt.



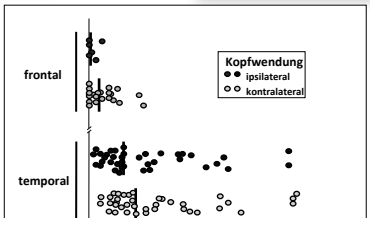
Ipsi-lateral **Contra-lateral**



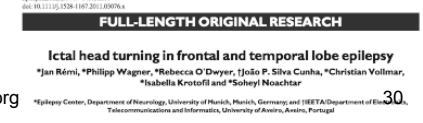


O'Dwyer Cunha et al., Young Invest. Award, Epilepsy Congress 2005, Paris
O'Dwyer, Cunha et al., *Epilepsia* 2007; 48: 524-530

- **38 TLE Sz (31 Pat) + 22 FLE Sz (14 Pat)**
- **Head rotation occurrs sooner and is shorter in FLE**
- **Angular speed did not differ from ipsi to contralateral (against the literature)**



Rémi et al., *Epilepsia* 2011
O'Dwyer et al., *Epilepsia* 2007; Godoy et al., *Neurology* 1990
Jayakar et al., *Neurology* 1992; Dobesberger et al., *Neurology* 2005



automotorisch **hypermotorisch**

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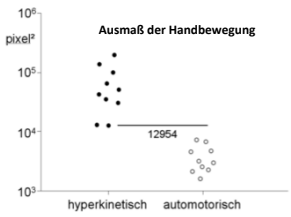
TLE vs. FLE

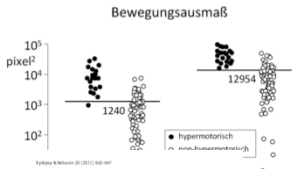
1.Training set

- **10 hypermotor and 10 automotor seizures**
- **Extent of movement threshold estimation.**



2. Analysis of 100 consecutive recorded seizures from LMU database

- **Excelent separation of hypermotor and non-hypermotor seizures (p<0.001)**
  - **Sensitivität 95,9 – 100%**
  - **Spezifität ~60%**
- **Results combination:**
  - **Identifikation hypermotorischer Anfällen: 100%**
  - **Falsch positive Identifikation: <0,06%.**



Rémi, Cunha et al., *Epilepsy Behav* 2011

jcunha@i

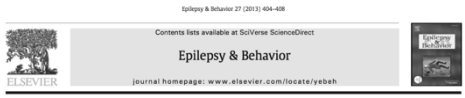
[redacted]

Table 3: Movement parameters of seizures characterized by automatisms in patients with TLE and FLE.

	Duration of automatisms/ duration of seizure [95% CI]	Movement quantitative parameters (median values)		
		Movement extent (pixel²)		Le
		ipsi	contra	ipsi
TLE (n=38)	0.36 [0.28; 0.44]	3101	1544.5	
p-value ipsi vs. contra			ns	
FLE (n=20)	0.63 [0.51; 0.75]	22089	24496	
p-value ipsi vs. contra			ns	
p-value TLE vs. FLE	**p<0.001***	**p<0.001***	**p<0.001***	

** statistically significant difference Wilcoxon Matched-Pairs Signed-Ranks Te*

Cunha et al., *Epilepsy & Behav., 2013*

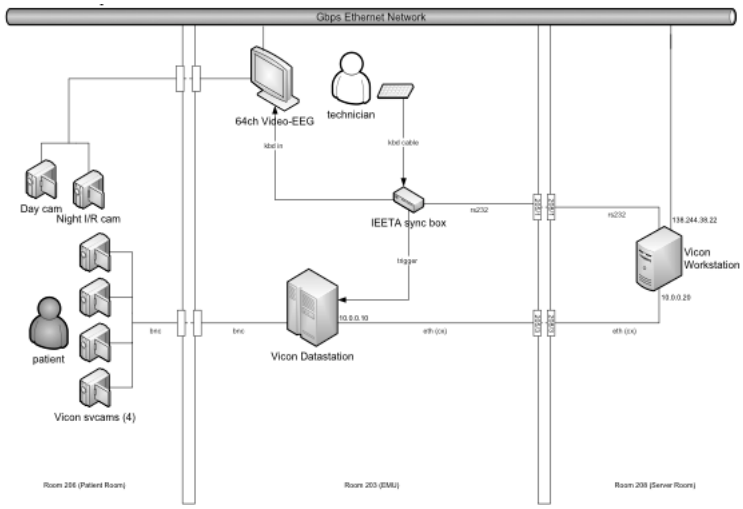


Upper limb automatisms differ quantitatively in temporal and frontal lobe epilepsies

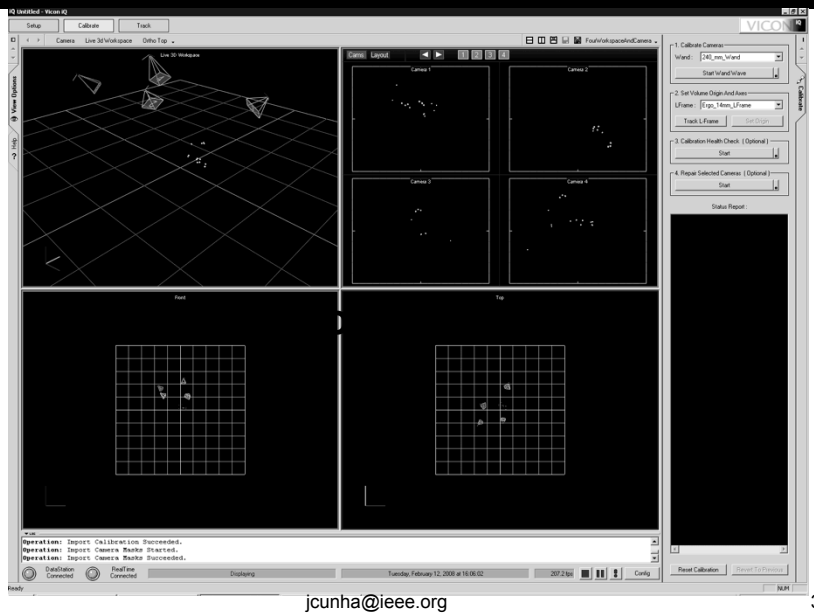
João P. Silva Cunha [a,b,1], Jan Rémi [c,1], Christian Vollmar [c], José M. Fernandes [a,b], Jose A. Gonzalez-Victores [c], Soheyl Noachtar [c,*]

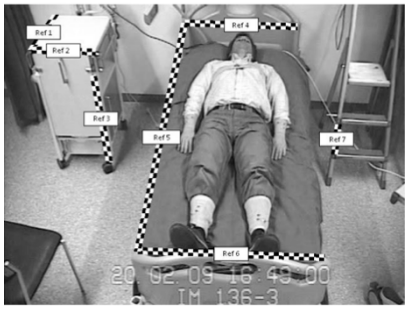
[a] Department of Electrical and Computer Engineering, Faculty of Engineering, University of Porto/INESC TEC, Porto, Portugal
[b] Portuguese Brain Imaging Research Network, Coimbra, Portugal
[c] Epilepsy Center, Department of Neurology, University of Munich, Munich, Germany

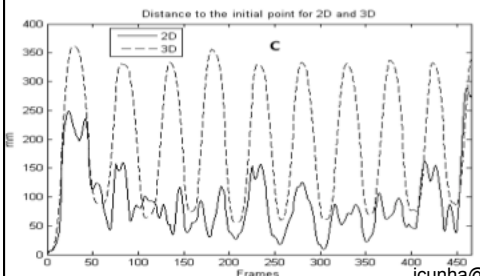
[redacted]

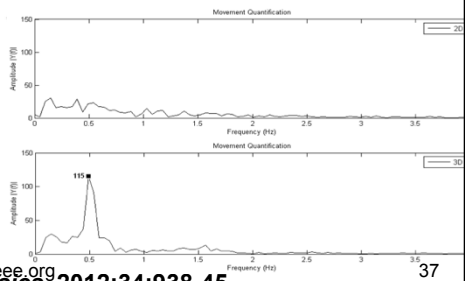


•High
•High frame rate (200 Hz)

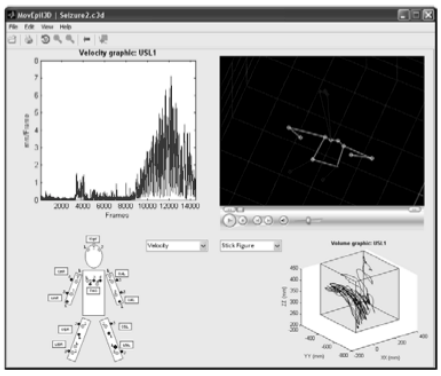


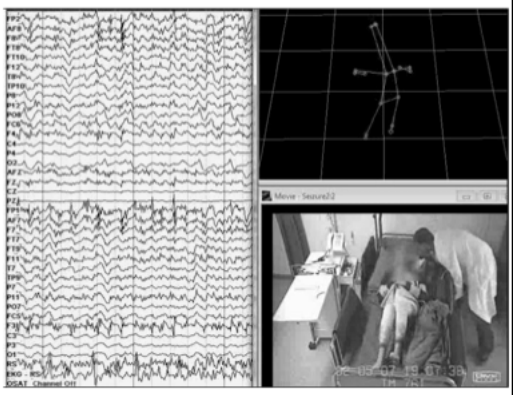




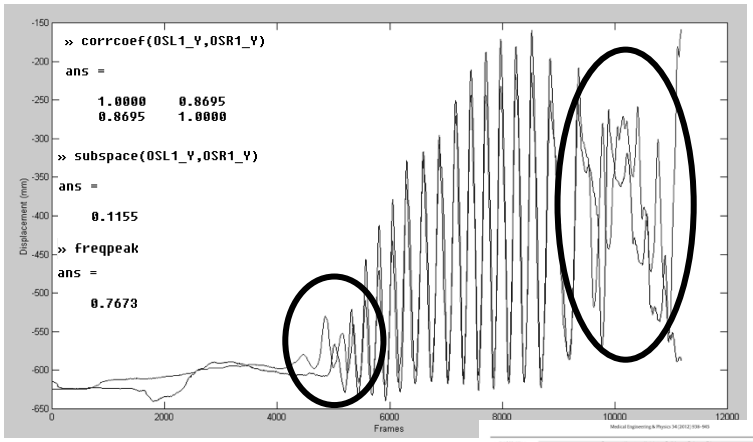


Cunha et al., *Medical Engineering & Physics*, 2012;34:938-45



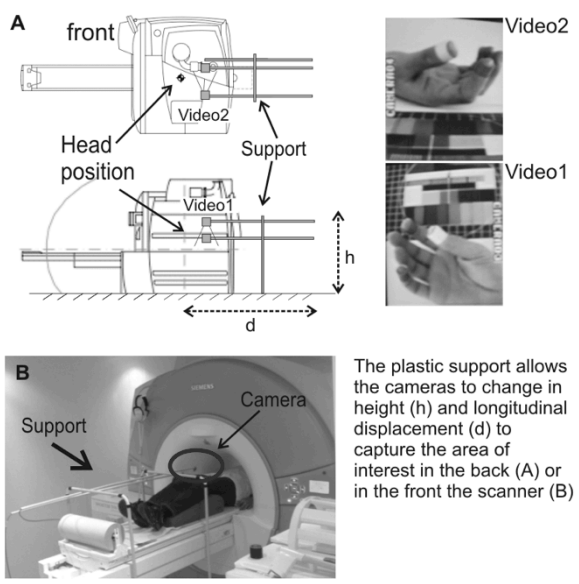


Cunha et al., *Medical Engineering & Physics*, 2012;34:938-45

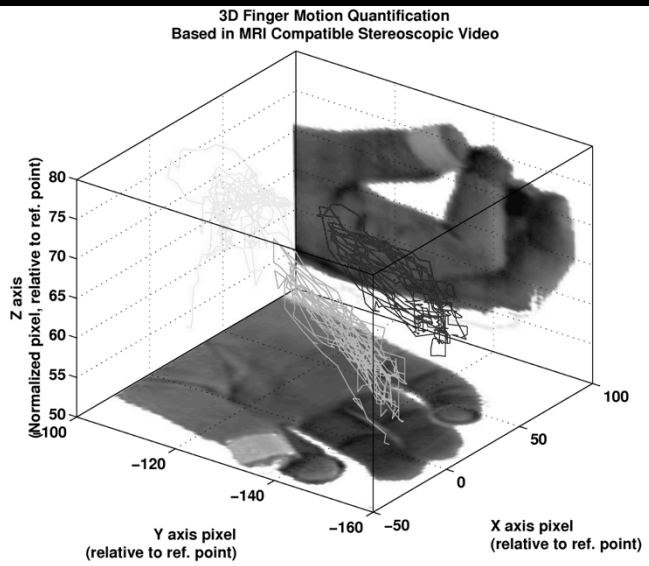


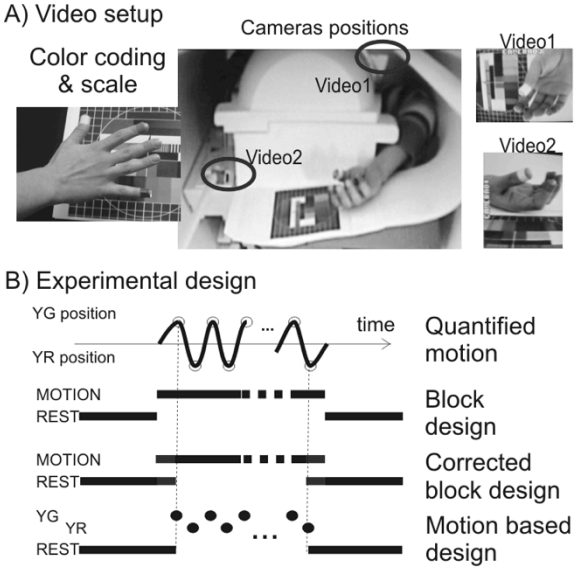
Resolution ~ 1mm³

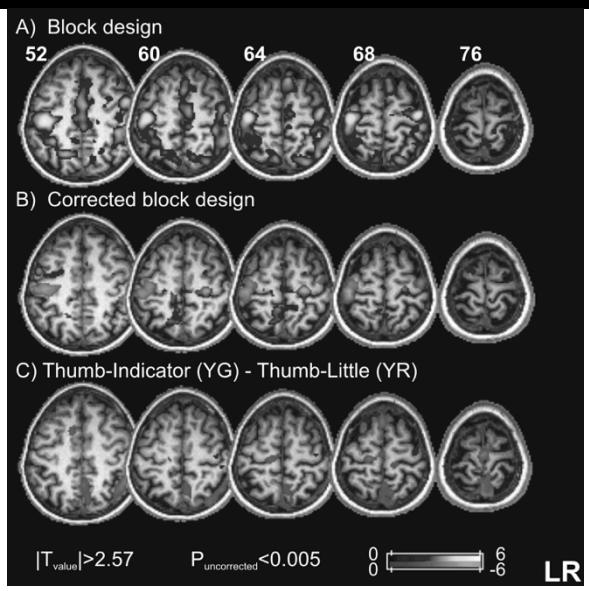
Cunha et al., *Medical Engineering & Physics*, 2012;34:938-45



The plastic support allows the cameras to change in height (h) and longitudinal displacement (d) to capture the area of interest in the back (A) or in the front the scanner (B)

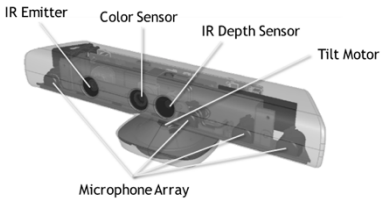

3D Finger Motion Quantification
Based in MRI Compatible Stereoscopic Video
Z axis
(Normalized pixel, relative to ref. point)
80
75
70
65
60
55
50
−100
−120
−140
−160
Y axis pixel
(relative to ref. point)
−50
0
50
100
X axis pixel
(relative to ref. point)


A) Video setup
Color coding
& scale
Cameras positions
Video1
Video2
Video1
Video2
B) Experimental design
YG position
YR position
time
Quantified
motion
MOTION
REST
Block
design
MOTION
REST
Corrected
block design
YG
YR
REST
Motion based
design

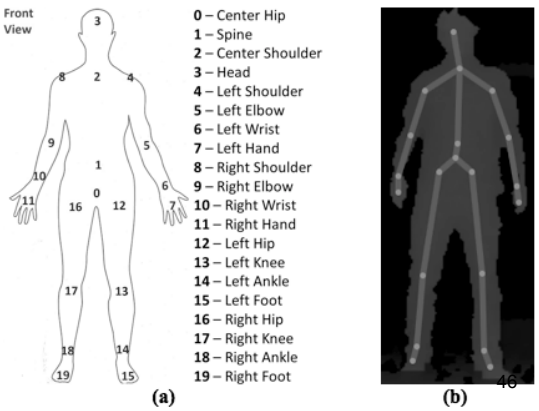


Cunha et al., *Human Brain Mapping* Conference, 2010;

45



- **RGB-D sensor**
- **Human skeleton extraction**
- **20 joints dynamic tracking**



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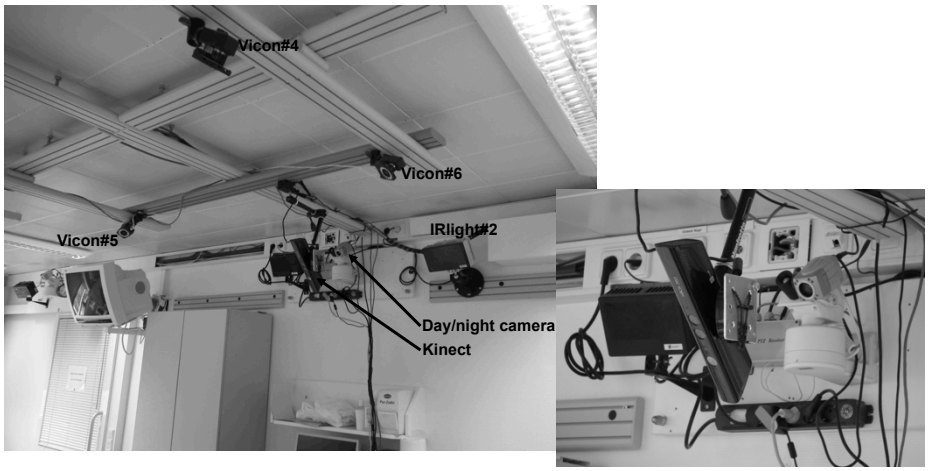
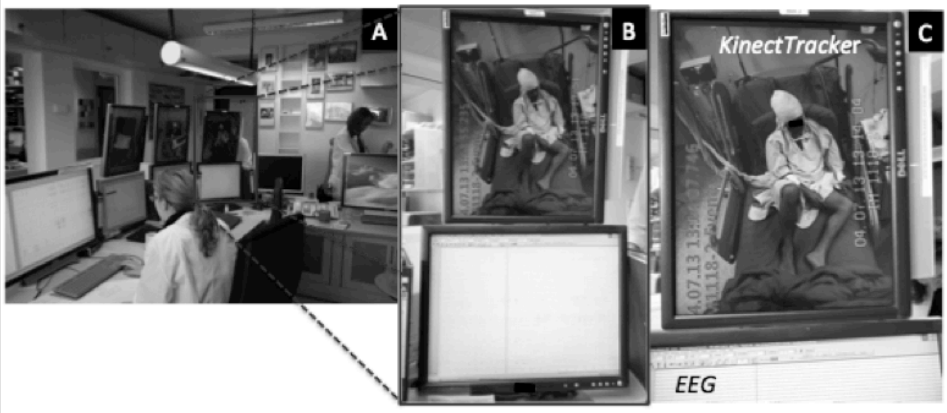
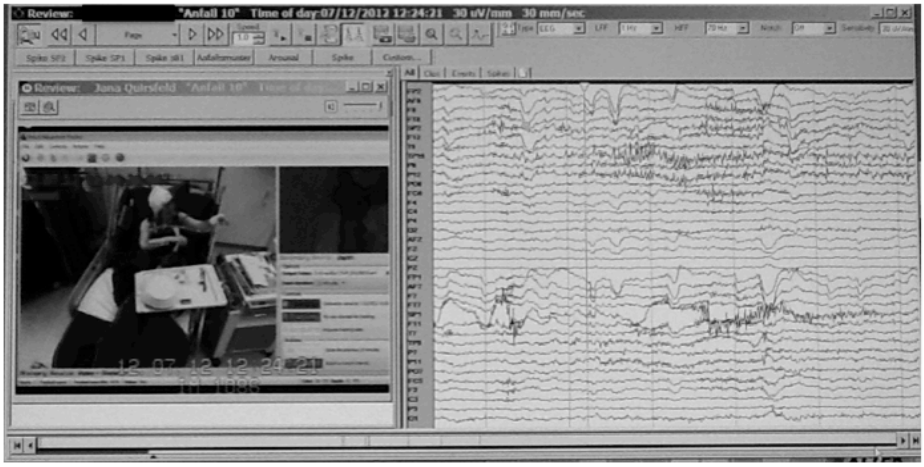
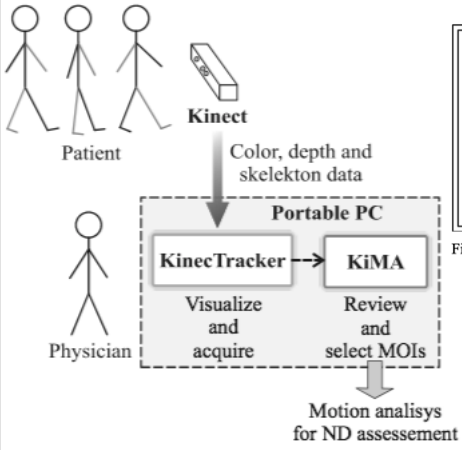

Vicon#4
Vicon#6
Vicon#5
IRlight#2
Day/night camera
Kinect


A
B
KinectTracker
C
EEG


Review:
"Anfall 10" Time of day:07/12/2012 12:24:21 30 uV/mm 30 mm/sec
Review: Jana Quirsfeld "Anfall 10"



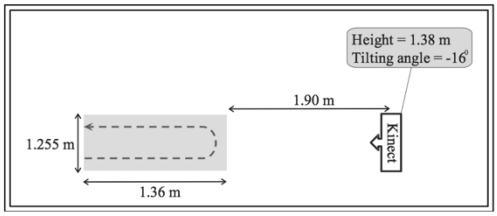


Fig. 1. Experimental setup used for data collection with a Kinect device.

Step quantitative parameters = 208

- **distance, cadence, duration**
- **speed, acceleration**
- **Averages, SD, etc.**

Sex (M/F)	Age	Height (m)	Weight (kg)	Most affected side (left/ right)
2/1	54 [47, 59]	1.68 [1.59, 1.8]	82.7 [78, 90]	0/3

PD patient	Months after DBS surgery	UPDRS III[a] (gait[b])	
		STIM ON	STIM OFF
P1	6	13 (1)	31 (1)
P2	1.5	7 (1)	26 (1)
P3	10	11 (0)	42 (2)

[a.] UPDRS score for part III (motor examination). The maximum score is of 108.
[b.] UPDRS sub-score for gait (item 29). Score ranges between 0 (normal) and 4 (cannot walk at all, even with assistance).

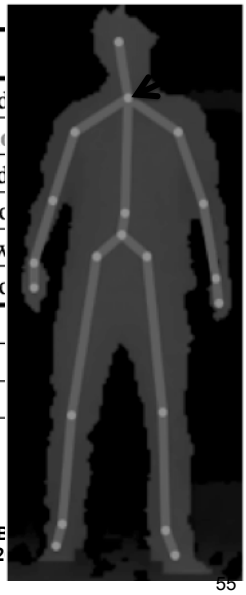
- **3 non-PD subjects also participated**

Parameter			Coefficient of correlation
Average	Acceleration	Left hand	**–0.83**
		Right hand	–0.53
	Distance	Ankles	**–0.85**
Median	Velocity	Right ankle	**–0.85**
		Left ankle	–0.26
Normalized variance	Velocity	Right ankle	**0.83**
		Left ankle	–0.63

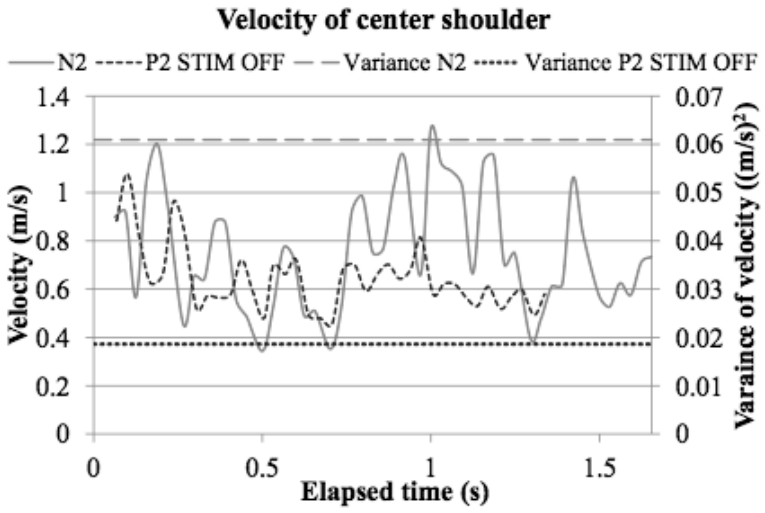
Submitted to MICCAI 2014, Cambridge, MIT
Forum de Neurologia 2014, Coimbra

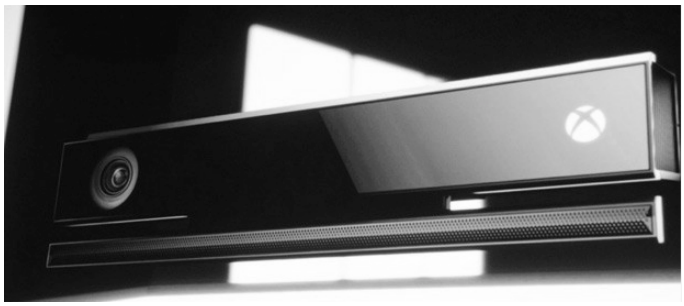
- **8/208 parameters discriminate (p<0.05):**
  - **3 Non-PD,**
  - **3 PD-stimON,**
  - **3 PD-stimOFF**
- **Literature typical paramenters are NOT the best ones**

Parameter		
Variance	Velocity	Head
		Center sho
		Should
	Acceleration	Center sho
	Distance	Elbow
Average	Acceleration	Center sho
Stride duration		
Stride length		
Cadence		



Submitted to IEEE EME
Forum de Neurologia 2





1080p HD resolution

6 high fidelity skeletons

USB 3 (2Gbit)

Xmas 2014

From: **Ben Lower** <Ben.Lower@microsoft.com>
Date: Tue, Sep 24, 2013 at 9:37 PM
Subject: K4W Wants You! (Please Read Carefully and Reply)
To: "jcunha@ieee.org" <jcunha@ieee.org>

Dear Joao:

(...)

Congratulations! I am delighted to notify you that the Kinect for Windows team is offering you ("INESC-TEC/University of Porto") a place in our upcoming developer kit program :-) As you know, this program will grant a select number of developers exclusive access to pre-release hardware and software.

We received thousands of applications to the program. Due to the high volume of interest, we won't have enough alpha hardware to admit everyone who applied to the program. Over the next few months, we will continue to notify successful program applicants.

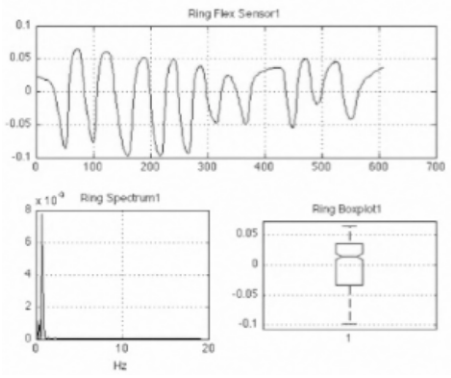
We're convinced that your combination of passion for Kinect, technical expertise, and the creativity of your idea will make you an awesome contributor to the evolution of NUI.

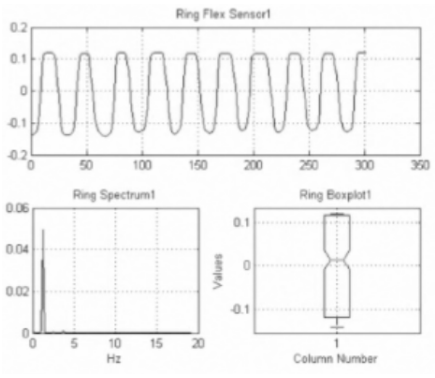
(...)

Wearable electronics for PD evolution quantification

Collaboration with HSJ, Porto

Antes **Depois**





- Neuroengineering is a growing interdisciplinary area
- FEUP and its partners are building up a program offering (R&D and course) in this exciting area
- Qmov has been one of the focus.
- Many exciting new opportunities are going on and many more to come…
- We are committed to make this area grow with the help of our partners
- … so, if you have ideas in this area, just contact us ☺

- All references are part of
  - Cunha, JPS, “Motion Analysis in Neurological Diseases: A permanent challenge (review)”, to be submitted