DU LABORATOIRE AU DÉSERT MAROCAIN, LE PROJET XTREMLOG

INSTITUT NATIONAL
DE RECHERCHE
EN INFORMATIQUE
ET EN AUTOMATIQUE

INRIA

centre de recherche
GRENOBLE - RHÔNE-ALPES

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UN RÉSEAU DE CAPTEURS AU 25ÈME MARATHON DES SABLES

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

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centre de recherche GRENOBLE - RHÔNE-ALPES

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Bernard Espiau, DDT INRIA
Christine Azevedo, Equipe Projet INRIA DEMAR
Nicolas Horvais, Salomon Sports

ORIGIN

Ultra running - for longer periods and longer distances

Marathon des Sables...

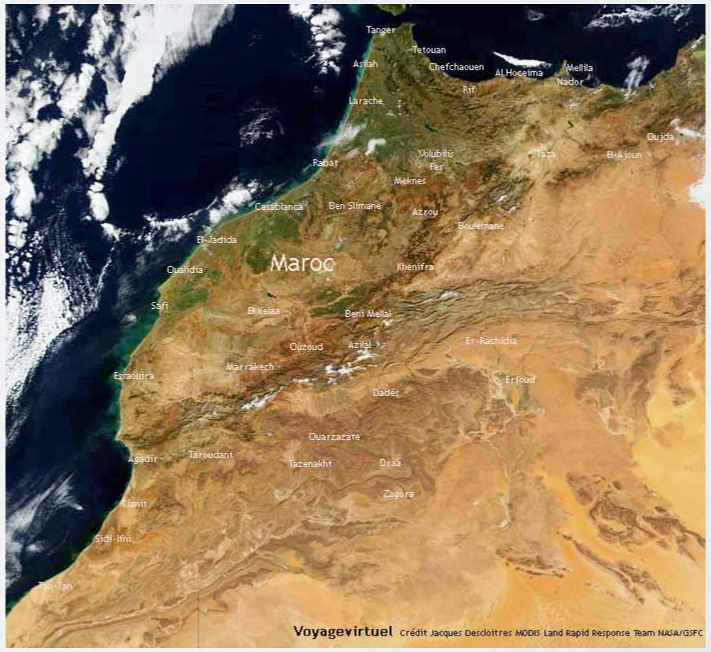
The 20 greatest / hardest races in the world... (Ultrafondus n°57, march 2009) :

- Ultra Trail Mont Blanc
- **Marathon des Sables**
- Badwater
- ...

25th Marathon des Sables

Where : morocco desert, around Merzouga

rock desert : reg
sand desert : ergs



25th Marathon des Sables

6 stages

250km

Night running

1 long stage (80km)

1 marathon stage

25th Marathon des Sables

Typical day schedule :

- 05:45 - wakeup
- 06:00 ~ 07:00
  - bivouac dismounted
  - breakfast in self-sufficiency
- 07:00 ~ 08:00 - water distribution
- 08:30 ~ 09:00 - stage start
- end of day
  - dinner
  - footcare
  - sleep

25th Marathon des Sables

self-sufficiency

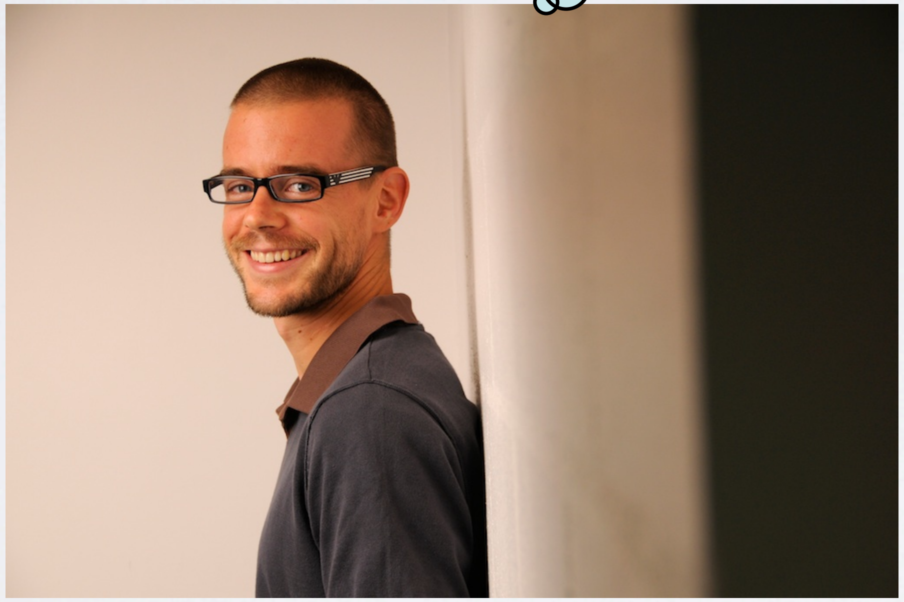
no assistance

Food : 2000KCal / day

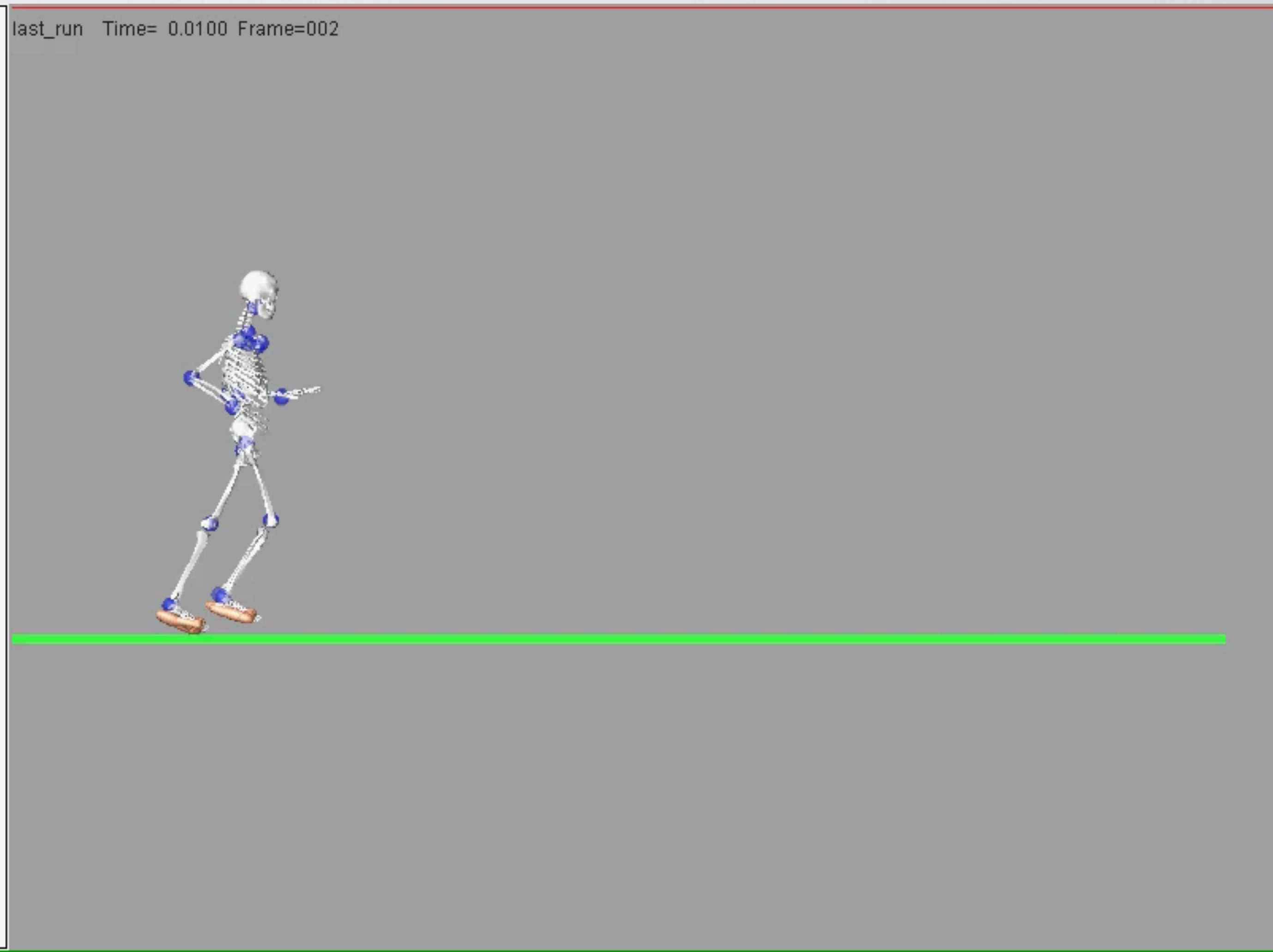
Sleeping bag, clothes, *etc.*

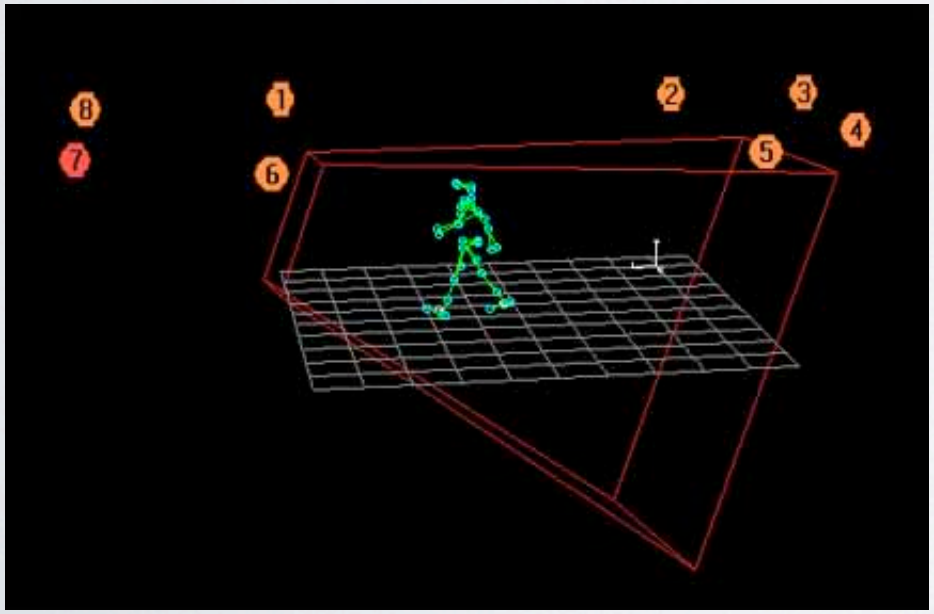
Optimized backpack ~8 kg

And what about science ?

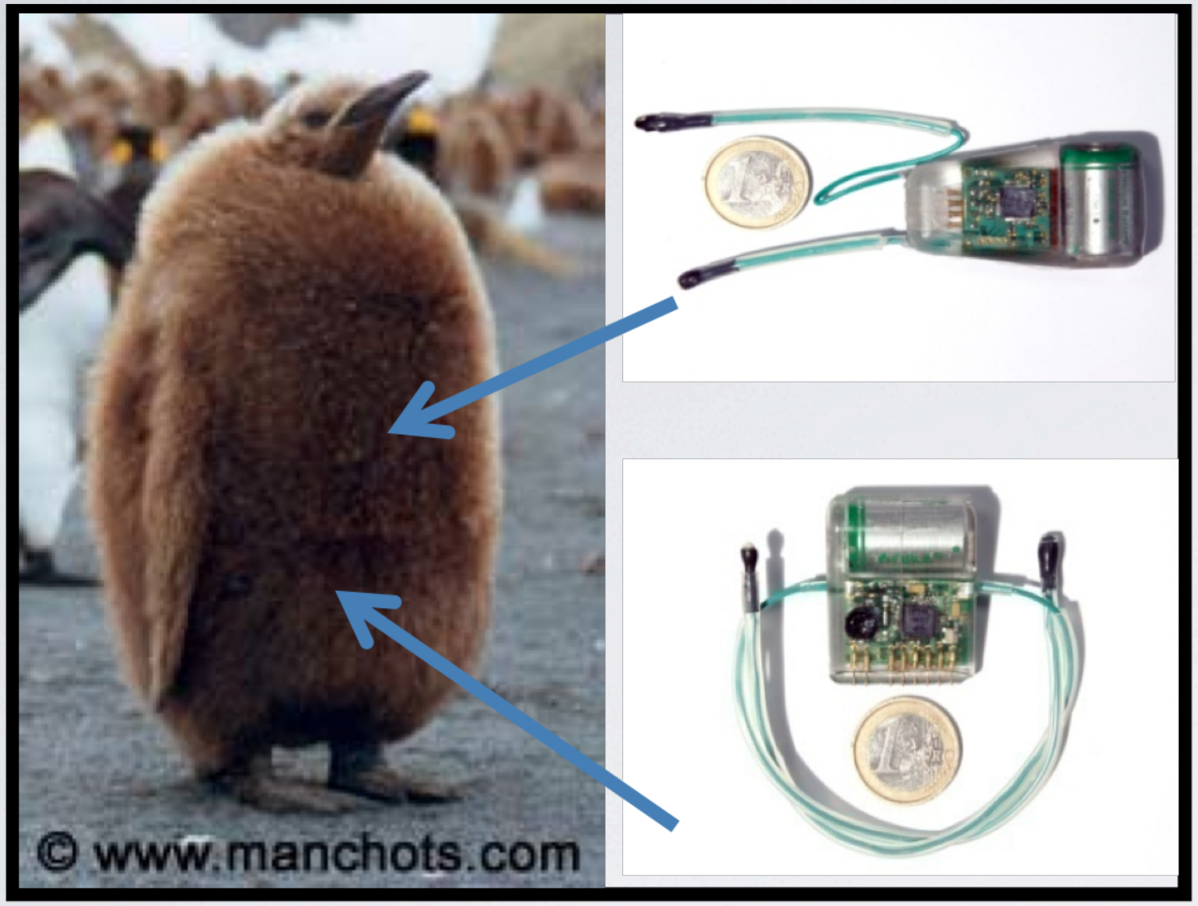



CONTACT FORCES
John_GRX_Lfoot_1-none-y_component-(filter)
John_GRX_Lfoot_1-none-y_component-(filter)
John_GRX_Rfoot_1-none-y_component-(filter)
Force (newton)
2000.0
1500.0
1000.0
500.0
0.0
-500.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
No Units


last_run Time= 0.0100 Frame=002

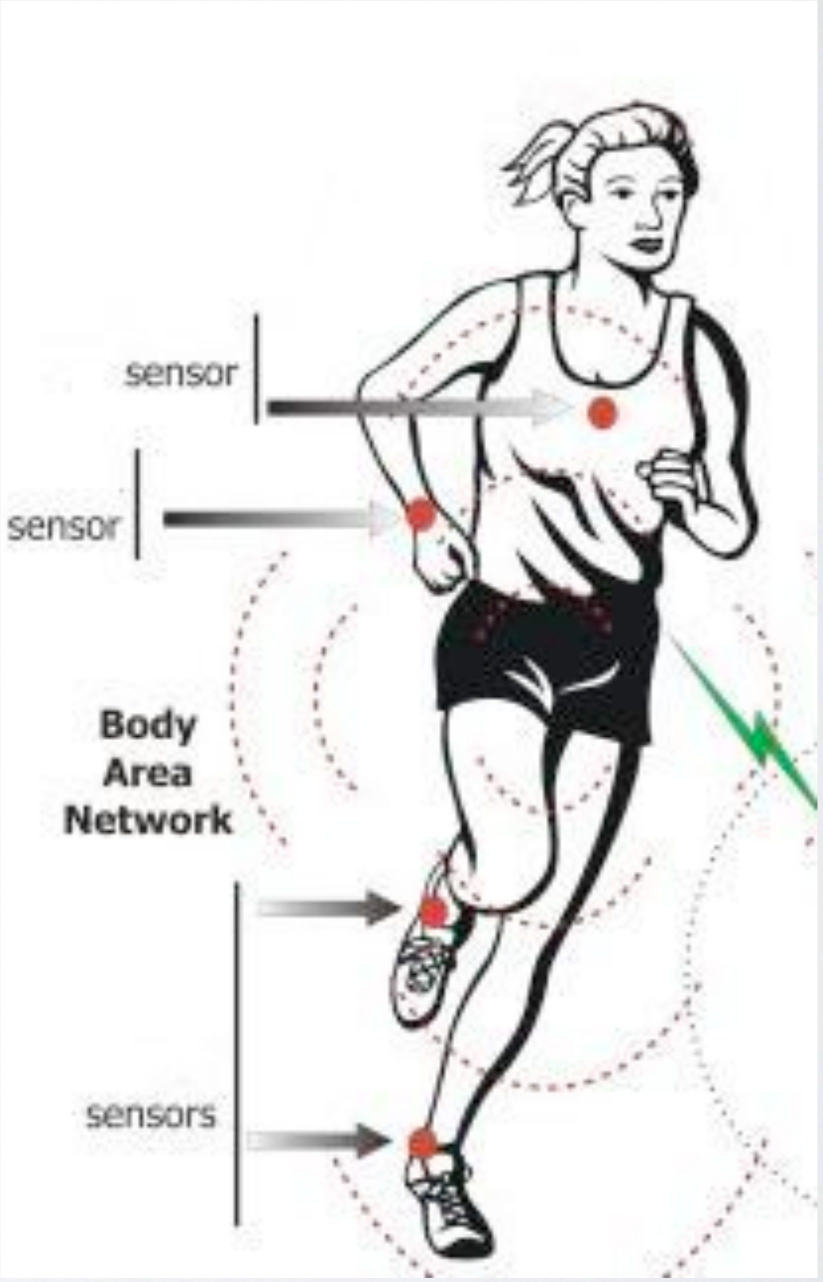


VS



Similar to biologging

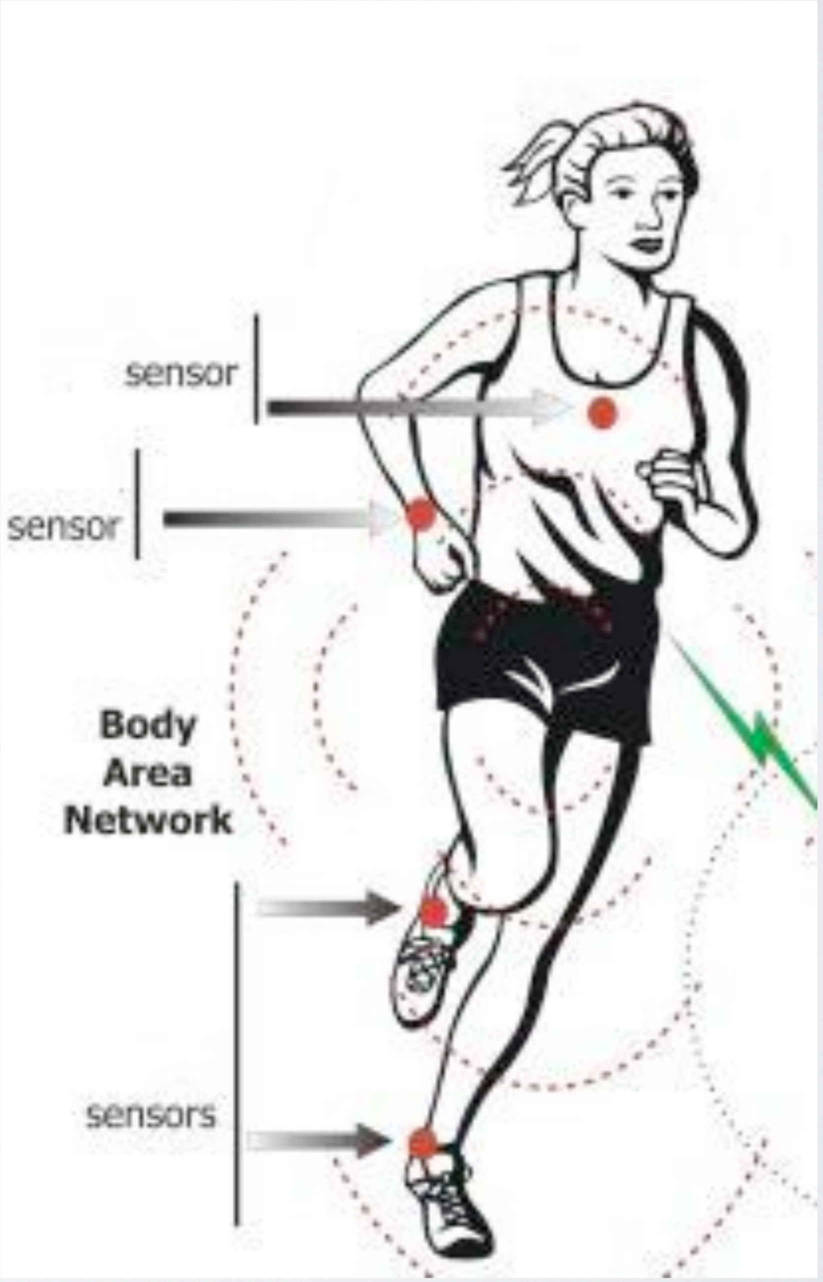
A Body Area Network (BANet)



A Body Area Network (BANet) at the MdS

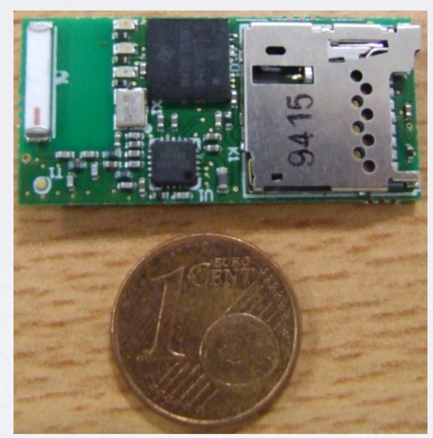
A technological challenge :

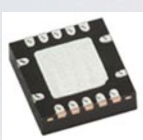
- autonomy
- ergonomic
- robustness
- weight
- reliability
- data synchronization
- ...



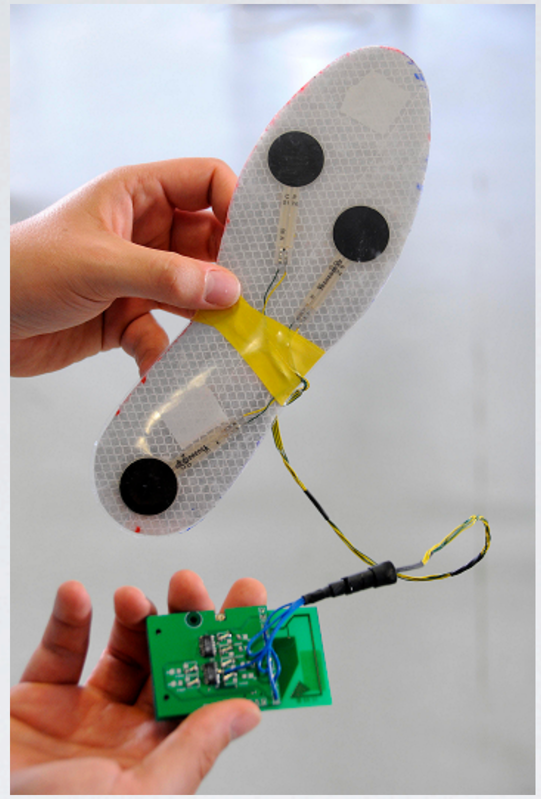
SENSOR NETWORK CONCEPTION

Building a sensor node

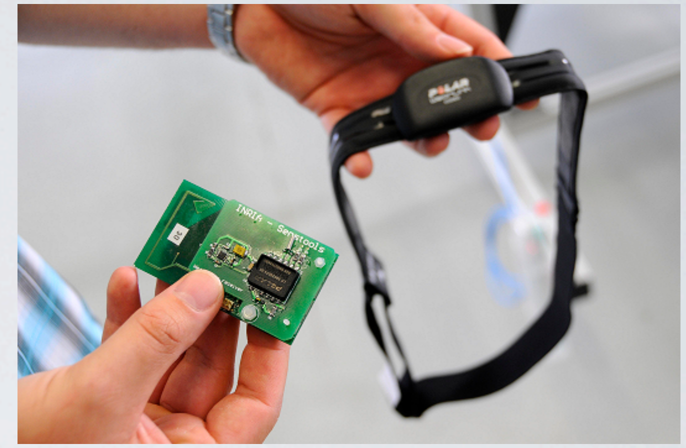




The sensors



Force Pressure Sensitive (FSR)

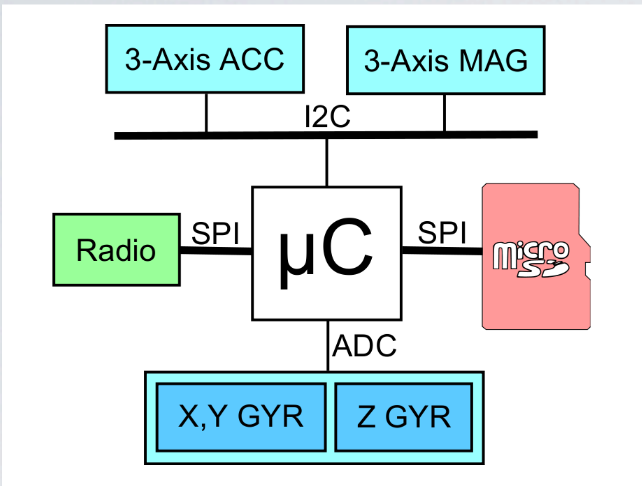


Cardio Frequency Meter

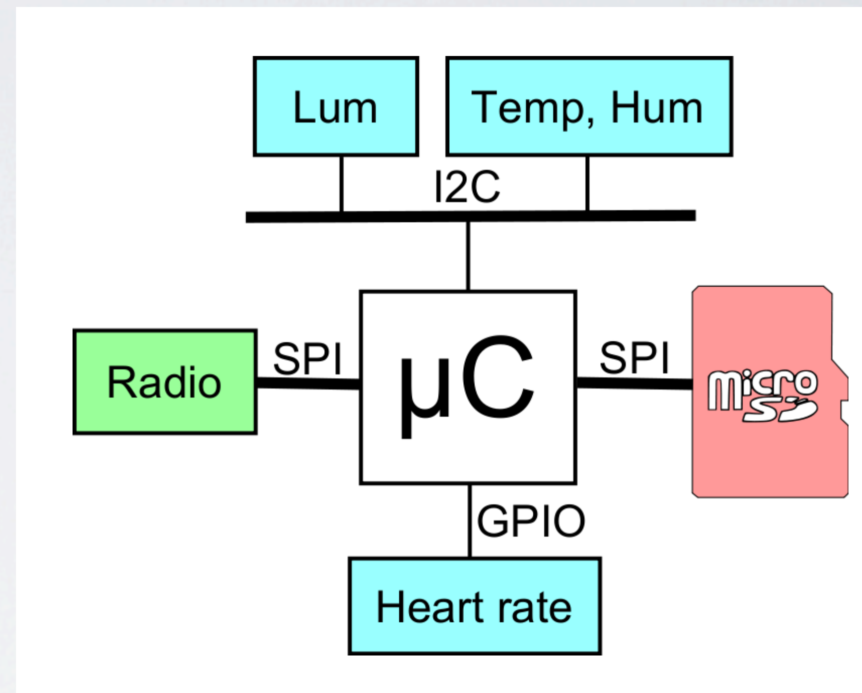
Inertial Motion Units (IMUs)

Environmental :T°, H

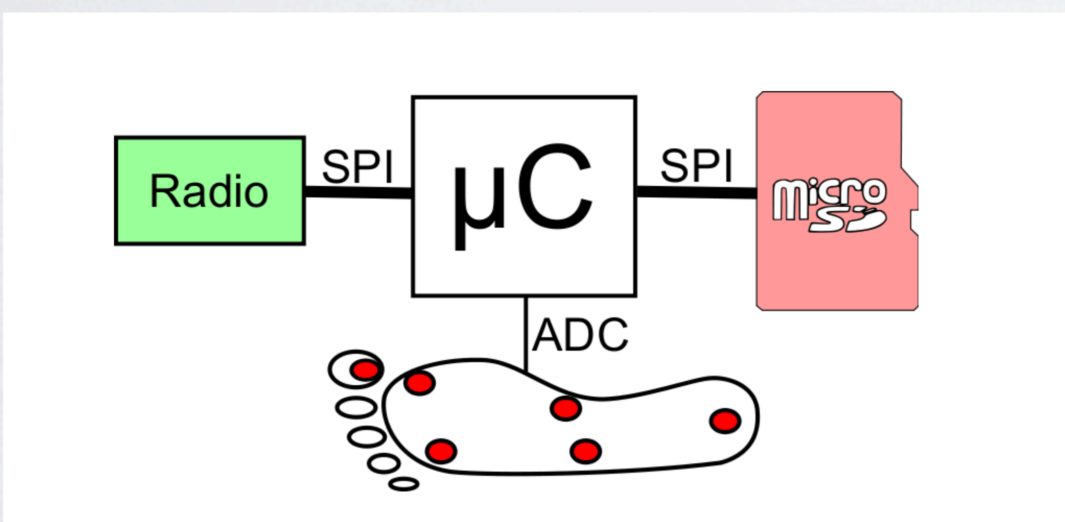
Building a Half-Distributed Body Area Network



IMU node



Master node



FSR node

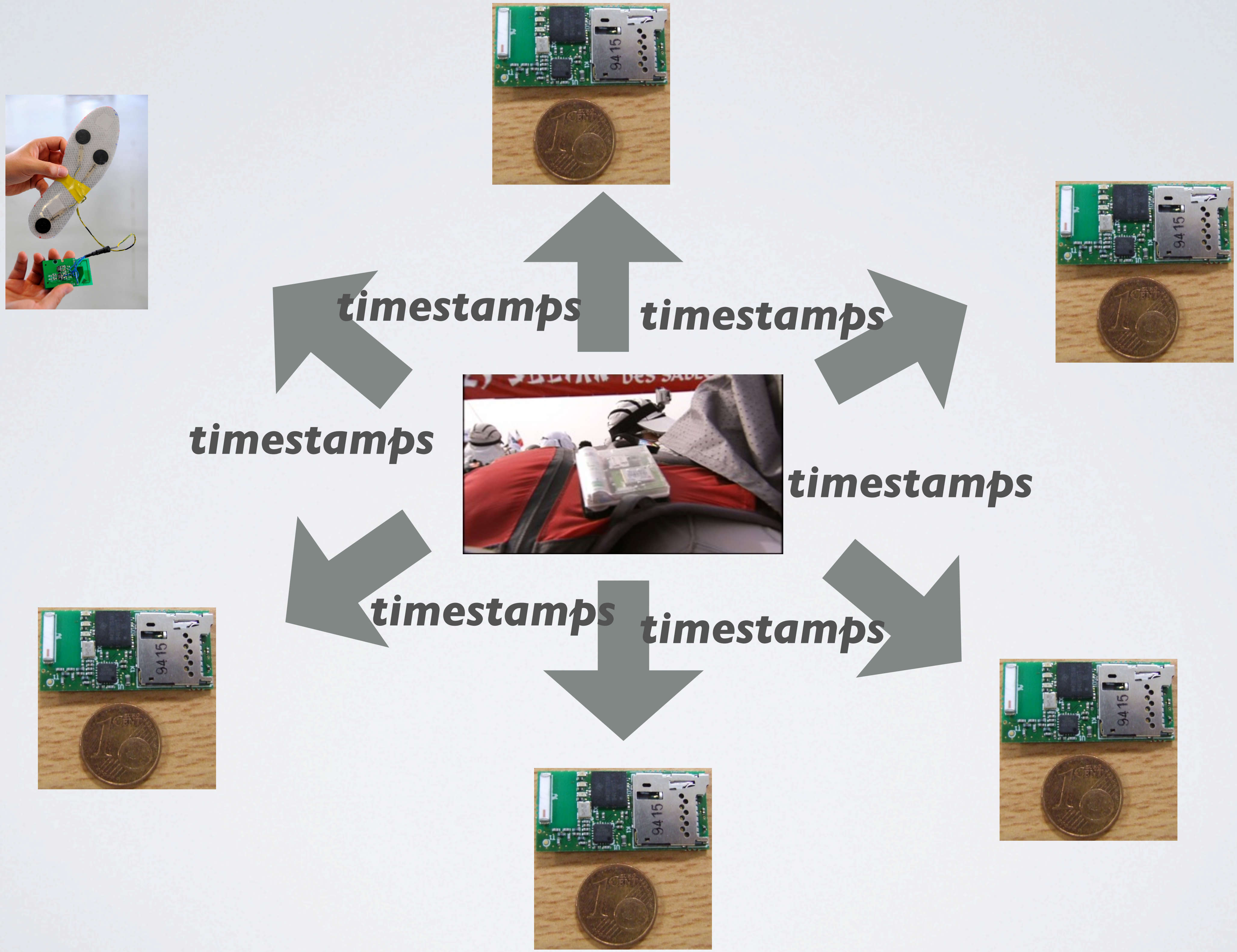
Building a Half-Distributed Body Area Network

Each node operates independantly from the others

Each node logs its data internally

Time synchronization is performed through the radio protocol

Building a Half-Distributed Body Area Network



Time synchronization

Master node : periodical emission of timestamp packets

Slave nodes : periodical reception of timestamp packets

Activity scheduling : sleep / tx|rx / sleep /tx|rx / sleep

Tradeoff : radio activity, i.e. energy consumption vs synchronization accuracy

Time synchronization

Timestamps period : 153.4ms

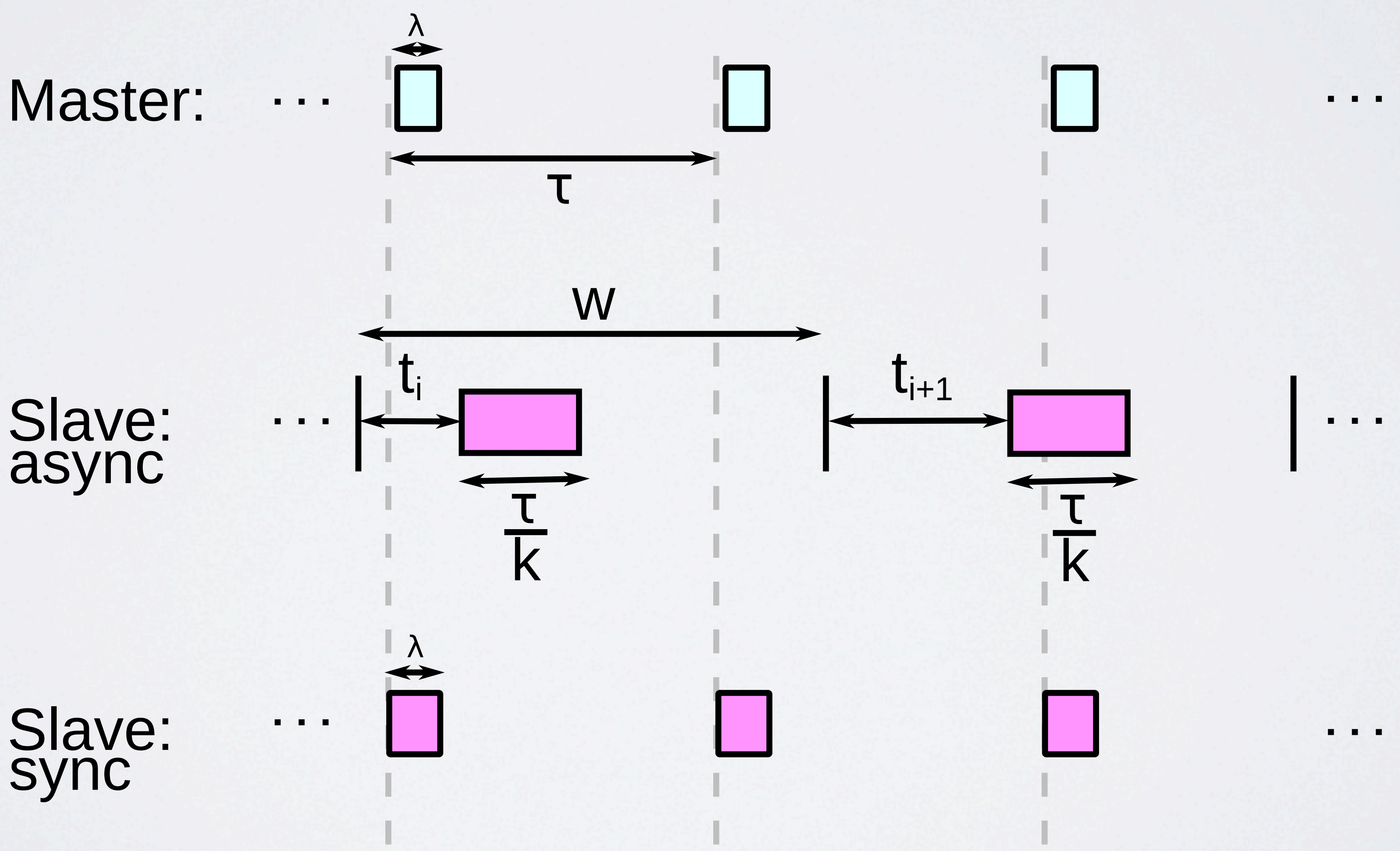
Maximum clock drift : 30ppm, *i.e.* ~4us *btw* timespamps

Hypothesis : linear clock drift *btw* timestamps

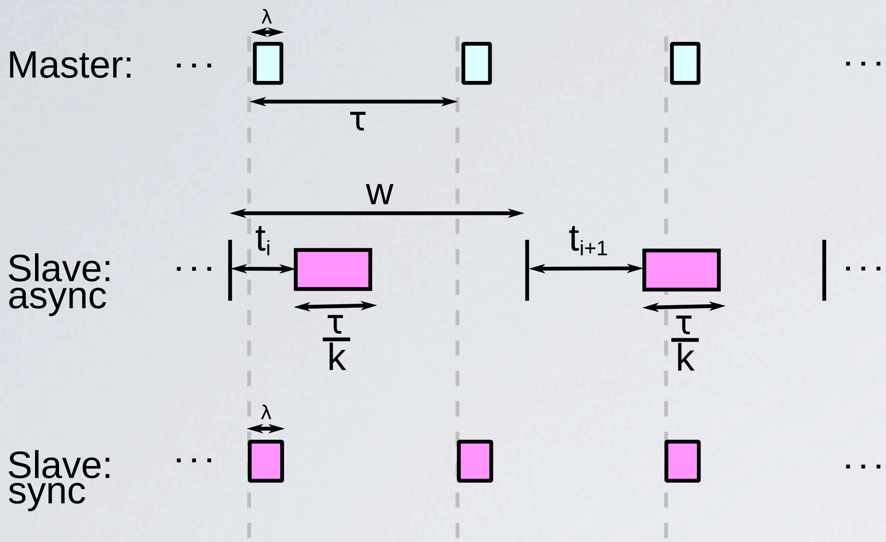
$$t_G(m) = t_m^1 + \frac{(t_m^2 - t_m^1)}{(t_s(t_m^2) - t_s(t_m^1))}(t_s(m) - t_s(t_m^1))$$

Activity scheduling & synchronization

Asynchronous & distributed discovery & synchronization protocol



Activity scheduling & synchronization

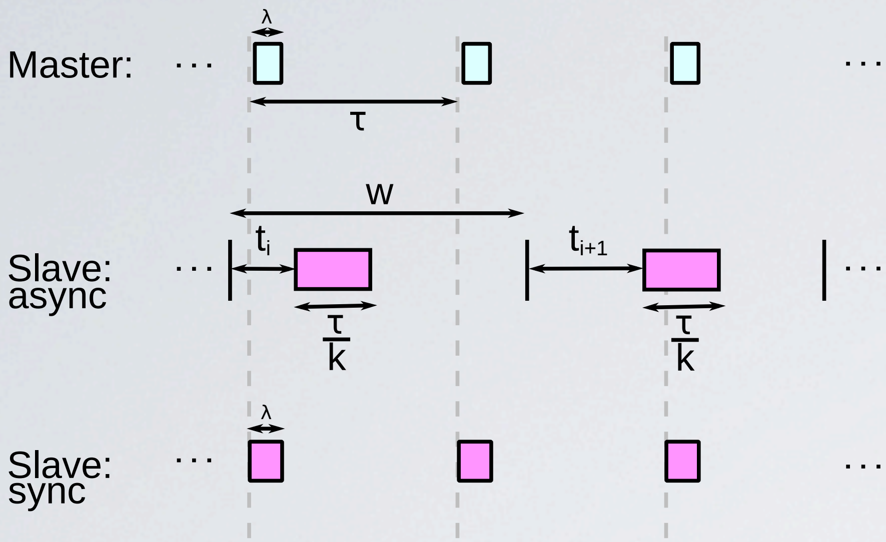


$$P\left(R_i\right) = E\left(\frac{W}{\tau}\right)\frac{\frac{\tau}{n} - \lambda}{W - \frac{\tau}{n}} = p$$

$$P\left(R_i \bigwedge_{k=0}^{i-1} \bar{R}_k\right) = p\left(1-p\right)^i = p_i$$

$$T = W\sum_{i=0}^{\infty} i p_i = W\sum_{i=0}^{\infty} i\left(1-p\right)^i p$$

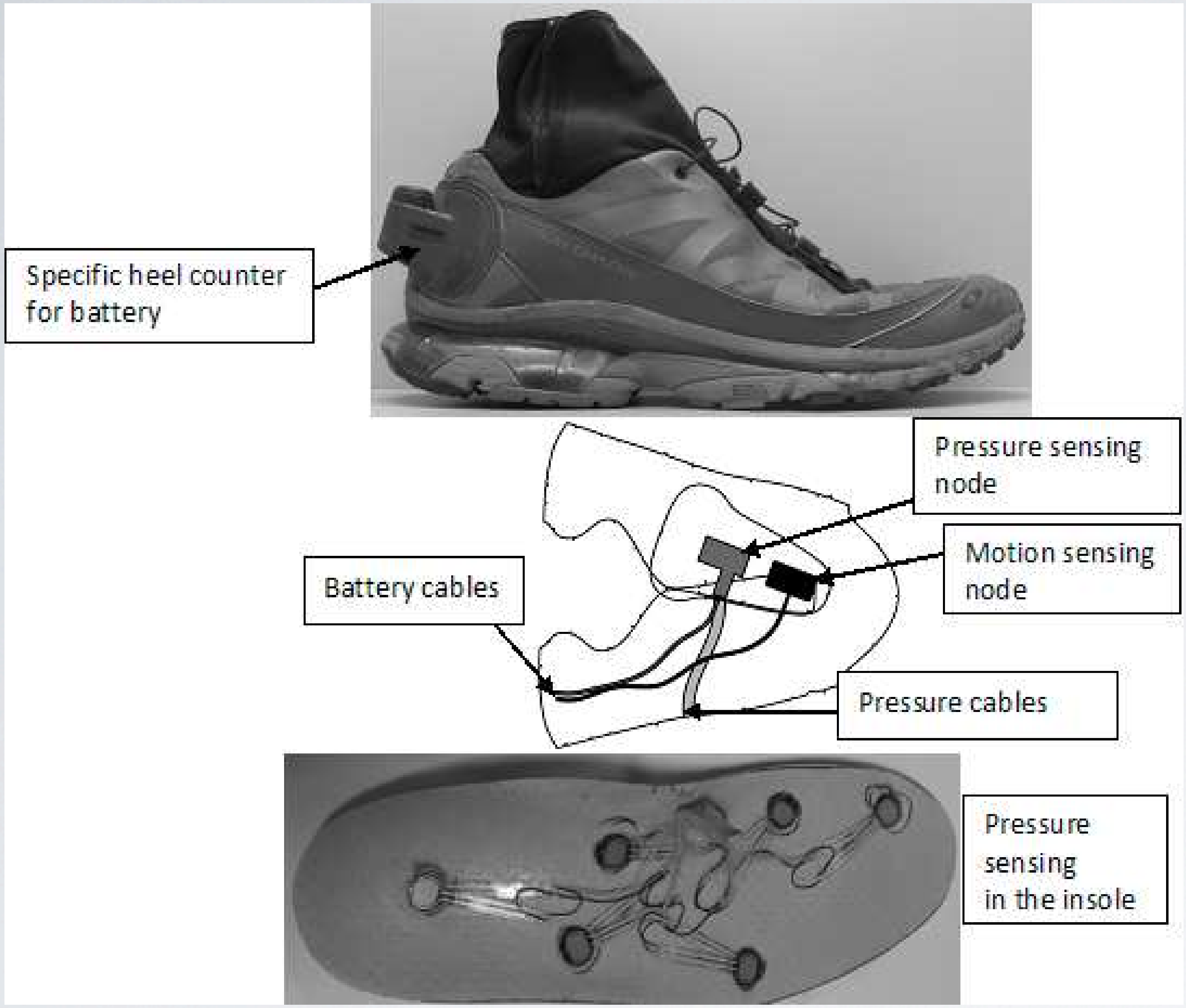
Activity scheduling & synchronization

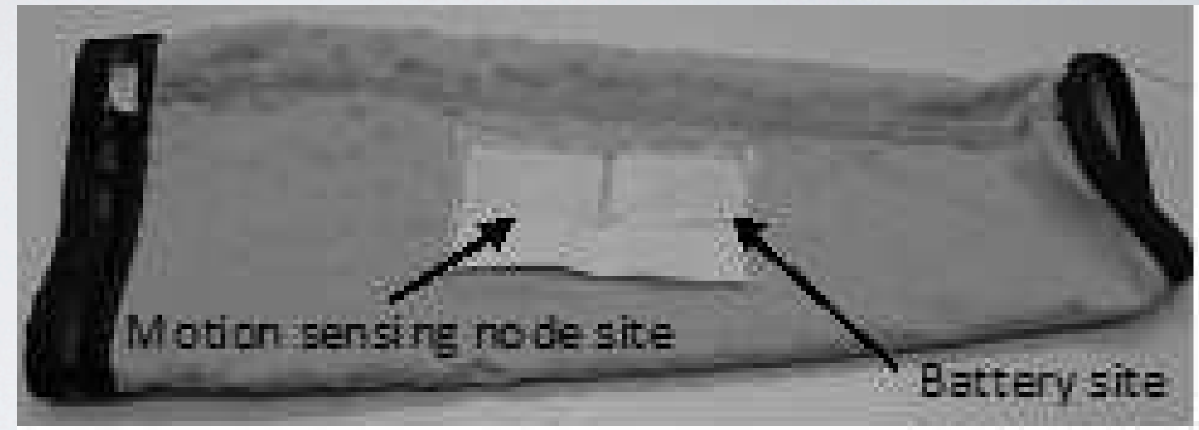


$$T = W\left(\frac{1}{p} - 1\right) = W\left(\frac{W - \frac{\tau}{n}}{E\left(\frac{W}{\tau}\right)\left(\frac{\tau}{n} - \lambda\right)} - 1\right)$$

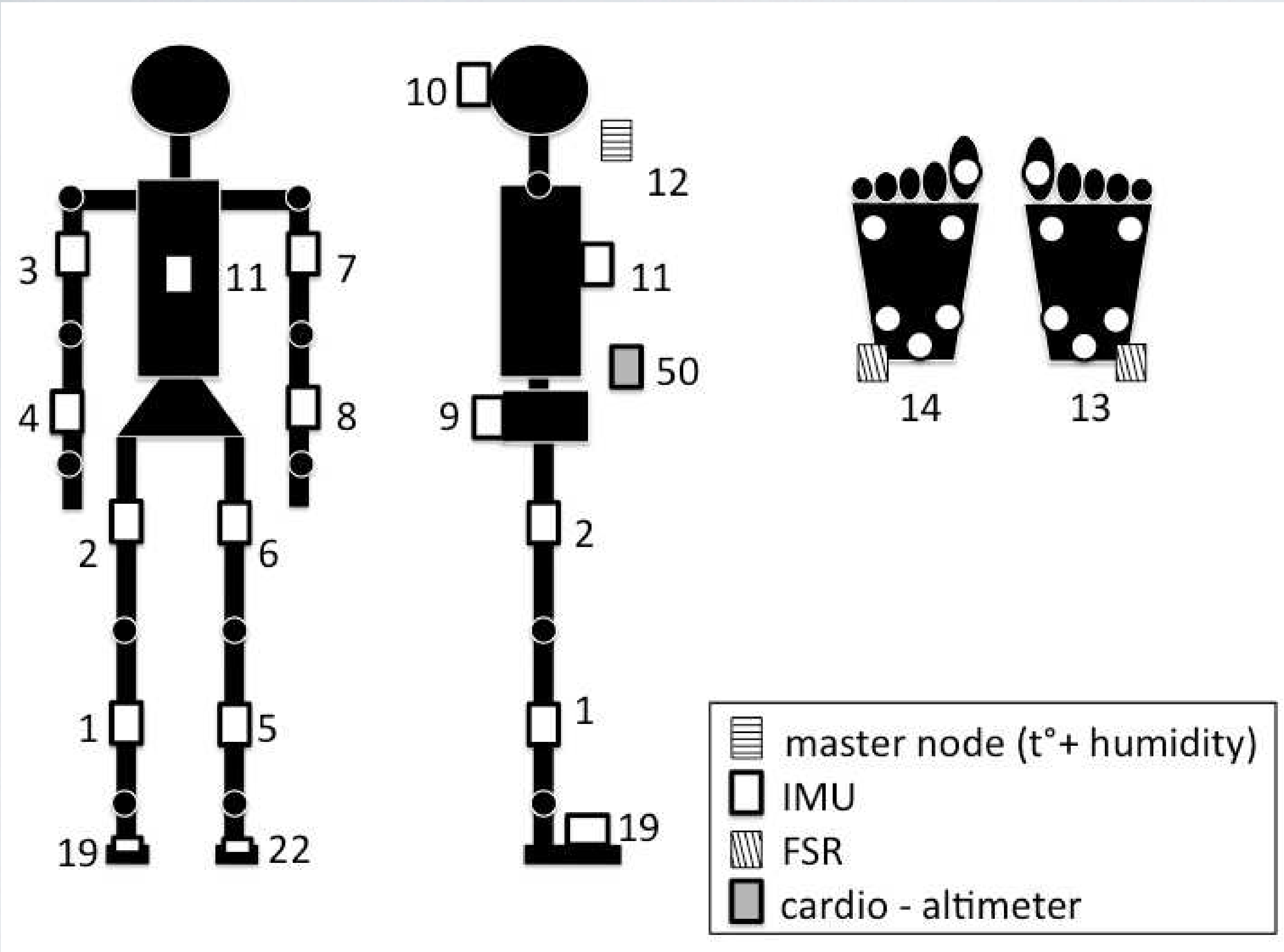
$$T = (n-1)\,W$$

Tradeoff : radio activity, i.e. energy consumption vs synchronization latency





Integrating the BANet into the runner equipment

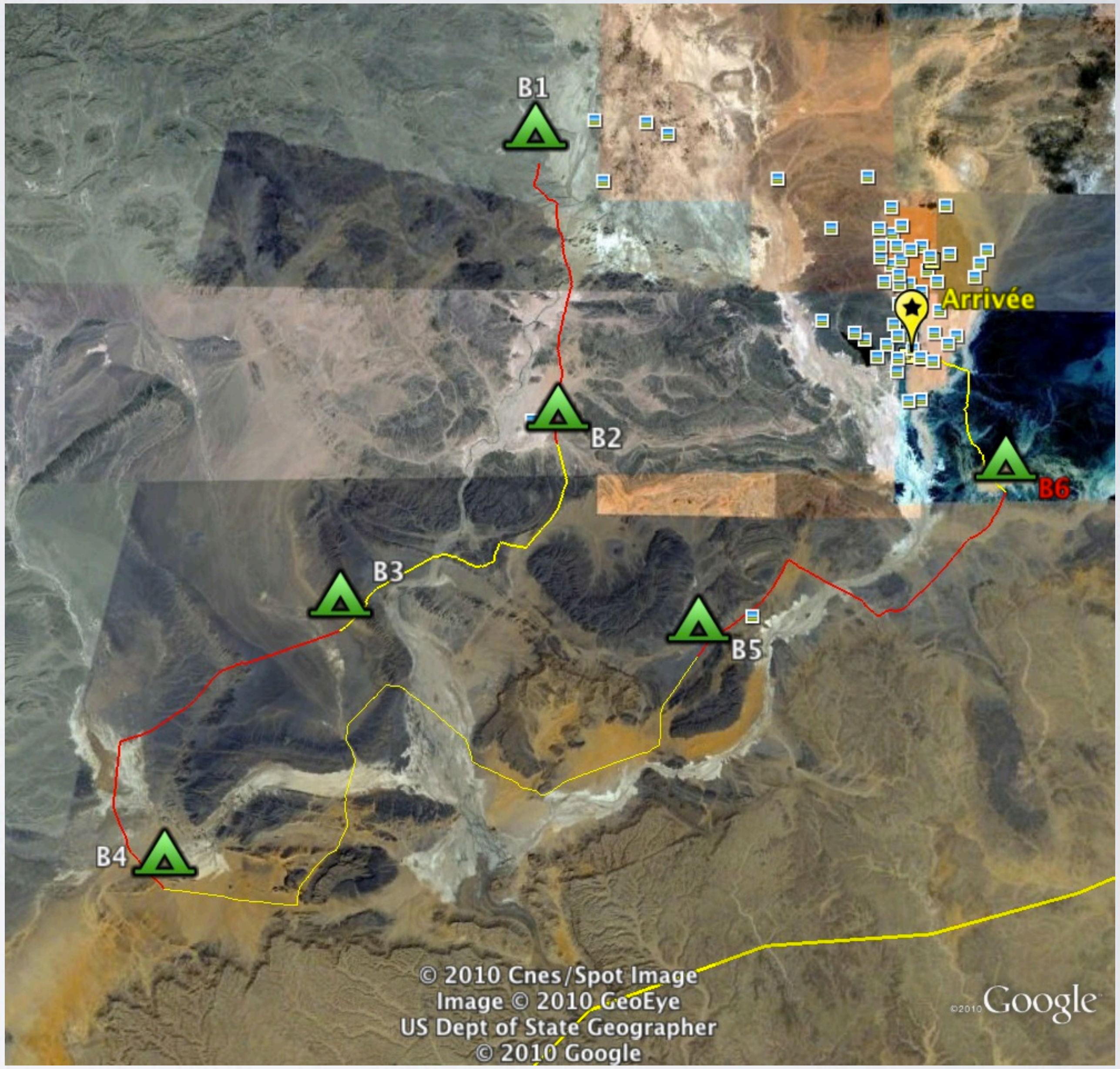

3
11
7
4
8
2
6
1
5
19
22
10
12
11
50
9
2
1
19
14
13
master node (t°+ humidity)
IMU
FSR
cardio - altimeter


266

THEN, THE RACE

At least a sportive success ! ☺

Stage 1 - 29km	3:30
Stage 2 - 35km	4:54
Stage 3 - 40km	5:08
Stage 4 - 82km	11:58
Stage 5 - 42km	4:43
Stage 6 - 22km	2:00



~32h race

66th over 1016 competitors

Hard conditions

T° > 50°

H ~ 15%

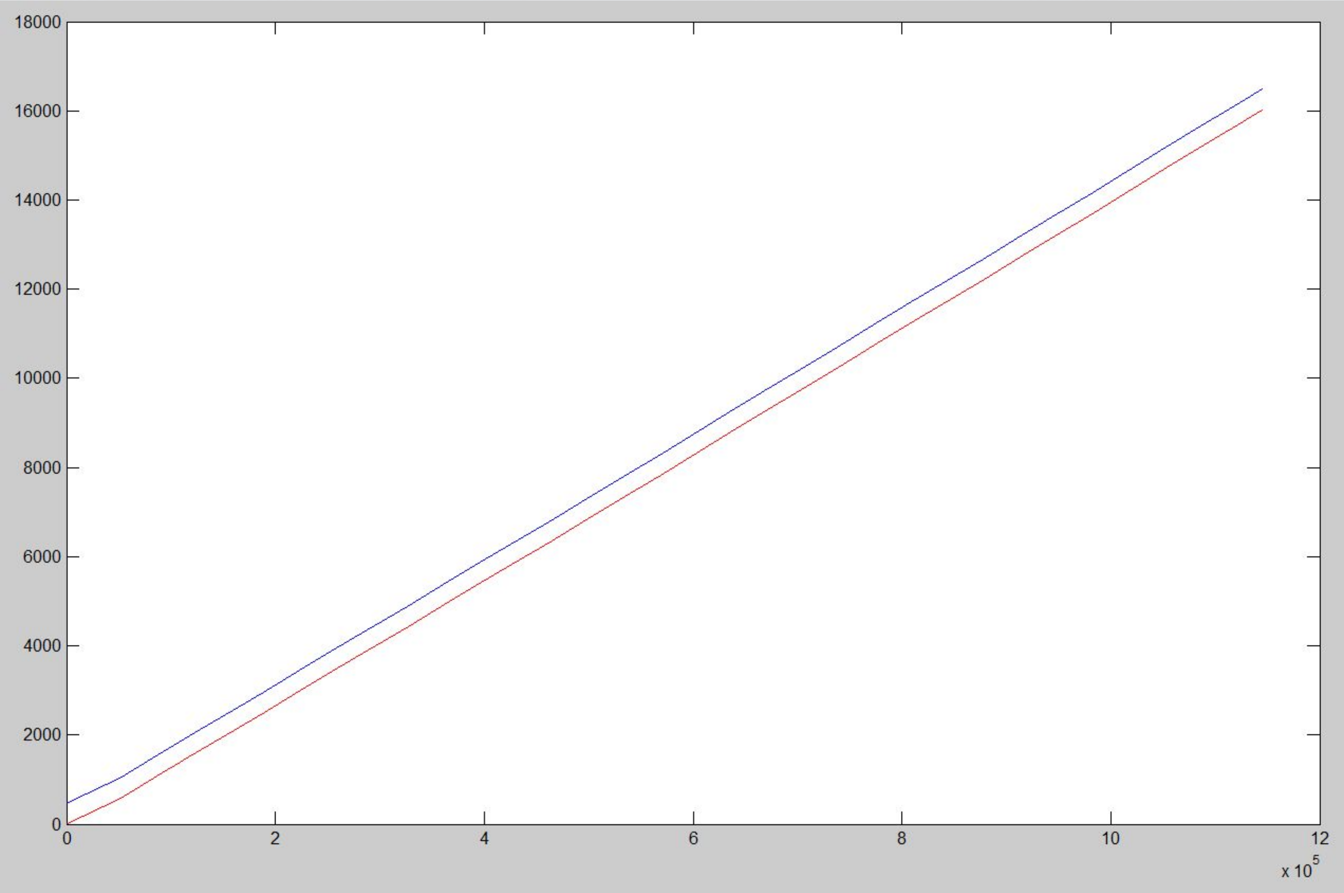
THE EXPERIMENT

Good news ! ☺

protocol

ategy

Few rad



Low clock drift among sensors

Bad news ! ☹

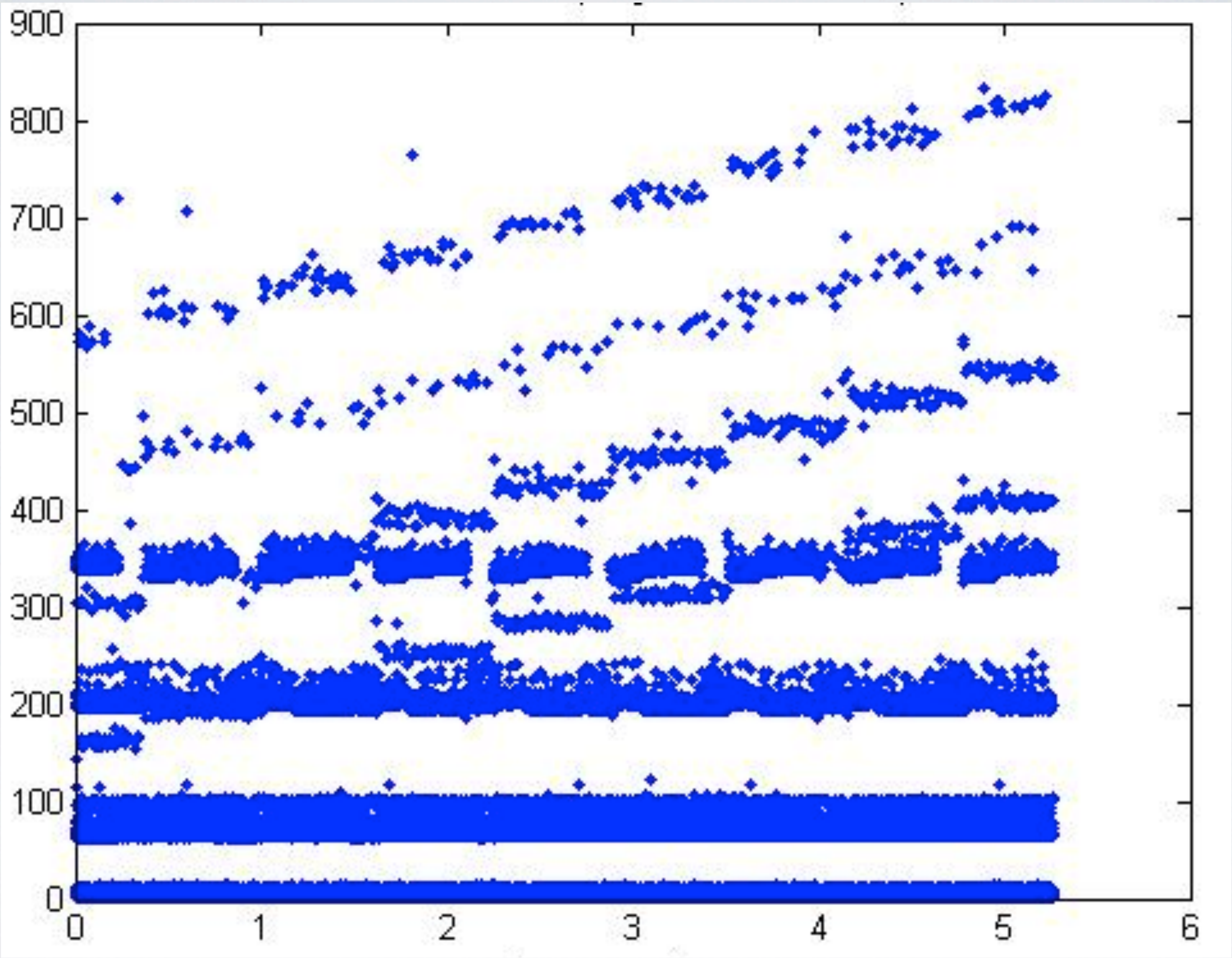
Concurrent processes induced loss of data

ACC reading vs uSD card writing

Non optimized file system access

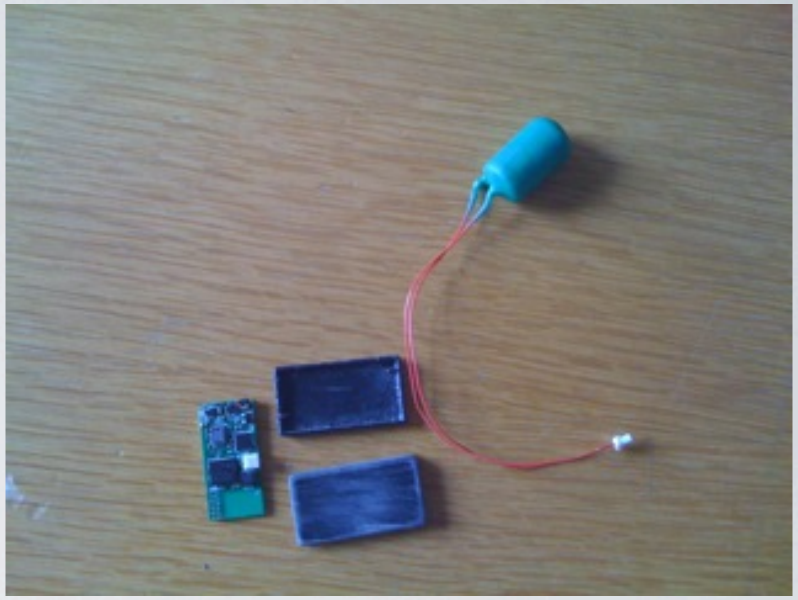
Non optimized cache

Specific to SD storage



900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6

Other bad news ! ☹

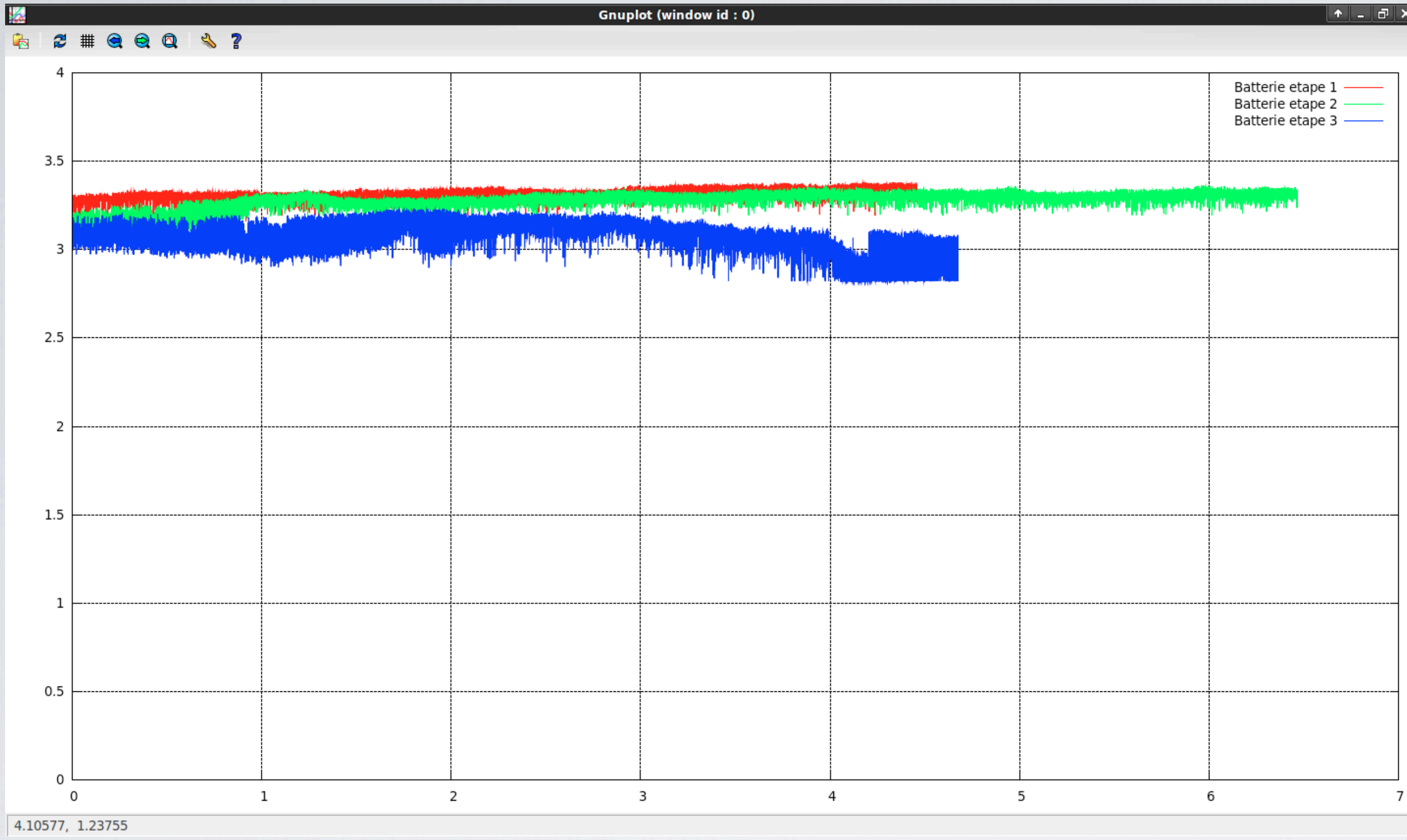


Robustness of connectors was not sufficient

Due to repeated impacts

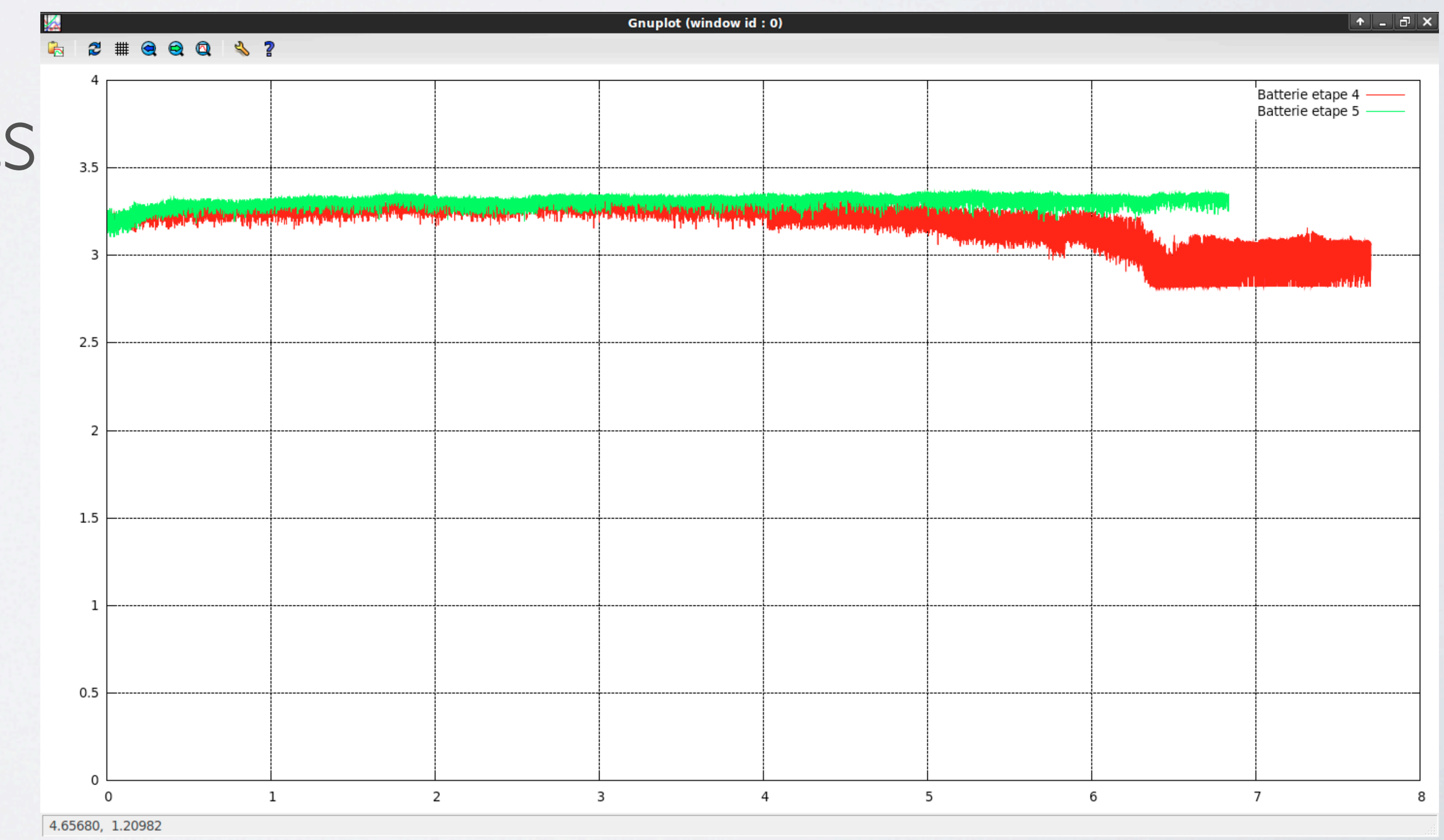
Due to sweat, water....

System files were partially corrupted

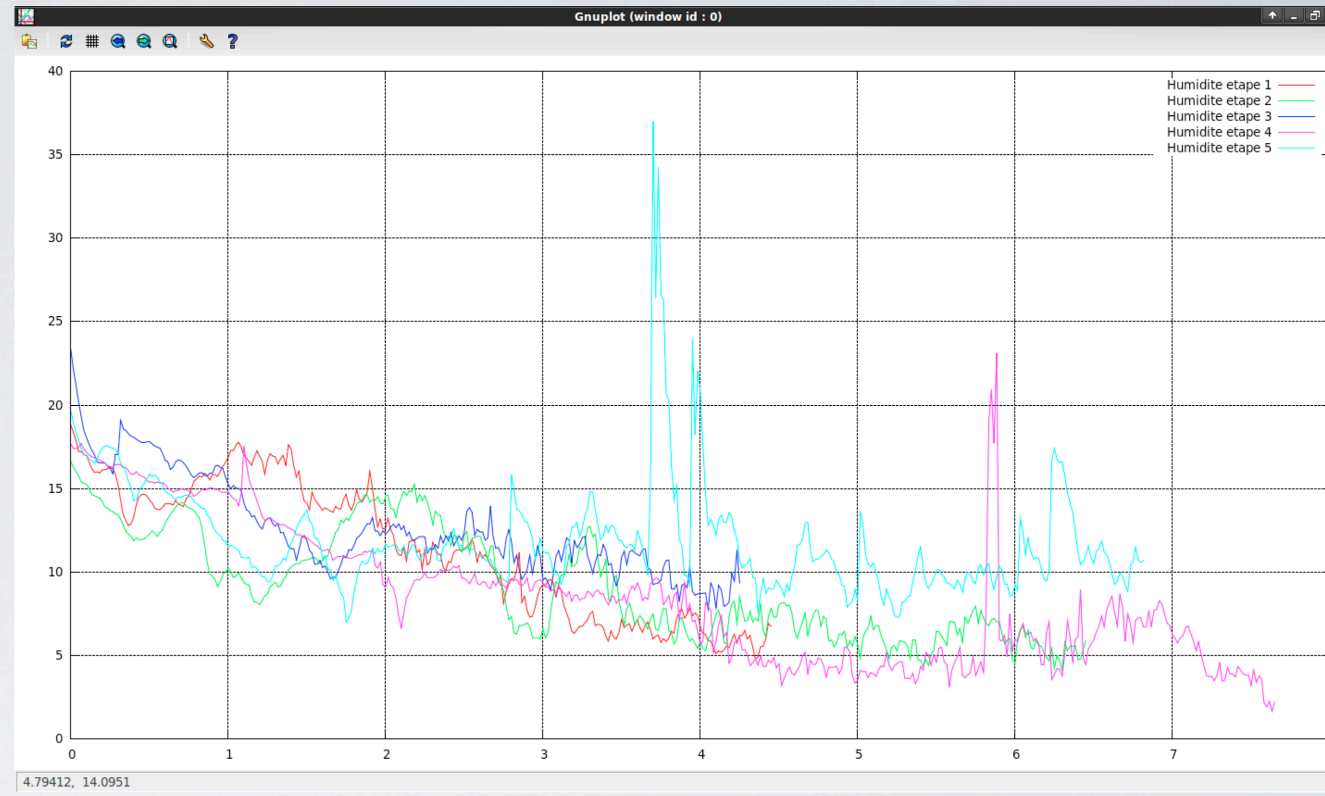


☺

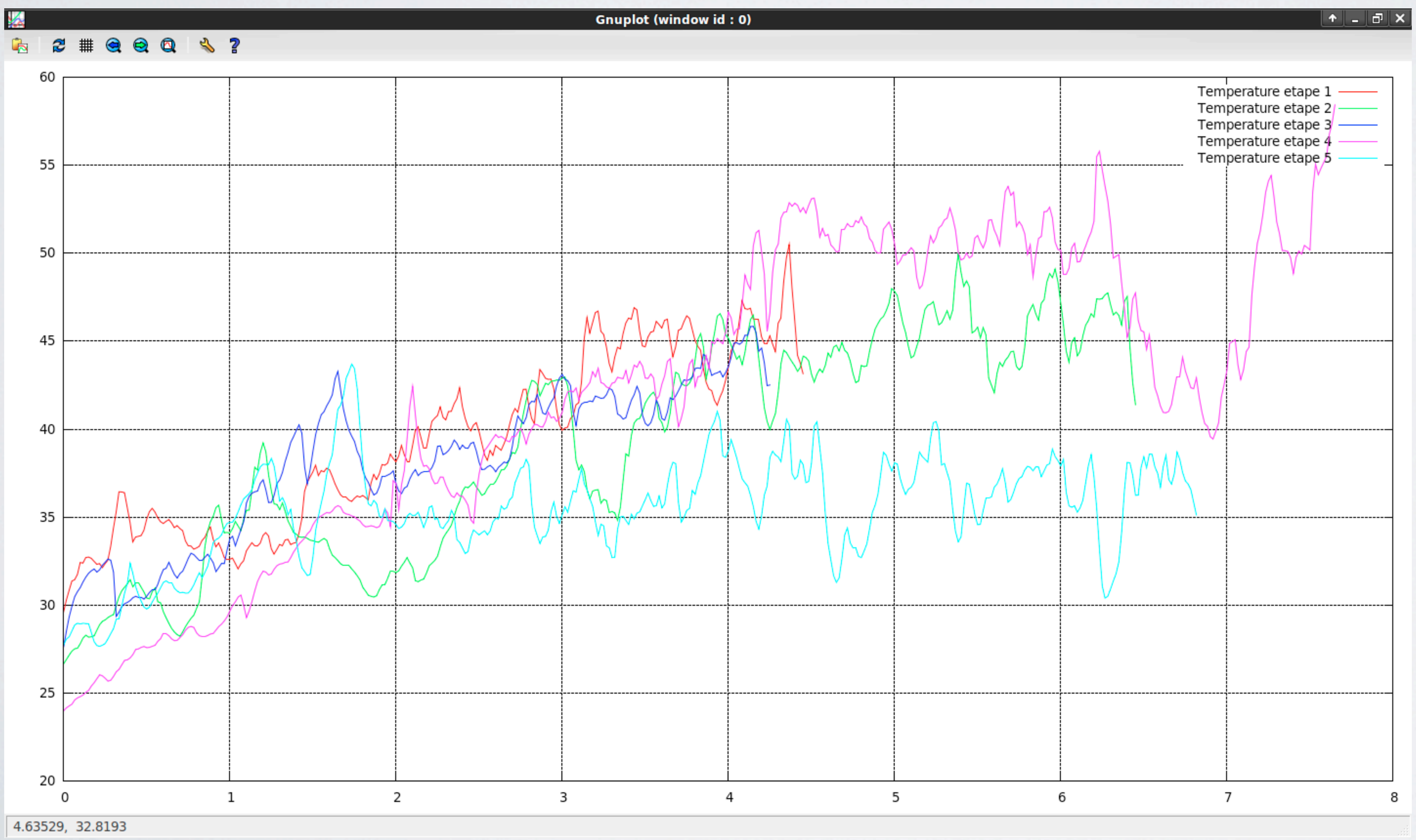
Battery profile was well managed



Some data



Gnuplot (window id : 0)
Humidite etape 1
Humidite etape 2
Humidite etape 3
Humidite etape 4
Humidite etape 5
4.79412, 14.0951



Gnuplot (window id : 0)
Temperature etape 1
Temperature etape 2
Temperature etape 3
Temperature etape 4
Temperature etape 5
4.63529, 32.8193

Clearly enough data to analyze !

Race stage	Functional nodes
1	1, 3, 8, 9, 10, 12, 19, 14, 15
2	1, 3, 9, 10, 12
3	12
4	7, 12, 19
5	3, 7, 12, 19
6	12

DATA ANALYSIS

Original objectives :

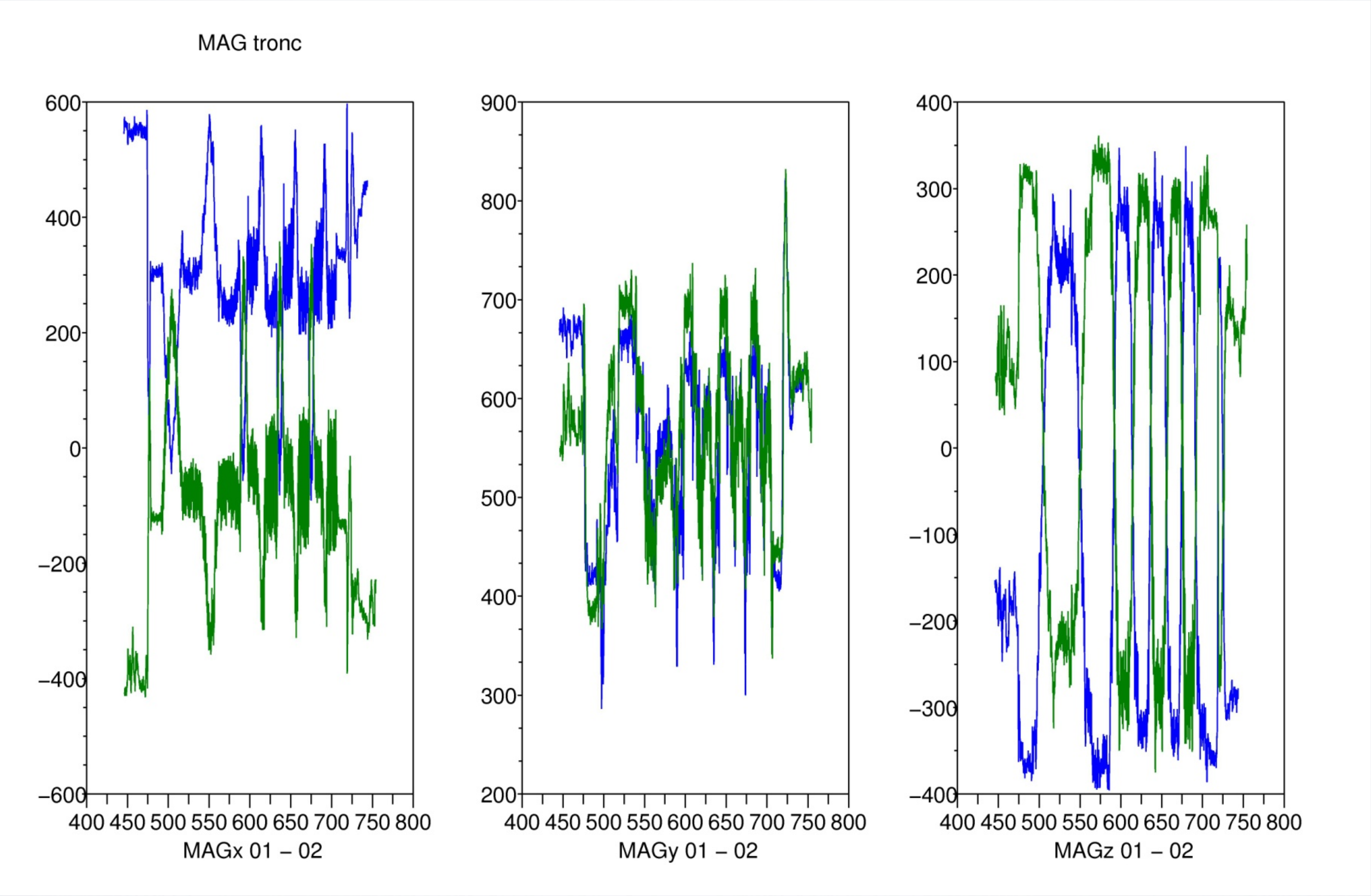
- Movement segmentation
- Determination of qualitative & quantitative parameters
  - on the movement
  - on the subject
  - on the environment

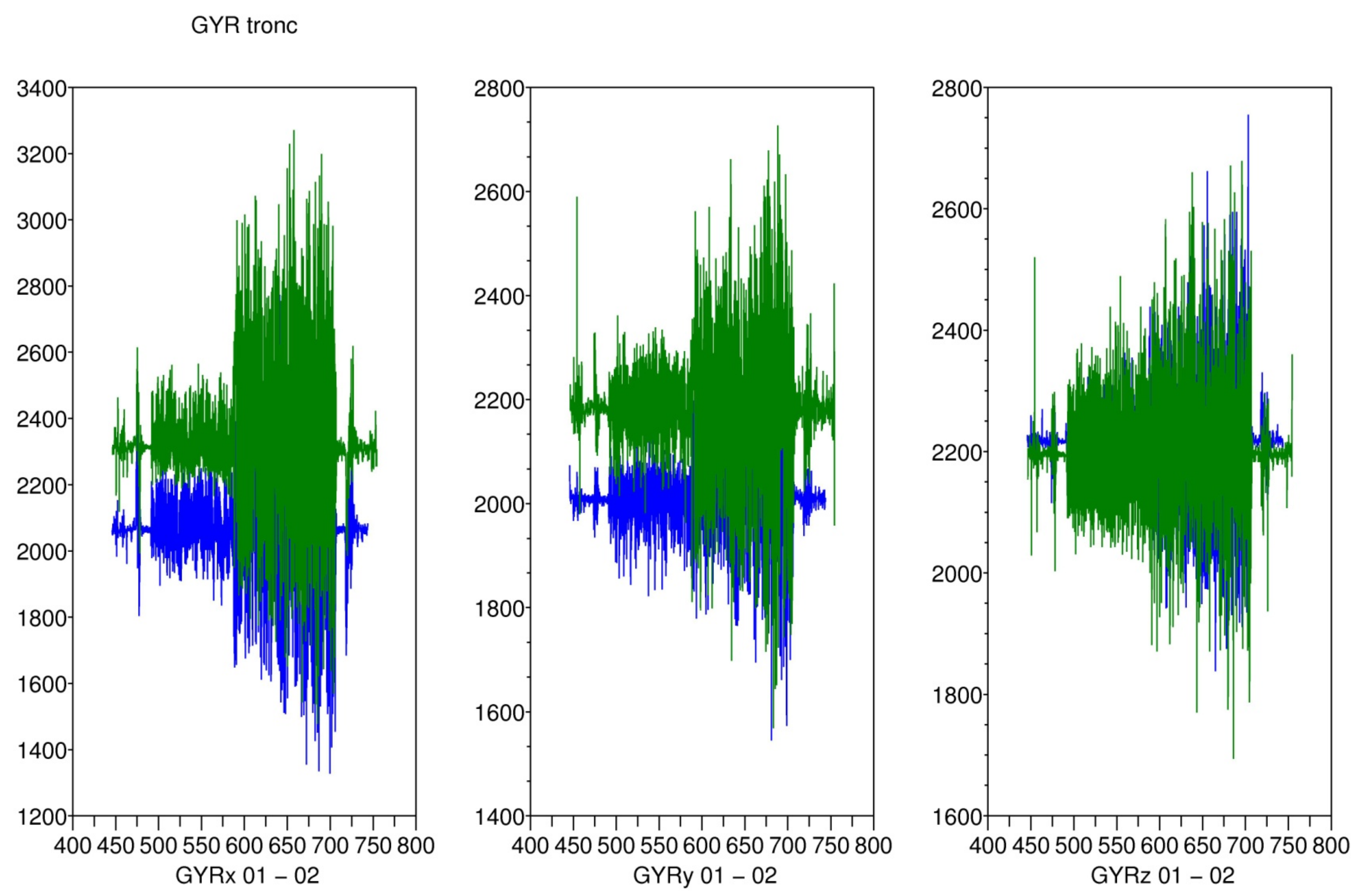
OFFLINE ANALYSIS !

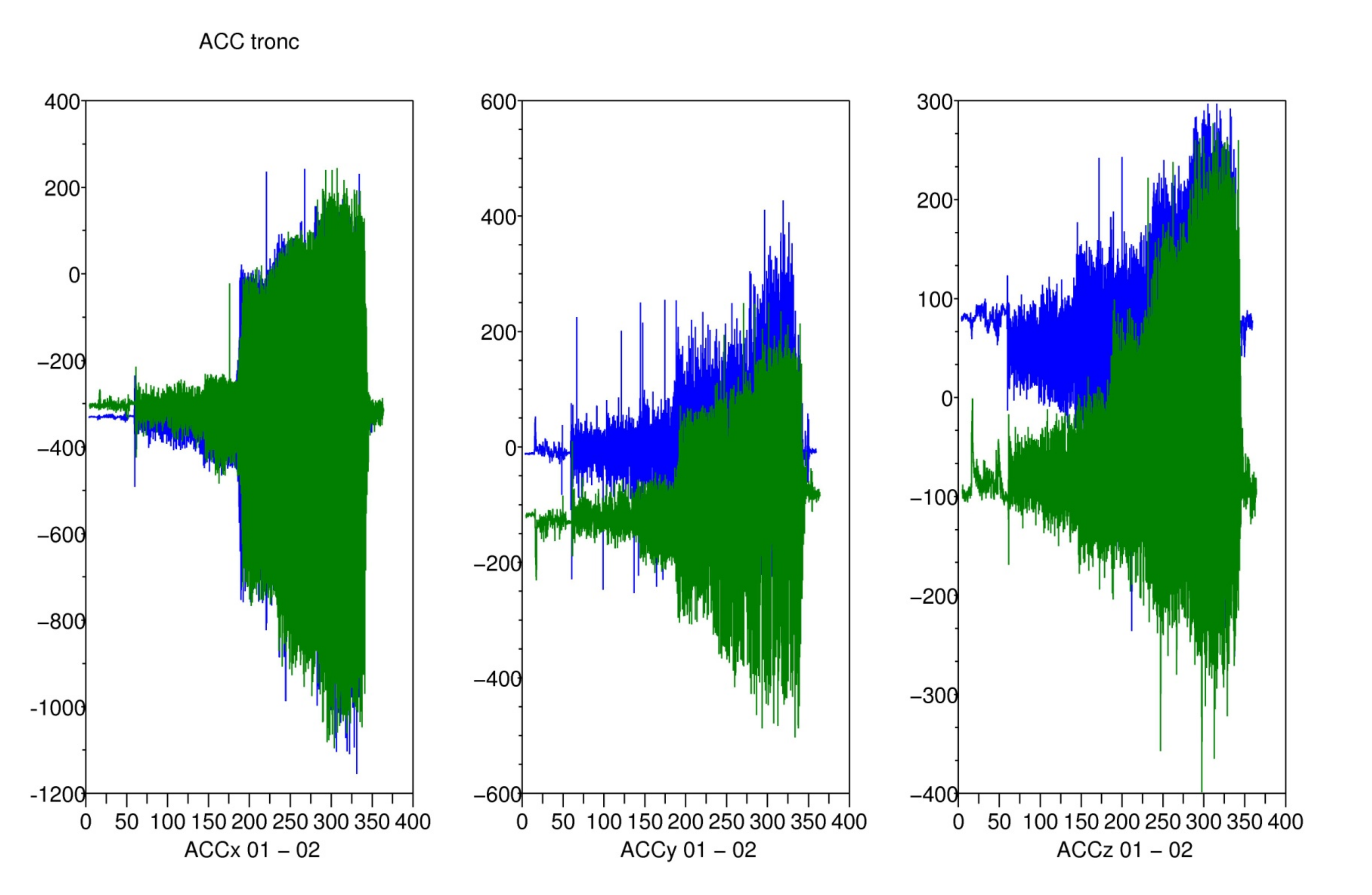
Examples :

- Segmentation & classification
  - walk vs run vs stop
  - fast vs slow
- Descent vs ascent
- Hard ground vs soft ground
- Average speed, instantaneous speed
- Back angle, gait analysis
- Foot movement and pressure in shoes
- Correlation with physical and environmental parameters

EVERYTHING WE CAN !


MAG tronc
600
400
200
0
−200
−400
−600
400 450 500 550 600 650 700 750 800
MAGx 01 − 02
900
800
700
600
500
400
300
200
400 450 500 550 600 650 700 750 800
MAGy 01 − 02
400
300
200
100
0
−100
−200
−300
−400
400 450 500 550 600 650 700 750 800
MAGz 01 − 02


GYR tronc
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
400 450 500 550 600 650 700 750 800
GYRx 01 – 02
2800
2600
2400
2200
2000
1800
1600
1400
400 450 500 550 600 650 700 750 800
GYRy 01 – 02
2800
2600
2400
2200
2000
1800
1600
400 450 500 550 600 650 700 750 800
GYRz 01 – 02



ACC tronc
400
200
0
−200
−400
−600
−800
-1000
-1200
0 50 100 150 200 250 300 350 400
ACCx 01 − 02
600
400
200
0
−200
−400
−600
0 50 100 150 200 250 300 350 400
ACCy 01 − 02
300
200
100
0
−100
−200
−300
−400
0 50 100 150 200 250 300 350 400
ACCz 01 − 02

3-axis accelerometer, 100Hz, 6bits

3-axis gyrometer, 100Hz, 6bits

3 axis magnetometer, 50Hz, 6bits

~175MB per IMU for a 32h race

13 IMU sensor nodes

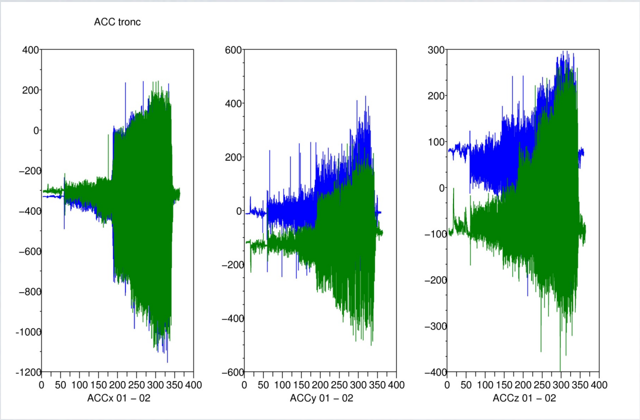
~2.275GB for IMU data only !

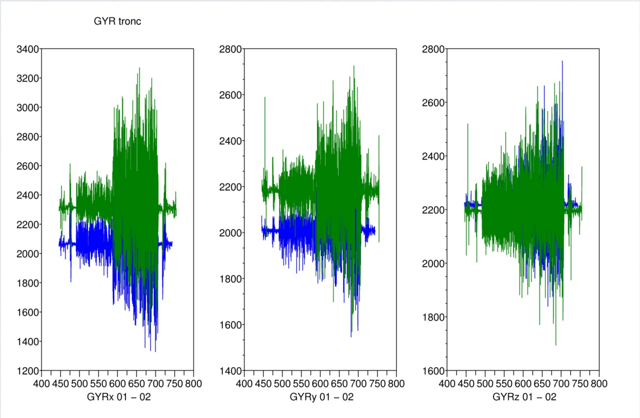
6-point insole, 100Hz, 12bits

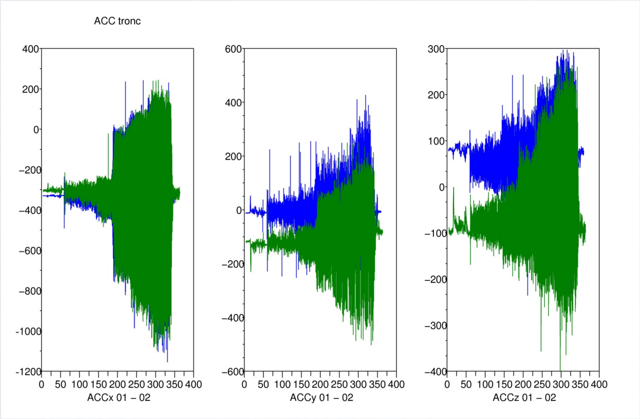
~104MB per insole for a 32h race

2 insole sensor nodes

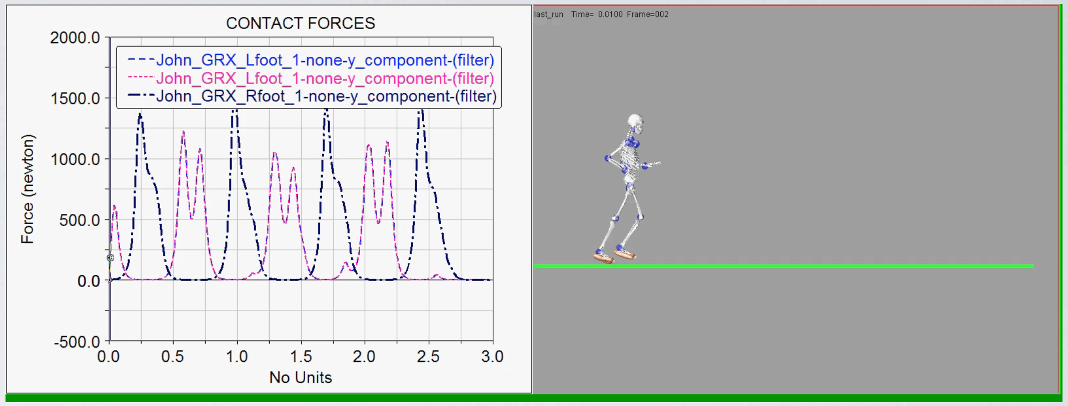
~207MB for insole data only !



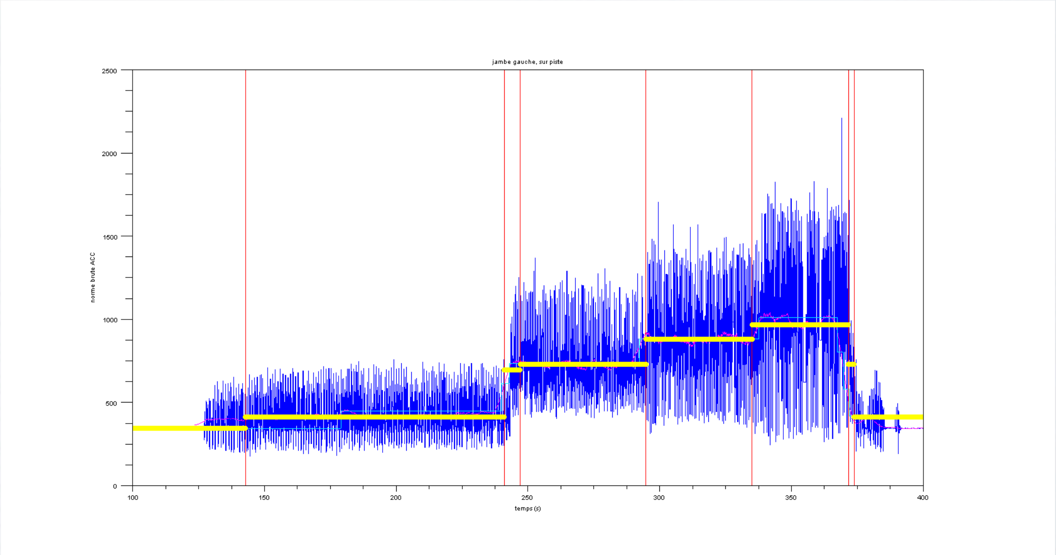




deterministic analysis e.g., gait reconstruction



statistical analysis e.g., run segmentation

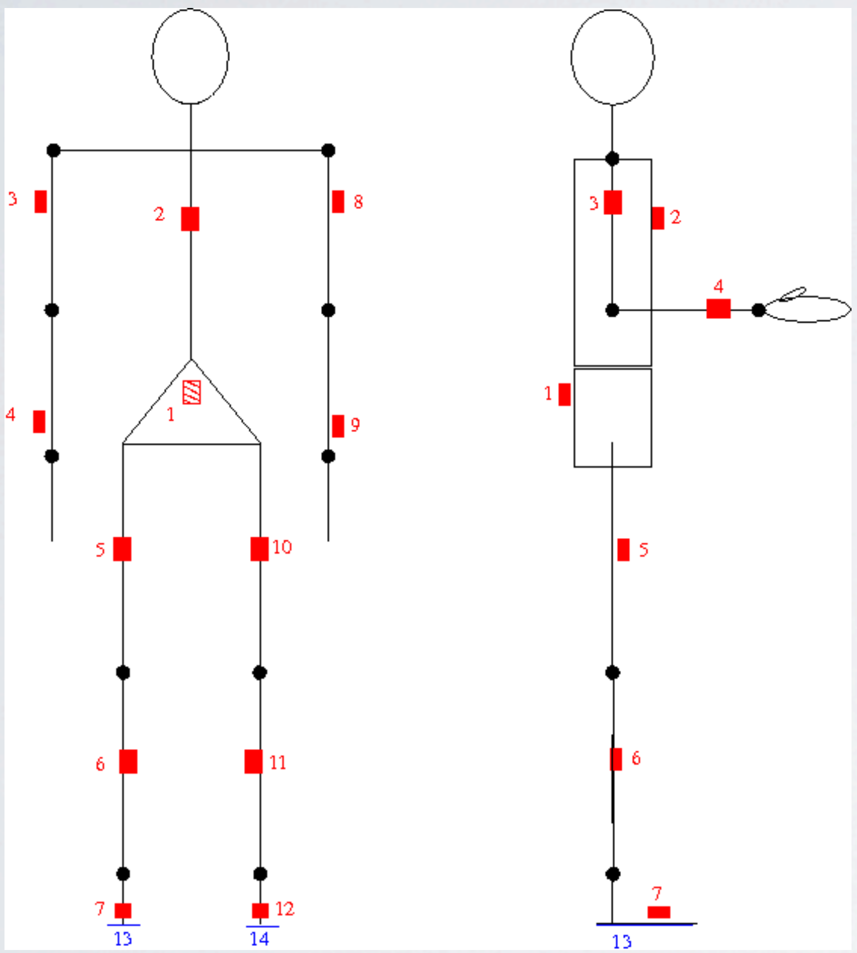


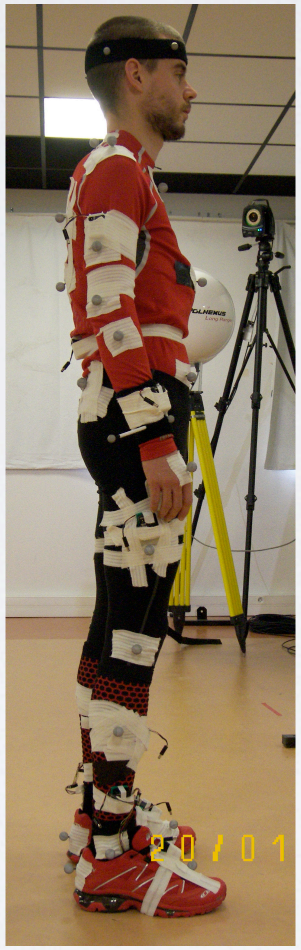
First experiments in laboratory and on the beach...

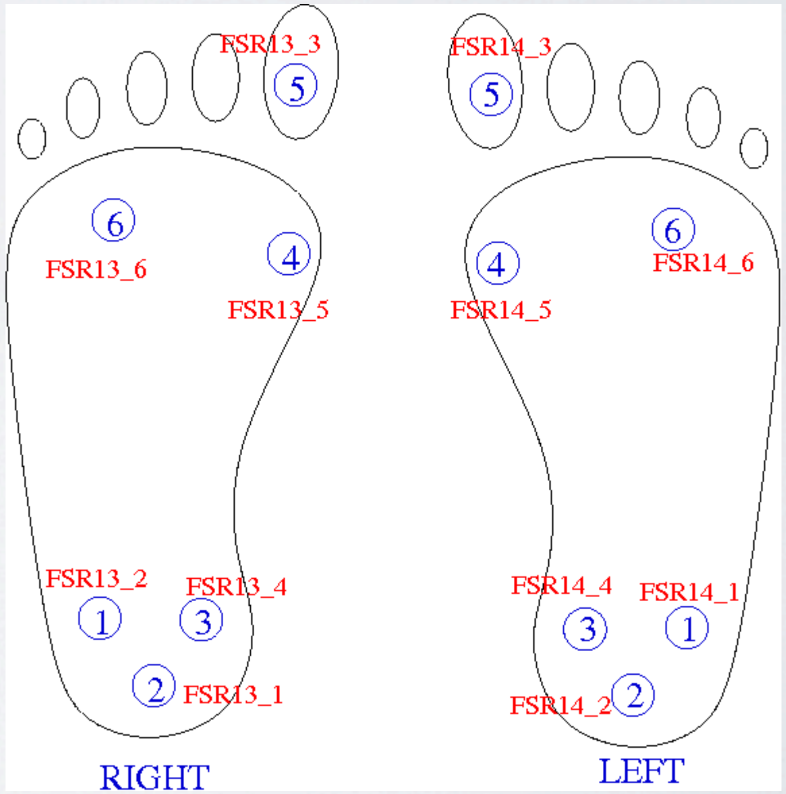
Janvier 2010, Montpellier

1. Moving walkway
2. Stadium
3. Beach of Palavas: sand, backpack, «real conditions»

Experimentations



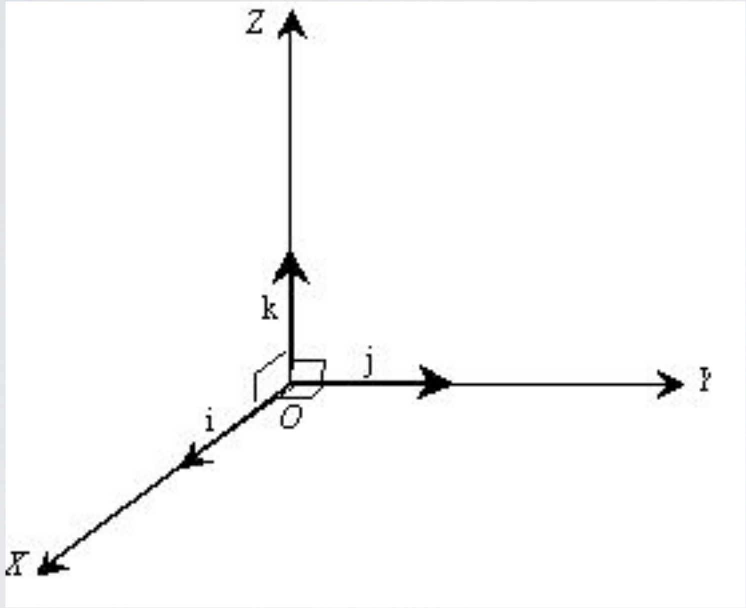




DATA ANALYSIS

deterministic analysis

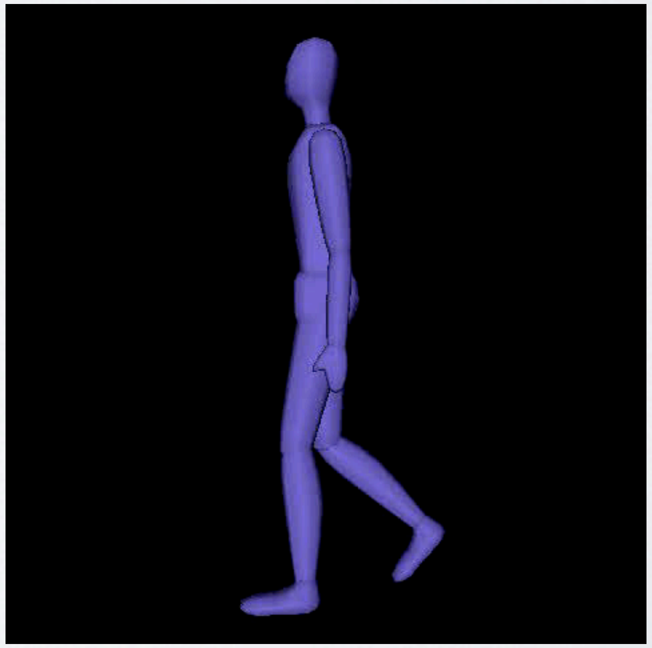
From mono IMU attitude reconstruction



Done !
ADT INRIA SENSAS

To multiple IMUs reconstruction

The HuMAnS Toolbox



At work ! ☺
ADT INRIA SENSAS

DATA ANALYSIS

statistical analysis

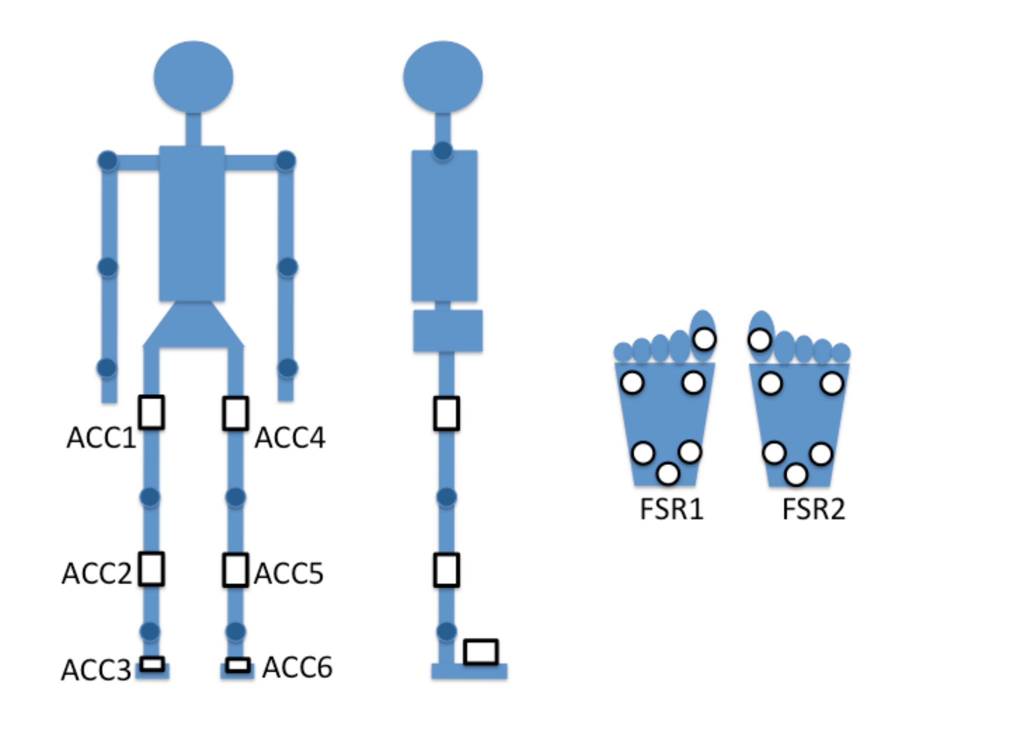
Objective :

Segment and classify the runner movement...

Based on accelerometer and pressure data

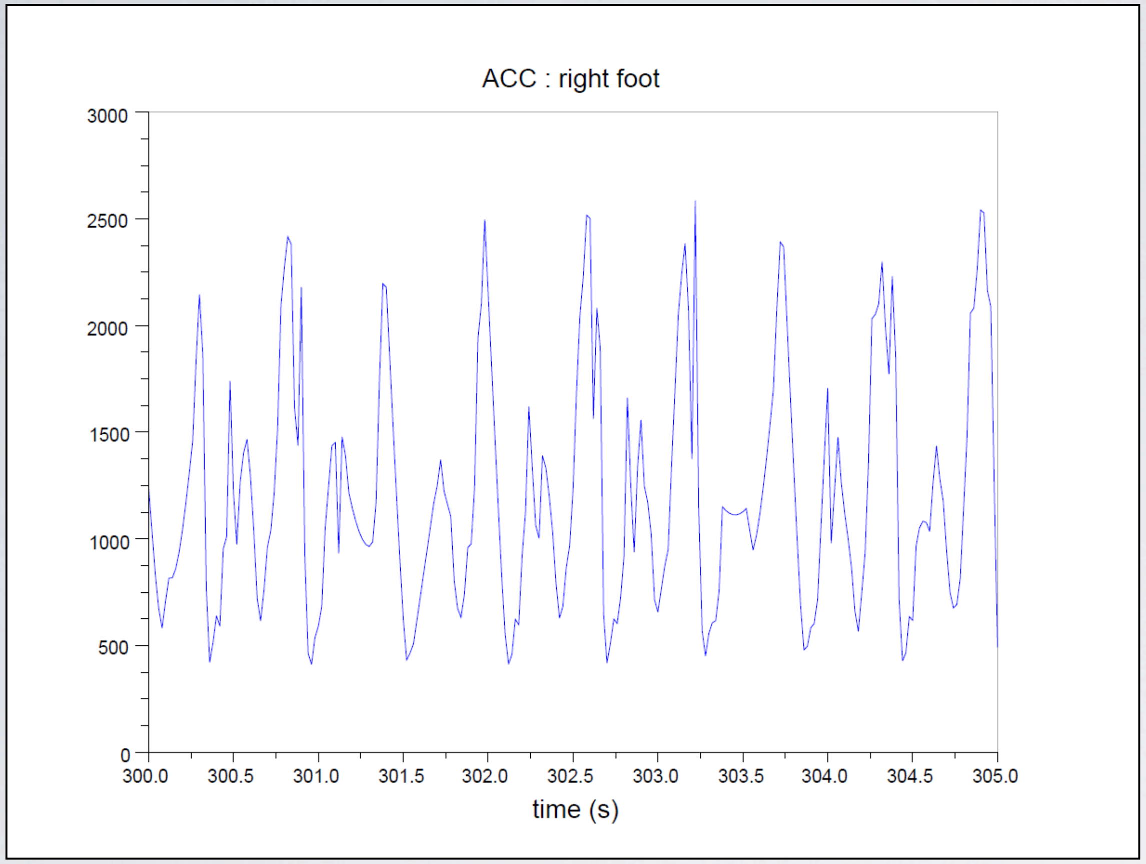
Without reconstructing the movement

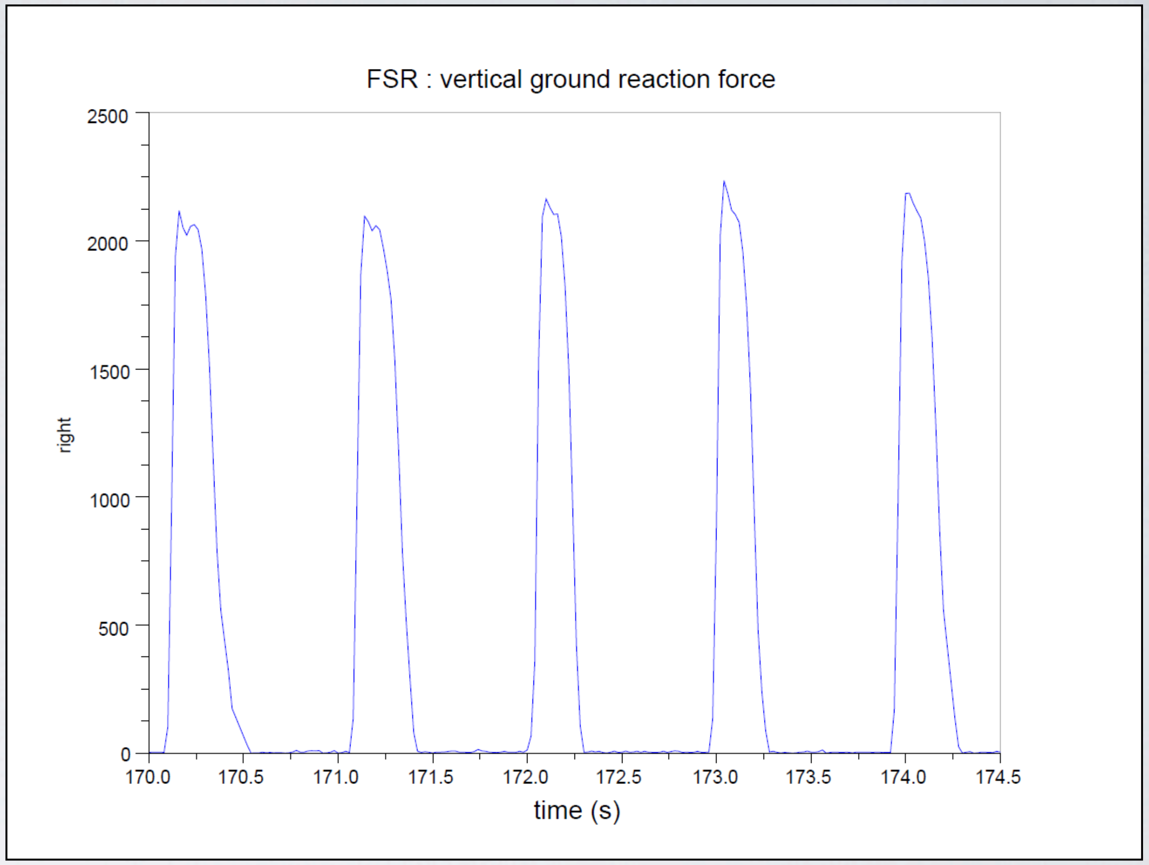
Sensors :

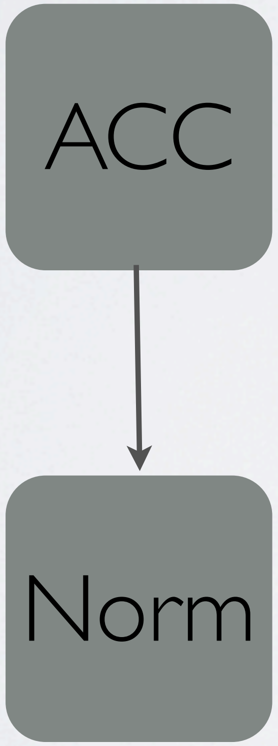


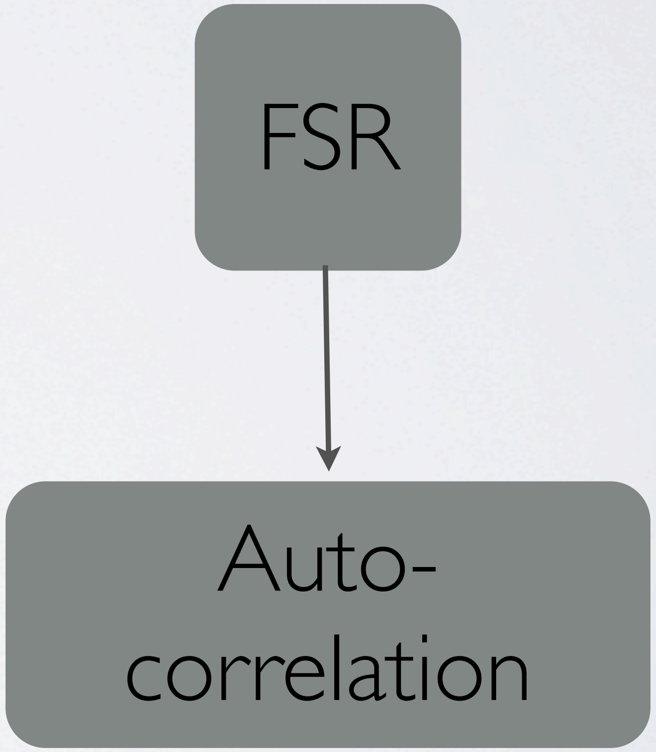
ACC : 3-axis accelerometers

FSR : sole pressure sensors


ACC : right foot
3000
2500
2000
1500
1000
500
0
300.0
300.5
301.0
301.5
302.0
302.5
303.0
303.5
304.0
304.5
305.0
time (s)

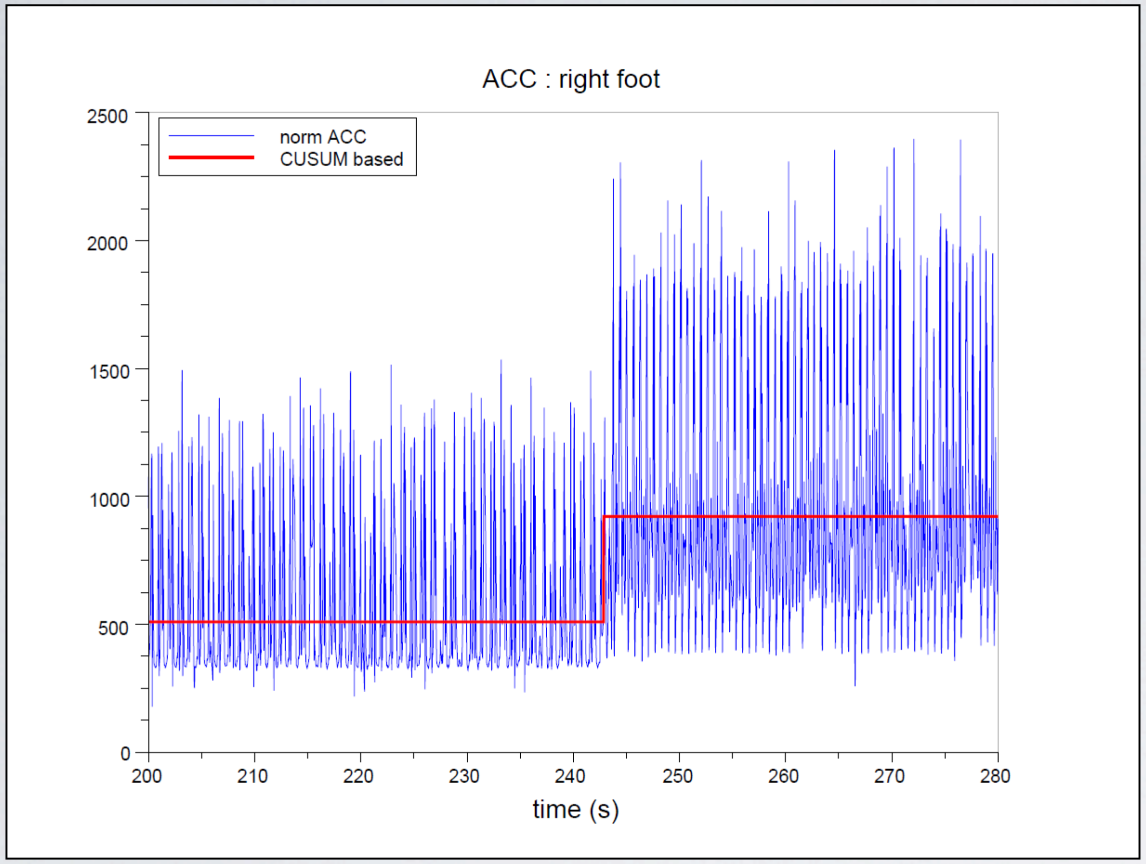

FSR : vertical ground reaction force
2500
2000
1500
1000
500
0
right
170.0
170.5
171.0
171.5
172.0
172.5
173.0
173.5
174.0
174.5
time (s)

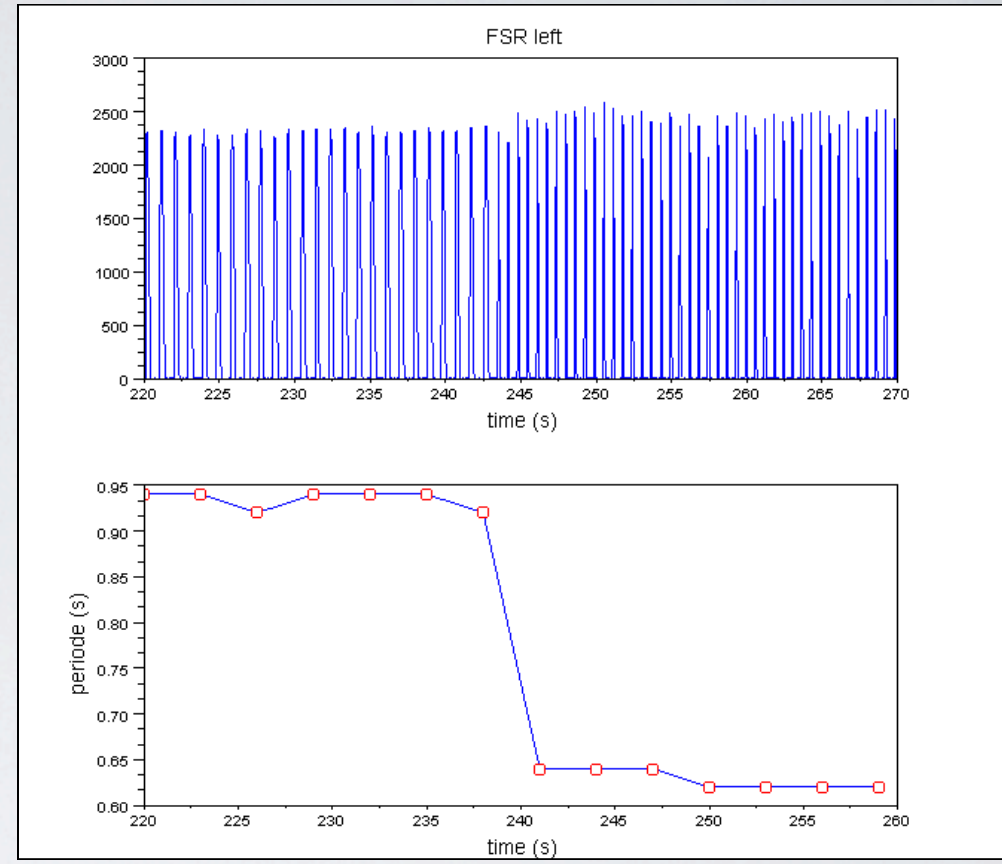

ACC
Norm


FSR
Auto-
correlation

Auto-correlation:

A FSR provides a measurement of the local value of the vertical component of the force field.
This signal is periodic during a steady-state locomotion.
The period is computed by sliding autocorrelation.





Norm

↓

CUMSUM based Jump detection

Auto-correlation

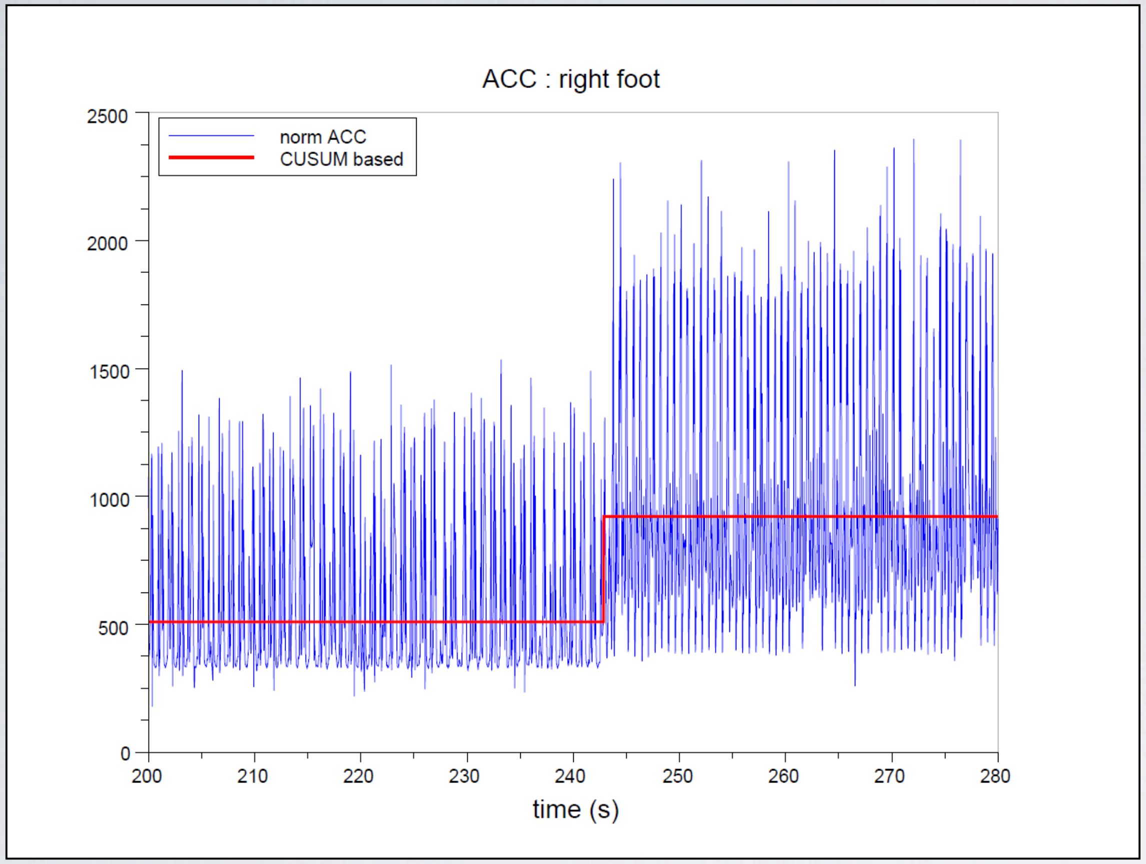
↓

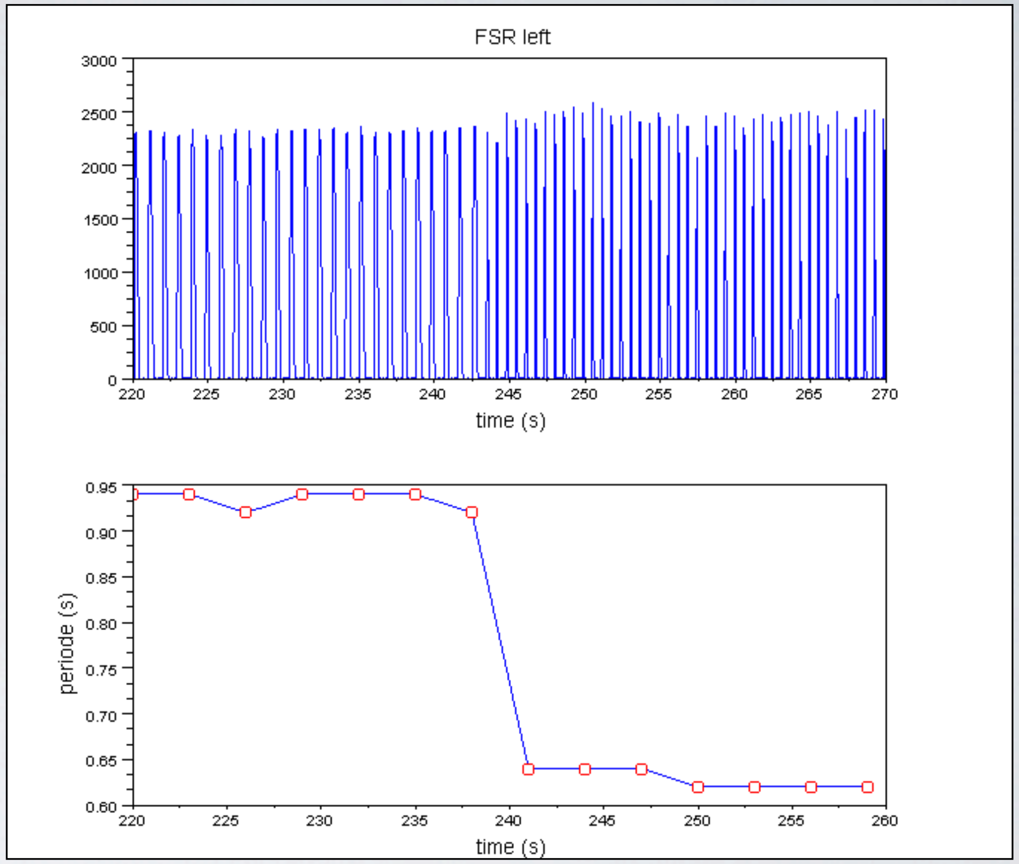
CUMSUM based Jump detection

Jump detection, intervals:

We assume that the norms of accelerometer signals and the frequency of impacts are composed of successive intervals within which the process is stationary, separated by abrupt jumps.
The detection of these jumps is performed using independent sequential tests of detection of abrupt changes [1].
A sequence of steady-state intervals is obtained for each sensor.

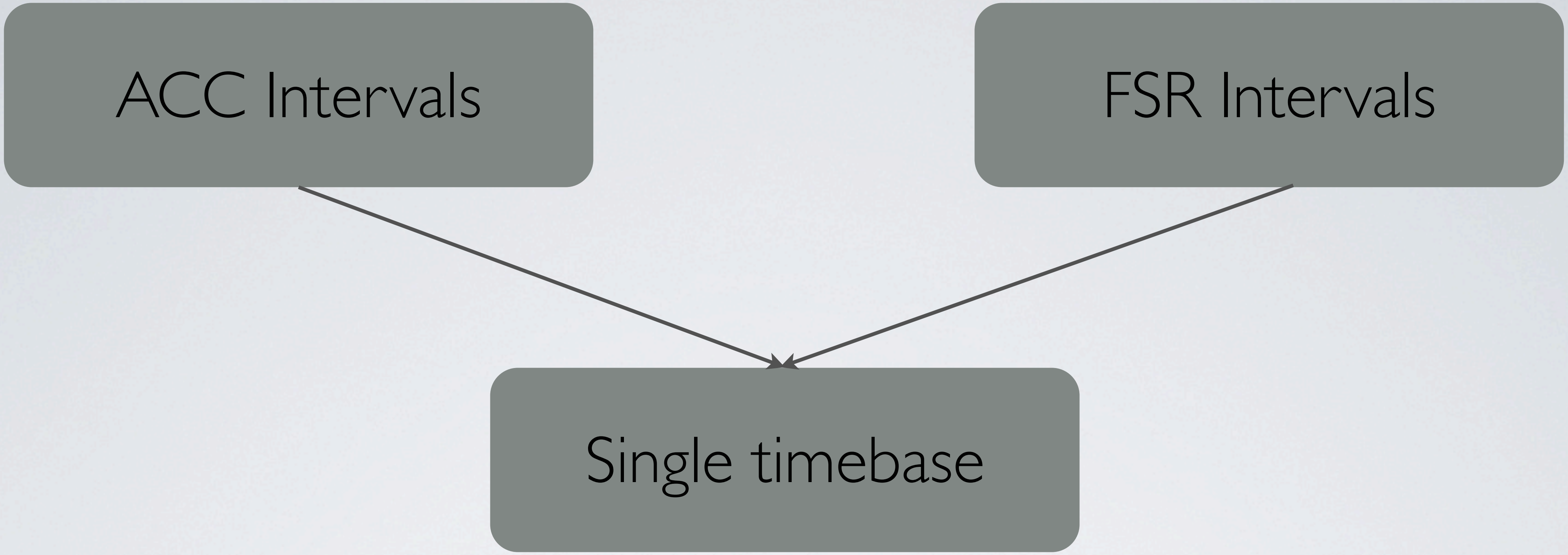
[1] M. Basseville and I.V. Nikiforov, Detection of abrupt changes - theory and application, Prentice Hall, Inc., 1993





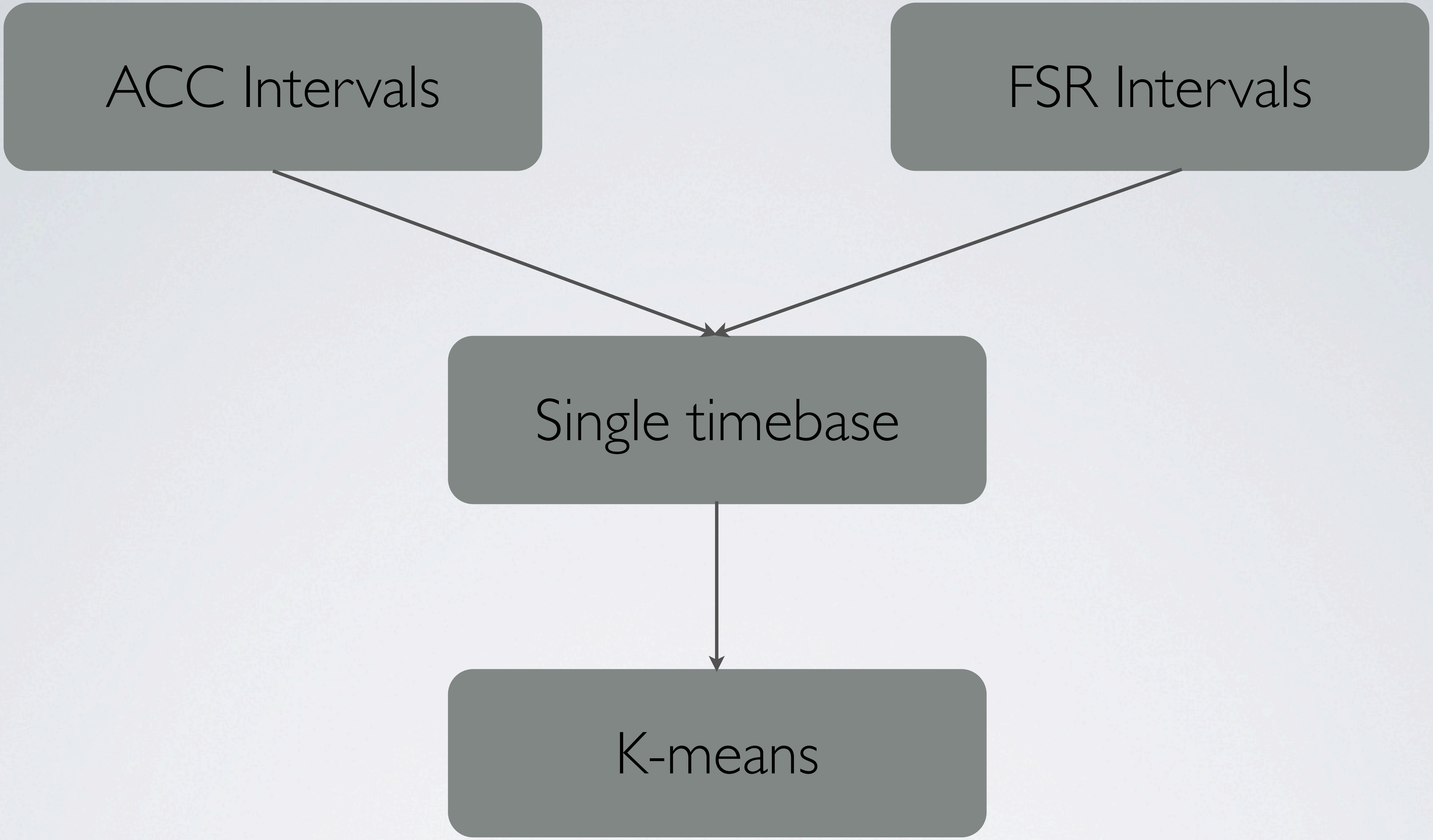
Norm → CUMSUM based Jump detection → ACC Intervals

Auto-correlation → CUMSUM based Jump detection → FSR Intervals


ACC Intervals
FSR Intervals
Single timebase

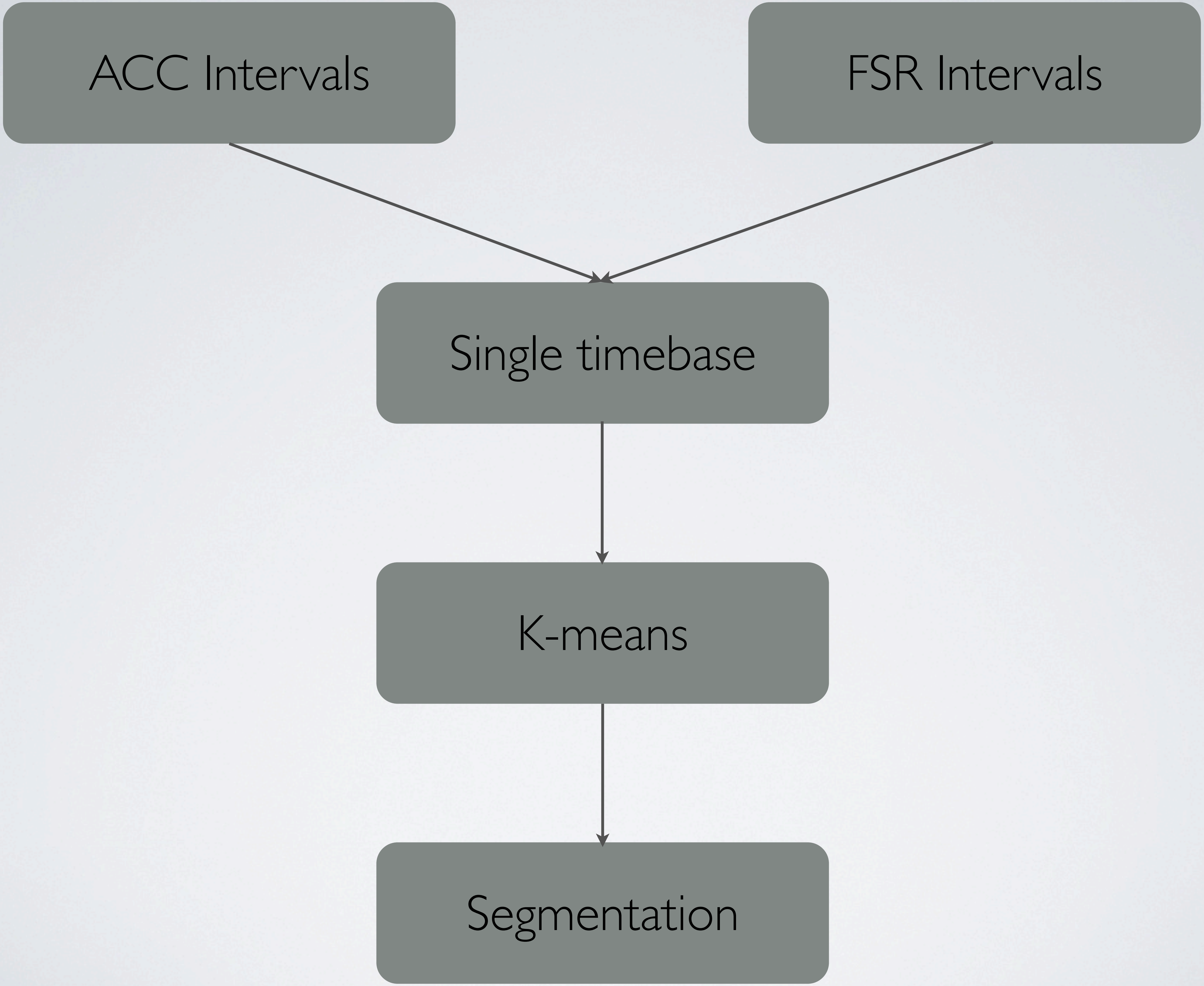
Single timebase:

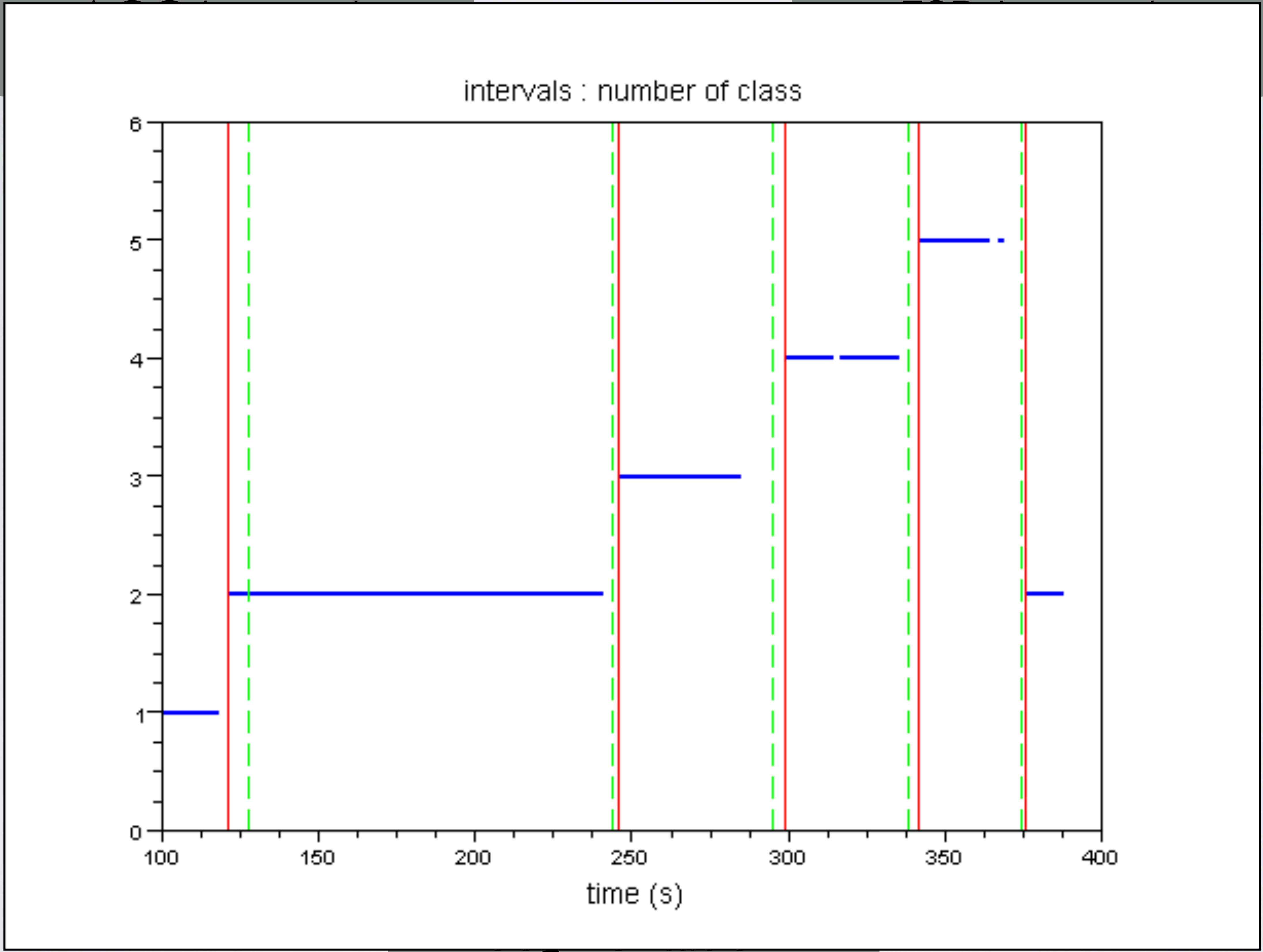
Intervals obtained for each sensor can be gathered as a one-dimensional ordered sequence.
By projecting all (or some selection of) the sequences of intervals on a single timebase, we get a one-dimensional ordered sequence of M intervals.

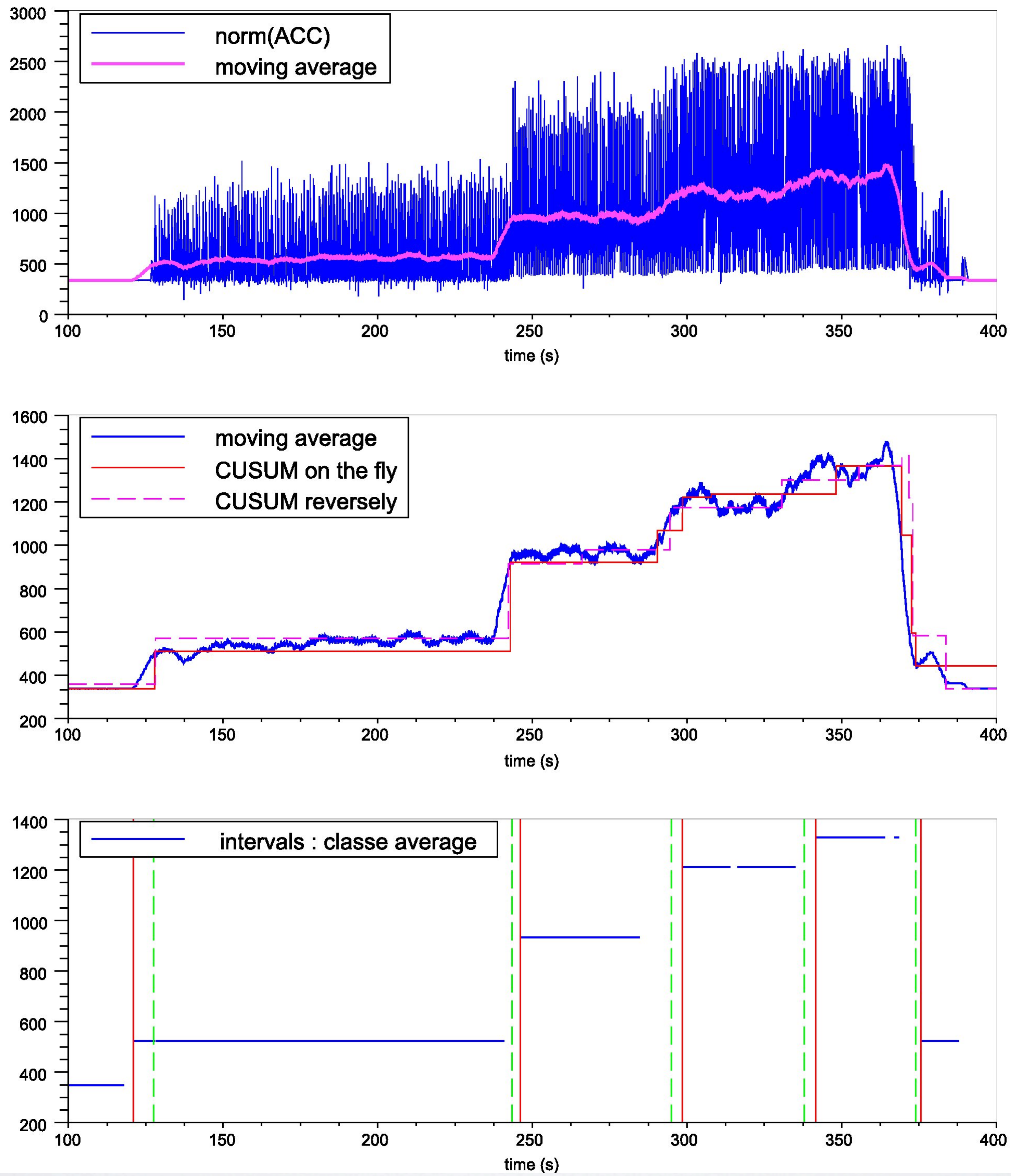

ACC Intervals
FSR Intervals
Single timebase
K-means

K-means:

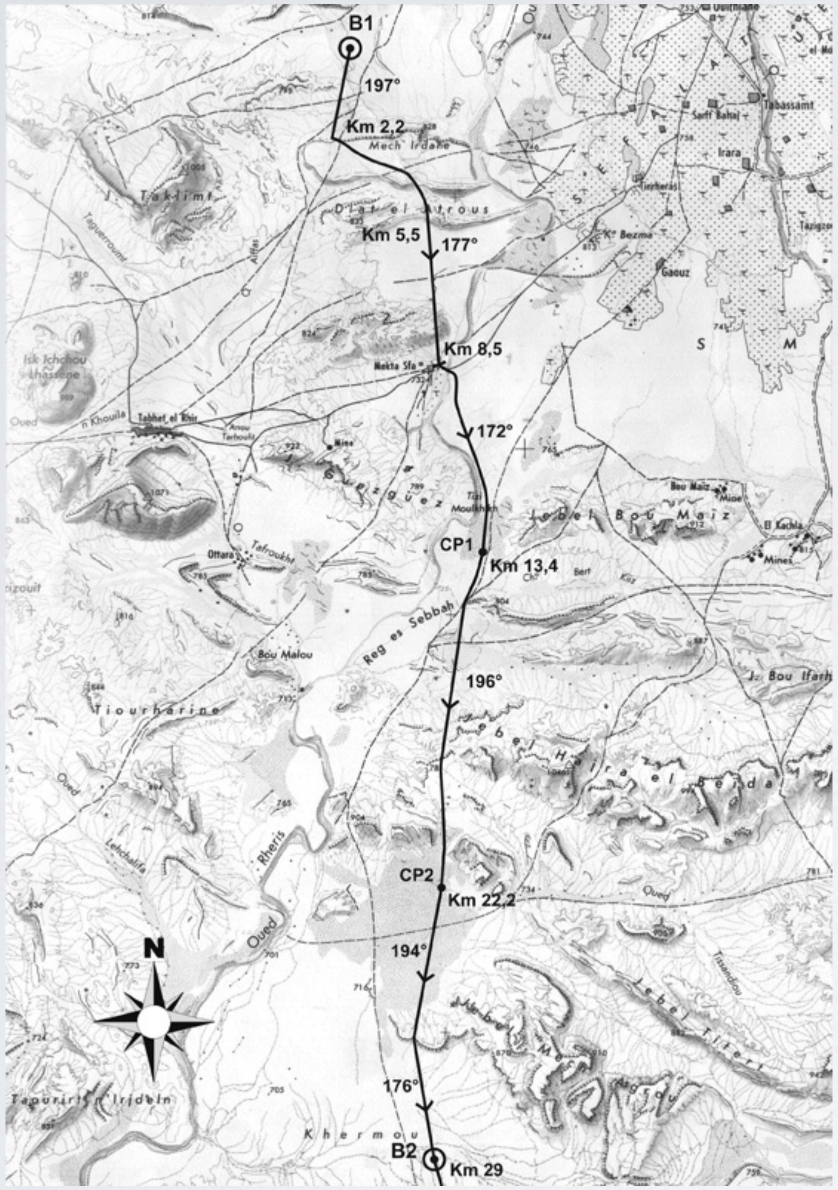
A simple classification method allows assigning each interval to one of the various walking and running defined classes.

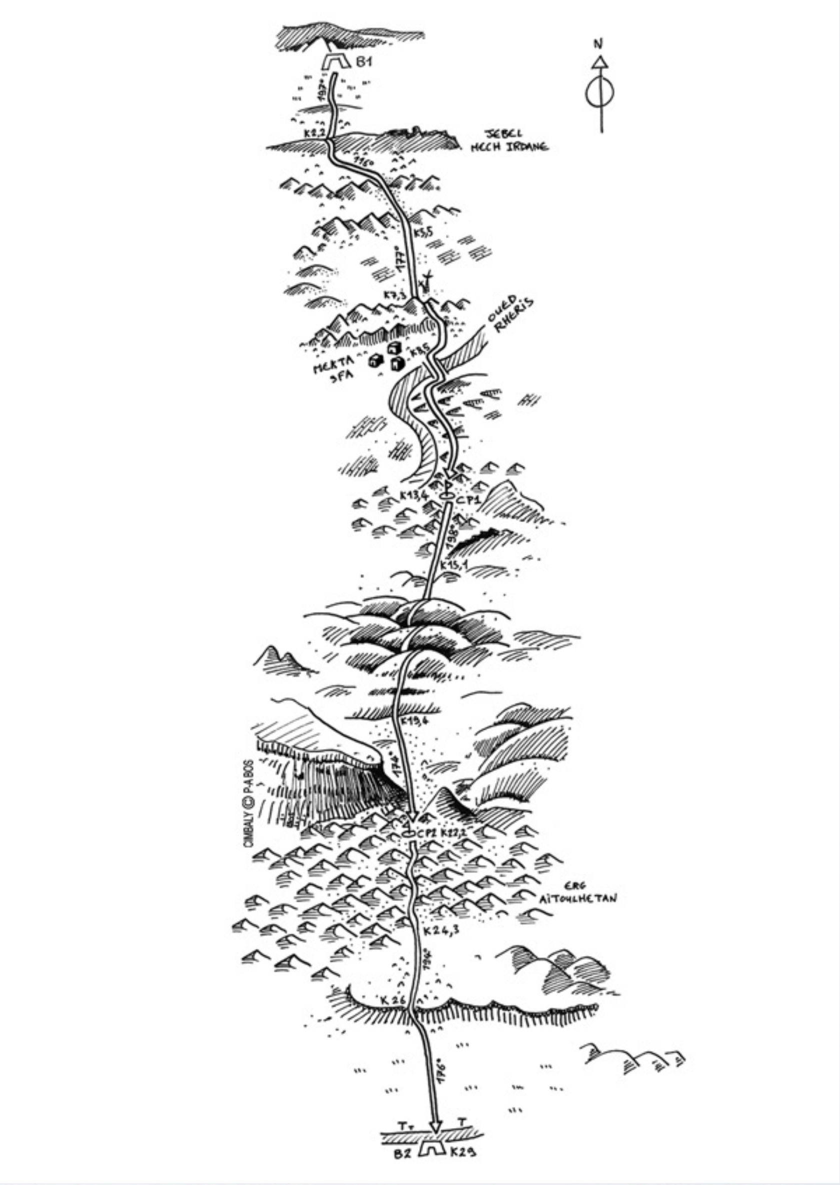

ACC Intervals
FSR Intervals
Single timebase
K-means
Segmentation

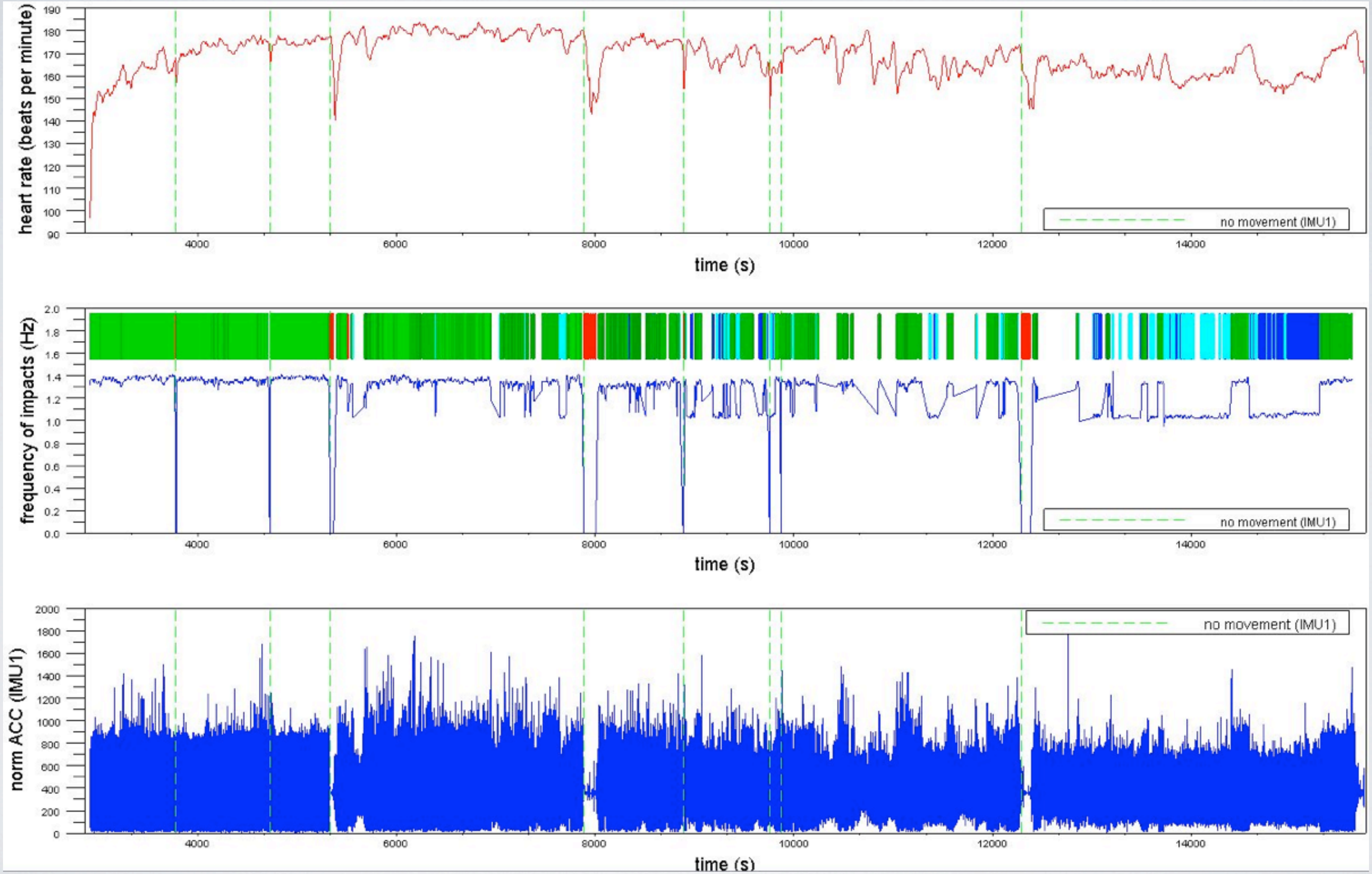

intervals : number of class
0
1
2
3
4
5
6
100
150
200
250
300
350
400
time (s)


norm(ACC)
moving average
3000
2500
2000
1500
1000
500
0
100
150
200
250
300
350
400
time (s)
moving average
CUSUM on the fly
CUSUM reversely
1600
1400
1200
1000
800
600
400
200
intervals : classe average

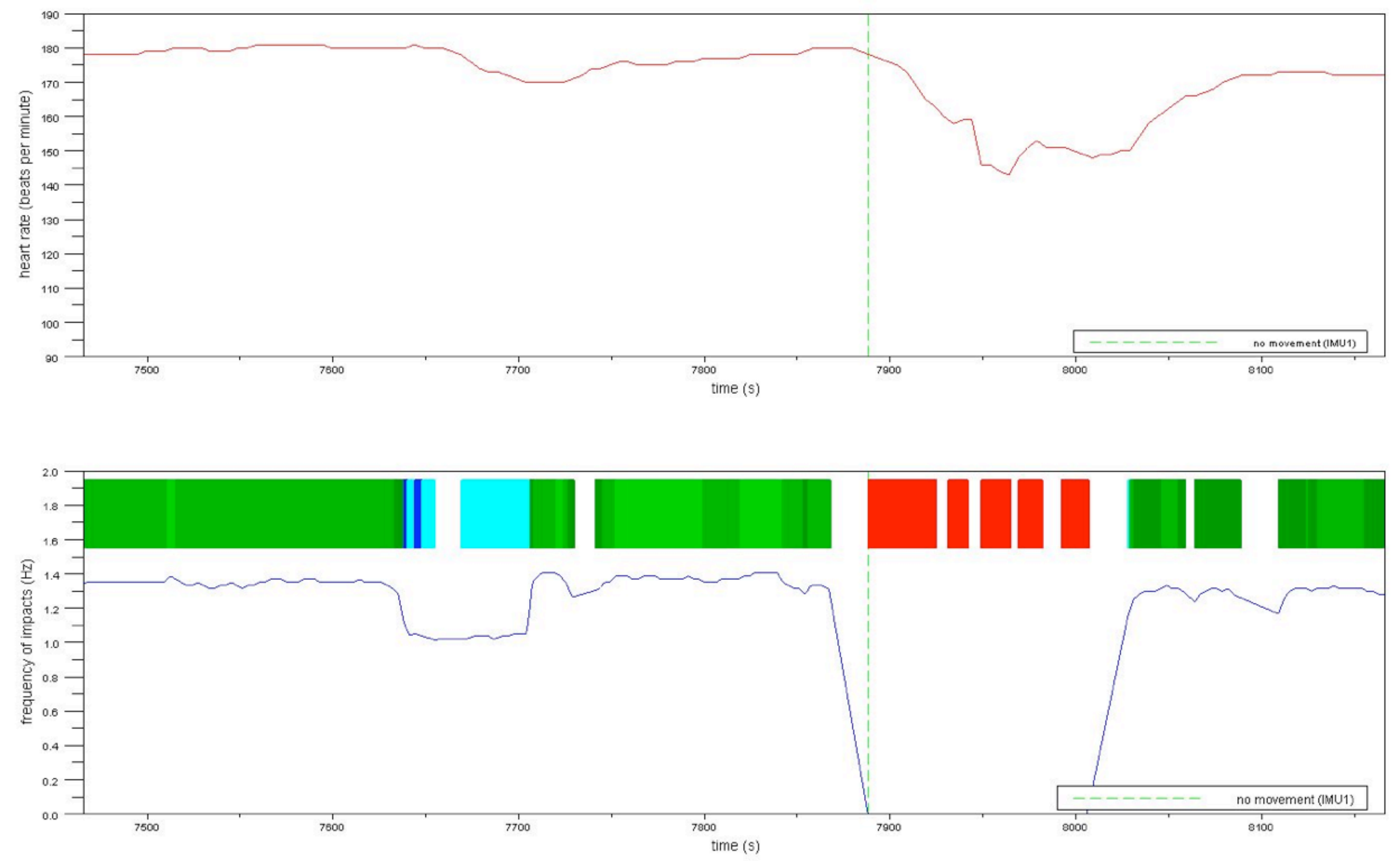
STAGE 1


B1
197°
Km 2,2
Km 5,5
177°
Km 8,5
172°
CP1
Km 13,4
196°
CP2
Km 22,2
194°
176°
N
B2
Km 29

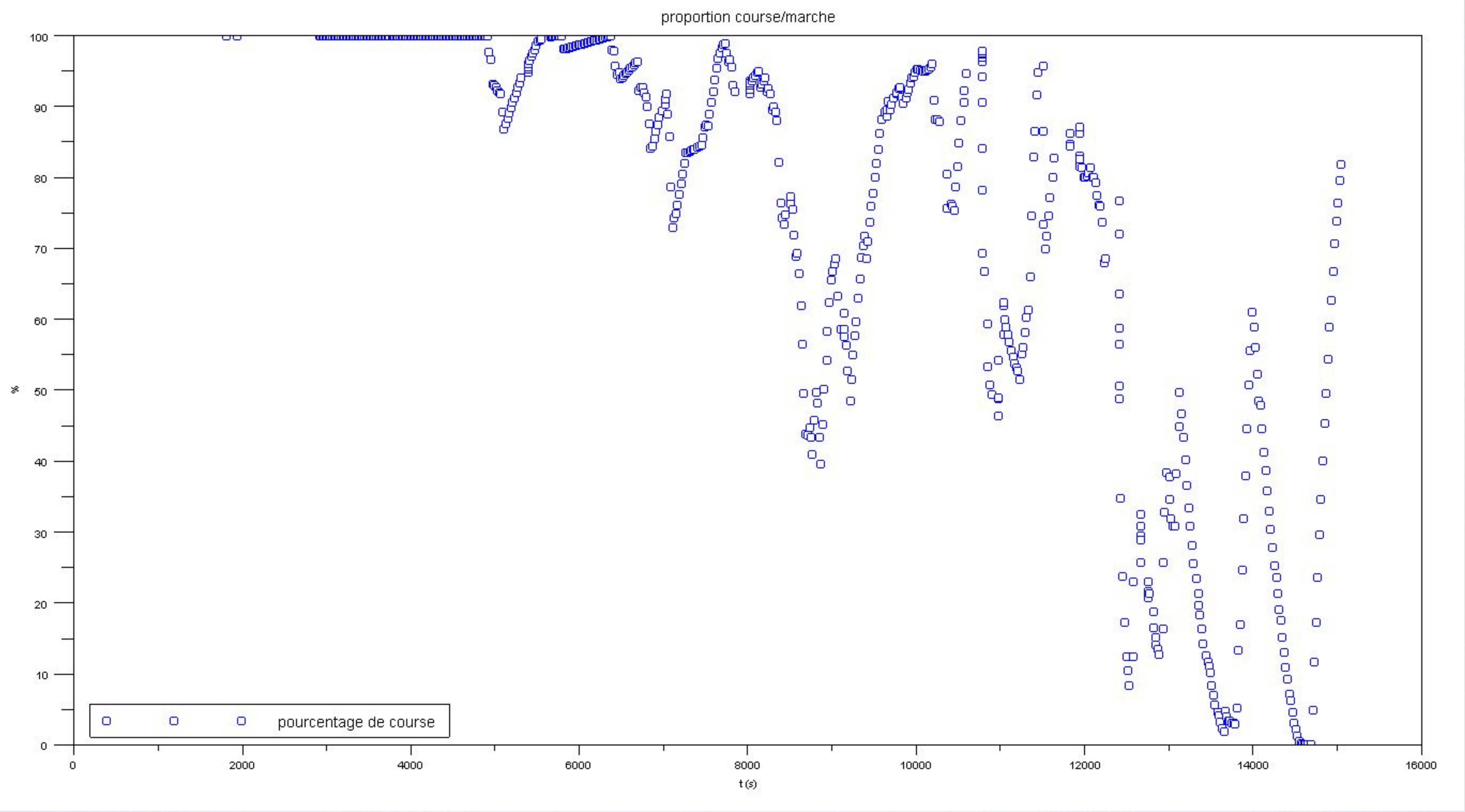

N
B1
JEBEL MECH IRDANE
OUED RHERIS
MEKTA SFA
ERG AÏTOULHETAN
B2
K29



heart rate (beats per minute)
no movement (IMU1)
time (s)
frequency of impacts (Hz)
no movement (IMU1)
time (s)
norm ACC (IMU1)
no movement (IMU1)
time (s)

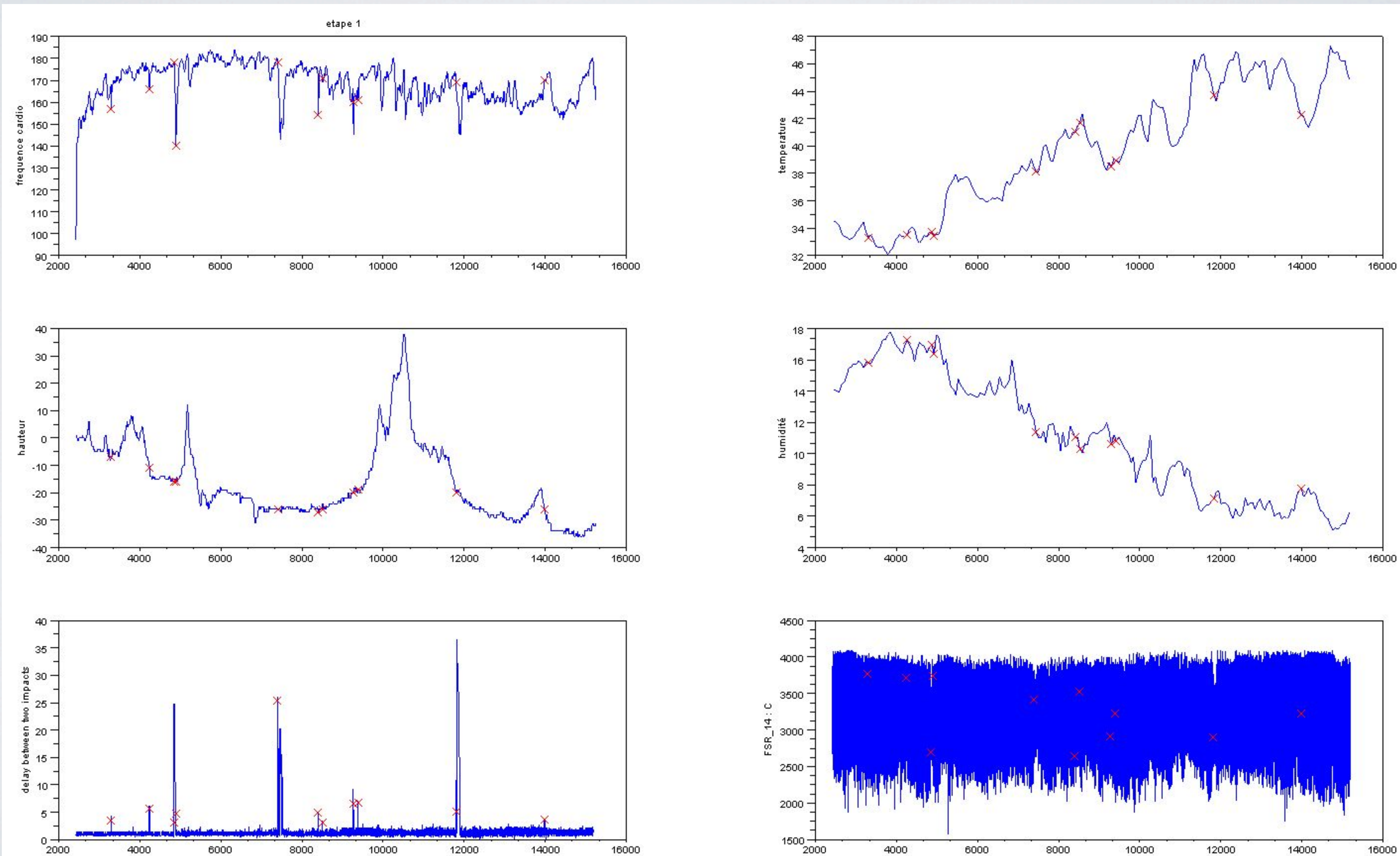


heart rate (beats per minute)
190
180
170
160
150
140
130
120
110
100
90
7500
7600
7700
7800
7900
8000
8100
time (s)
no movement (IMU1)
frequency of impacts (Hz)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
7500
7600
7700
7800
7900
8000
8100
time (s)
no movement (IMU1)



proportion course/marche
%
t (s)
pourcentage de course
0
10
20
30
40
50
60
70
80
90
100
0
2000
4000
6000
8000
10000
12000
14000
16000

Still a lot to do ! ☺



PERSPECTIVES

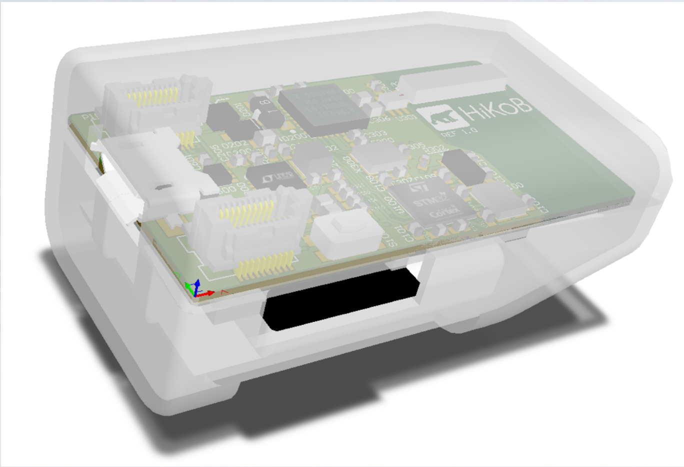
Advancing on data analysis

e.g. Multiple IMUs reconstruction

Offering software tools to manipulate IMU data

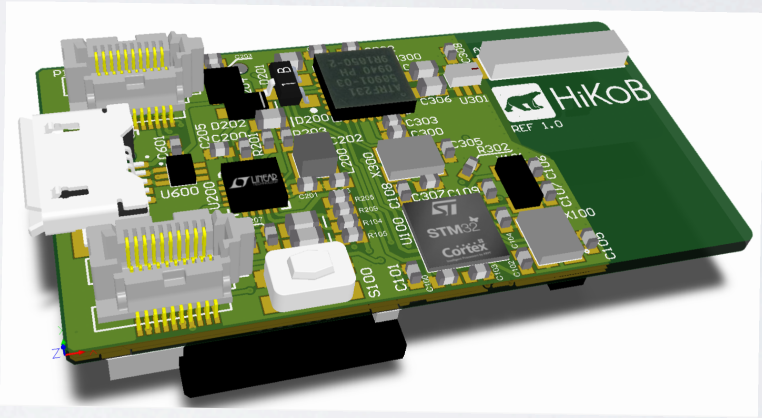
ADT SENSAS WP SENSBIO

VALORIZATION



Next generation sensor nodes

New sensors



HiKoB

HiKoB project

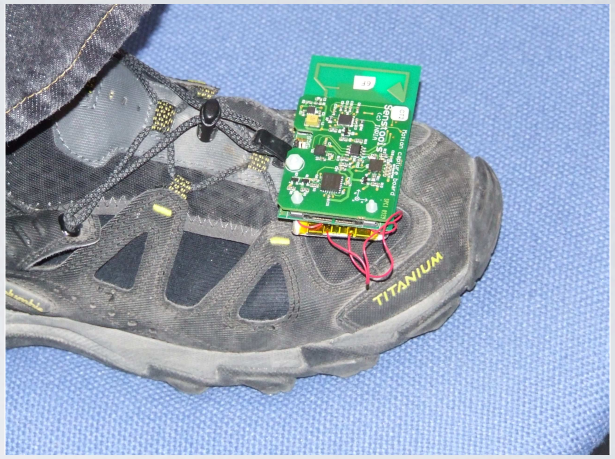
Collaborations

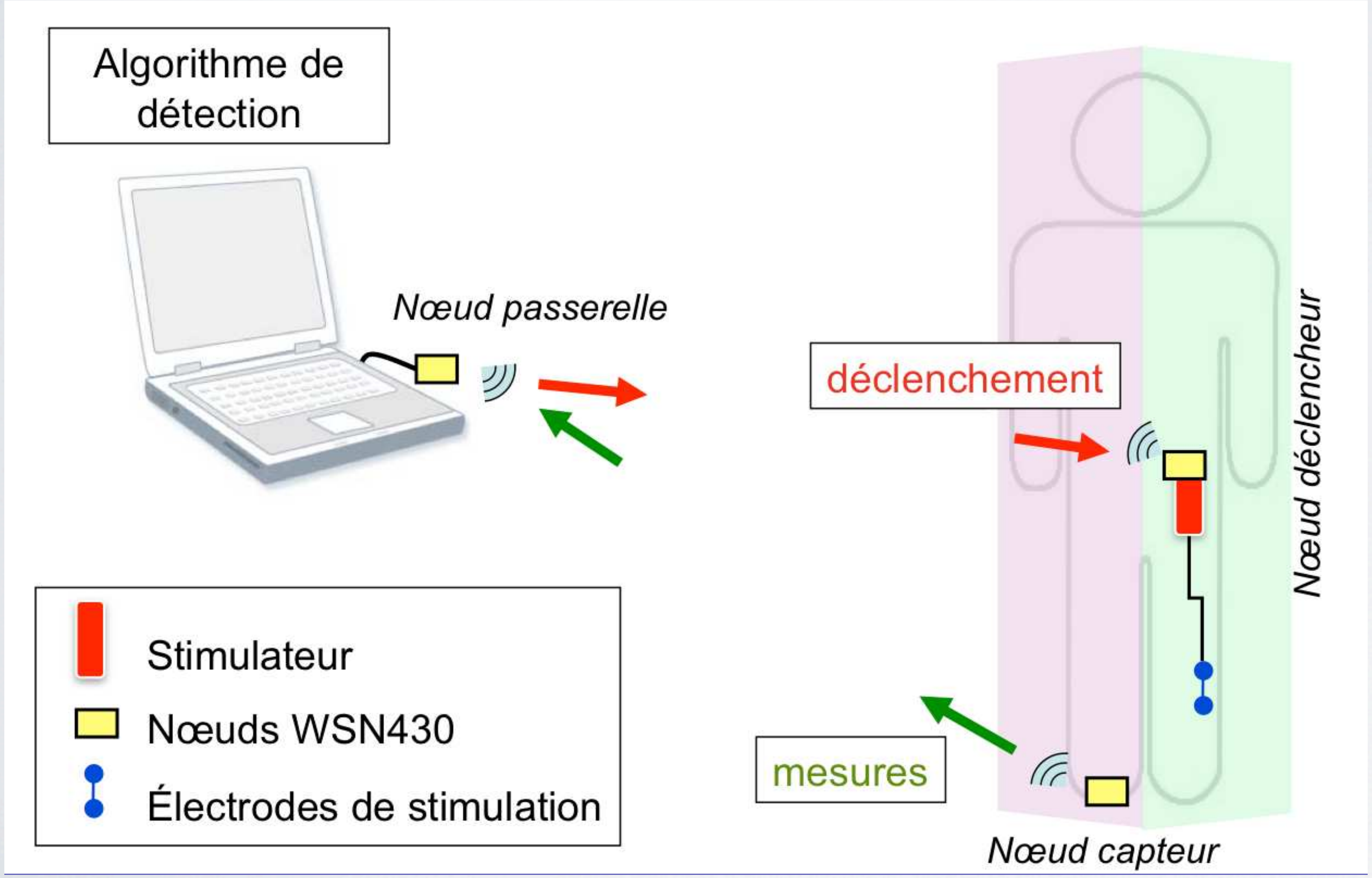
Sport with SALOMON

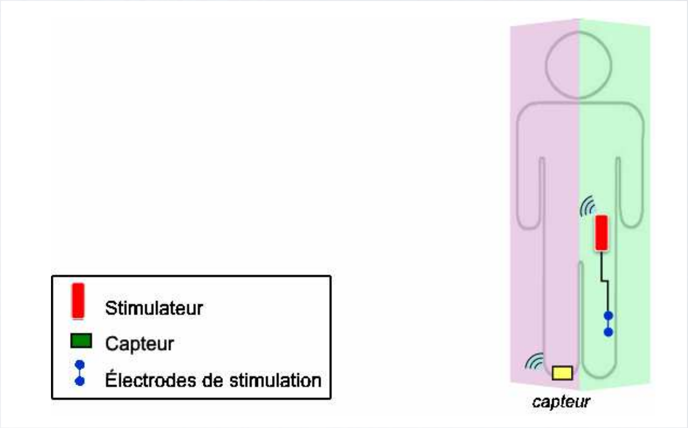
Functional rehabilitation with MASEA project (EPI DEMAR)

Biologging with CERFE, DEPE/IPHC

Functional rehabilitation with MASEA project (EPI DEMAR)

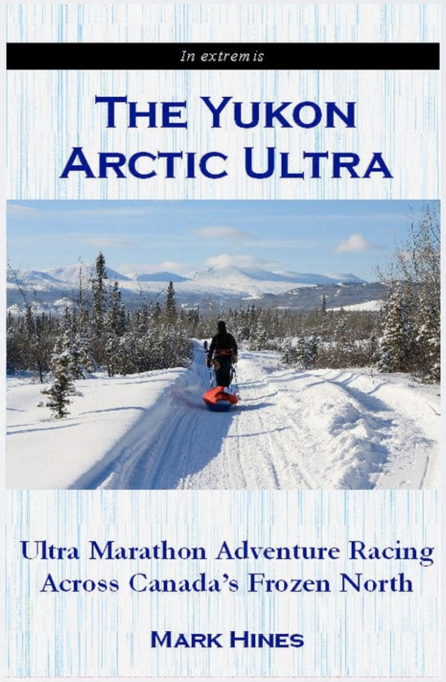






Experimentations to come ?

ULTRA-TRAIL® DU MONT-BLANC
ultratrailmb.com



MANY THANKS TO :

INRIA Direction

INRIA UR Grenoble Rhône-Alpes Direction

INRIA UR Grenoble Rhône-Alpes Communication

INRIA Communication

INRIA UR Grenoble Rhône-Alpes RH

INRIA UR Grenoble Rhône-Alpes DTI

ADT INRIA SENSTOOLS

REFERENCES :

http://www.inrialpes.fr/Xtremlog/

G. Chelius, C. Braillon, M. Pasquier, N. Horvais, R. Pissard Gibollet, B. Espiau and C. Azevedo, A Wearable Sensor Network for Gait Analysis: a 6-day Experiment of Running Through the Desert, IEEE Trans. on Mechatronics (under submission)

M. Pasquier, B. Espiau and C. Azevedo, Signal-based segmentation of human locomotion using embedded sensor network, ICASSP 2011, May 2011