Use of Inertial Measurement Units for short and long-term physical activity monitoring

Juan Jesús García Domínguez & Ana Jiménez Martín
Department of Electronics, University of Alcalá
(Alcalá de Henares, Madrid, Spain)

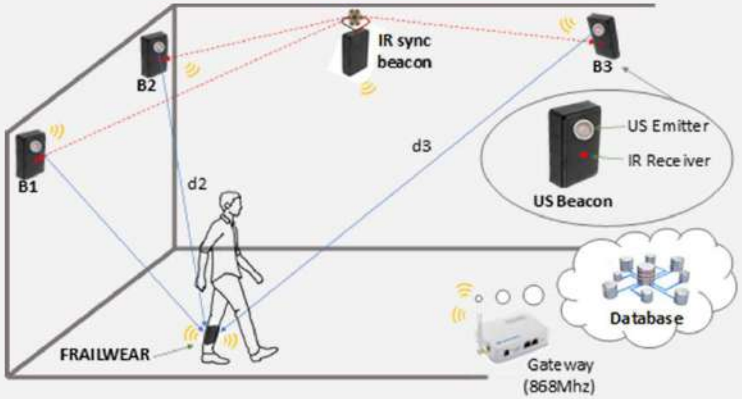
23rd April 2021

About us

GEINTRA Research Group – US&RF

Research lines

- Indoor/outdoor Local Positioning Systems
  - US, Light, IMUs, WiFi, BLE



- SoC Architectures

- Smart environments for Independent Living

Talk structure

Use of Inertial Measurement Units for short and long-term physical activity monitoring

Physical Activity Monitoring. Focusing on the elderly

Speaker: Juan Jesús García Domínguez

IMUs for Rehabilitation Monitoring

Speaker: Ana Jiménez Martín

Physical Activity Monitoring

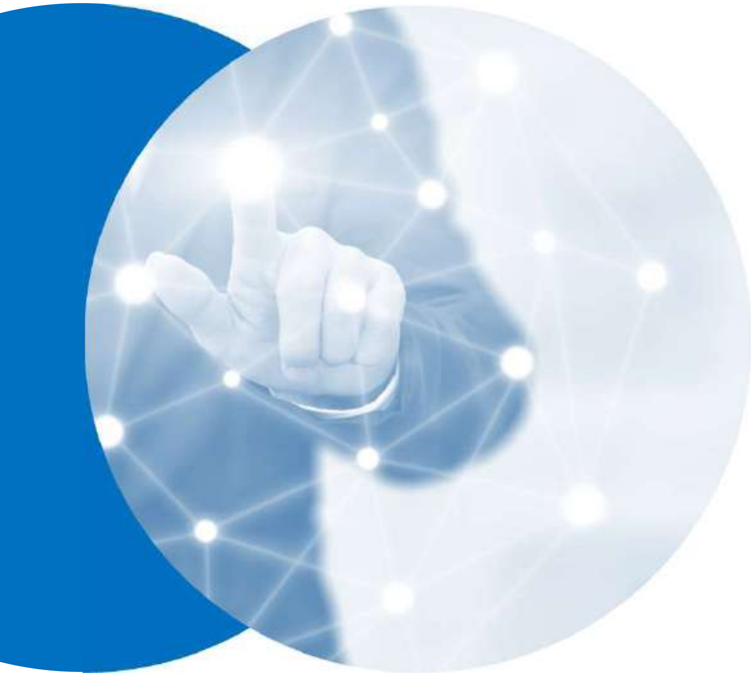
Focusing on the elderly

IEEE

Universidad de Alcalá

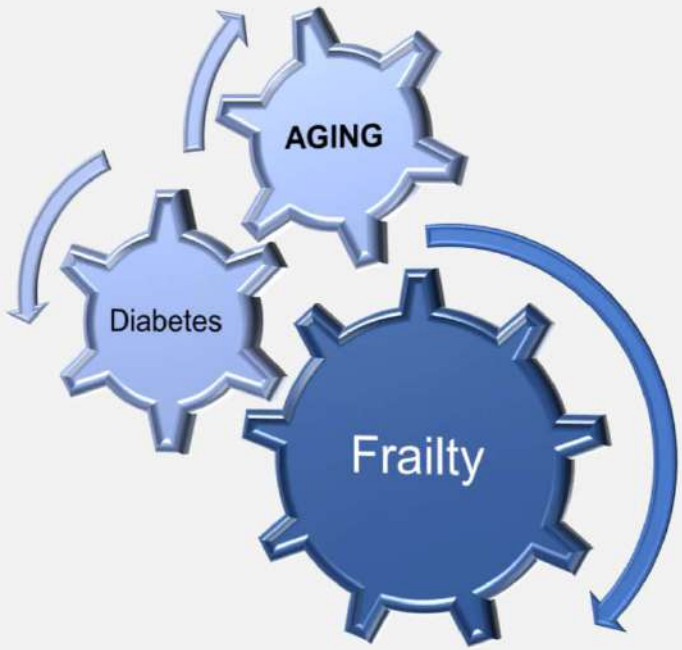
J. Jesús
García Domínguez
jjesus.garcia@uah.es

Summary



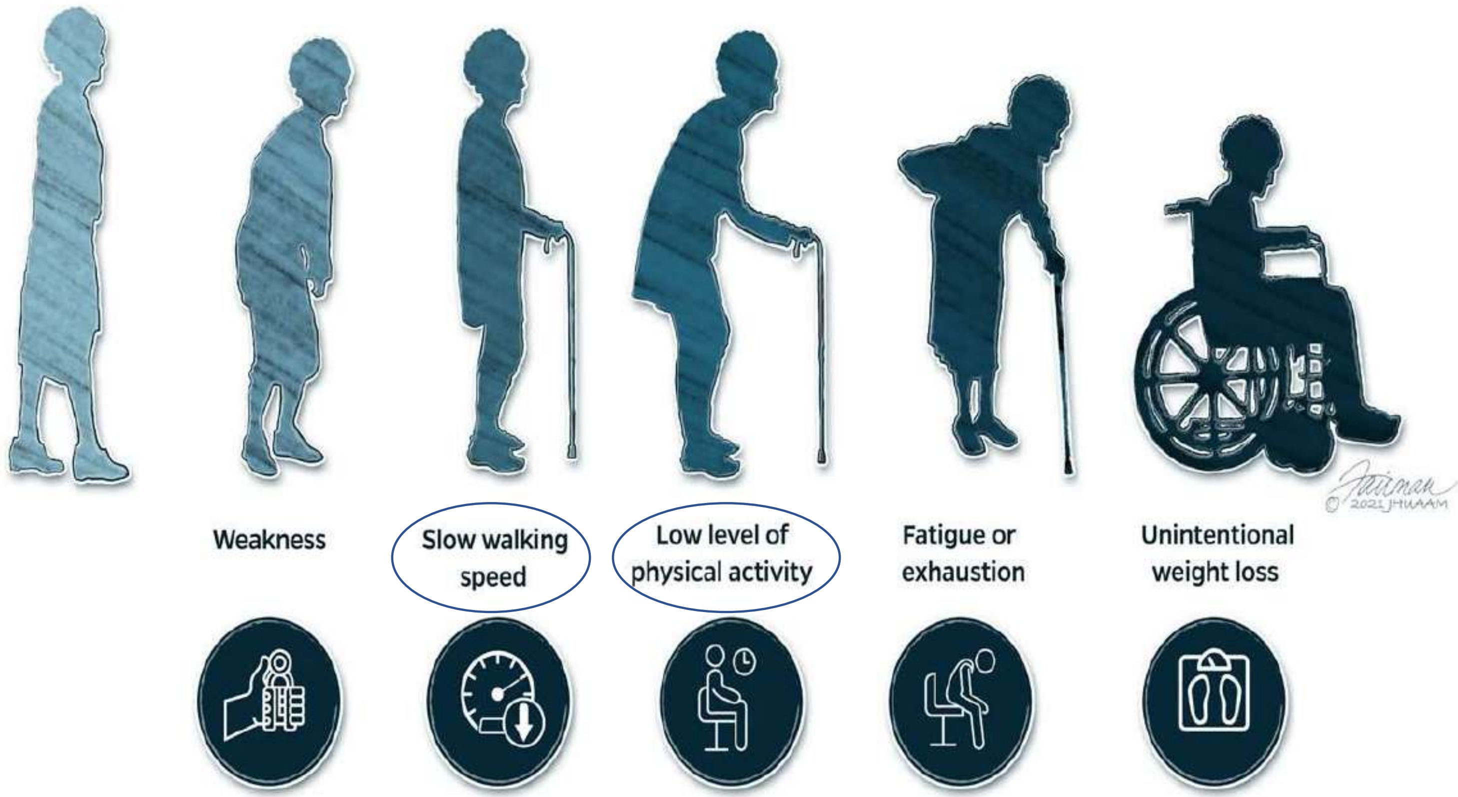
Introduction

- Growing interest in monitoring people
- Wearable devices are very popular
- Society is aging …



Introduction

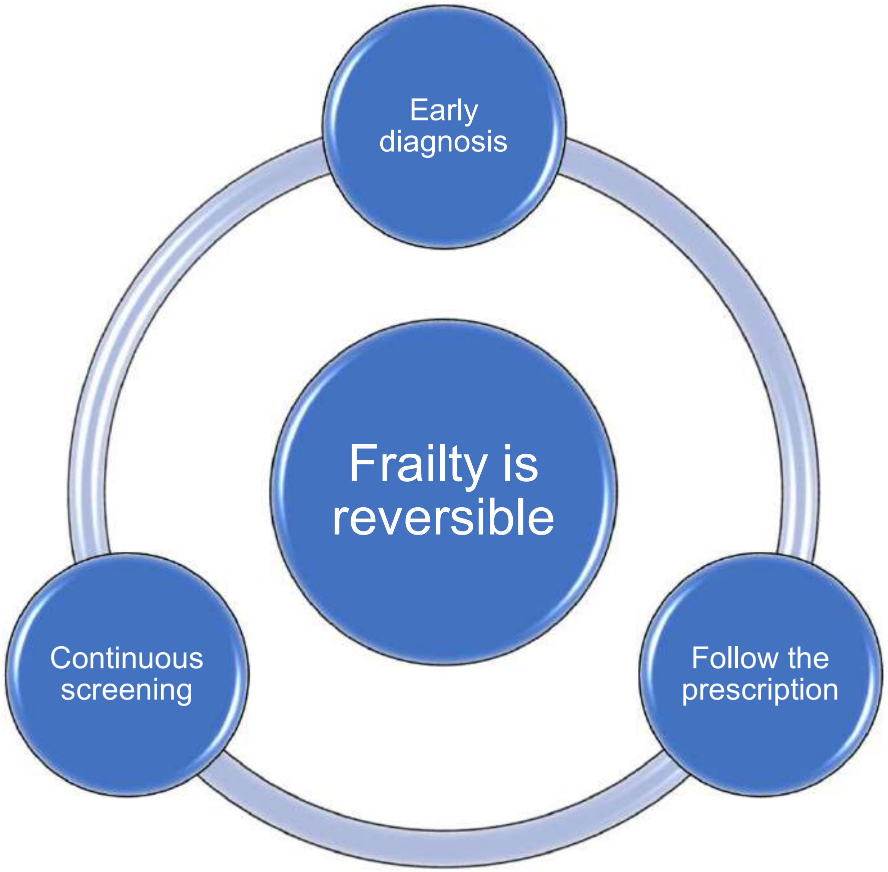
Frailty

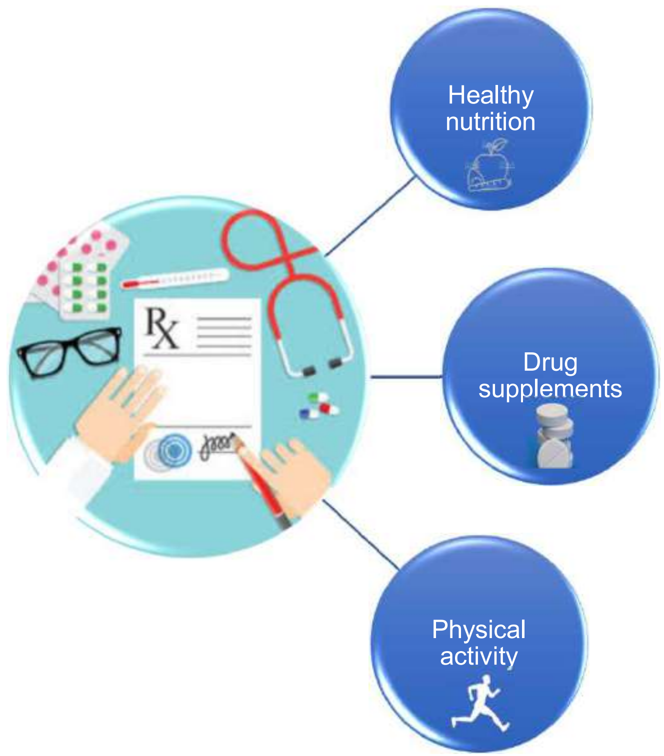


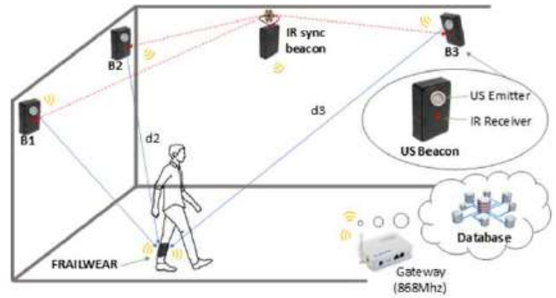
Credit: Jennifer Fairman

Introduction

Frailty





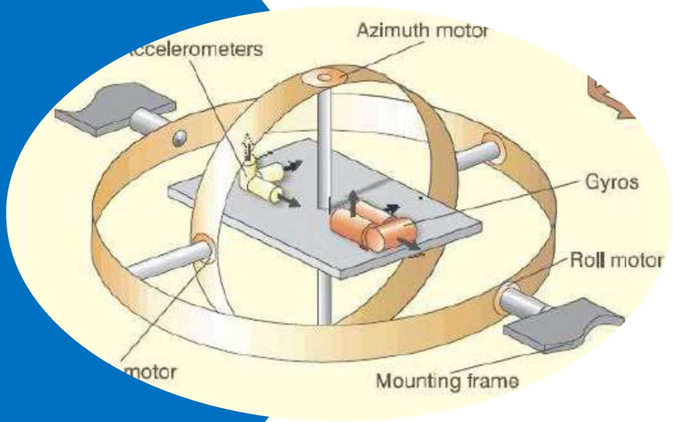


Local positioning systems

Walking speed

Physical activity

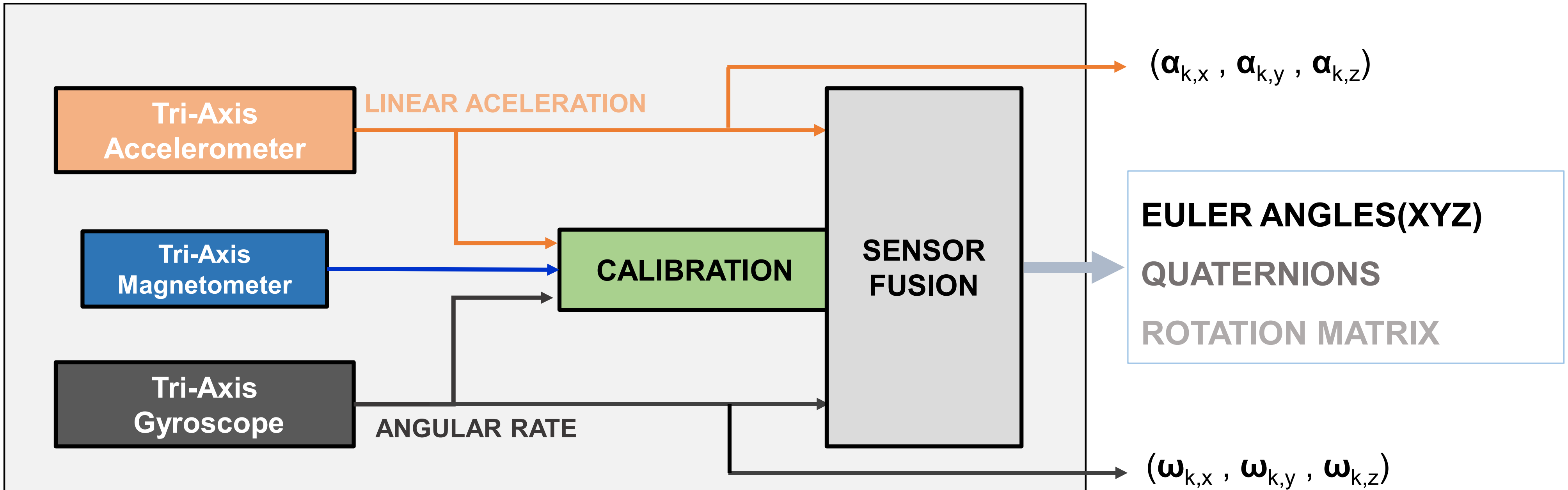
Inertial Measurement Units, IMUs



- Provide inertial information
  - 3 accelerometers measuring “specific force” (m/s^2) caused by motion and gravity
  - 3 gyroscopes measuring angular rate (rad/s)
  - Some incorporate a 3-axis magnetometer
  - Other sensors: barometer, WiFi, BLE
- Through inertial information
  - Positioning
  - Speed

Inertial Measurement Units

How to work with IMUs

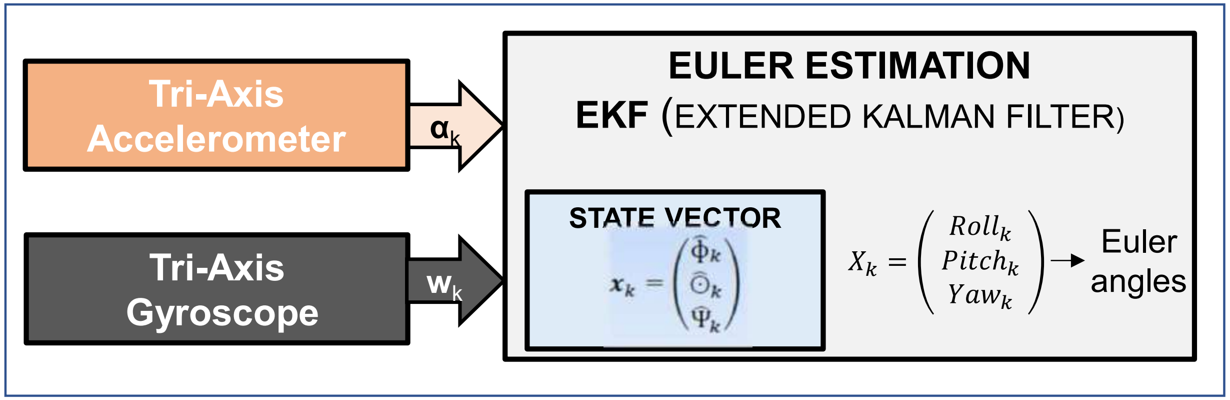


IMU based on three types of sensors

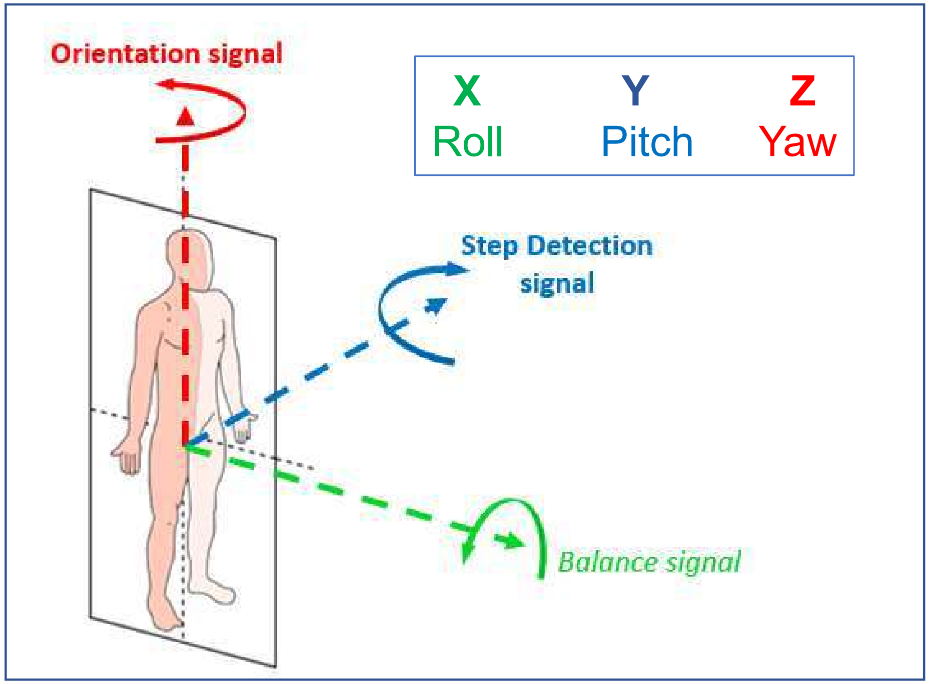
Inertial Measurement Units

How to work with IMUs

Basic Euler angles estimation diagram



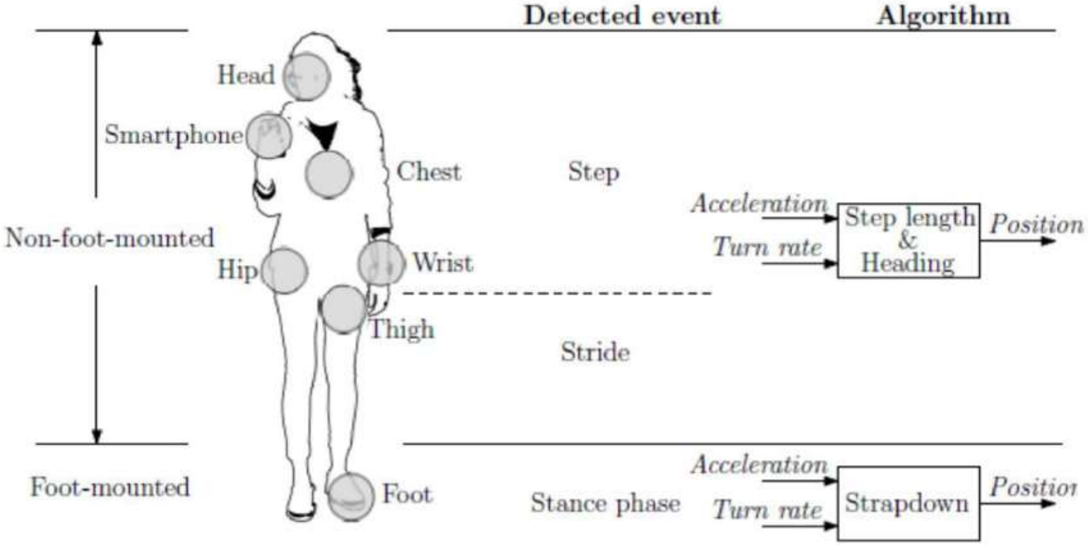
Euler angle / information

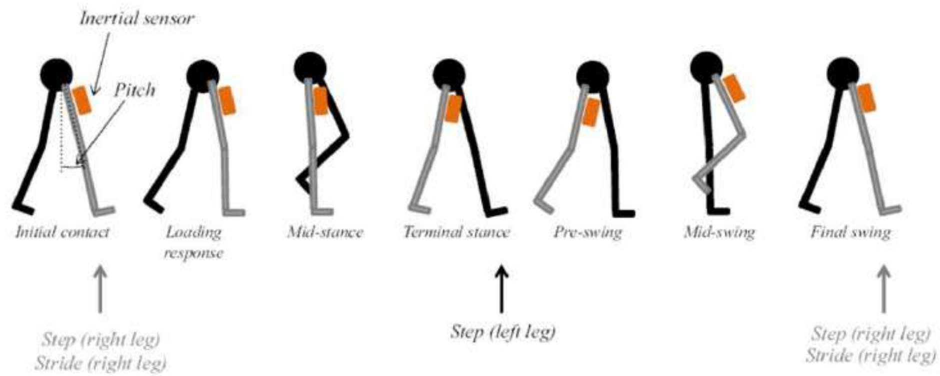


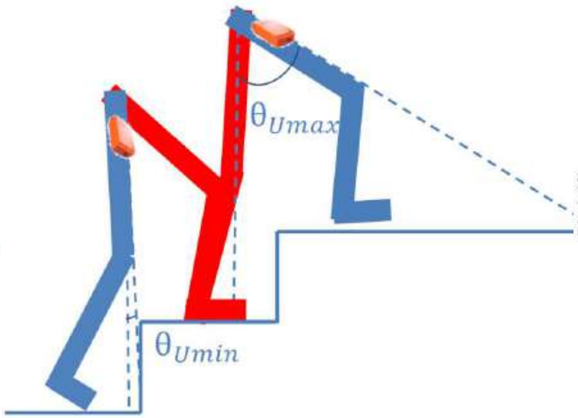
If a person carries an IMU on the body, it is possible to detect steps or strides

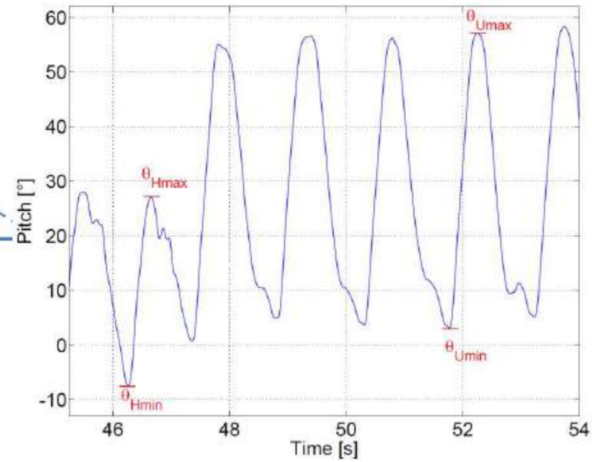
Inertial Measurement Units

Positioning Algorithms. Where to locate the IMU









$$\Delta\theta = \theta_{H_{max}} - \theta_{H_{min}}$$

$$SL = a \cdot \Delta\theta + b$$

Inertial Measurement Units

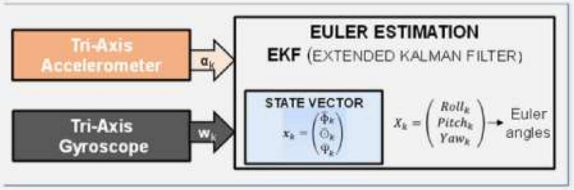
Positioning – Step Length & Heading

1 Euler Angles Estimation

2 Steps Detection

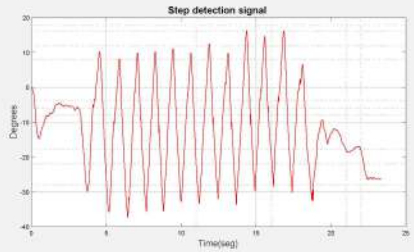
3 Step Length Estimation

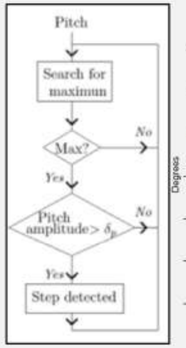
4 Relative Positioning

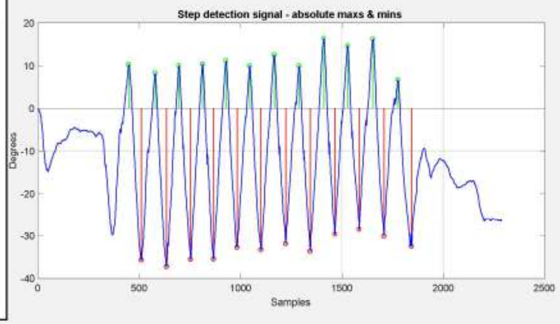


$Pitch\ \theta^k$

$Yaw\ (heading)\ \psi^k$

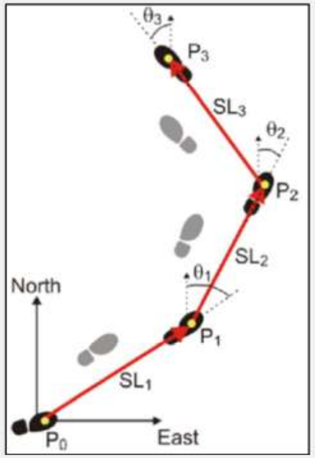






$$\Delta\theta^k = \theta_{H_{max}} - \theta_{H_{min}}$$

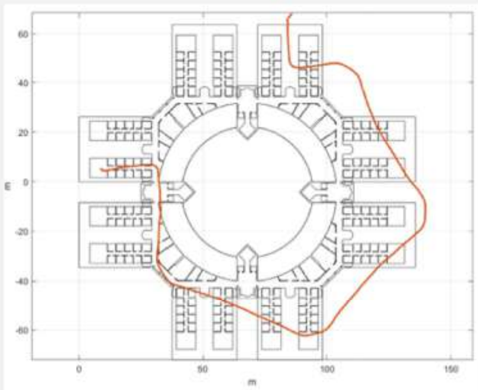
$$SL^k = a \cdot \Delta\theta^k + b$$



$$X^k = X^{k-1} + SL^k \cdot \cos\psi^k$$

$$Y^k = Y^{k-1} + SL^k \cdot \sin\psi^k$$

$$\psi^k = \psi^{k-1} + \Delta\,\psi$$



Physical Activity Monitoring

- Most of commercial wearables include an IMU

- They can measure physical activity
  - But from a recreational point of view

- For **frailty** assessment
  - Accurate information
  - Data recording
  - Data access

Physical Activity Monitoring

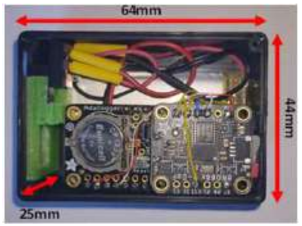
IMU selection

25€

~2000€

~1000€ - 4000€

~400€

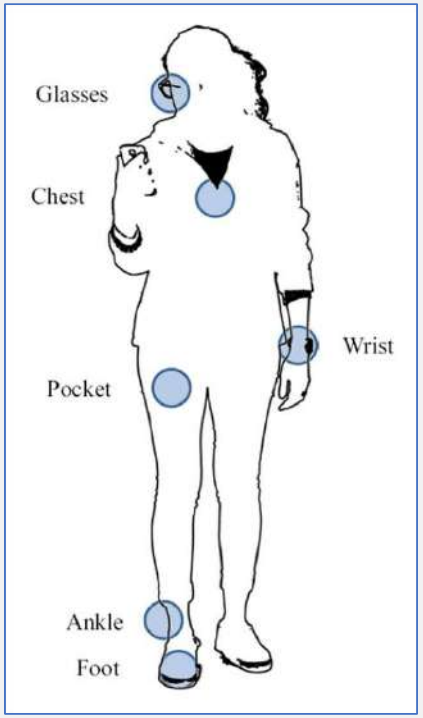


Own design

~50€

?

Where to wear it: body position



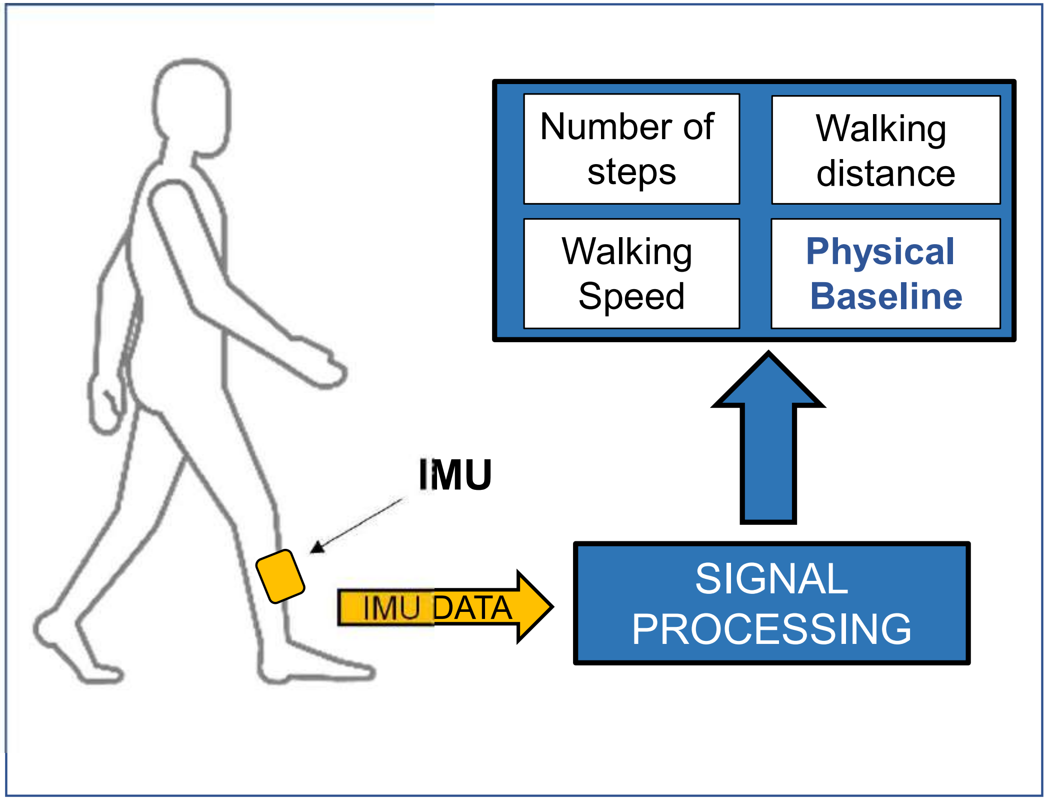
We need:

- Accuracy
- Steps
- Steps length
- Speed

Feature	Foot	Ankle	Pocket	Wrist	Chest	Glasses
Stride detection error [%]	-0.2	-0.03	-2.9			
Step detection error [%]				18.1	25.4	26.7
Stride detection	Yes	Yes	Yes			
Steps detection				Yes	Yes	Yes
Stairs observed	Yes	Yes	Yes			
Sitting observed			Yes			
Device hidden		Yes	Yes	Yes	Yes	Yes

Physical Activity Monitoring

Experimental approach

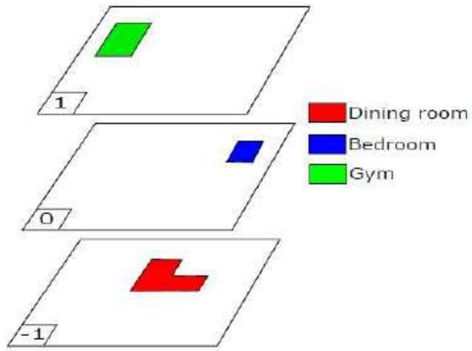


Setup

IMU sensors

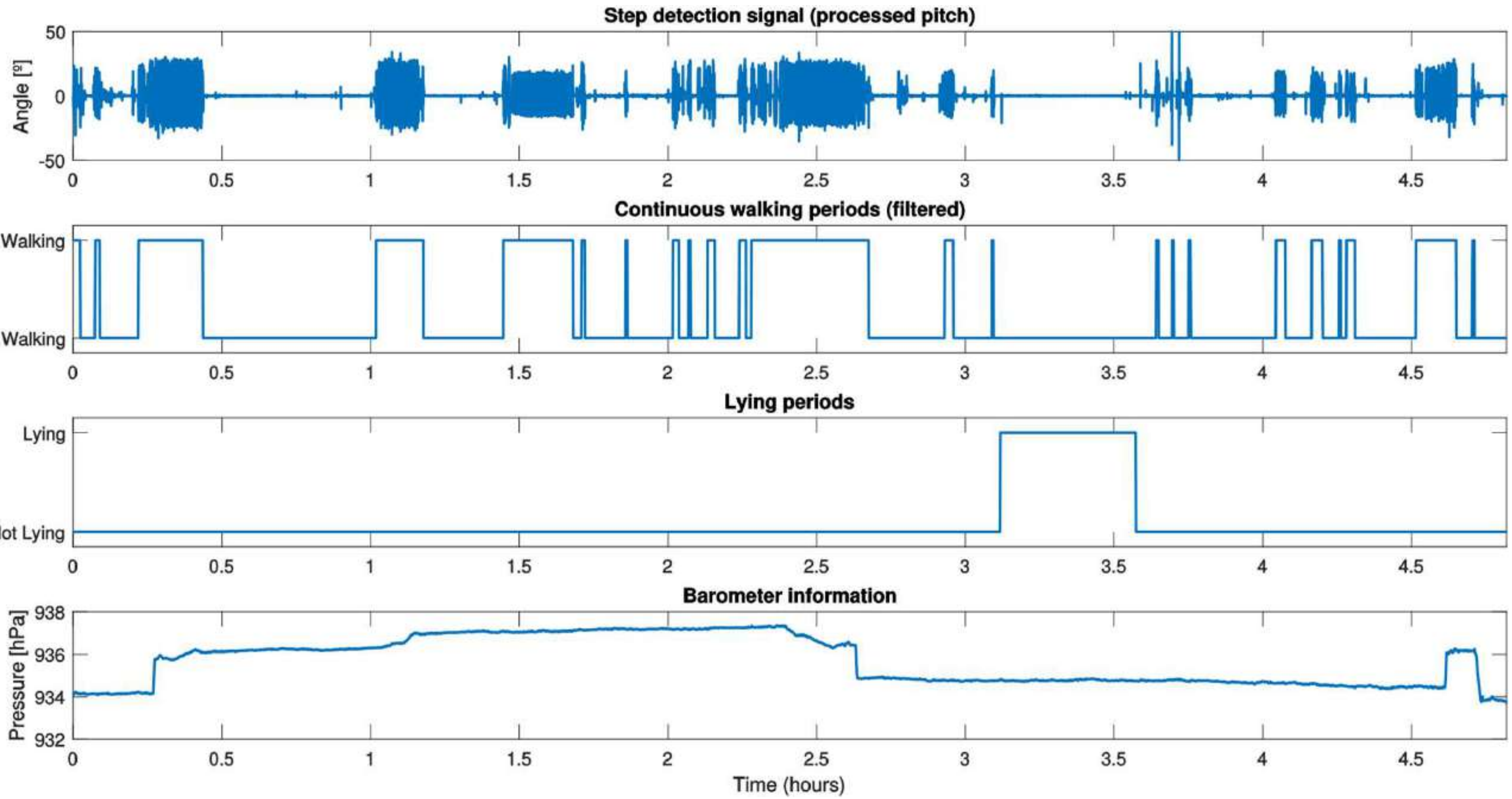
- 3-axis accelerometer
- 3-axis gyroscope
- 3-axis magnetometer
- Barometer
- WiFi connectivity

Environment: **nursing home**



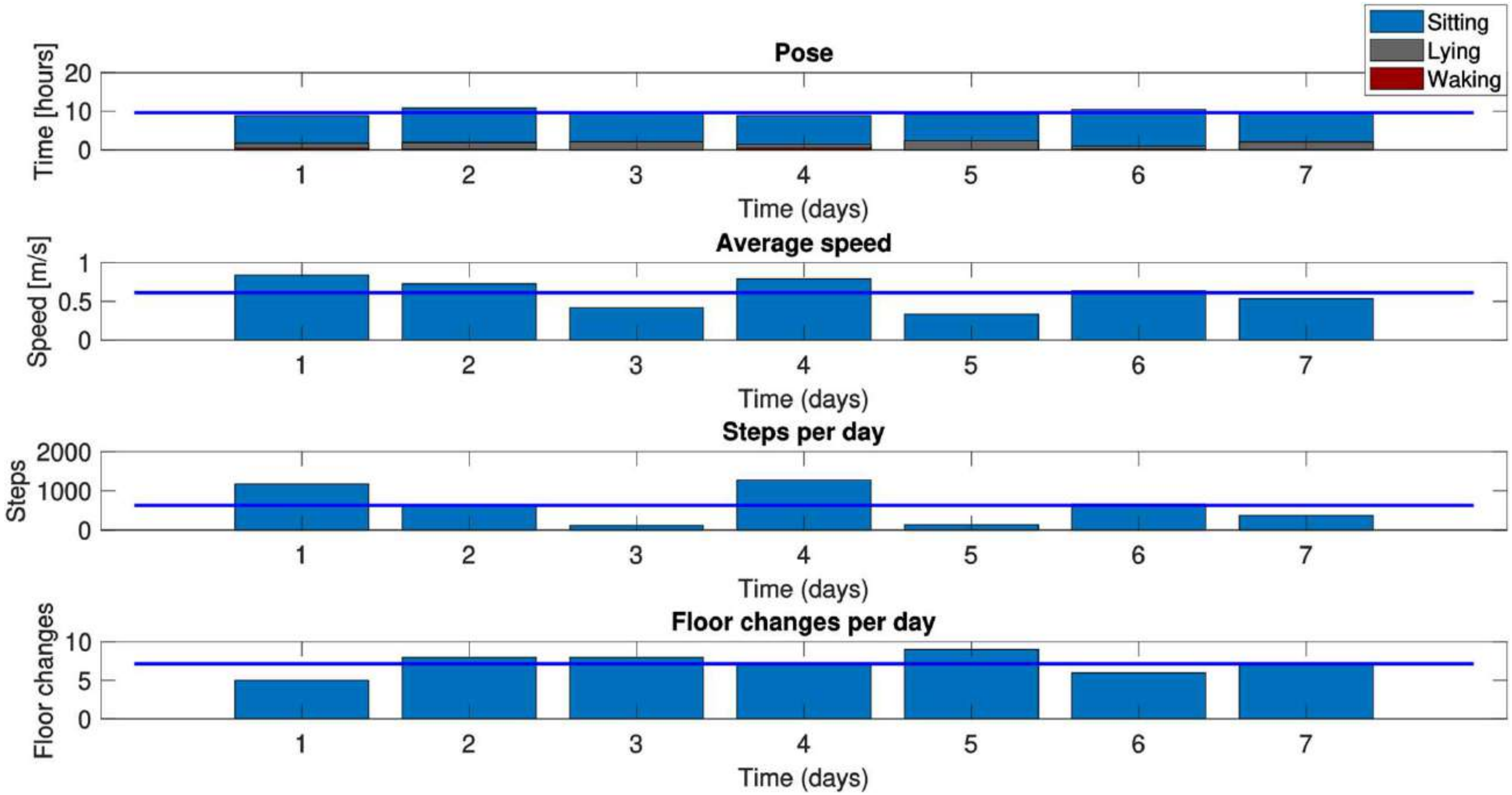
Physical Activity Monitoring

Short-term results: one day



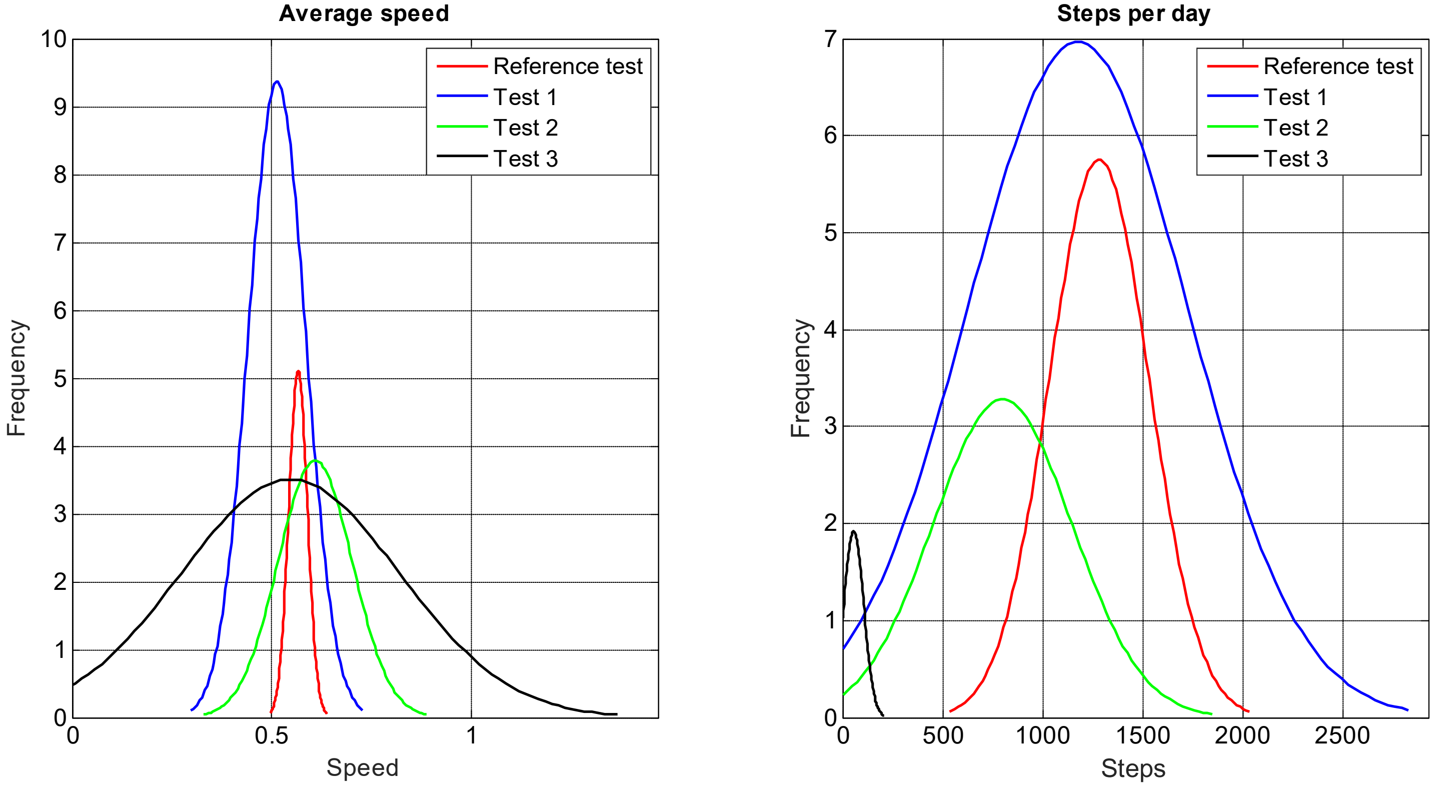
Physical Activity Monitoring

Short-term results: one week



Physical Activity Monitoring

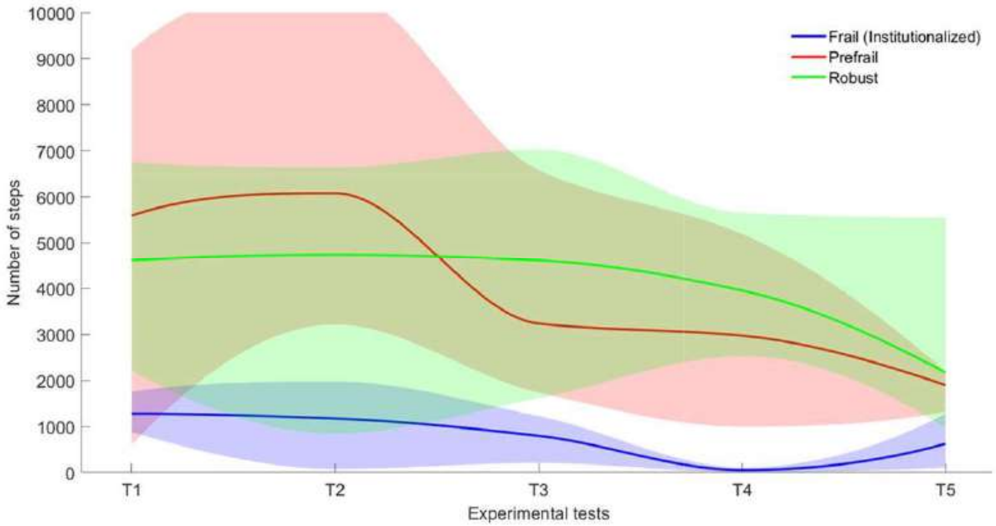
Long-term results: several weeks

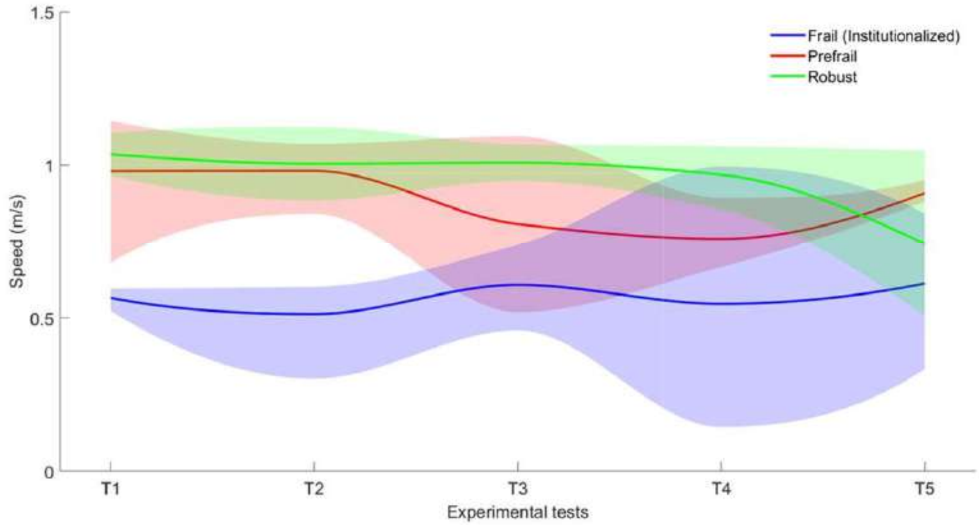


Frail patient: 92-year-old

Physical Activity Monitoring

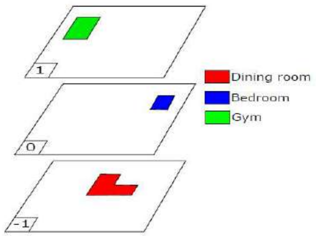
Long-term results: several months



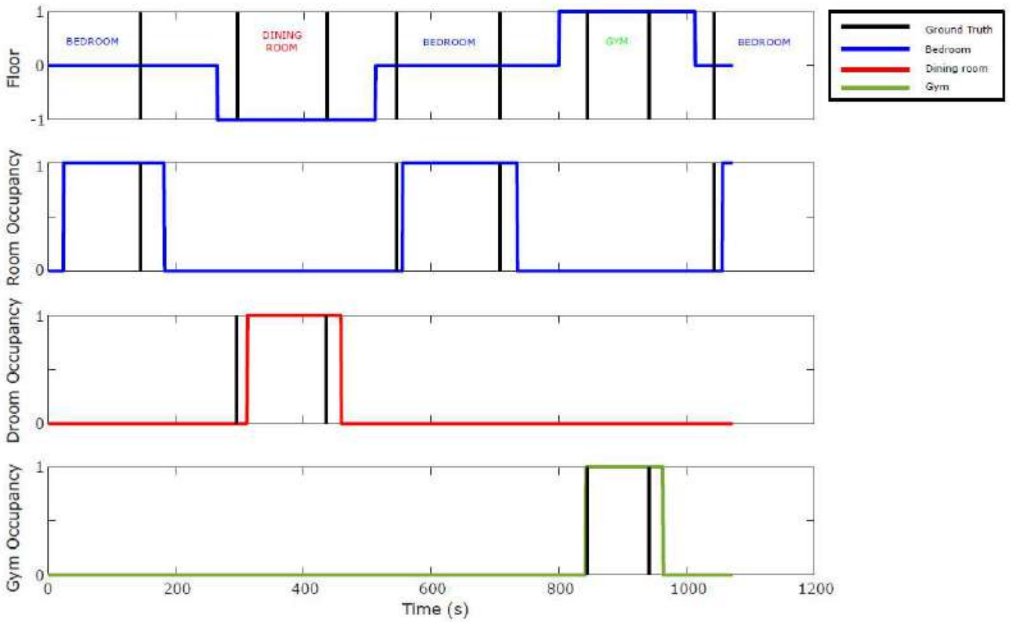


Physical Activity Monitoring

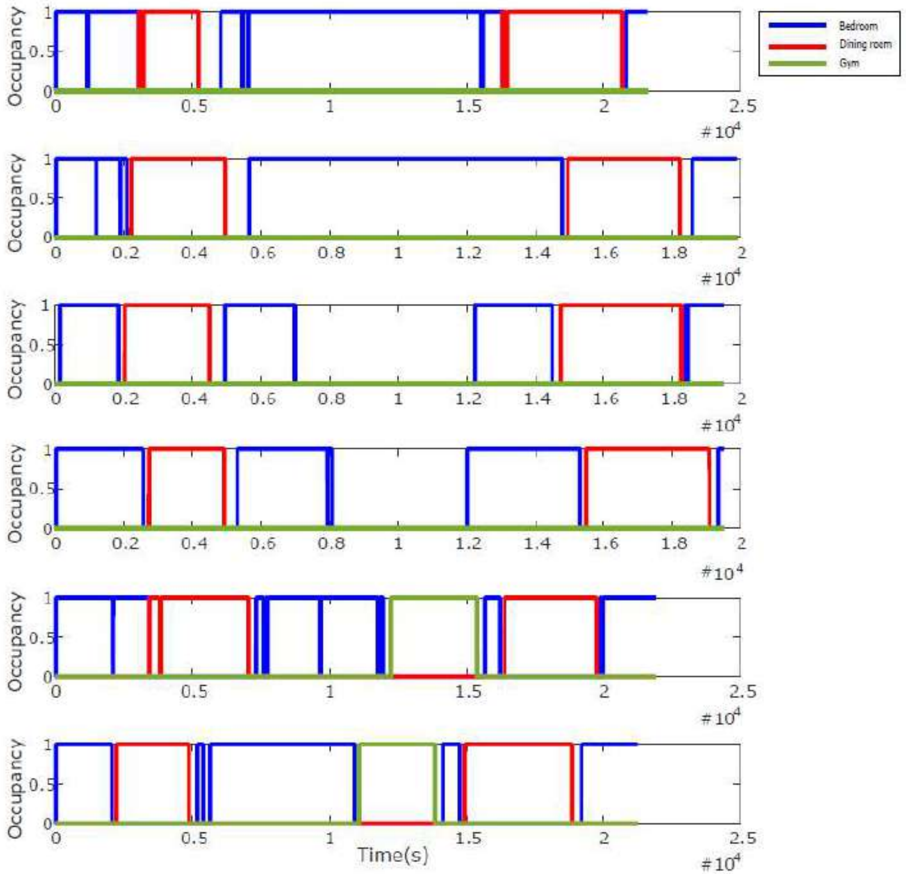
Routine analysis: IMU / Barometer / WiFi fusion



One day



Six days

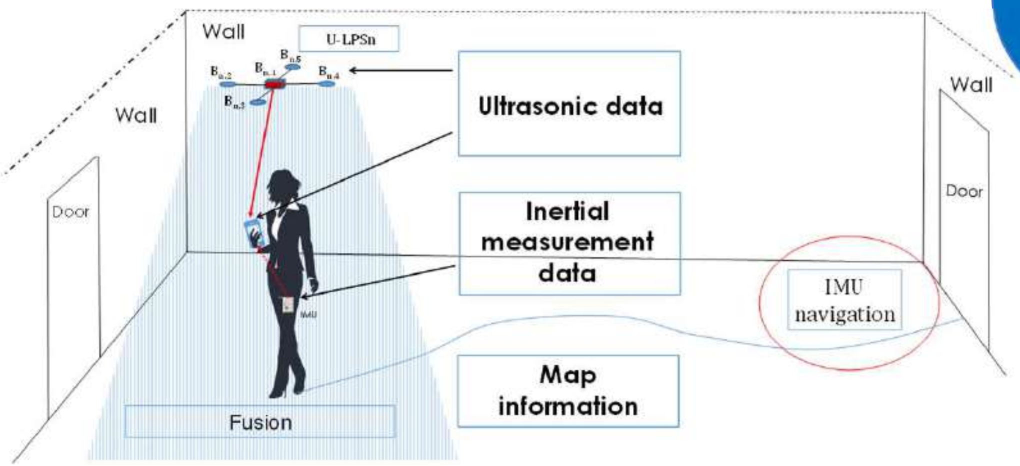


Physical Activity Monitoring

Research environment

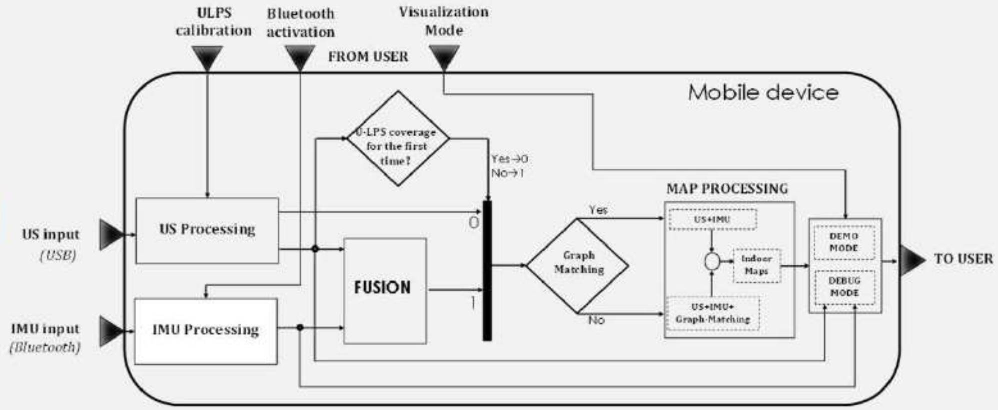
Smart Environment

- Ultrasonic Beacons
- Map information
- IMU



Smart Processing

- Mobile phone




9:51
Buscar
LOCATE-IO

Conclusions

Conclusions

Physical Activity Monitoring

This monitoring can be objectively carried out with positioning systems

Inertial Measurement Units

Can provide information about movement and positioning

Frailty

Common elderly illness, that can be mitigated through physical activity

Thanks !

geintra

IMUs for Rehabilitation monitoring

Ana Jiménez Martín
University of Alcala
ana.jimenez@uah.es

Summary

Introduction

- Heathy aging
- Technology: IMUS
- Two approaches

Biomechanical model

- Overview
- Reference system
- Biomechanical model

ML models

- Overview
- Data base
- Diferent approaches
- Results

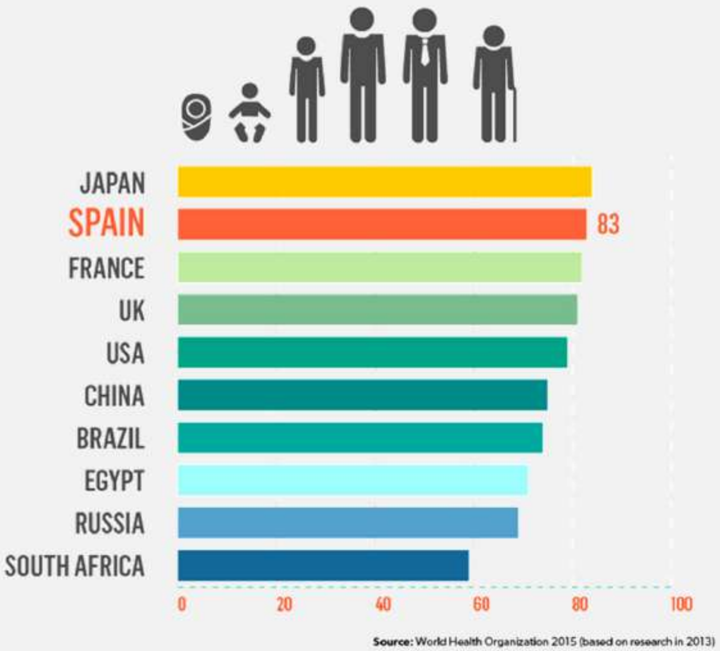
Conclusions

0

Rehabilitation Introduction

Rehabilitation

Workd Life Expectancy



Chronic illness increasement

Requirement of specialized healthcare workers

Rise of health care costs

Active ageing

Training routines

IMUs for rehabilitation monitoring

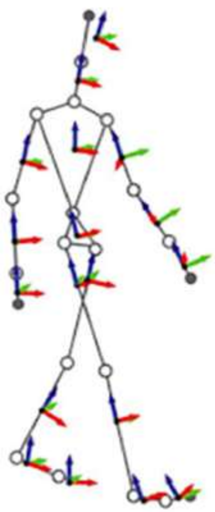
I. Biomechanical models

Joint angles are estimated from IMU velocity and acceleration data.

joint location

Respect IMU

length characterization



II. Machine Learning models

Identification of movement or assessment of whether it is right or wrong.

RF

Random Forest

DT

Decision Tree

NB

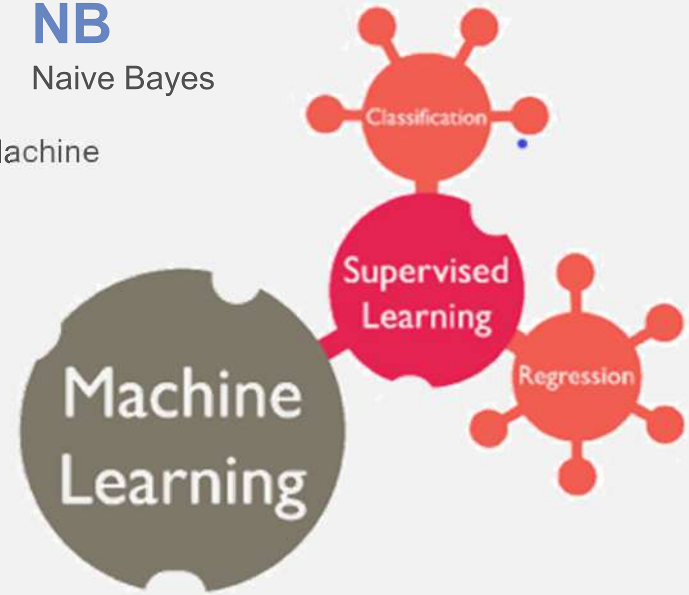
Naive Bayes

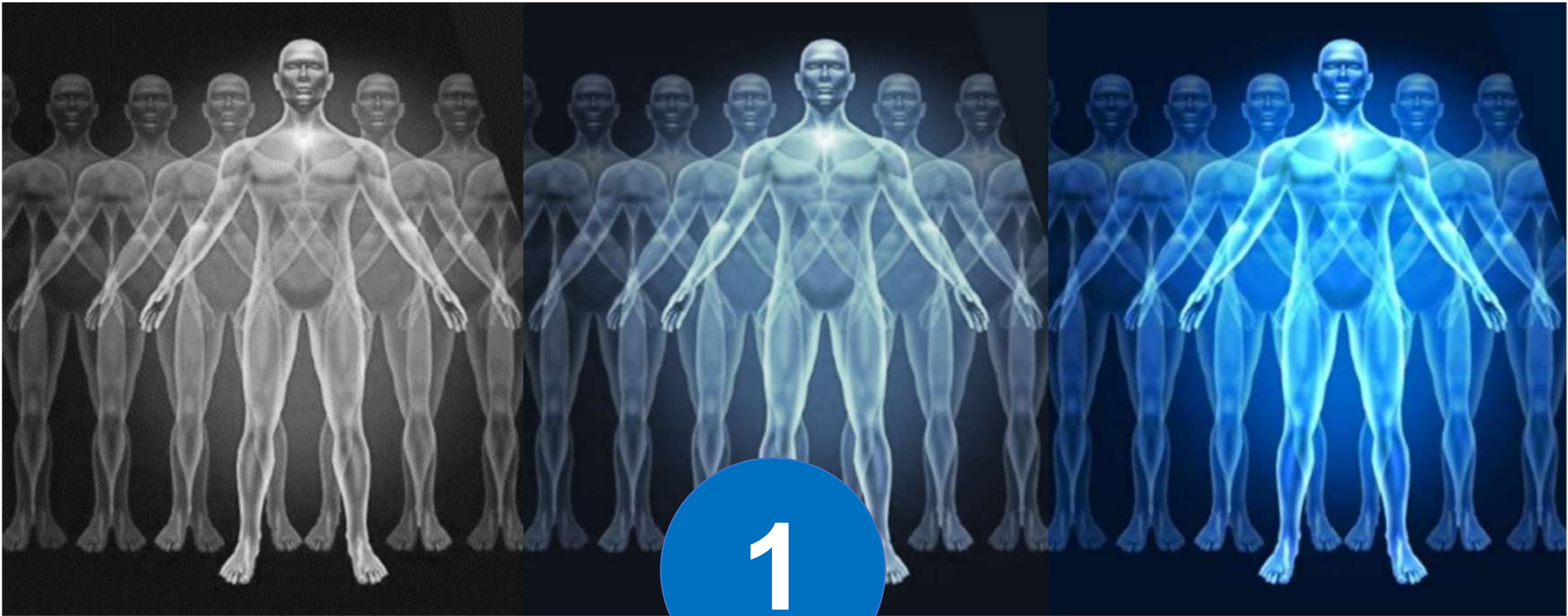
SVM

Support Vector Machine

KNN

k-Nearest Neighbors





1

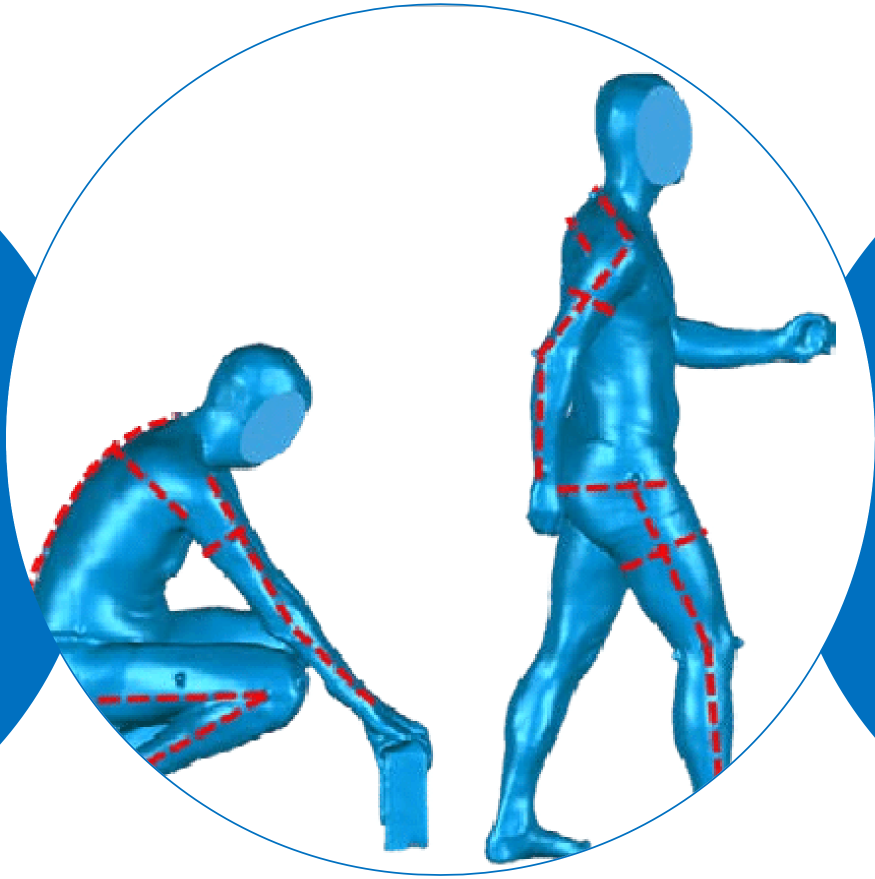
Biomechanical model

I. Biomechanical models

Overview

Reference system.

Join location: Estimating the relative position of the IMU to the joint axes → ArVed

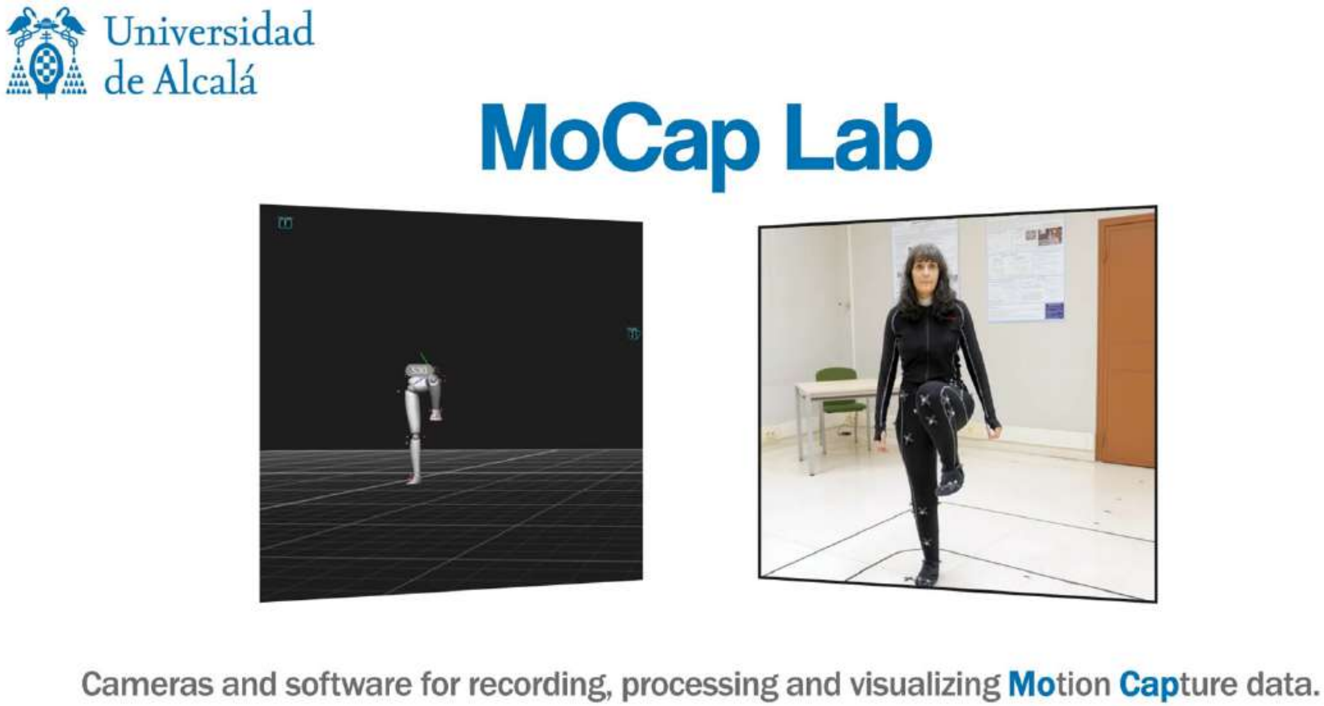


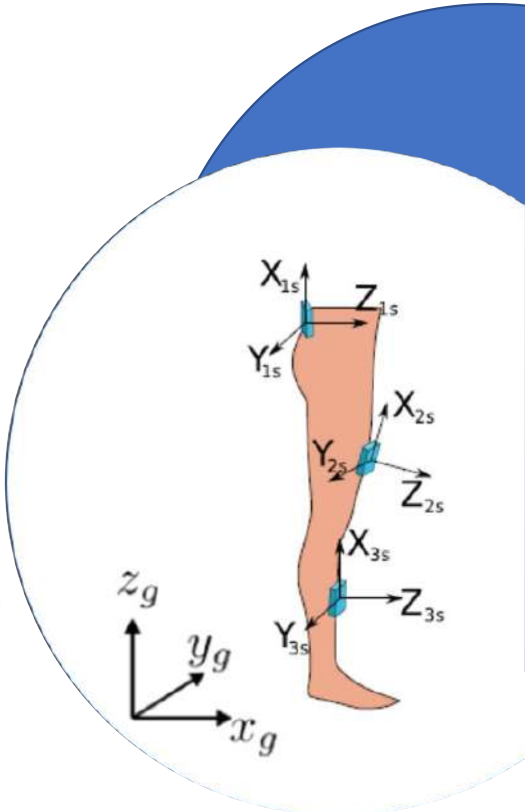
Model.

From the IMU position and the IMU measurements of angular velocity and acceleration, the joint angle is estimated.

Experimental setup

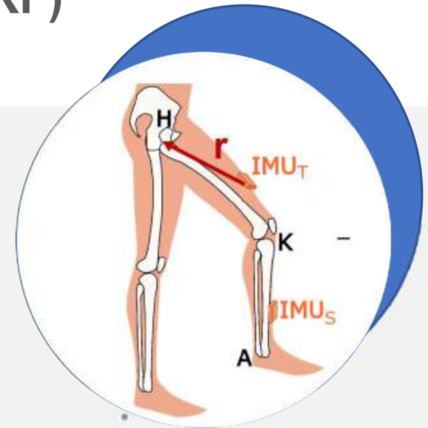
Reference system

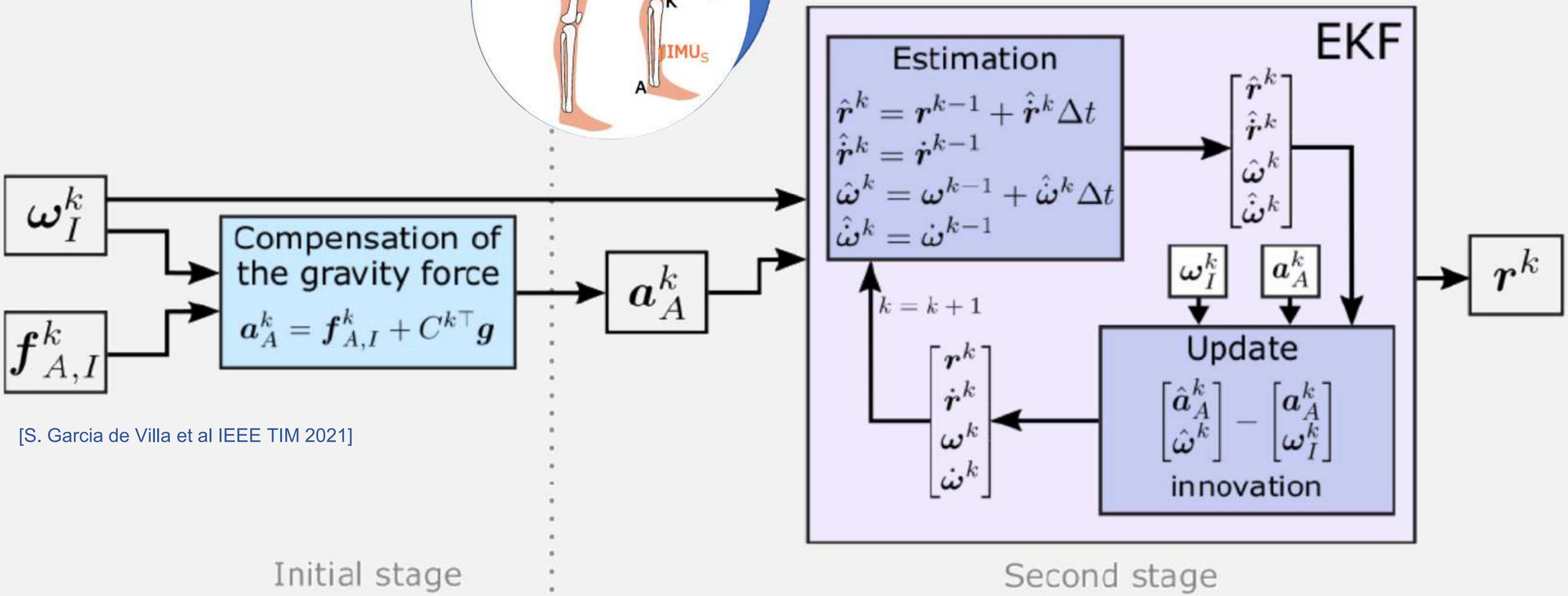




Reference system: ArVed Flowchart

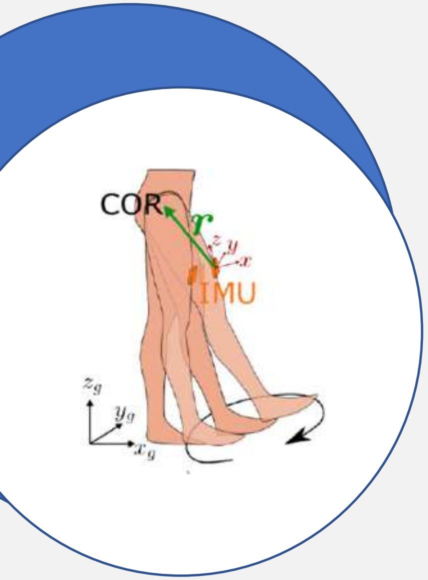
Extended Kalman Filter (EKF)





[S. Garcia de Villa et al IEEE TIM 2021]

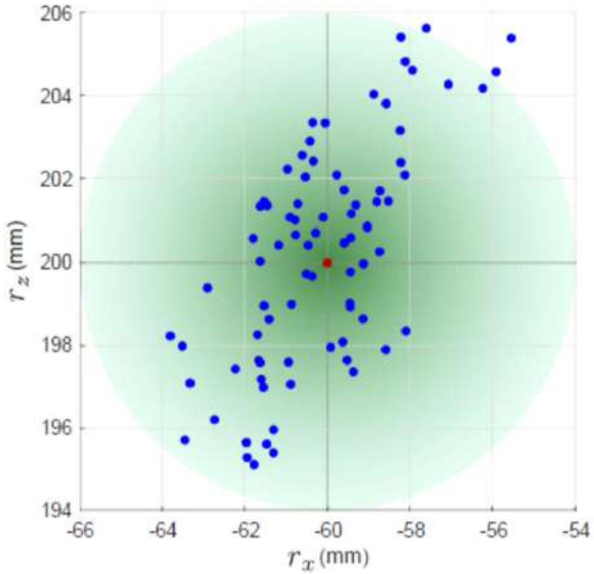
ArVEd results



[S. Garcia de Villa et al IEEE TIM 2021]

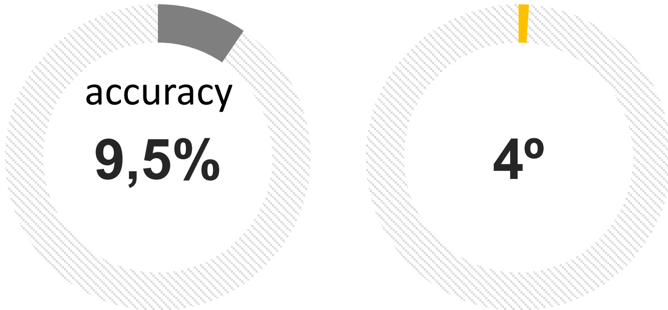
Synthetic data

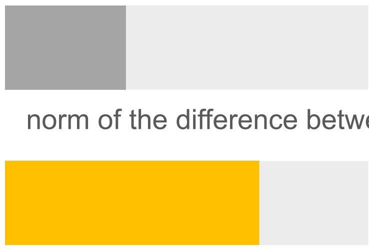
Projection of the points estimated by ArVE in planes XZ



Estimated points are in blue and the ground truth in red

Experimental data





|Δr| mm

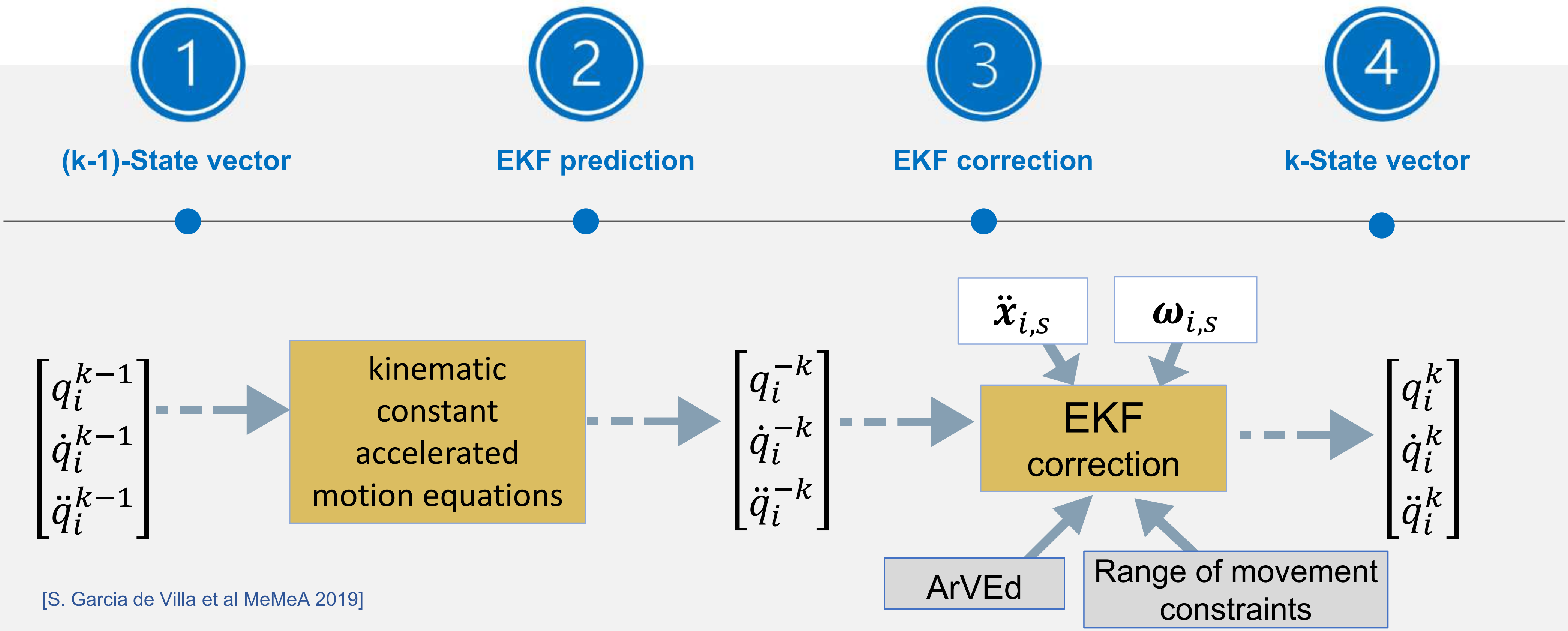
norm of the difference between the reference r_{ref} and r.

γº

Deviation angle, between r_{ref} and r.

Biomechanical model

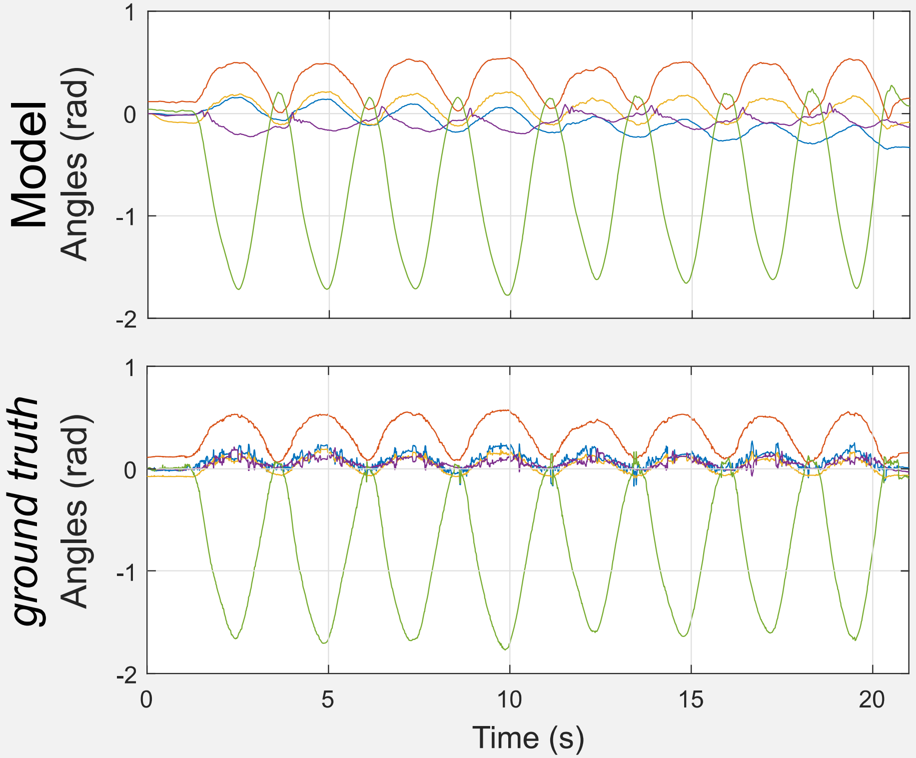
Flowchart

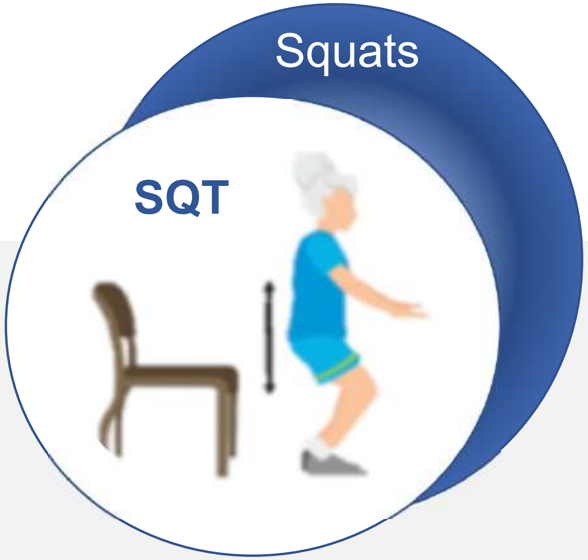


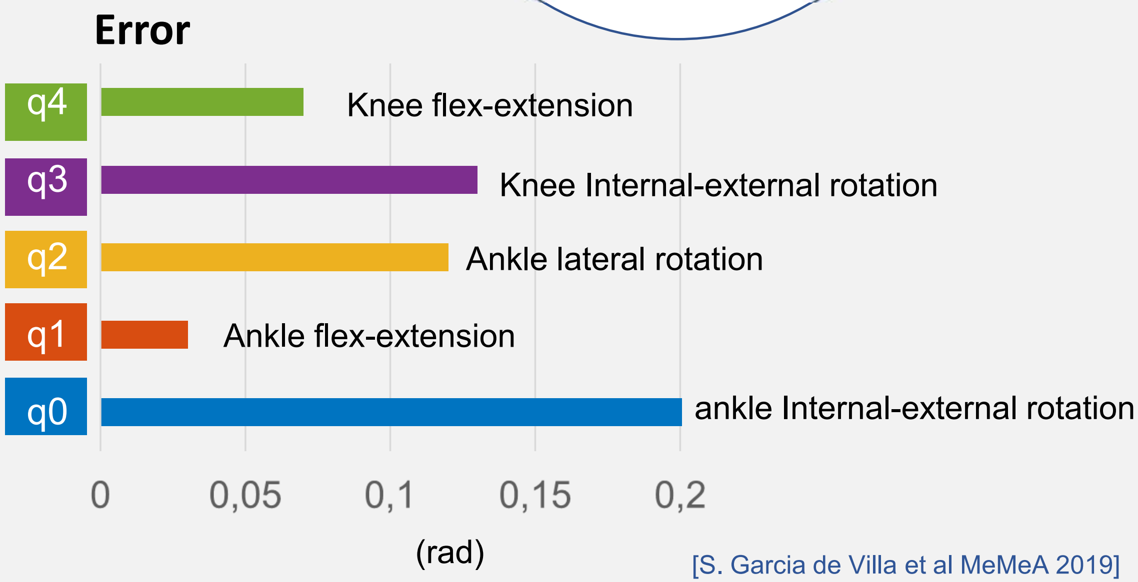
[S. Garcia de Villa et al MeMeA 2019]

Biomechanical model

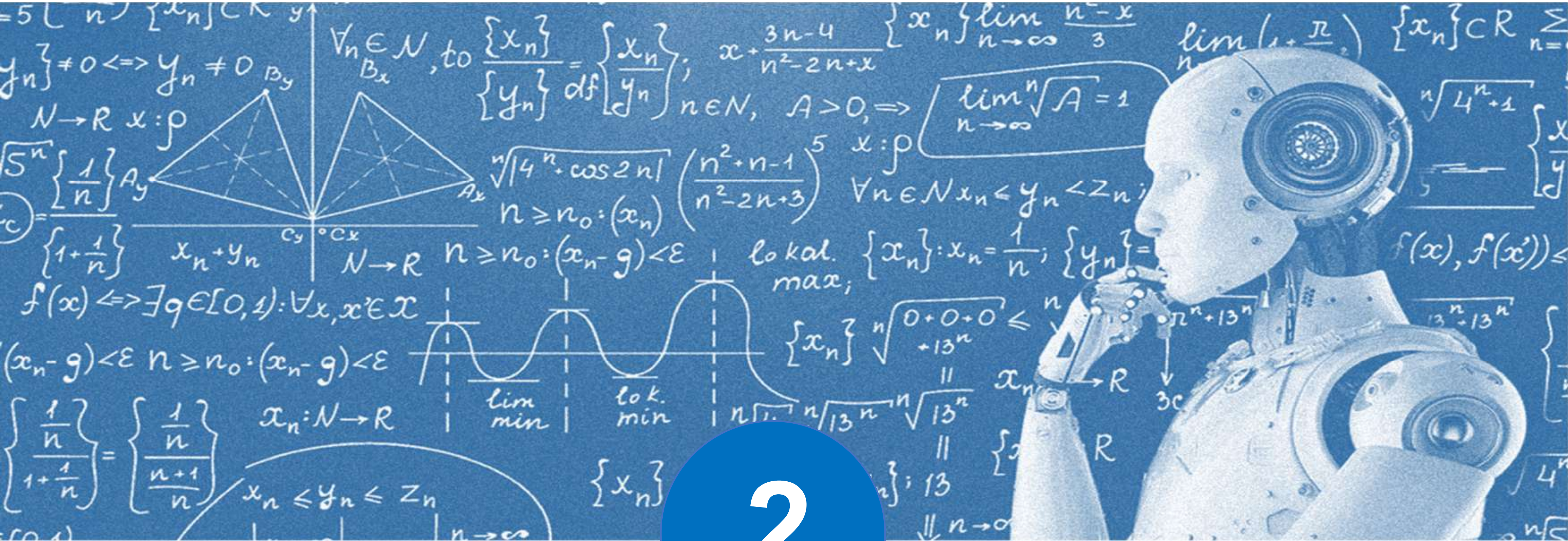
Results







[S. Garcia de Villa et al MeMeA 2019]

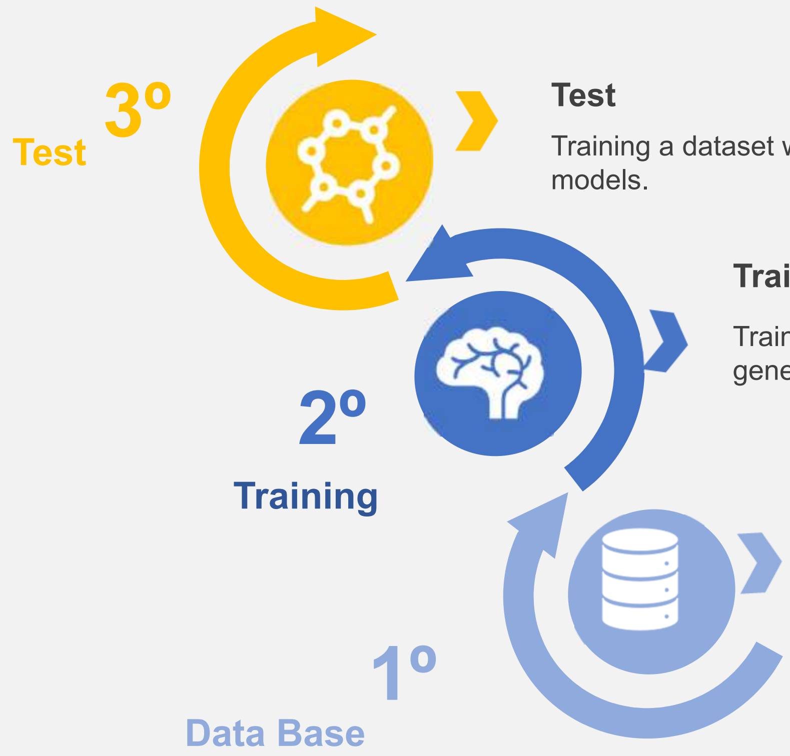


2

Machine Learning models

ML models

Overview



Test

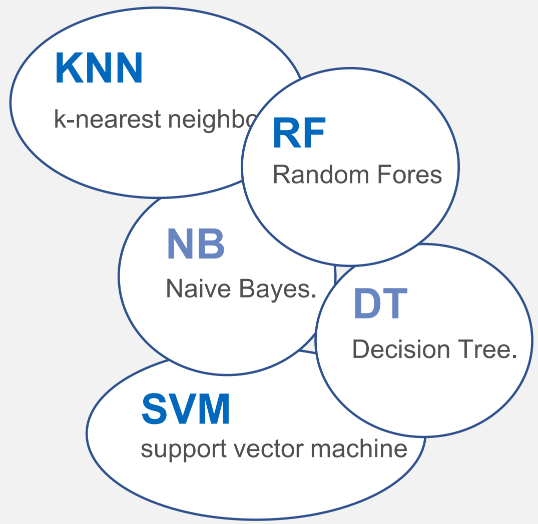
Training a dataset with different ML classifiers to generate models.

Training

Training a dataset with different ML classifiers to generate models..

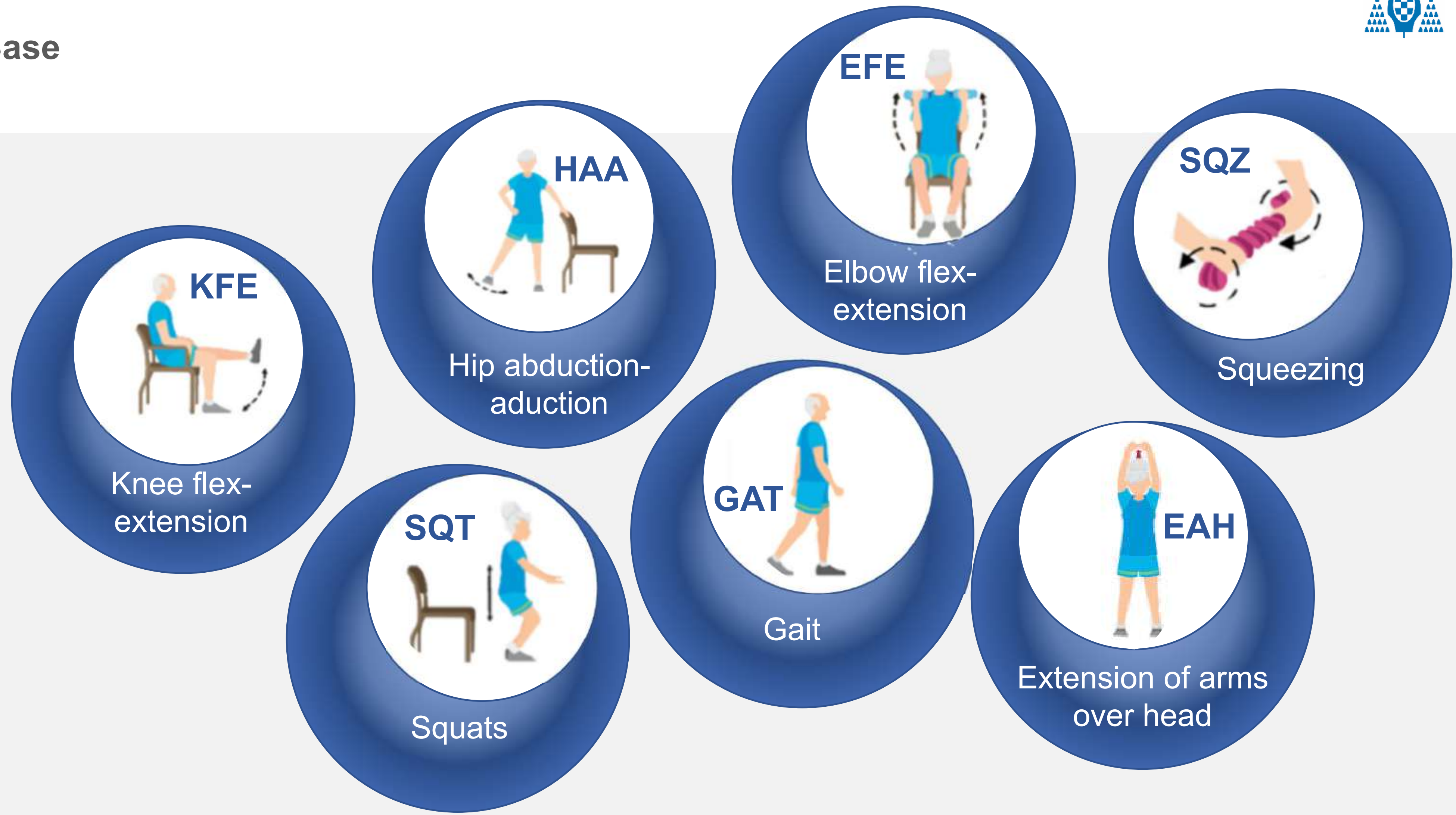
BBDD

Creation of a database with different volunteers performing a collection of correct and poorly executed exercises.

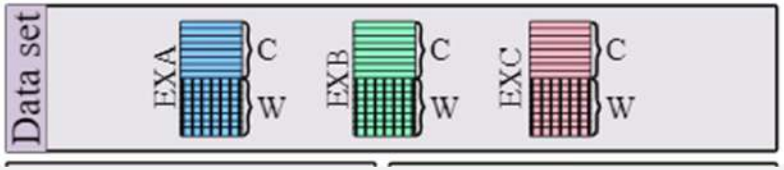


ML models

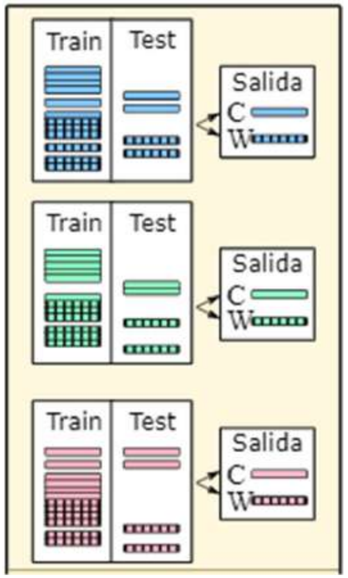
Data Base



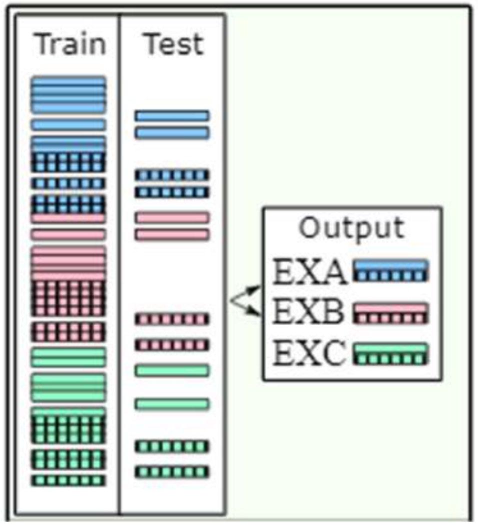
ML model approaches



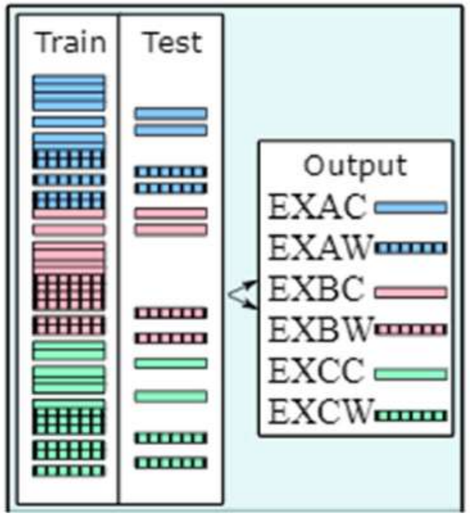
Assessment (As)



Identification (ID)



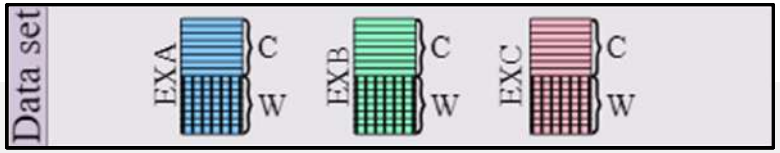
ID & As



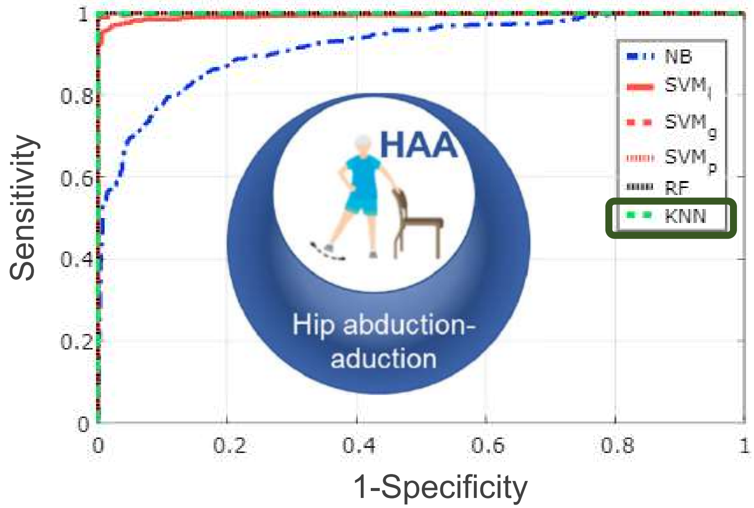
[S. Garcia de Villa et al MeMeA 2021]

ML model results

Assessment / Identification



Assessment (As)



Identification (ID)

Predicted (columns) / Real (rows)

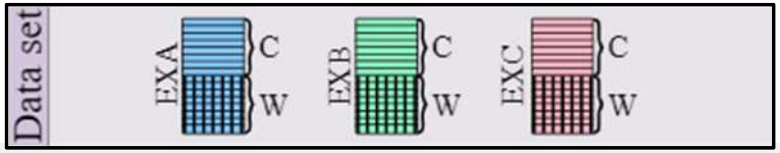
	fes	*sqt*	*haa*	*gai*	*Afes*	*Aele*	*Asqz*
fes	113	0	0	0	0	0	0
sqt	0	128	0	1	0	0	0
haa	0	0	123	0	0	0	0
gai	0	0	0	100	0	0	0
Afes	0	0	0	0	119	0	1
Aele	0	0	0	0	0	127	0
Asqz	0	0	0	0	0	0	128

accuracy
99,9%

[S. Garcia de Villa et al MeMeA 2021]

ML model results

Identification & Assessment

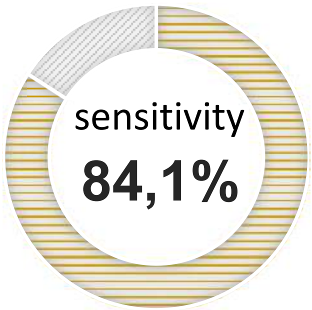


ID & As

Predicted

Real

	fesC	*fesW*	*sqtC*	*sqtW*	*haaC*	*haaW*	*gaiC*	*gaiW*	*AfesC*	*AfesW*	*AeleC*	*AeleW*	*AsqzC*	*AsqzW*
fesC	84	0	0	0	0	0	0	0	0	0	0	0	0	0
fesW	0	82	0	0	0	0	0	0	0	0	0	0	0	0
sqtC	0	0	86	0	0	0	0	0	0	0	0	0	0	0
sqtW	0	0	0	89	0	0	0	0	0	0	2	0	0	0
haaC	0	0	0	0	88	0	0	0	0	0	0	0	0	0
haaW	0	0	0	0	0	77	0	0	0	0	0	0	0	0
gaiC	0	0	0	0	0	0	94	0	0	0	0	0	0	0
gaiW	4	0	0	0	0	0	0	60	0	0	0	0	0	0
AfesC	0	3	0	0	0	0	0	0	54	0	0	0	0	0
AfesW	0	0	4	0	0	0	0	0	1	56	0	0	0	0
AeleC	0	0	0	2	0	0	0	0	0	0	59	0	0	0
AeleW	0	0	0	0	1	0	0	0	0	0	0	53	1	1
AsqzC	0	0	0	0	0	4	0	0	0	0	0	0	59	0
AsqzW	0	0	0	0	0	0	2	0	0	0	0	0	0	68



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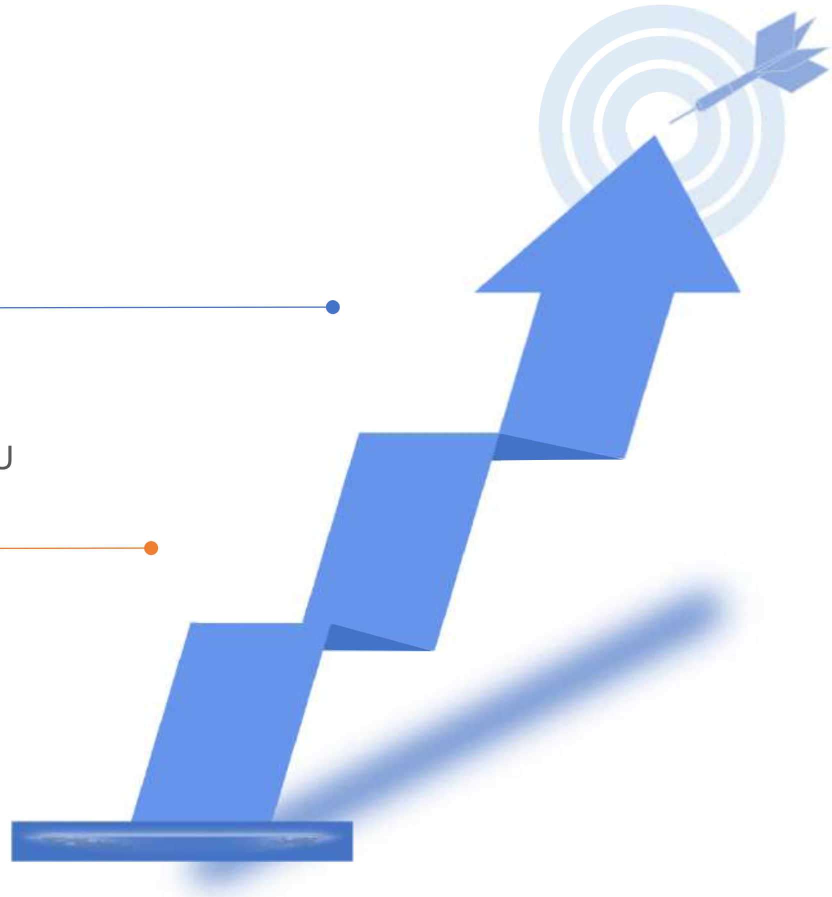
Conclusions

Conclusions

machine learning models
Identification and assessment.

biomechanical models
relative location of the centre of rotation and the IMU
Kinematic constrains

IMUs
Inertial systems are a very attractive technological option for monitoring rehabilitation exercises.



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Thanks

Ana Jiménez Martín
University of Alcala
ana.jimenez@uah.es