

11 May 2022

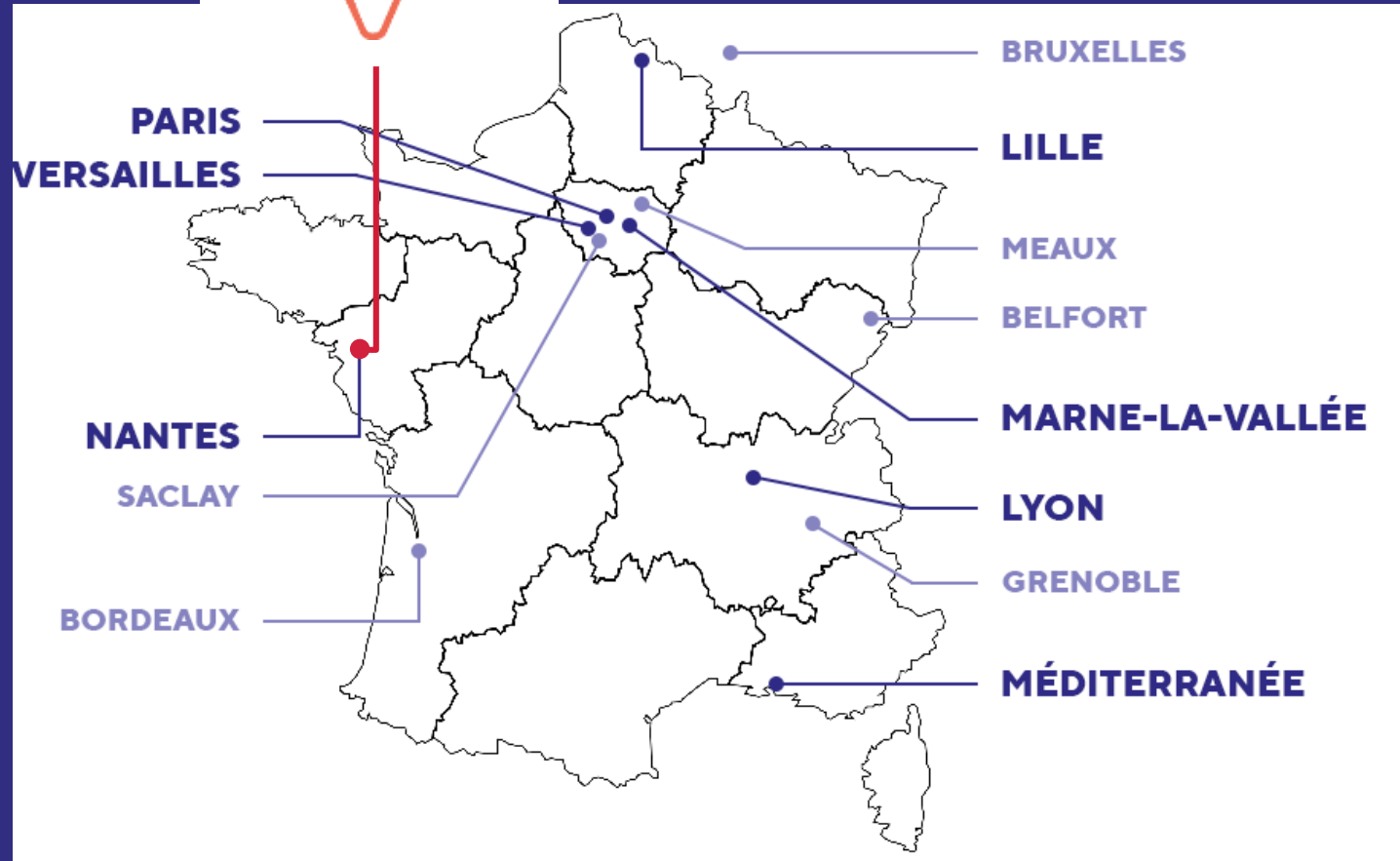
RENAUDIN Valérie

From Inertial Signals to Precise Pedestrian Indoor Positioning: Assessing Human Gait



IEEE
INERTIAL2022
The 9th IEEE International Symposium on Inertial Sensors & Systems
Avignon, France | May 8-11, 2022

UNIVERSITY GUSTAVE EIFFEL



2020 Creation

7 main locations

17'000 students

500 PhD students

1'200 researchers and professors

1'300 admin and technical staff

POSITIONING AND NAVIGATION: A CATALYST FOR NEW FORMS OF MOBILITY



TEAM
GEOLOC

INDOOR POSITIONING AND NAVIGATION

A prerequisite for many applications and services whose needs and requirements are completely different



CURRENT AVAILABLE SOLUTIONS



**Radio
Beacon
Network**

**A-priori
Mapping
of Signal
Characteri
stics**

RADIO BEACON NETWORK

Installation of beacons in a specific infrastructure

Measurements of signal propagation for trilateral or passing by a landmark

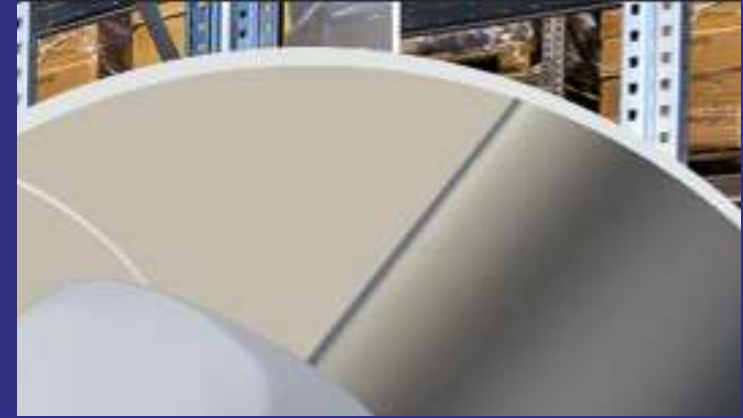
Technologies in use: UWB, BLE, RFID, ultrasound, light

Benefit

- Absolute location in the indoor maps
- Scalable

Drawback

- Costly
- Obstruction
- Numerous calibration needed
- Accuracy versus density



A-PRIORI MAPPING OF SIGNAL CHARACTERISTICS

Fingerprinting Method

- Offline: Gridding of space and geotag signals prints
- Operational: minimization of the “any” distance

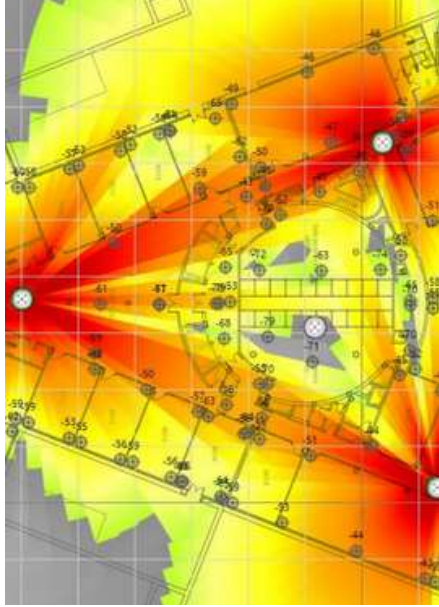
Technologies in use: any signals of interest, Wifi/Magnetic Fields being popular

Benefit

- Absolute location in the indoor maps
- Use geometrical constrains to increase accuracy (Bayesian Approach)

Drawback

- Main assumption - *static radio signals patterns* - is rarely true
- Difficulties in updating the database
- Attenuation of high frequencies by the human body: what about the crowd?
- Cost of establishing the database (urgency?)



INERTIAL NAVIGATION SYSTEMS

1st and 2nd Newton's laws applied to acceleration and angular rates

Time based evolution of the...

...speed & position ($\dot{\mathbf{x}}, \mathbf{x}$), $\forall u \in [t, \Delta t]$

$$\dot{\mathbf{x}}_{t+\Delta t}^n = \int_t^{t+\Delta t} \ddot{\mathbf{x}}^n du = \dot{\mathbf{x}}_t^n + \ddot{\mathbf{x}}^n \Delta t$$

$$\mathbf{x}_{t+\Delta t}^n = \int_t^{t+\Delta t} \dot{\mathbf{x}}^n du = \mathbf{x}_t^n + \dot{\mathbf{x}}_t^n \Delta t + \frac{1}{2} \ddot{\mathbf{x}}^n \Delta t^2$$

...attitude angles (\mathbf{q}_b^n) using angular rates to create the rotational increment (\mathbf{q}_ω^b)

$$\mathbf{q}_b^n(t + \Delta t) = \mathbf{q}_b^n(t) \circ \mathbf{q}_\omega^b(t)$$

Benefit

- No infrastructure deployment
- No knowledge of the map
- Functional without mobile cellular network coverage
- Accessible to a larger population
- Private by design: General Data Protection Regulation (GDPR)

Drawback

- Propagation of measurement errors: t^2 for acceleration errors, t^3 for angular rate errors

KEEP YOUR ORIENTATION WITH THE INERTIAL SENSORS

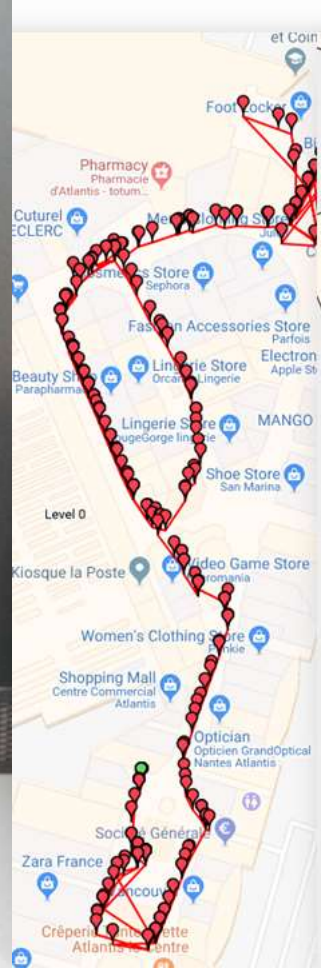
Positioning error larger than 10 km after 2 minutes walk with handheld inertial sensors

“ I am lost! ”

Backbone of pedestrian navigation...

1. Search for continuous calibration tricks to mitigate the error of low cost sensors
2. Fusion with other measures to compensate for the errors
3. Use kinematic and contextual information to model the motion





TESTING IN REAL LIFE CONDITIONS: A NECESSITY!

INDOOR POSITIONING CHALLENGE ORGANIZED BY THE ANR AND DGA IN FRANCE

DGA and ANR launched the challenge **MA**îtrise de la Localisation **I**ndoor (MALIN) 2017-2021

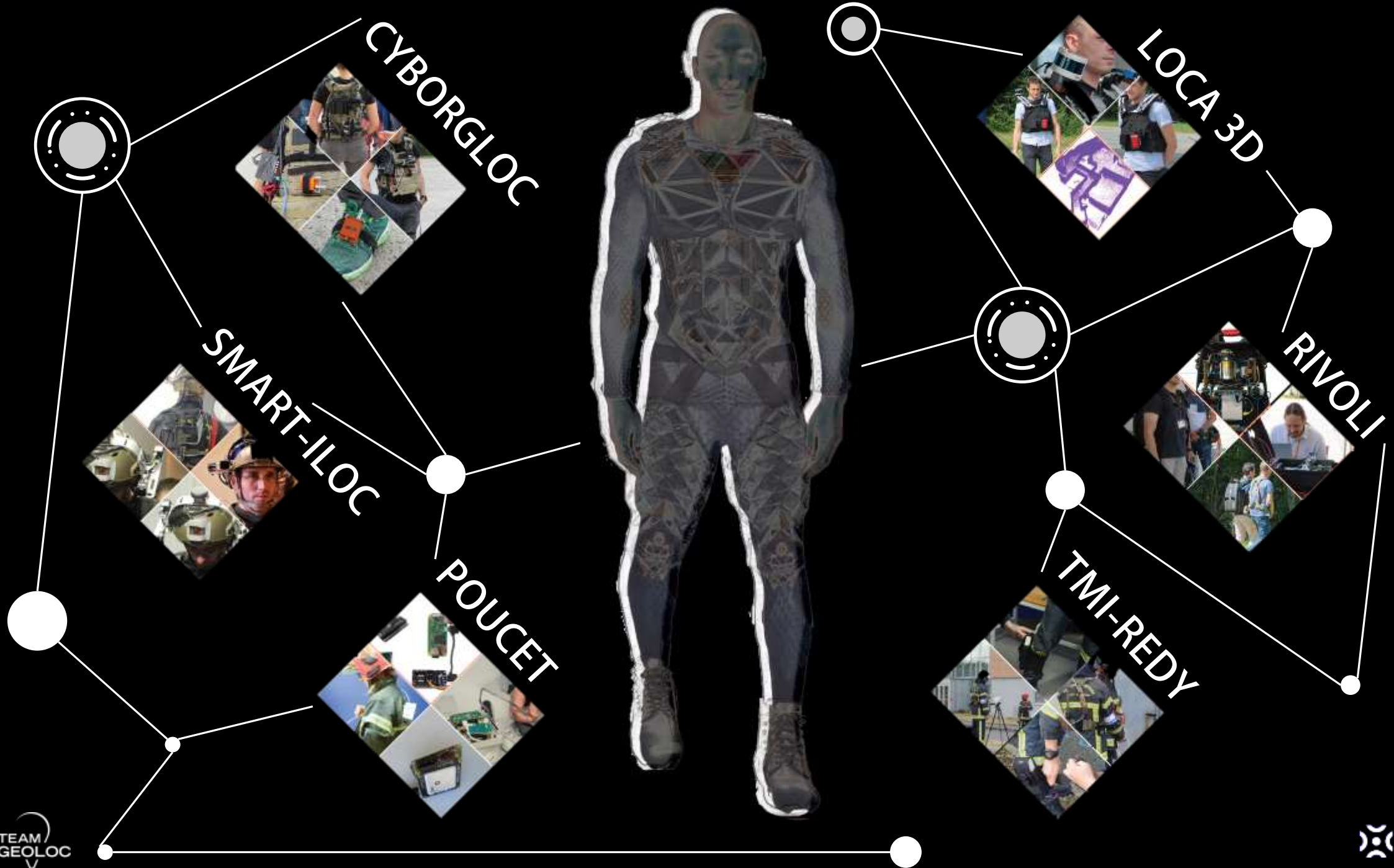


indoor positioning in non collaborative environment

Objectives

- compare different architectures enabling the positioning of persons in complex environments such as buildings or undergrounds in the absence or partial availability of GNSS signals
- support innovation in the domain of autonomous positioning of soldiers and emergency response officers
- address the issue of Indoor-Outdoor transitions



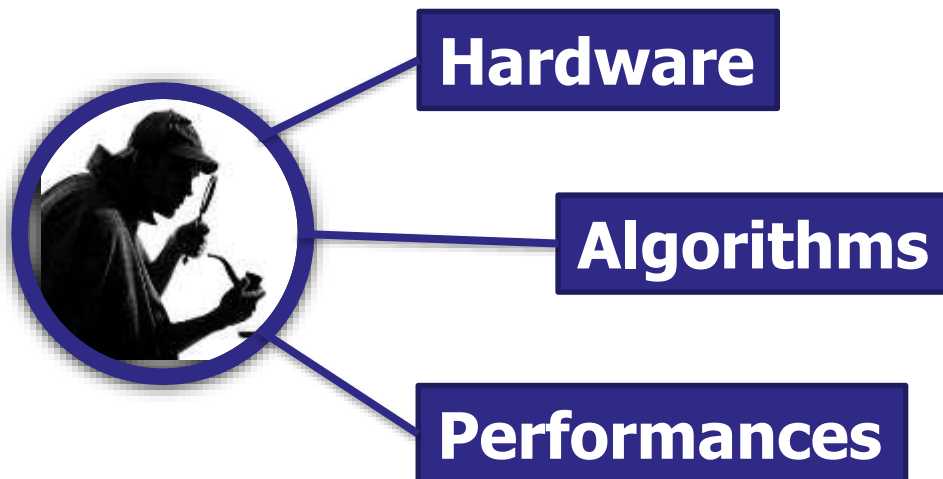


TEAM CYBORGLOC



Technologies

- For the positioning
Foot mounted inertial, magnetic field sensors
Barometer and GNSS on the torso
- For mapping
Camera on the shoulder



CYBORGLOC: HARDWARE

GNSS M8N

Computing cluster

Stereo camera/
inertial
Realsense
D435i

Barometer

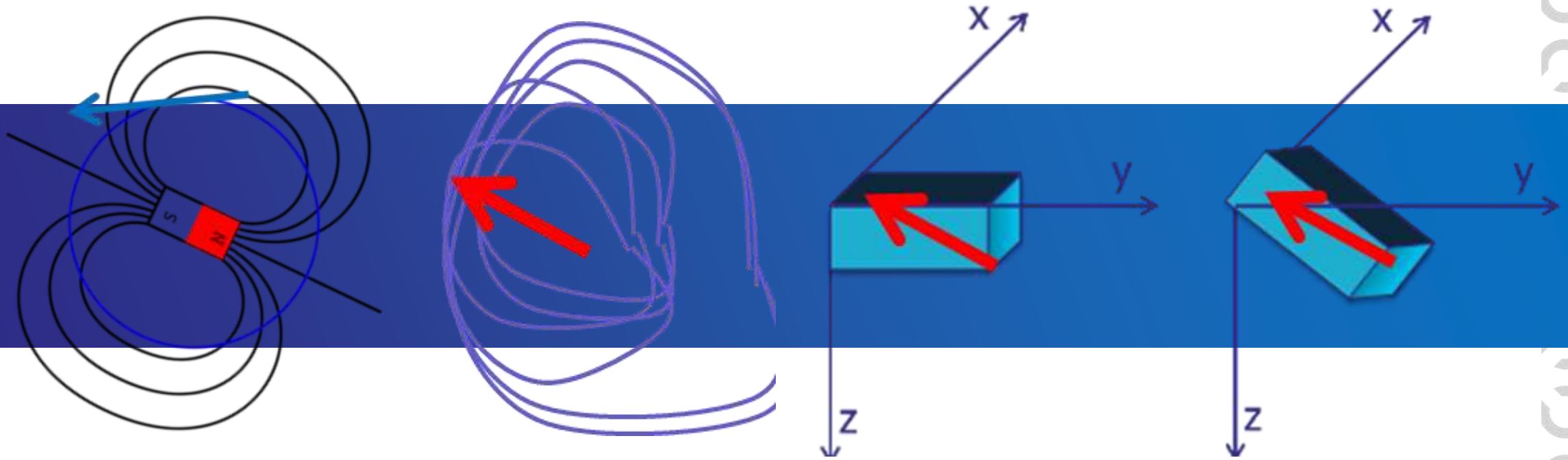
PERSY



Components and characteristics

Weight	< 300 g
Gyroscope drift	0,5 %/h
Accuracy of the estimated trajectory (% of the distance travelled)	0,3 %
STIM300 (Sensoror)	
Sampling Frequency	160 Hz
Triaxial accelerometer	
Triaxial gyroscope	
HMC5983 (Honeywell)	
Sampling Frequency	160 Hz
Triaxial magnetometer	
NEO-M8T (Ublox)	
Single-frequency, dual-constellation GNSS receiver	5 Hz
SD card	
Battery	
Battery life	4 hours

POSITIONING ALGORITHMS: MITIGATING GYROSCOPES' ERROR WITH MAGNETOMETER



When the local magnetic field is static, even indoors, 2 corrections are possible

1. Quasi Static Field Update: All measured magnetic field in the local map frame are the same
2. Magnetic Angular Rate Update: Quaternions derived from the magnetic and gyroscope angular rates over a same period are the same

POSITIONING ALGORITHMS: MITIGATING THE PROPAGATION OF ACCELEROMETER ERRORS

Biomechanics features in walking gait captured by foot mounted

Zero Velocity Update: during the stance phase, the foot velocity equals zero

$$\dot{\mathbf{x}}^n = \mathbf{0}$$

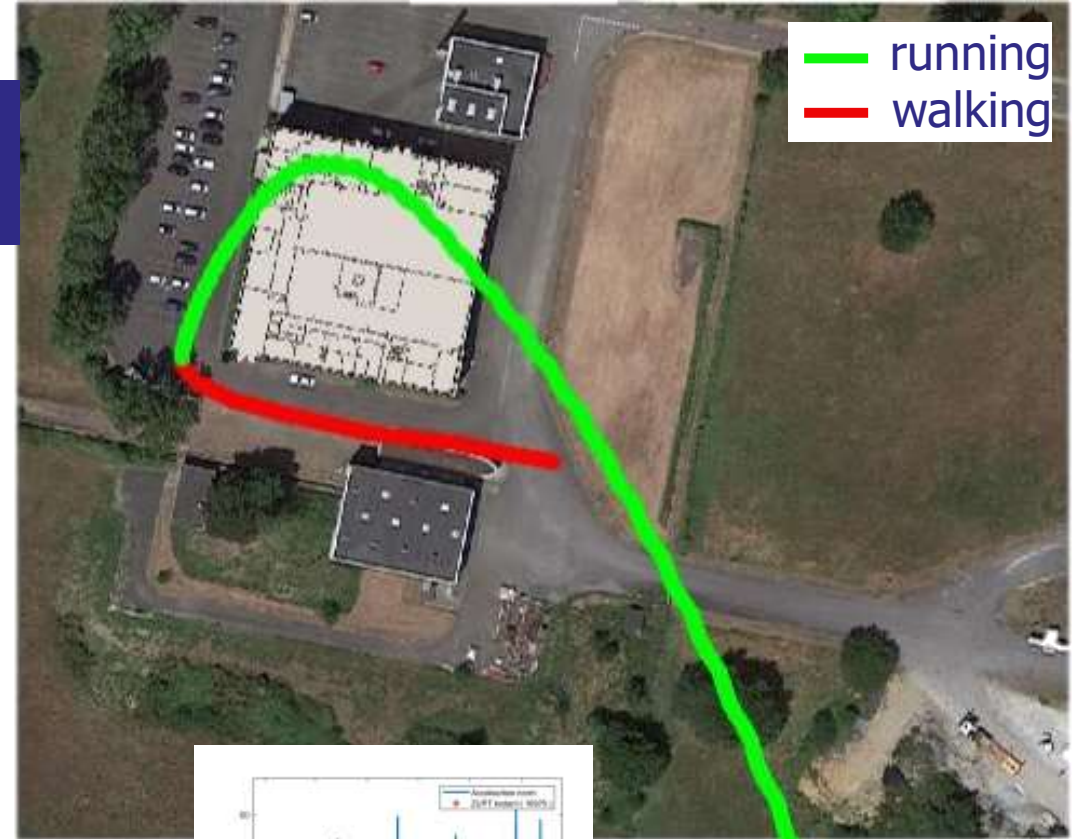
Observation Equations: δ is the perturbation of the state

$$\begin{bmatrix} 0 \\ \delta \dot{\mathbf{x}}^n \end{bmatrix} = \mathbf{q}_b^n \circ [0 \quad (\mathbf{f}^n - \mathbf{b}_f^n)^T]^T \circ (\mathbf{q}_b^n)^{-1} \delta t + \begin{bmatrix} 0 \\ \mathbf{g}^n \end{bmatrix} \delta t$$
$$\begin{bmatrix} 0 \\ \delta \mathbf{x}^n \end{bmatrix} = \dot{\mathbf{x}}^n \delta t + \frac{\mathbf{q}_b^n}{2} \circ [0 \quad (\mathbf{f}^n - \mathbf{b}_f^n)^T]^T \circ (\mathbf{q}_b^n)^{-1} \delta t^2 + \begin{bmatrix} 0 \\ \mathbf{g}^n \end{bmatrix} \delta t^2$$

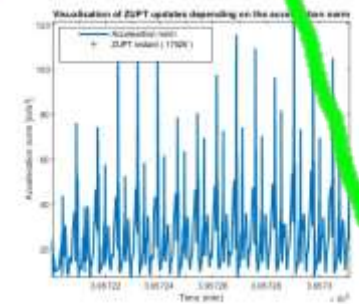
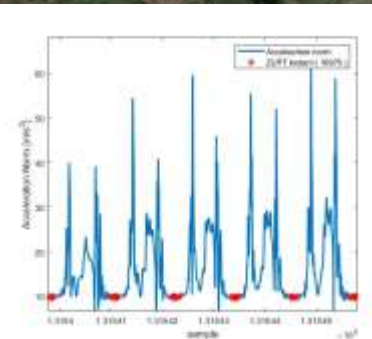
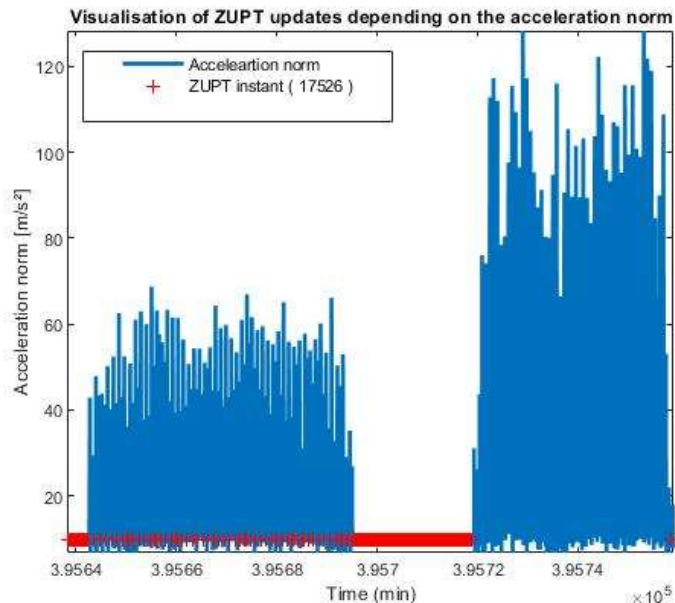


POSITIONING ALGORITHMS: CORRECTLY DETECTING ZERO VELOCITY INSTANTS

- Main principals of zero velocity detectors
- Use of activity thresholds
- Adopt time windows based analysis for real time application
- Process signals statistics: variance, norm, frequency components, etc.



— running
— walking



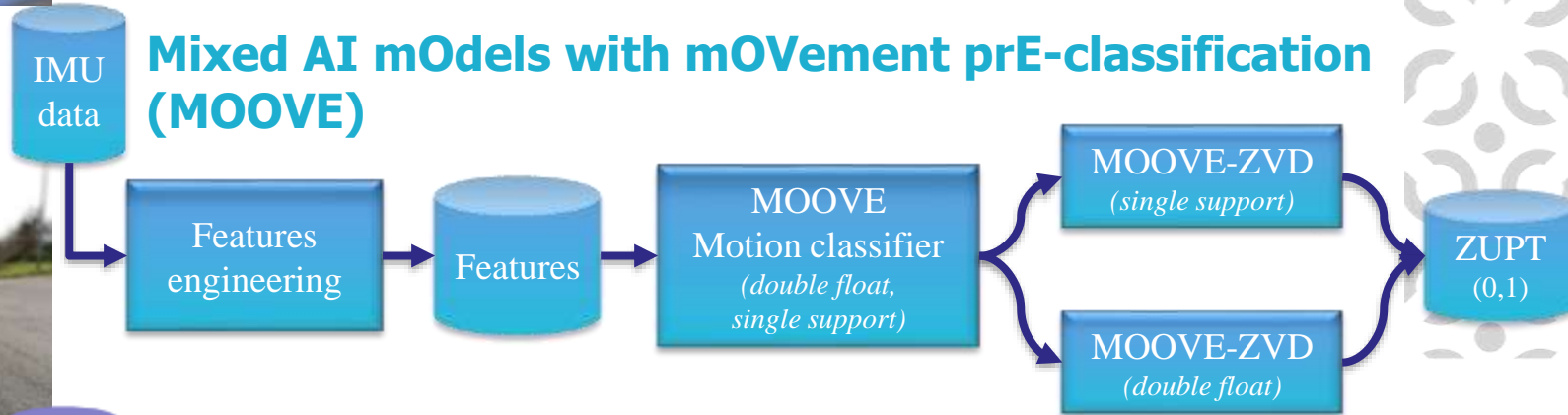
- Problems
- How to fix all thresholds?
- How to adapt to different motions or humans?
- Which window sizes?



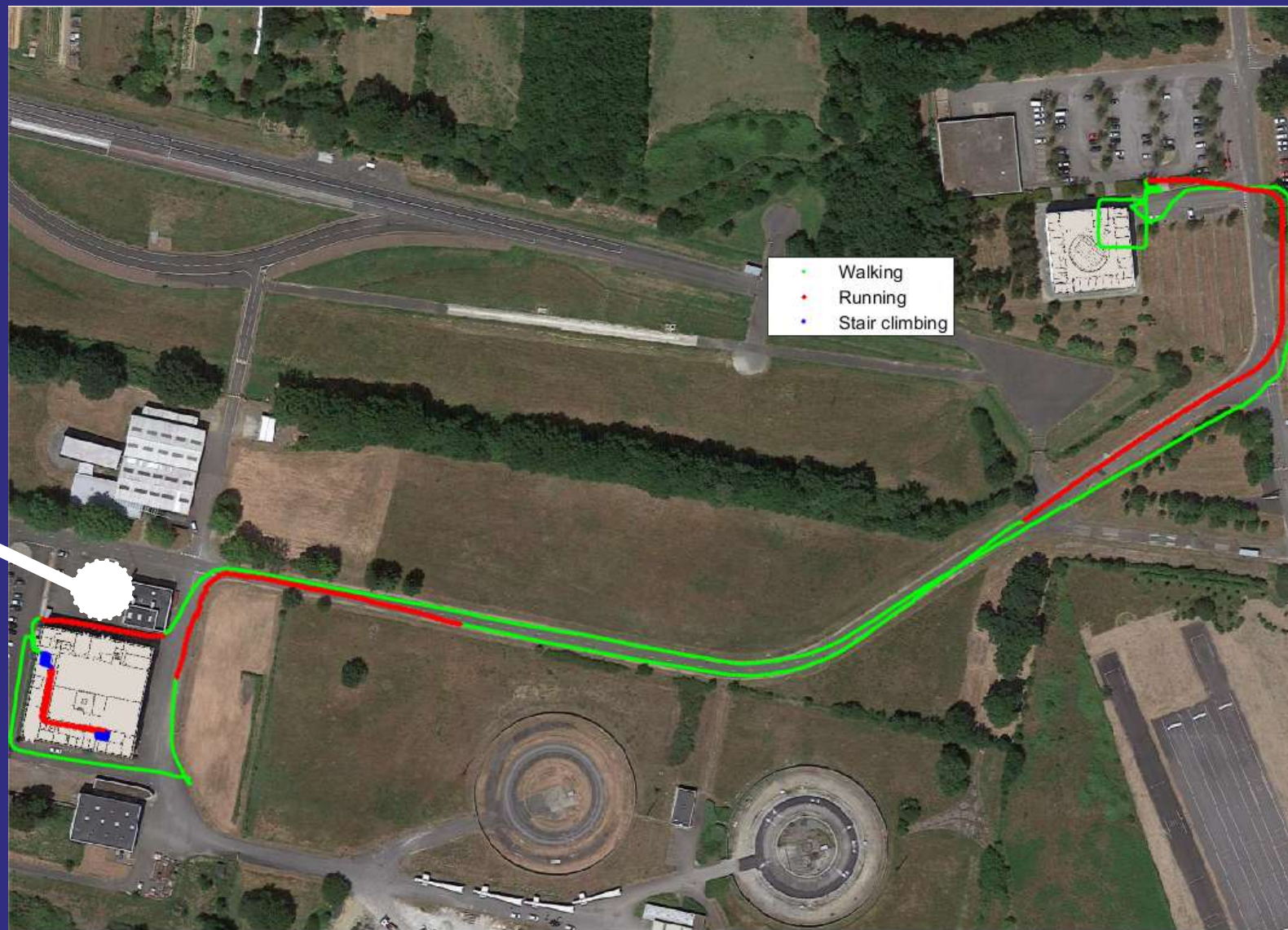
POSITIONING ALGORITHMS: CORRECTLY DETECTING ZERO VELOCITY INSTANTS

Adopting machine learning to detect a large variety of human dynamics

Creation of 2 models using hist gradient boosting approach



POSITIONING ALGORITHMS: CORRECTLY DETECTING ZERO VELOCITY INSTANTS



POSITIONING ALGORITHMS: 2 COMPLEMENTARY FILTERS

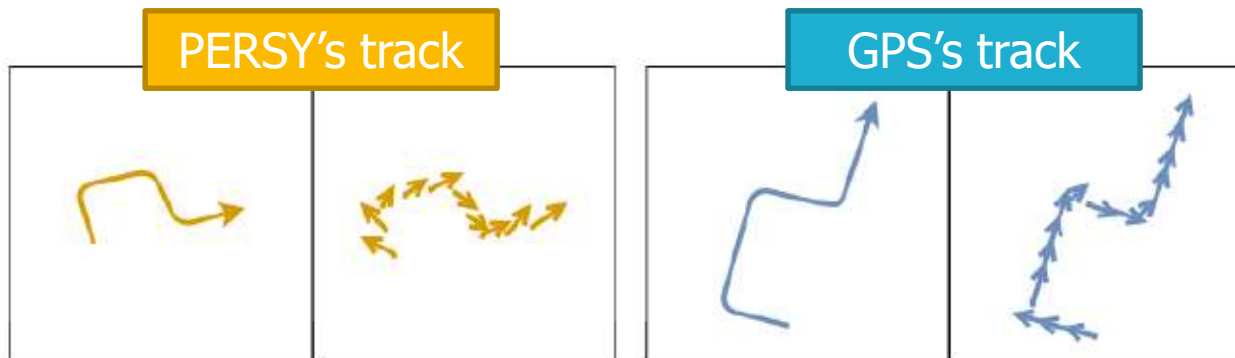
Altitude filter

- Use of barometer data to correct the estimated altitude:
 T_{ref} , P_{ref} temperature and pression of reference, h_t is the altitude at time t
 L , R and g_0 are fixed variables

$$\delta h_t^n = -\frac{T_{ref}}{L} \left(1 - \left(\frac{P}{P_{ref}} \right)^{\frac{-LR}{g_0}} \right) - h_{t_0 t}^n$$

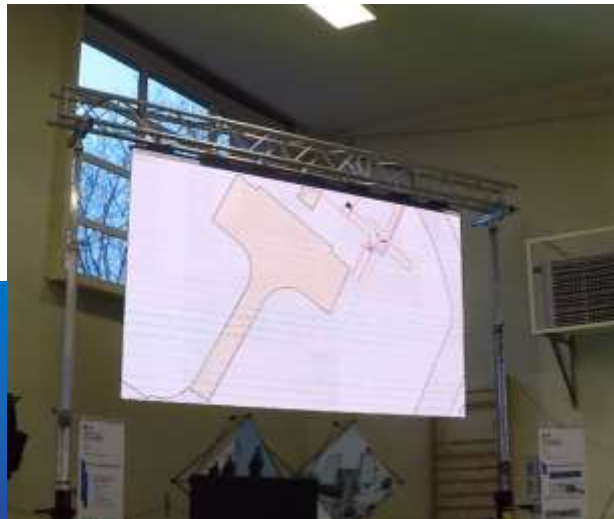
Rotation/Translation filter

- To mitigate misalignment issues between the inertial unit mounted on the foot and the walking direction (Rotation, Translation)
- Estimation of optimal 2D similarity between a track estimated by GPS signals and the track estimated by inertial and magnetic field signals
- Loose coupling introduces potential issues related to Non Line of Sight signals → Tight coupling



THURSDAY 27 FEBRUARY 2021: LAST COMPETITION!

Evaluation Scenario in real time with display of the track on a large screen



DEEP INDOOR COMPETITION

2.5

km

Total traveled distance
(without the vehicle part)

45

Min.

Total Duration

4/9

Levels/Motions

3 floors - 1 underground /
walking, running, stairs
climbing/backward descending,
crawling, ladder, side stepping,
treadmill, tour on itself



Deep indoor conditions (~100m tunnels)
Successful zero velocity detections for complex movements

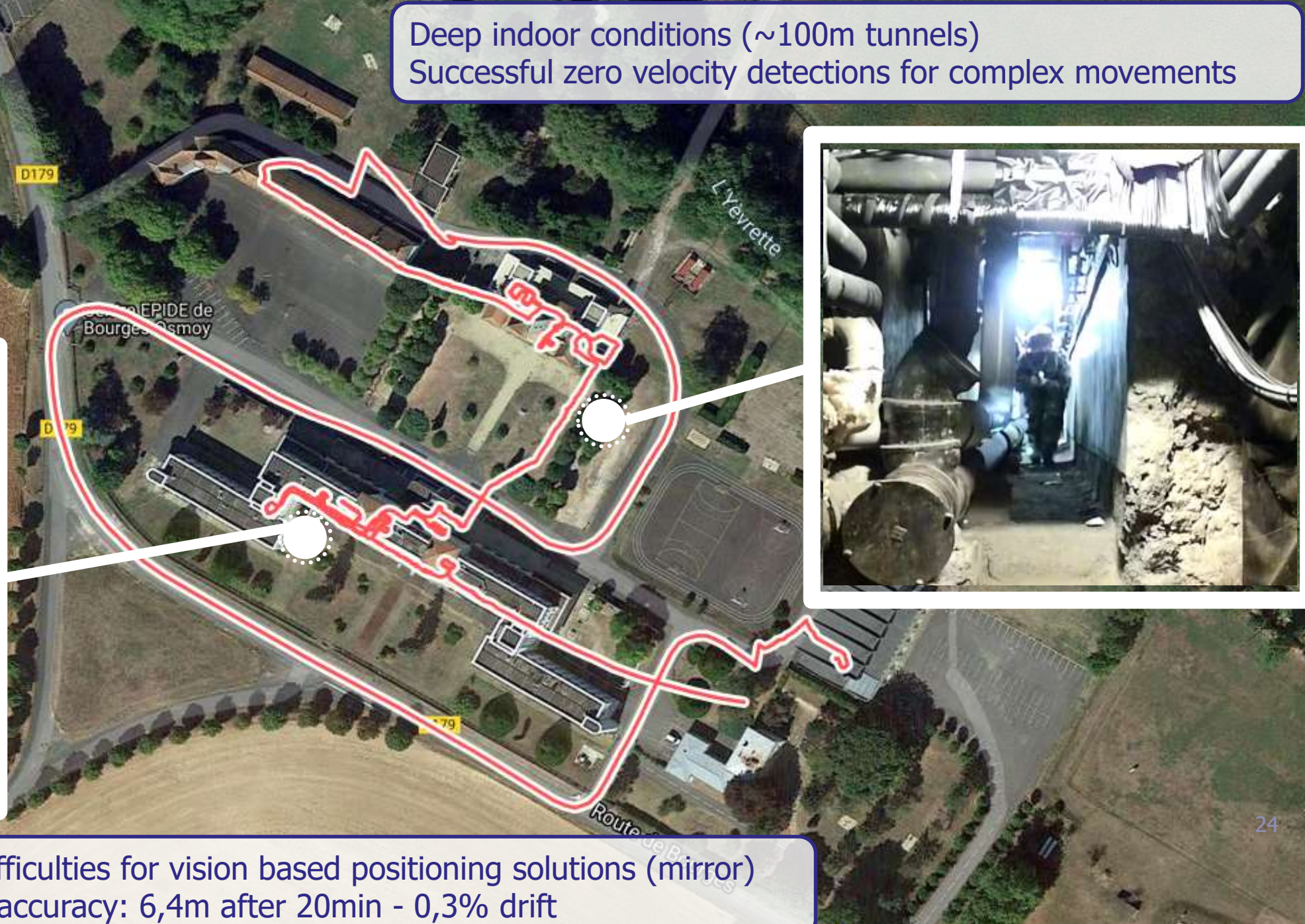


Illustration of difficulties for vision based positioning solutions (mirror)
Our positioning accuracy: 6,4m after 20min - 0,3% drift



OUR ACHIEVMENT IN SHORT

Winner of the competition!

0.27% Horizontal Positioning Error over the total traveled distance beyond state of the art (1% simpler condition, shorter distance) performances, especially in harsh conditions. **1.41 m Vertical Positioning Error (Q3)**

Fused Inertial Positioning solution is found to be more robust than Vision based solutions

Artificial intelligence implemented in real-time has successfully enabled the integration of a wide variety of human gait movements → **Understanding the physics is key!**

2.5

km

Total traveled distance
(without the vehicle part)

45

Min.

Total Duration

4/9

Levels/Motions

3 floors - 1 underground /
walking, running, stairs
climbing/backward descending,
crawling, ladder, side stepping,
treadmill, tour on itself

6.4

Meter

Horizontal positioning error
over traveled distance
(3rd Quartile)



MOVING TO WEARABLE DEVICE WORN BY THE PEDESTRIAN ON DIFFERENT PARTS OF THE BODY?

ESTIMATING STEP LENGTH AND HEADING WITH WEARABLE?



How to represent a pedestrian on a map?

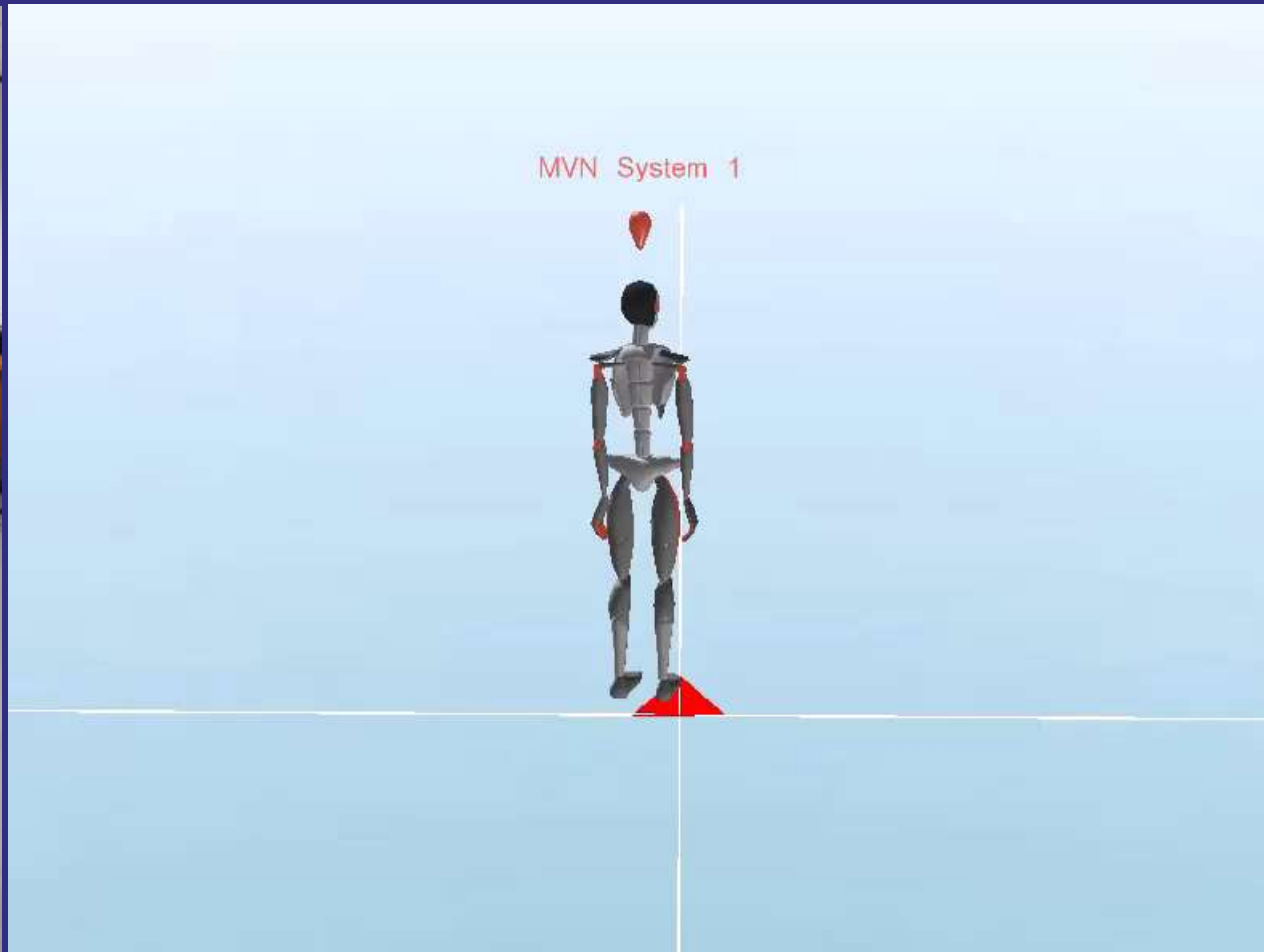
Where is the wearable, i.e. the measurement point (hand, pocket, bag...)?

Does the upper body part correspond to the motion of interest? Is it correlated with the legs?

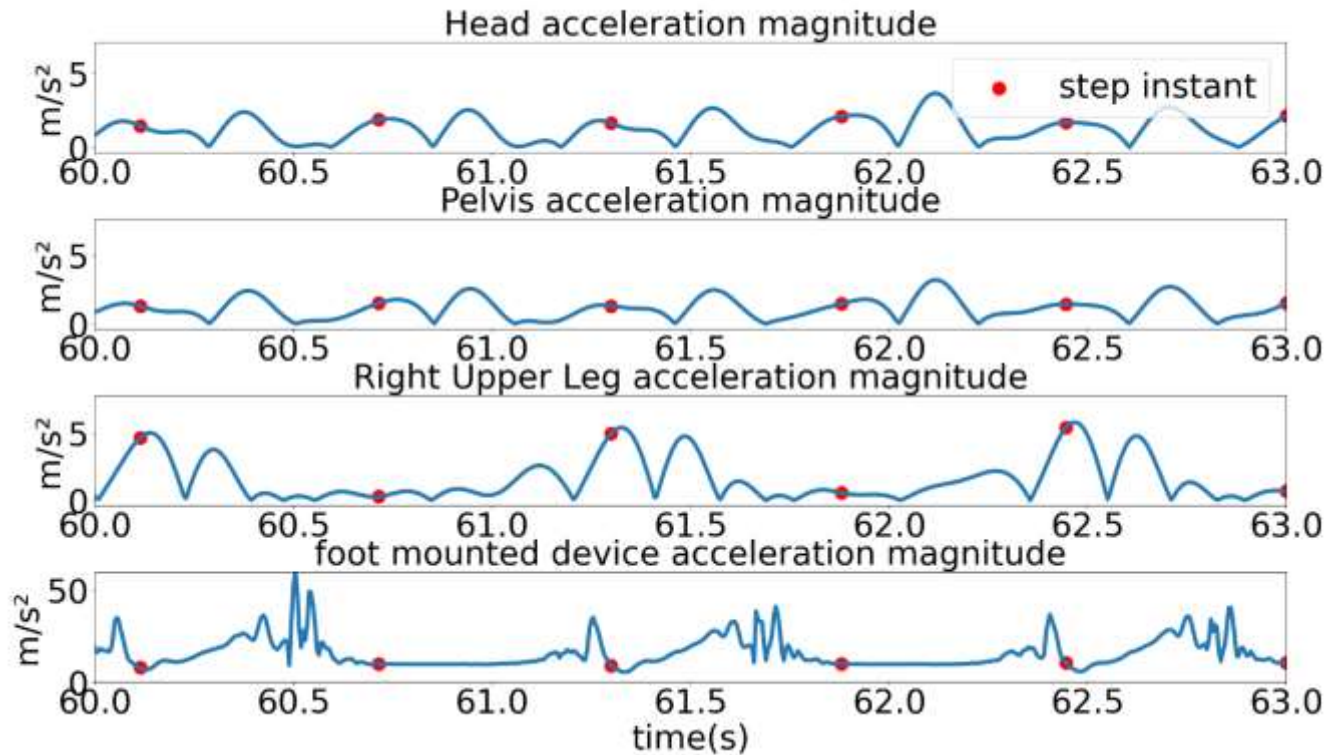
How to train any artificial intelligent model to recognize or estimate gait parameters?

What is the best strategy to label time series of inertial data for learning human gait features with artificial intelligence: physics or human interpretation?

LET'S HAVE A LOOK AT THE UPPER/LOWER LIMBS CORRELATION



POINTS OF INTEREST ARE NOT SYNCHRONIZED BETWEEN THE DIFFERENT BODY PARTS



Ground truth step instants (flat foot period) projected on the acceleration norms of different body parts



PHYSIC" VS "BRAIN": TWO LABELING STRATEGIES

Training dataset

10 subjects (6 Men and 4 Women) of various heights. Among the men, 2 are blind people. The full dataset has 753'121 observations, 1% being step instants.

Equipment

2 ULISS hardware: one fixed on the foot (reference) and one in hand

Physics Labeling



[Learn More](#)

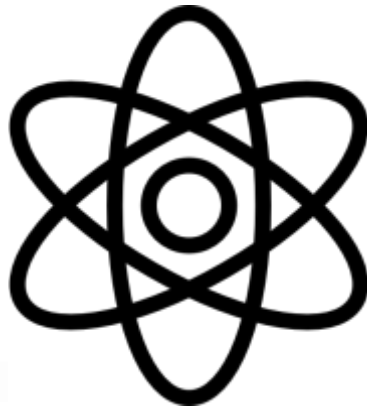
Koné Y, et al. (2021), "Zero Velocity Detection without Motion Pre-classification: Uniform AI Model for All pedestrian Motions (UMAM)", IEEE Sensors Journal

Brain Labeling



[Learn More](#)

Al-Abiad N, et al., "Smartstep: a robust STEP detection method based on SMARTphone inertial signals driven by gait learning", IEEE Sensors Journal, 2022



3 SCENARIOS FOR THE EXPERIMENTAL ASSESSMENT OF STEP DETECTION



sighted/in
hand/150m

A sighted person walked into an office building. The trajectory included stairs. The person walked in "texting" mode during the first 1/2 the recording, and "swinging" for the rest



sighted/in
pocket/150m

Same sighted subject and environment as Test 1 but the IMU sensor was in the subject's front trouser pocket (thigh)



blind/out
jacket/80m

A blind subject walked in a straight line and turned around in an outdoor park. The trajectory length is about 80m. The IMU was located in the jacket pocket (waist)



STEP DETECTION RESULTS FOR PHYSICS AND BRAIN LABELING STRATEGIES

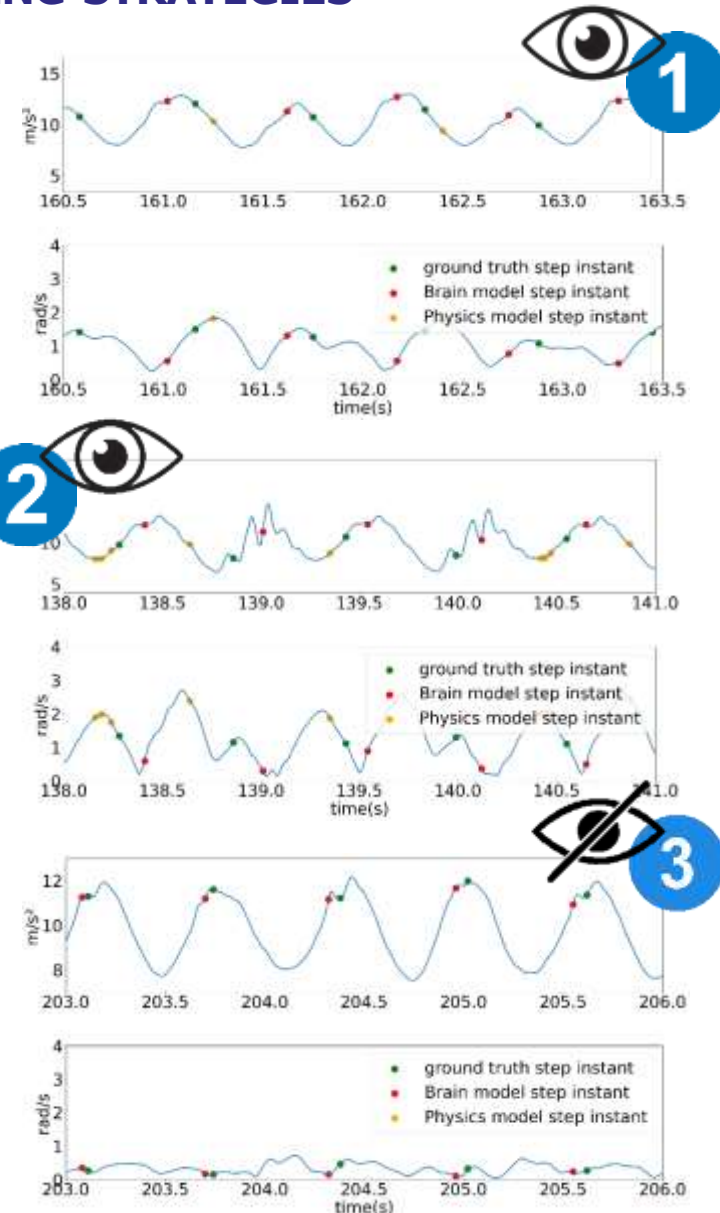
The "Brain" model detects over 85% of steps on all 3 tests and rarely over-detects

The "Physics" model gives almost random inferences on the first 2 tests and fails badly the third one with the IMU in the vest pocket

Test	N_{ref}	Physics			Brain		
		N_{pred}	TPR	ODR	N_{pred}	TPR	ODR
1	256	221	54.7	36.7	256	97.7	0
2	245	204	52.7	36.8	215	86.9	0.9
3	142	5	3.5	0	123	85.9	0.8

[Learn More](#)

Renaudin V. , et al (2022) "Physics" vs "Brain": Challenge of labeling wearable inertial data for step detection for Artificial Intelligence, the 9th IEEE International Symposium on Inertial Sensors & Systems, May 8-11, Avignon, France





Human diversity challenges personal navigation technology

Learning individual gait differences thanks to inertial signals in wearables is a key to support new mobility services with accurate positioning!

Which inertial signals based service will you adopt tomorrow to reduce your carbon footprint?



TEAM
GEOLOC
V

 Université
Gustave Eiffel

Valérie RENAUDIN

valerie.renaudin@univ-eiffel.fr

06 19 71 22 12

<https://geoloc.univ-gustave-eiffel.fr/>