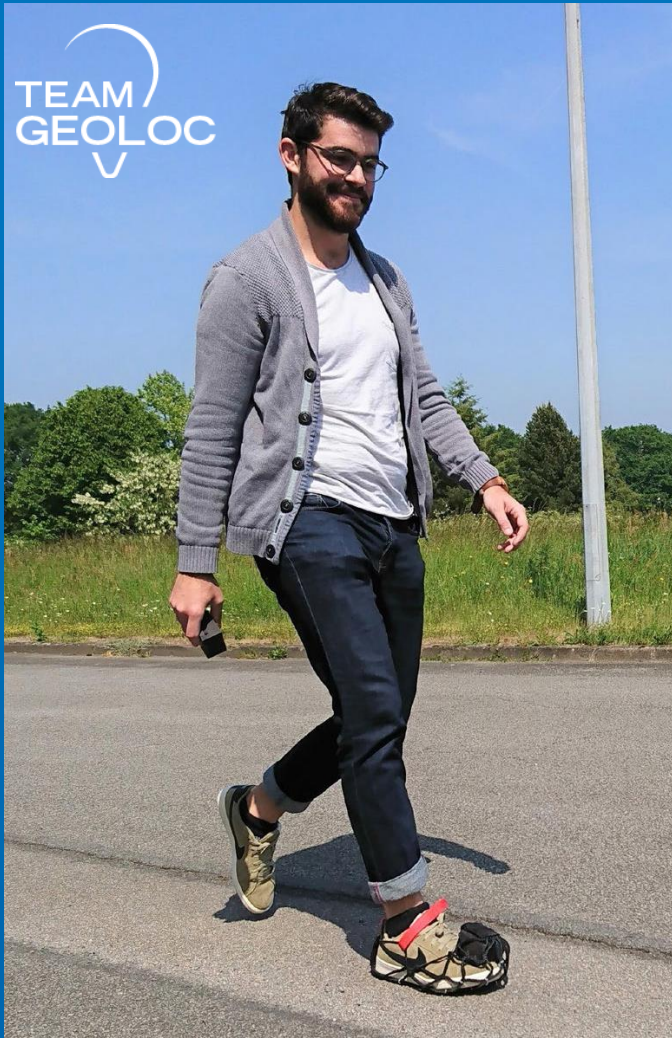


TEAM
GEOLOC
V



Integrating human dimension in the development of pedestrian navigation

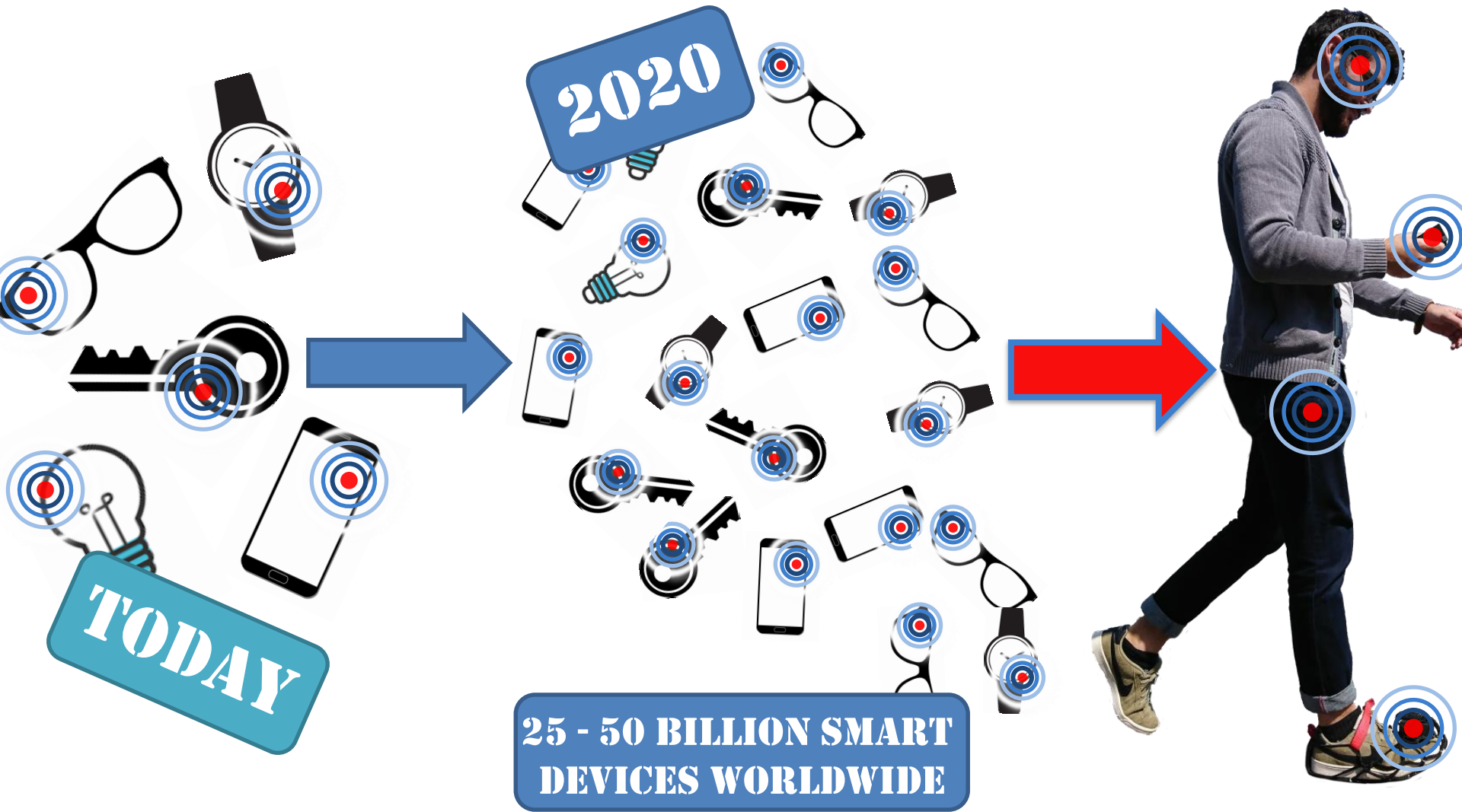
ITSNT
TOULOUSE
International Technical Symposium
on Navigation and Timing

Dr. Valérie Renaudin

15 November 2018, Toulouse, France



IFSTTAR



Development driven by market needs



Promote multimodal transport with the following priority rules : at first pedestrians, then cyclists, then motorists



Use crowdsourced data collected by a wide range of stakeholders to produce accessibility maps



Expand the prescription sports-health program to integrate the practice of walking and cycling in the treatment of patients

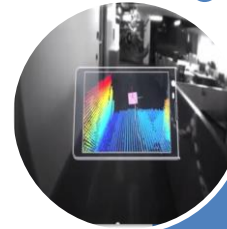
Technology Push & Sensors' Location on Human Body



Light Fidelity



Infrastructure based motion detection



Camera, mono, stereo, depth, ...



Sounds, radiowave, ...



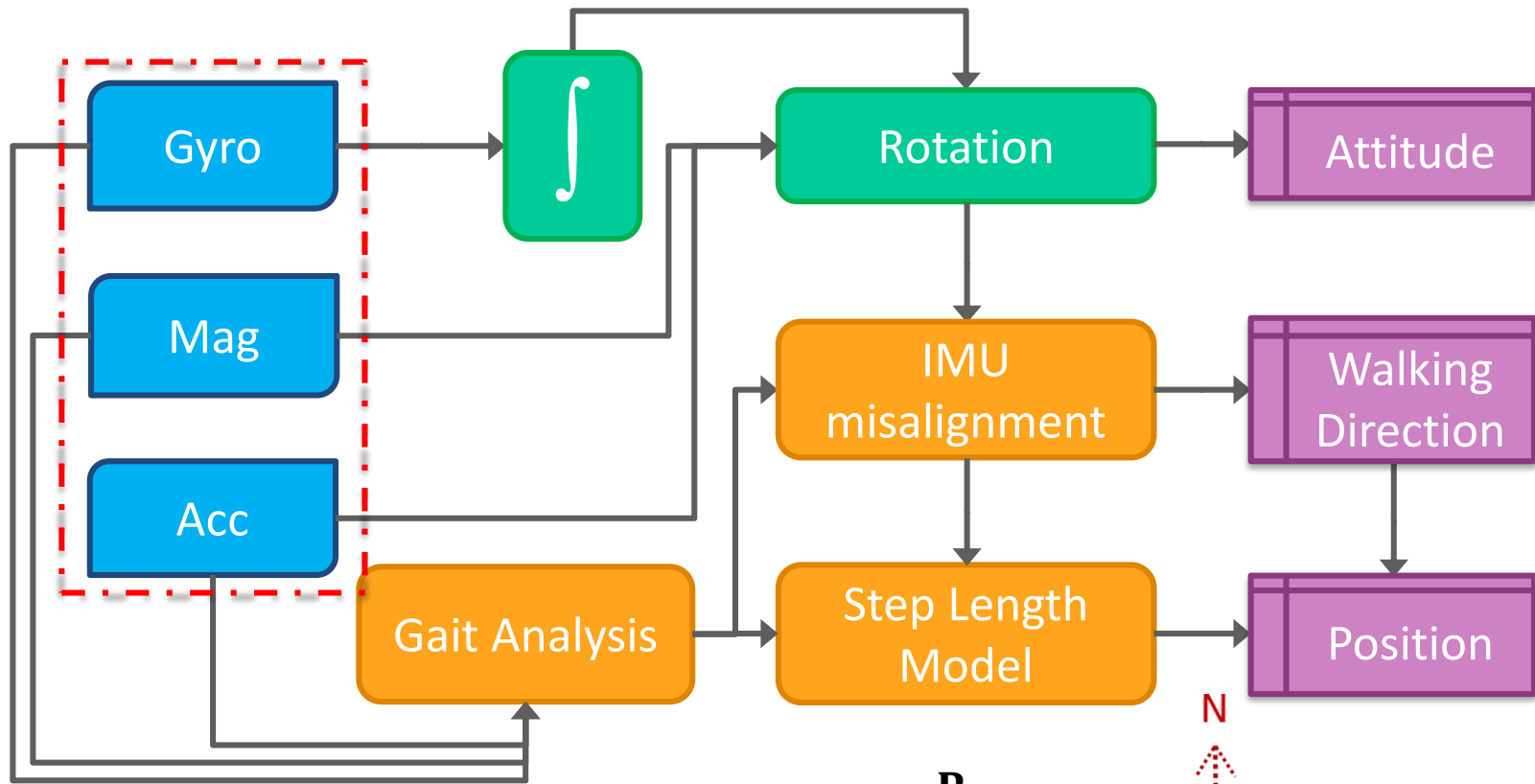
Inertial Sensors, Atomic, 3D glass shell



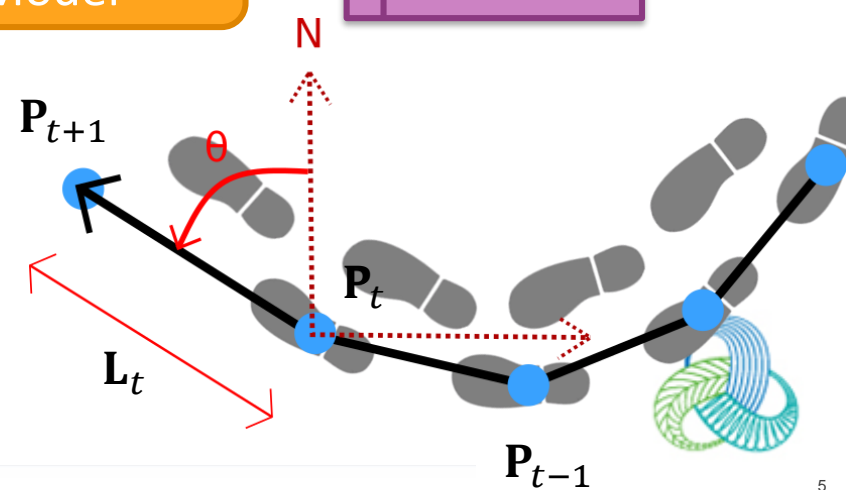
GNSS, lower consumption, multi-freq



Pedestrian Dead Reckoning

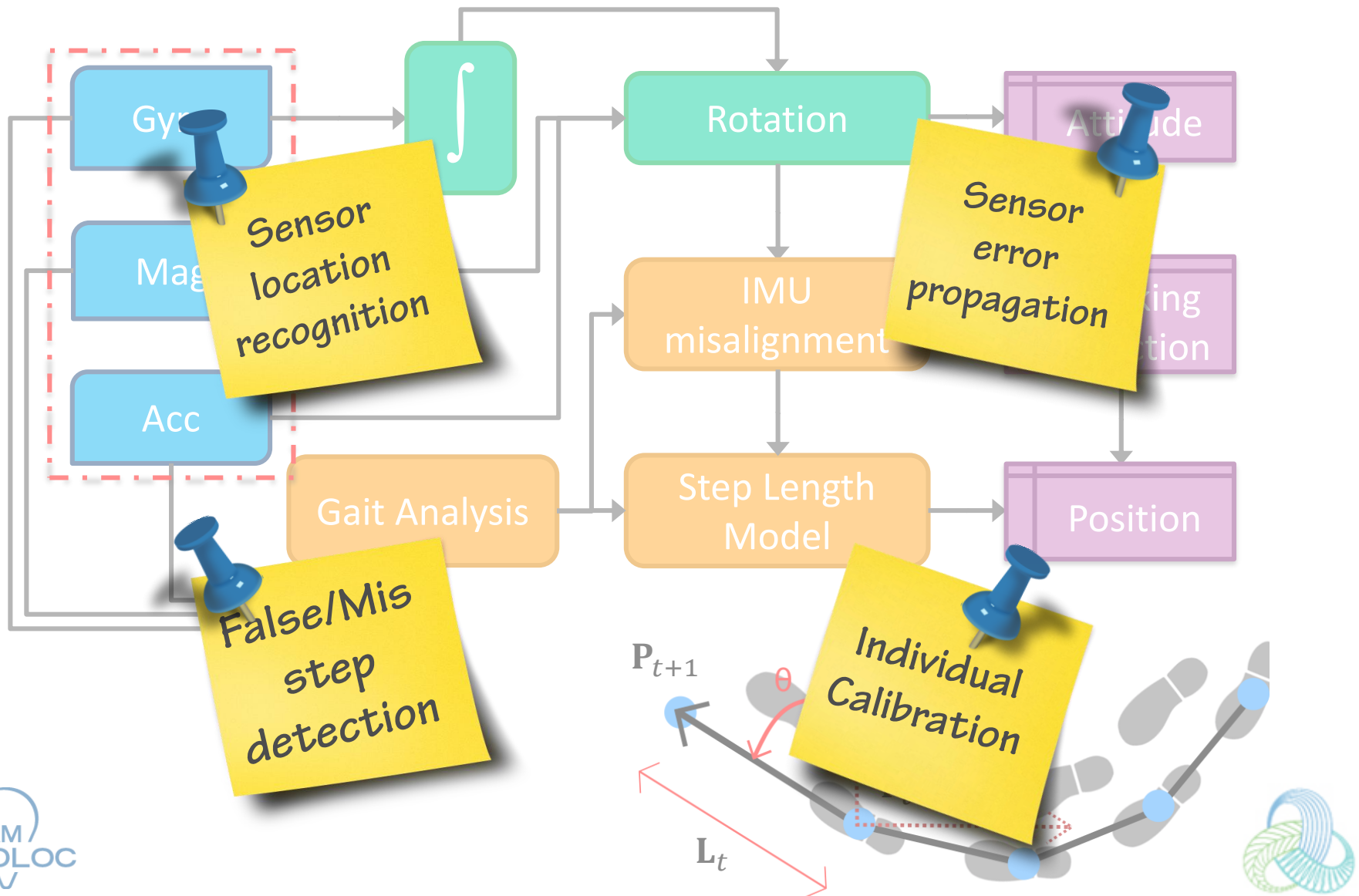


$$\mathbf{P}_t = \mathbf{P}_{t-1} + \mathbf{L}_{t-1} \cdot \vec{\theta} \quad \vec{\theta} = \begin{bmatrix} \sin \theta \\ \cos \theta \end{bmatrix}$$



t : time index, \mathbf{P}_t : Position estimate, \mathbf{L}_t : Step length, θ : Walking direction

Pedestrian Dead Reckoning





**Monocular
Visual
Odometry
Assisted by
Step Length**

Assisted Monocular Visual Odometry

Context

Monocular vision

Tracking Method

Visual odometry

Problem

Scale ambiguity

Solutions

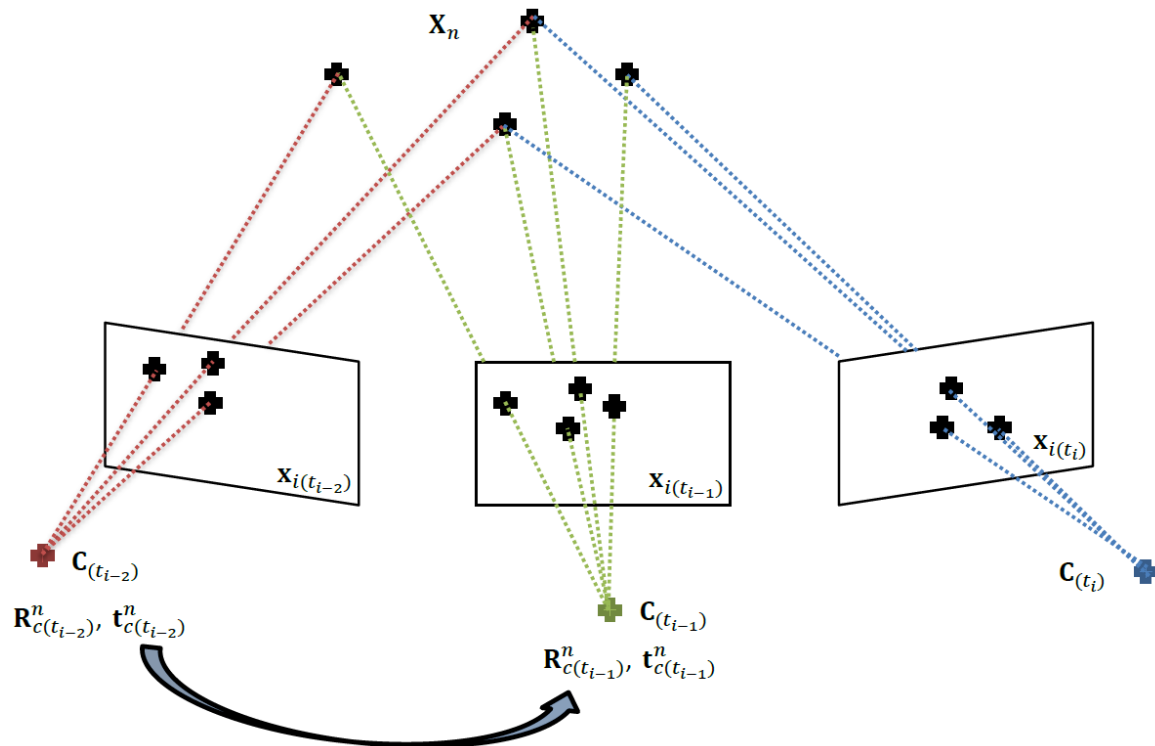
State-of-the-art

Use of perfectly known 3D objects (GIS)

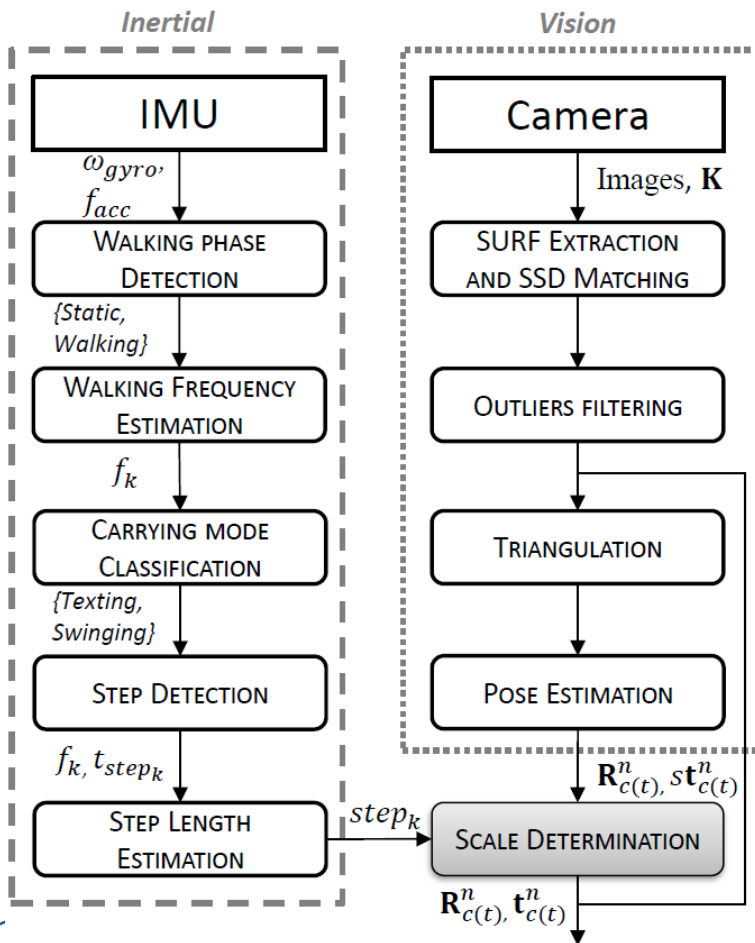
Calibration on known motions

Proposition

Using PDR step length estimates to solve for the ambiguity



Monocular Visual Odometry



Vision (VO)

- SURF features extraction
- Matching with SSD between $x_i(t_{i-2})$, $x_i(t_{i-1})$ and $x_i(t_i)$
- Outliers filtering with MSAC
- Triangulation
- Relative pose estimation

Inertial (PDR)

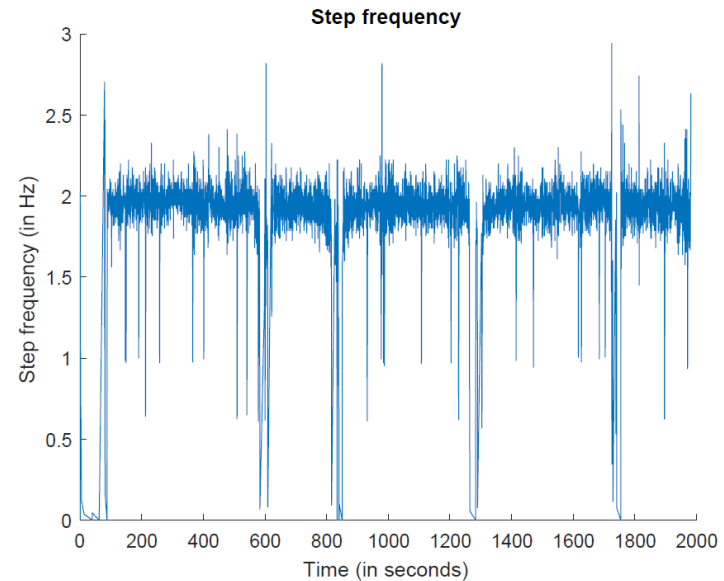
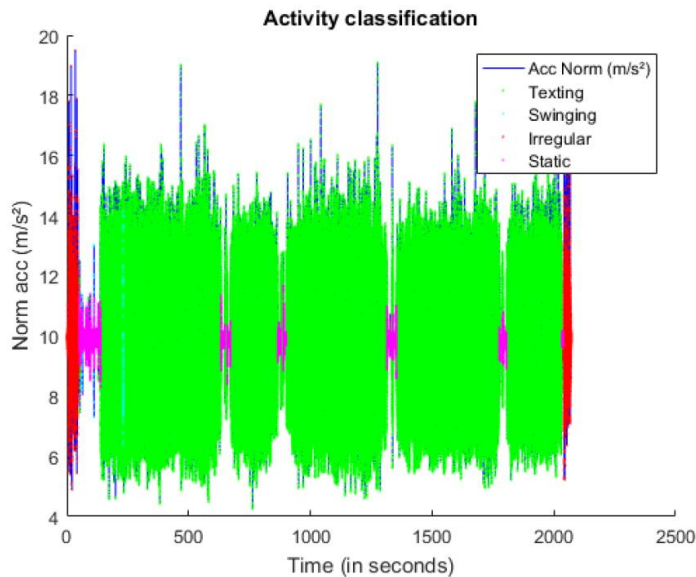
- PDR processing

Fusion Vision/Inertial

- Scale Determination

$$s_{tim} = \frac{D_{PDR}(t_{im})}{D_{VO}(t_{im})}$$

Step Length Model



Activity classification

Step frequency estimation (STFT, Energy in sub-bands): f_k

Step detection: t_{step_k}

Step length modeling:

$$step_k = h_{ped} * (a * f_k + b) + c$$

Synchronization between step events and visual odometry is important

Height changes extracted from Digital Terrain Model considering a fixed height of the hand

Experimentation

Scenarios

800 m walk in urban environment
Stops in front of 2 reference objects
3 pedestrians

Hardware

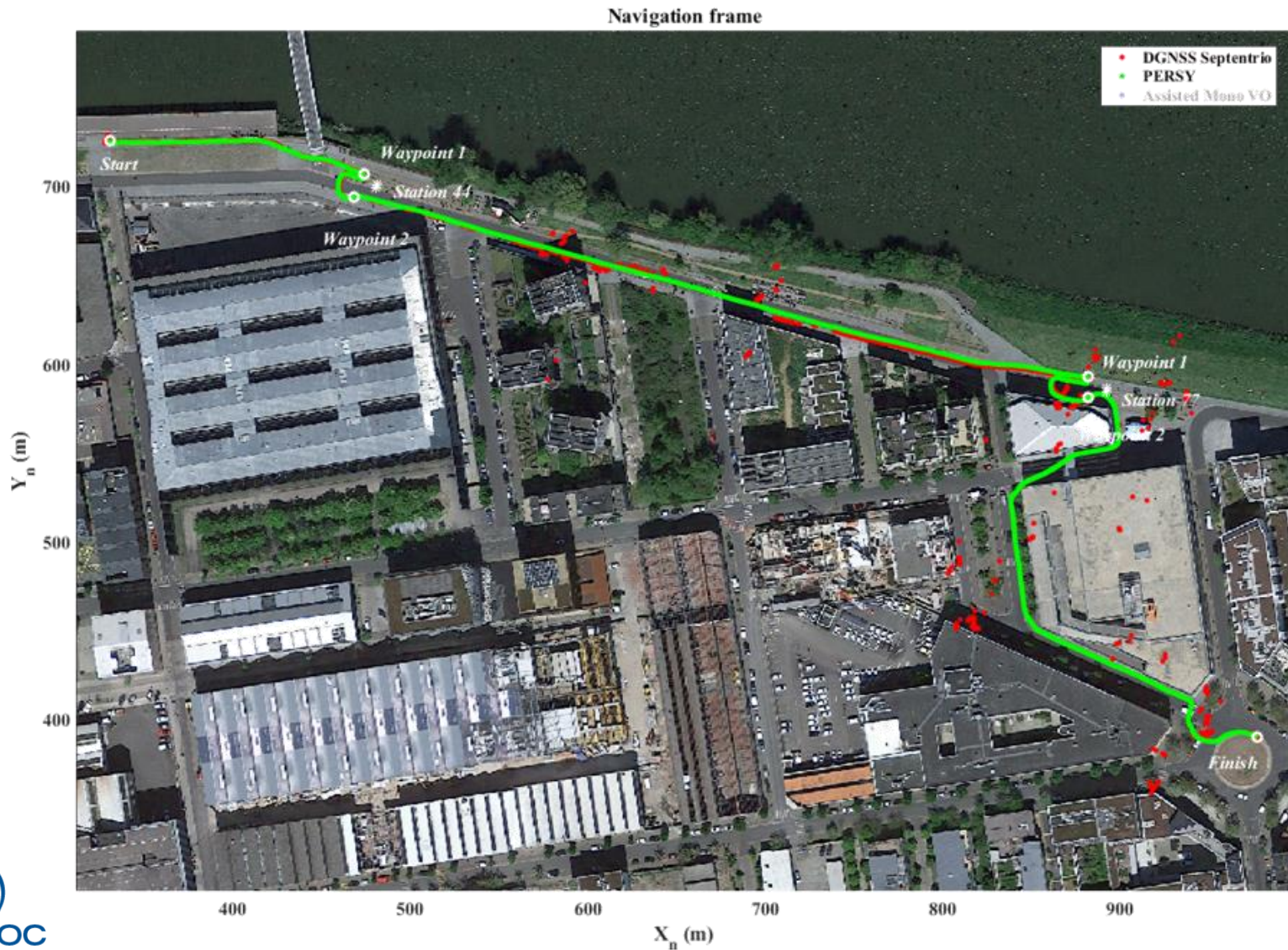
Handheld IMMU: **ULISS** (Ubiquitous Localization with Inertial Sensors and Satellites) at 200 Hz
1920*1080 visual measurements at 10 Hz with a Garmin monocular **Camera**

Reference

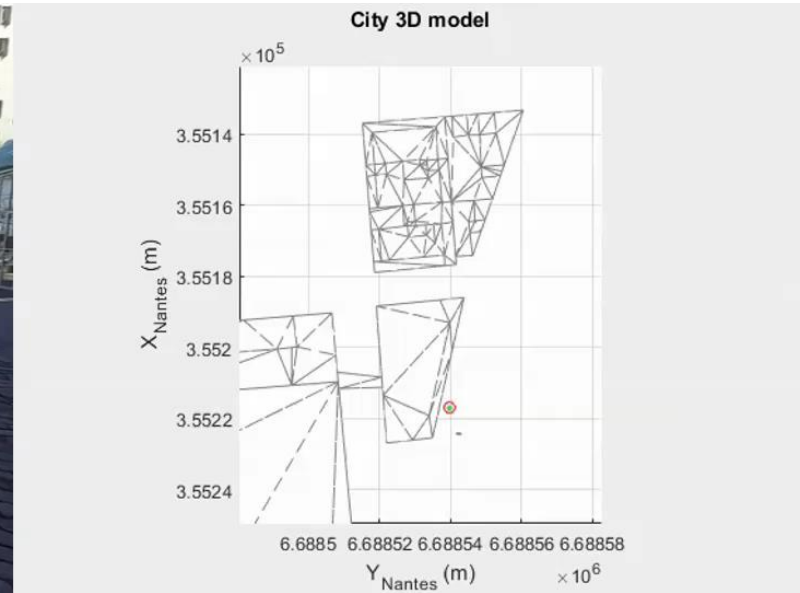
Differential GNSS (handheld helicoidal antenna + Septentrio)
Foot mounted **PERSY** (PEdestrian Reference SYstem) : positionning error 0,3% traveled distance



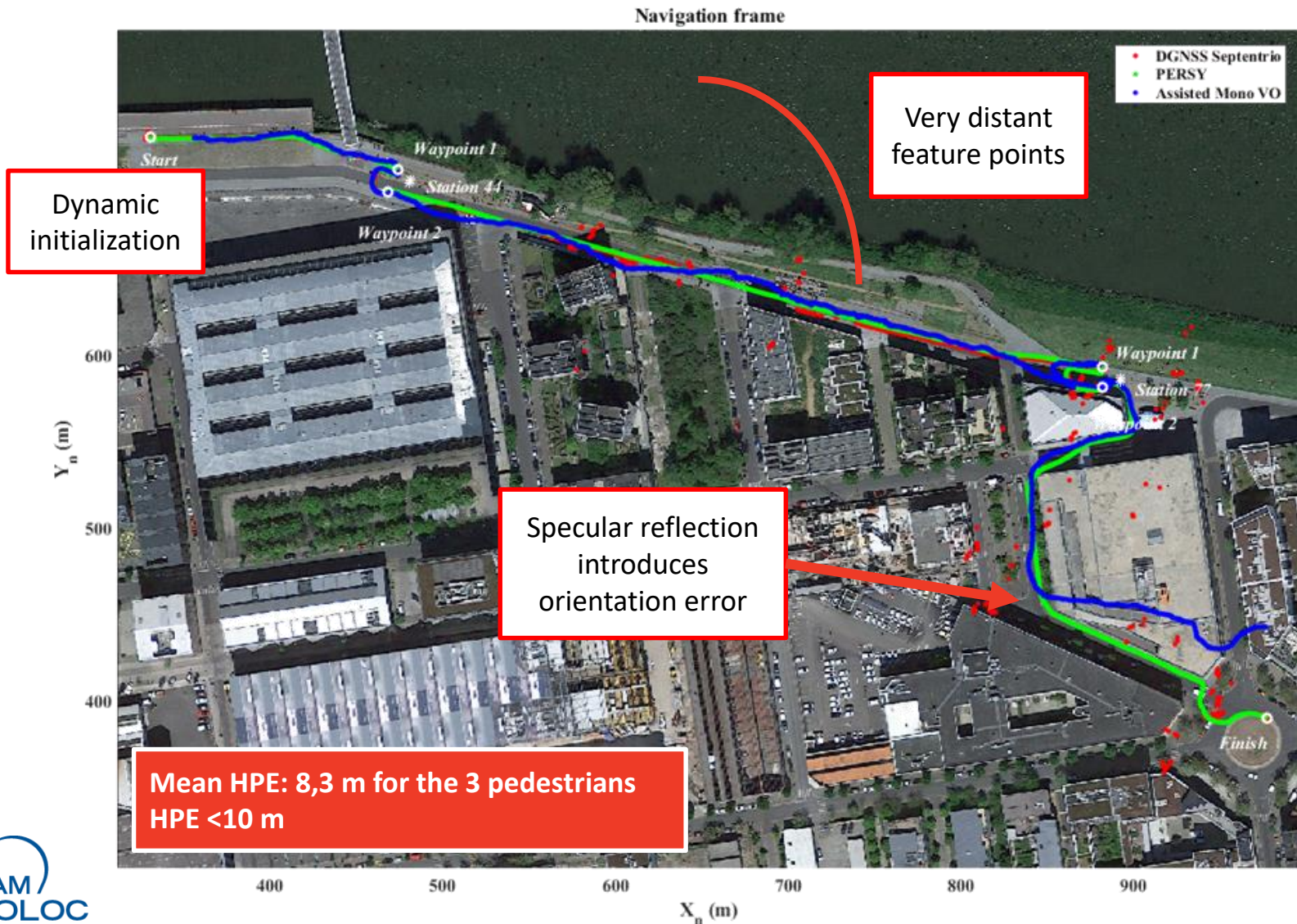
Pedestrian path in urban environment



Accurate Vision/PDR PVT Estimates



Pedestrian path in urban environment

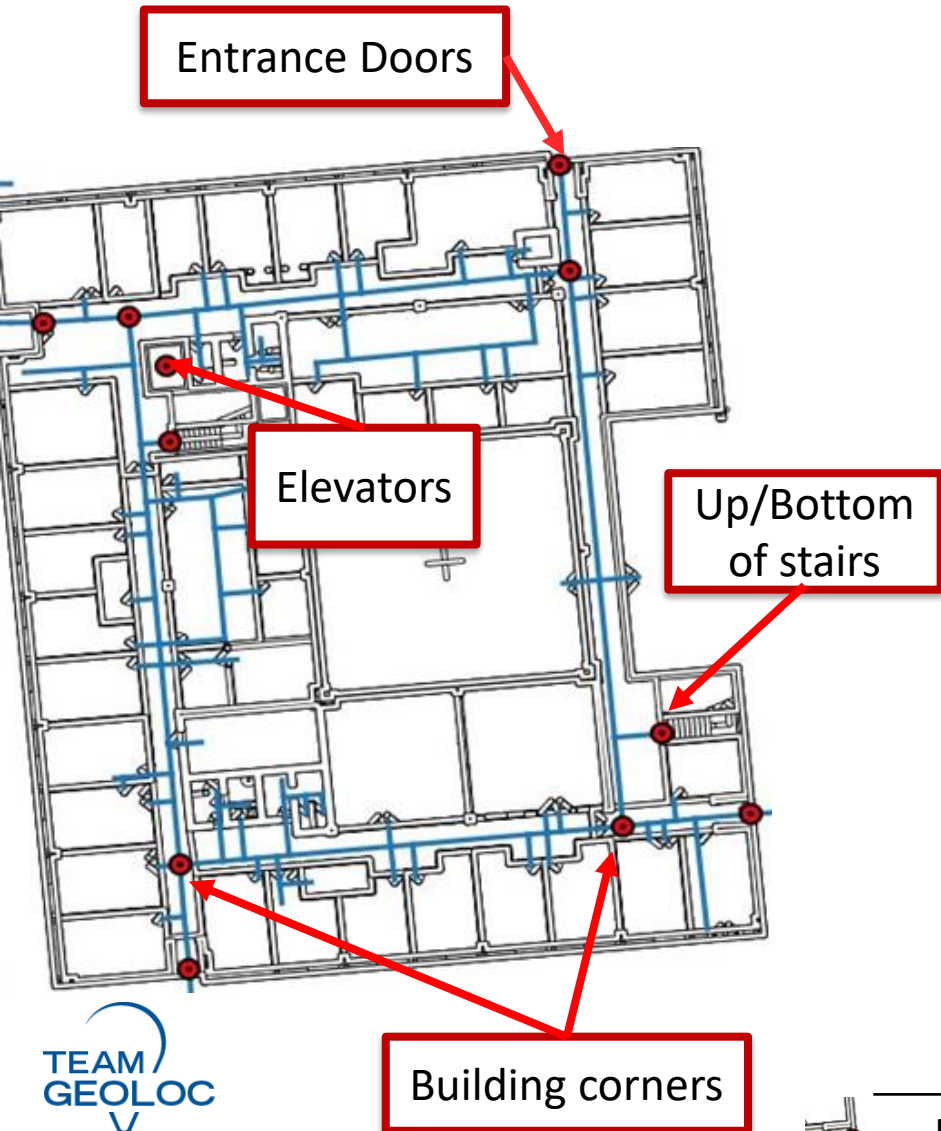


**Linking Human
Motion and
Map Locations**



**Monocular
Visual
Odometry
Assisted by
Step Length**

Position updates by means of human motion signal patterns recognition



Context

Pedestrian navigation with GIS content

Tracking Method

Particle Filter combined with topological graph

Problems

Graph mis-matching
PDR error mitigation

Solutions

State-of-the-art

Heading correction with principal building directions/corners

Position correction with lift locations

Adjust dynamic model to motion context (staircase, lift, ...)

Proposition

Associate recognized human motions with map regions (Point of Interest)



Id

E

N

Type



Graph Mis-Matching Mitigation

Collect data

Learn signal patterns

Link POIs to the map

- 4 women & 4 men
- Different motion speeds
- Six Buildings

- Feature Selection
- Different dataset for test and validation
- SVM, Random Forest, Neural Network

- 5 POI types
- Online signal segmentation & classification
- Online POI detection

Supervised Learning

Positioning



PDR error mitigation

Particle Filter Design

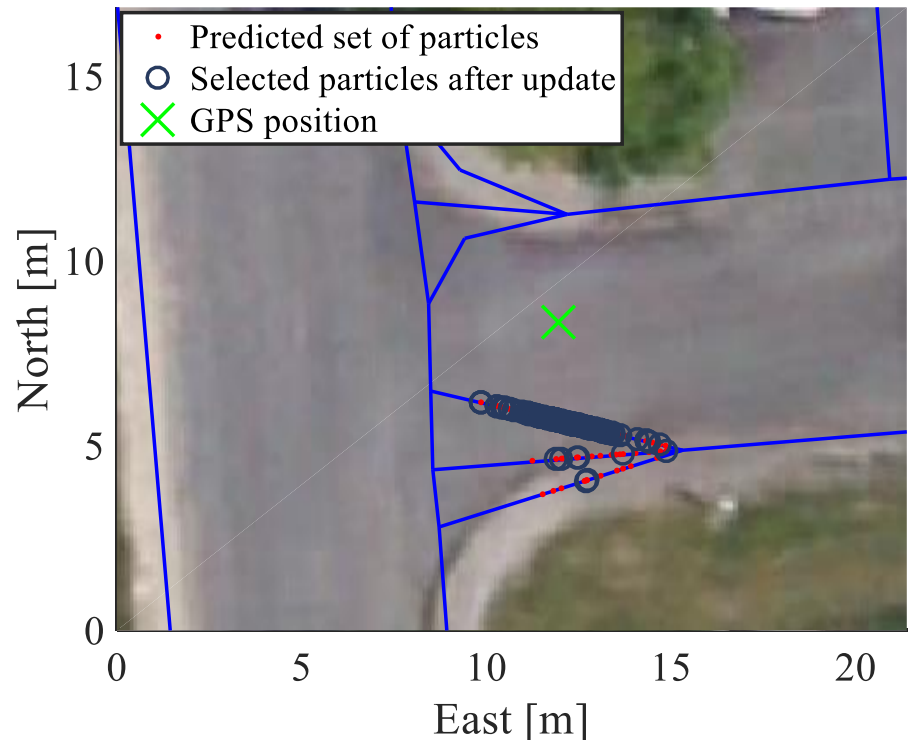
- Graph design
- Correction of step length estimates
- Correction of over/mis-step detection
- Correction of heading misalignment

Mechanization

PDR

Updates

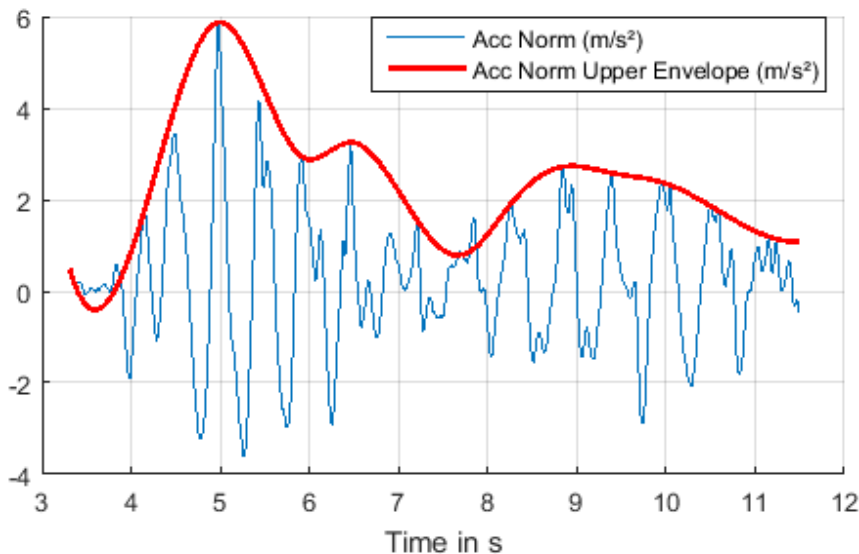
- Proximity distance between POI/GPS positions and graph
- Likelihood between PDR heading and graph



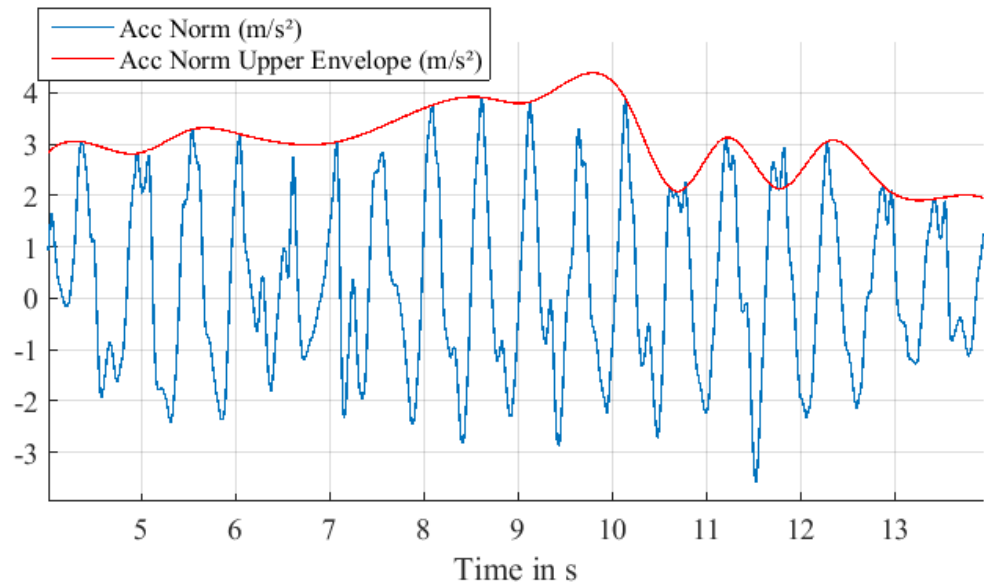
Signal patterns: indoor/outdoor transition (1/2)

IO transition event is marked by a parabolic form of the acc. norm upper envelope: deceleration - quasi-static phase - acc.

The duration of pattern depends on doors' type: shorter for sliding doors



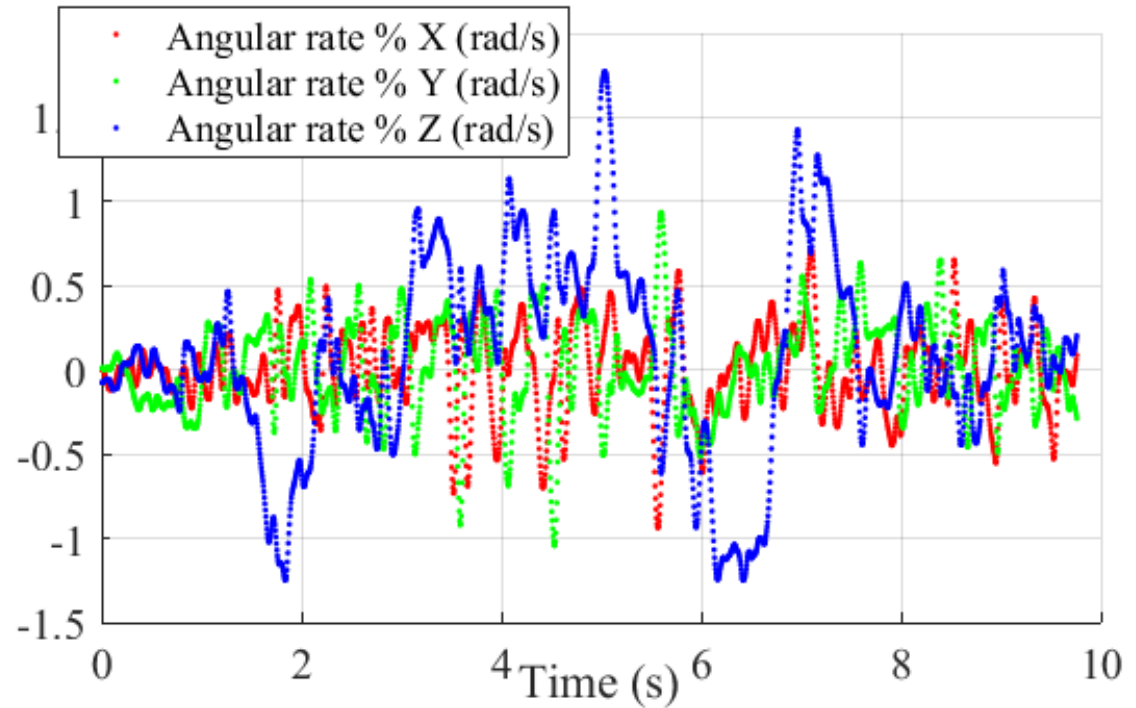
Swinging door (6-9s)



Sliding door (10-12s)

Signal patterns: indoor/outdoor transition (2/2)

In a texting mode, the vertical component of the angular rate has a greater variance during the indoor/outdoor transition



Swinging doors (4-6 s)

Finding the Right POI Using Signal Pattern

Motion classes = Normal walking, Descending/Mounting stairs, Taking an elevator down/up, Corridor change, Entering/Exiting a building

Considering motion sequence

Considering motion class

Normal walking + Descending stairs
Mounting stairs + Normal walking } → *Top of stairs*

Normal walking + Mounting stairs
Descending stairs + Normal walking } → *Bottom of stairs*

*Corner
Elevator
Building Gate*

Search for POIs' candidates

POI types

Nav. Filter

Selection of the nearest POI



Supervised Learning Perf. Assessment

Features selected using Mutual Information

Best performance obtained with Random Forest, especially for the indoor/outdoor transition case

| Corner | Entry / Exit | Down Stairs | Elevator Down / Up | Normal Walk. | Up Stairs |
|--------|--------------|-------------|-----------------------|--------------|-----------|
| 91.67 | 100 | 96.84 | 100 | 98.71 | 98.13 |
| 100 | 96.36 | 97.87 | 100 | 98.71 | 97.22 |

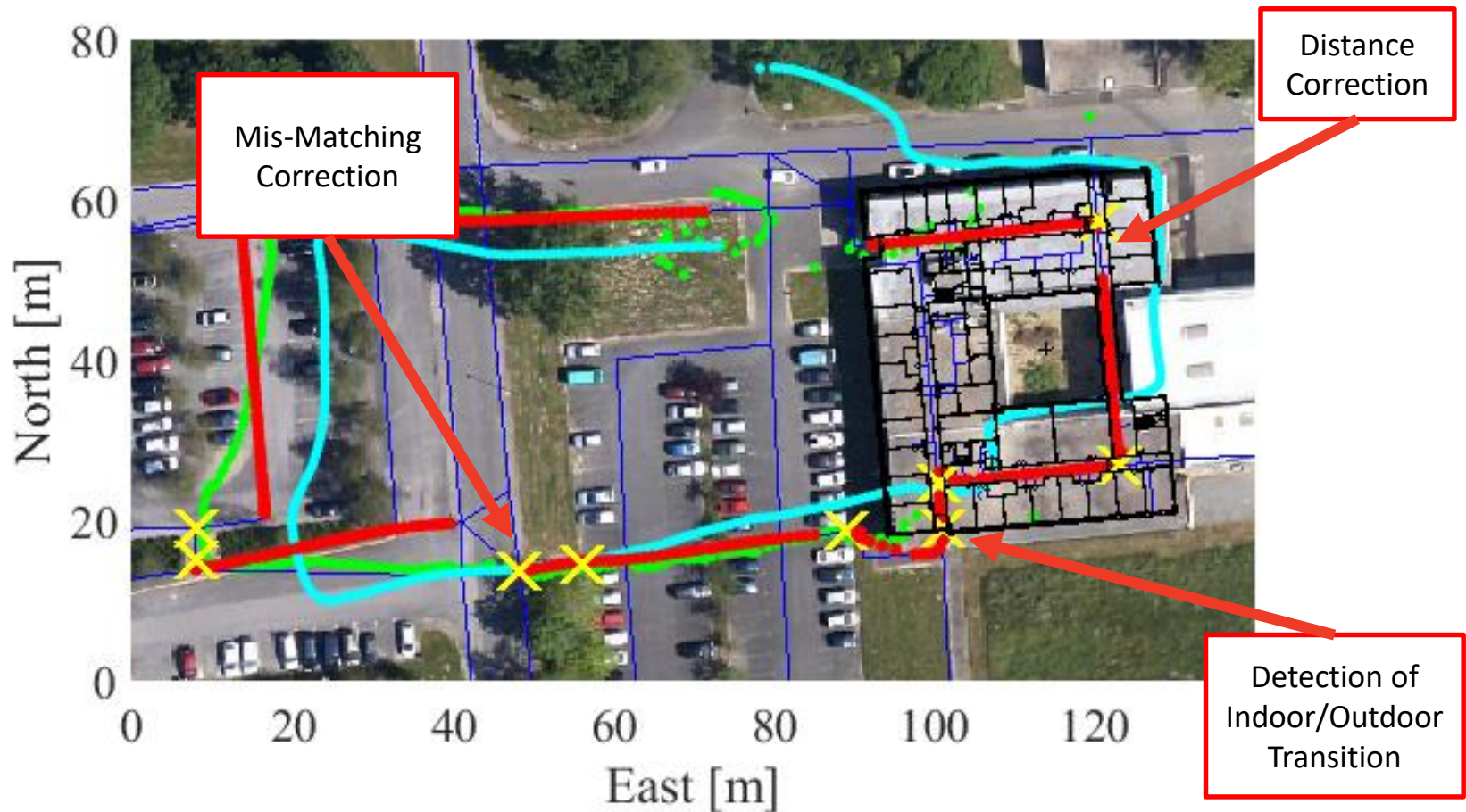
Precision: True positive / (True Positive + False Positive)

Sensitivity: True positive / (True Positive + False Negative)

Overall Detection/Classification Accuracy: 98.41M



Experimental Assessment



Intra-class variation affects the performance of classification
Intra-class variation is significantly related to cross-individual dispersion (Speed, Gait patterns, etc.)

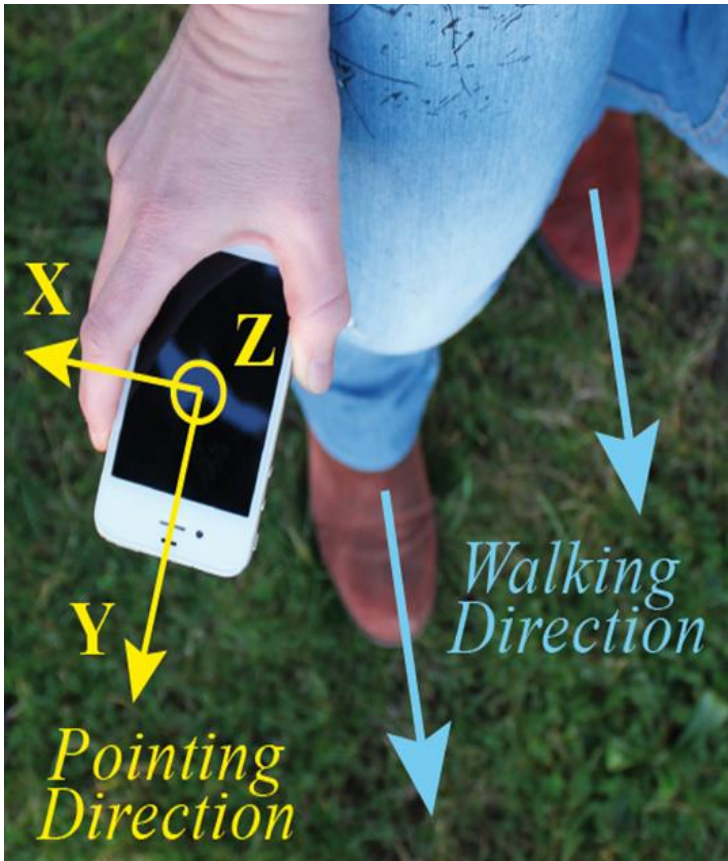
**Linking Human
Motion and
Map Locations**

**Building on
Modeling
Personal
Dynamic
Profile**

**Monocular
Visual
Odometry
Assisted by
Step Length**



Embedding Personal Dynamics Pattern in the Navigation Filters



Context

Improving personal mobility (transport) with mass market devices

Tracking Method

Kalman Filter, Complementary Filter, Machine Learning aiding

Problems

Varying physiological features

Impact of environmental changes (ground slopes)

Solutions

State-of-the-art

Calibration by fusing multiple signals

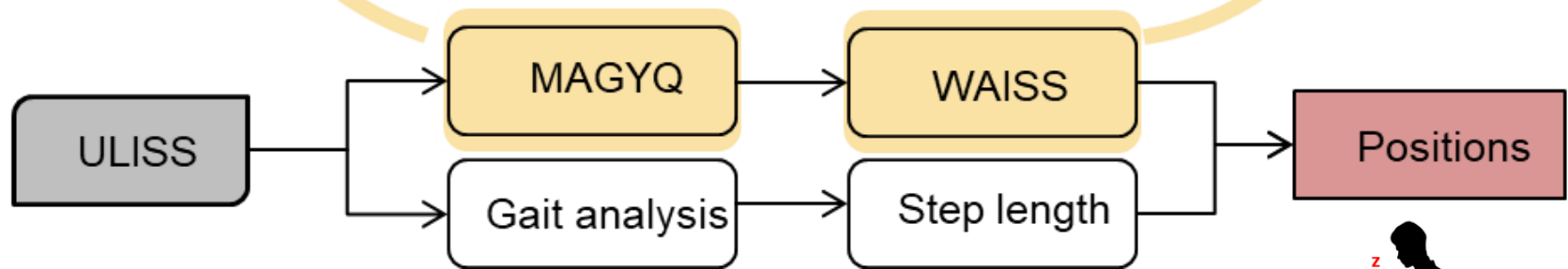
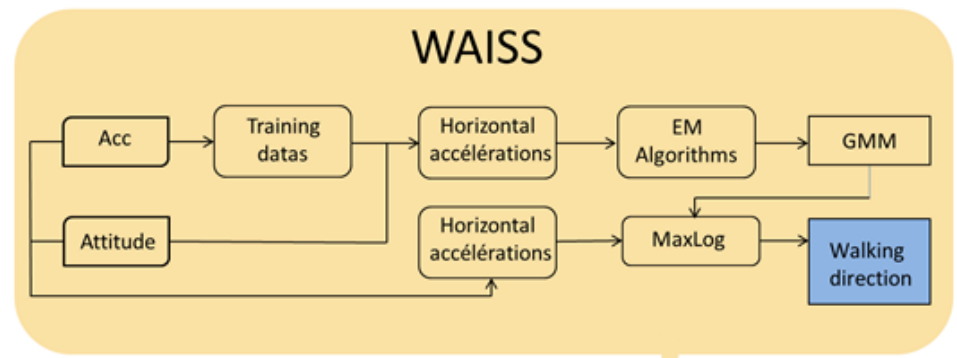
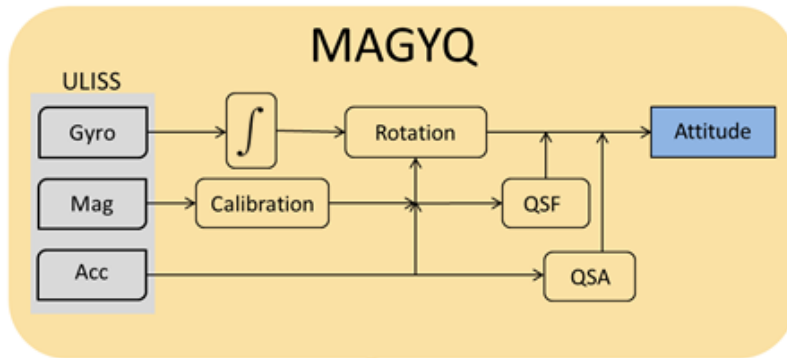
Calibration on known paths

Proposition

Modeling personal way of holding the sensor in hand to construct navigation filters

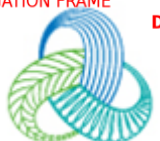
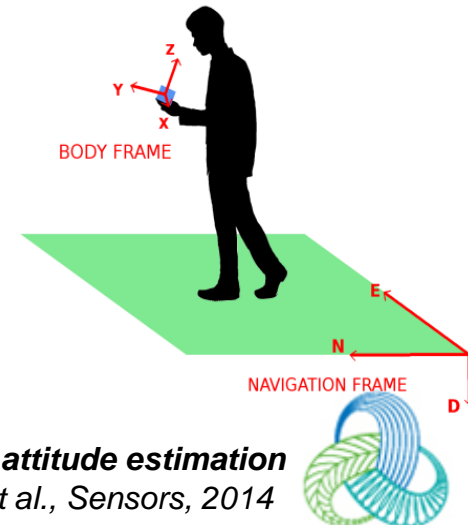


Attitude Estimation

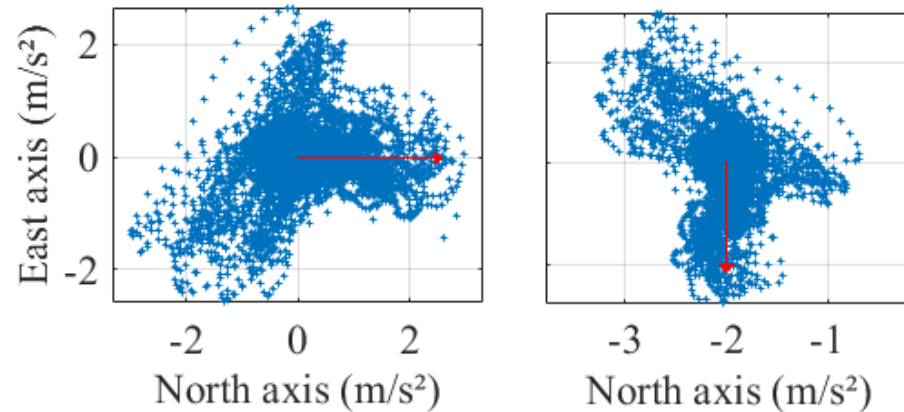


MAGYQ: Attitude estimation EKF filter based on quaternions (inertial and magnetometer data)

WAISS: Walking direction estimation based on statistical modeling of human gait features with handheld MIMU



WAISS Method: Building Individual Models



Distribution of horizontal accelerations depends on the walking direction

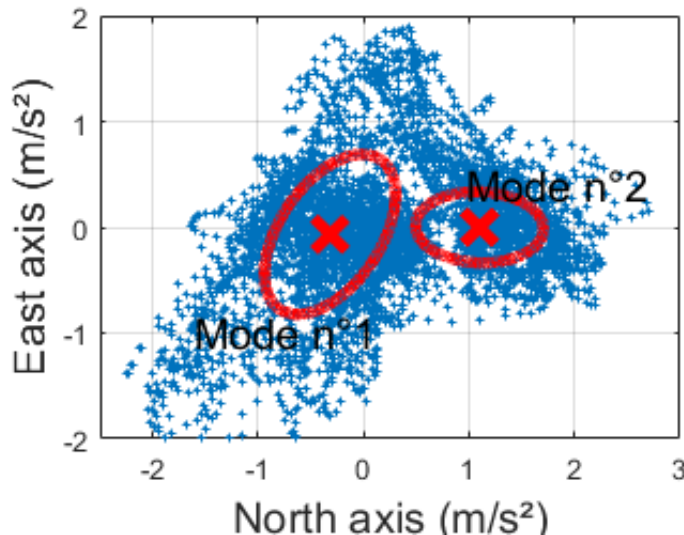
Distribution modeling with a Gaussian Mixture

$$f_{acc}(\mathbf{x}) = \sum_{k=1}^q \tau_k \mathcal{N}(\mathbf{x}, \mathbf{m}_k, \mathbf{P}_k)$$

Straight-line data set with 0° walking direction

Expectation Maximization algorithm

$$(Z_i | \mathbf{x}_i, (\tau_k^c, \mathbf{m}_k^c, \mathbf{P}_k^c)) = \frac{\tau_k^c \mathcal{N}(\mathbf{x}_i, \mathbf{m}_k^c, \mathbf{P}_k^c)}{\sum_{j=1}^p \tau_j^c \mathcal{N}(\mathbf{x}_i, \mathbf{m}_j^c, \mathbf{P}_j^c)}$$



$$L((Z_i)_{1 \leq i \leq n}, (\mathbf{x}_i)_{1 \leq i \leq n}, \Psi) = \sum_{i=1}^n \sum_{k=1}^p t_{ik} \log(\tau_k \mathcal{N}(\mathbf{x}_i, \mathbf{m}_k, \mathbf{P}_k))$$

Walking direction estimation based on statistical modeling of human gait features with handheld MIMU, C. Combettes et al., IEEE/ASME Trans. Mechatronics, vol. 22, 2017

WAISS Method: Walking Direction Estimation

Maximization of model likelihood with observations corresponding to one stride



$$L((\mathbf{x}_i)_{1 \leq i \leq n}, \theta) = \sum_{i=1}^n \log(f_{accM}(\mathbf{x}_i, \theta))$$

$$\theta_w = \arg \max_{\theta} (L((\mathbf{x}_i)_{1 \leq i \leq n}, \theta))$$

Experimental Assessment

Use of PERSY as angular reference

$$\alpha = \text{atan}\left(\frac{Y_{P2} - Y_{P1}}{X_{P2} - X_{P1}}\right) \quad R = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) & 0 \\ \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

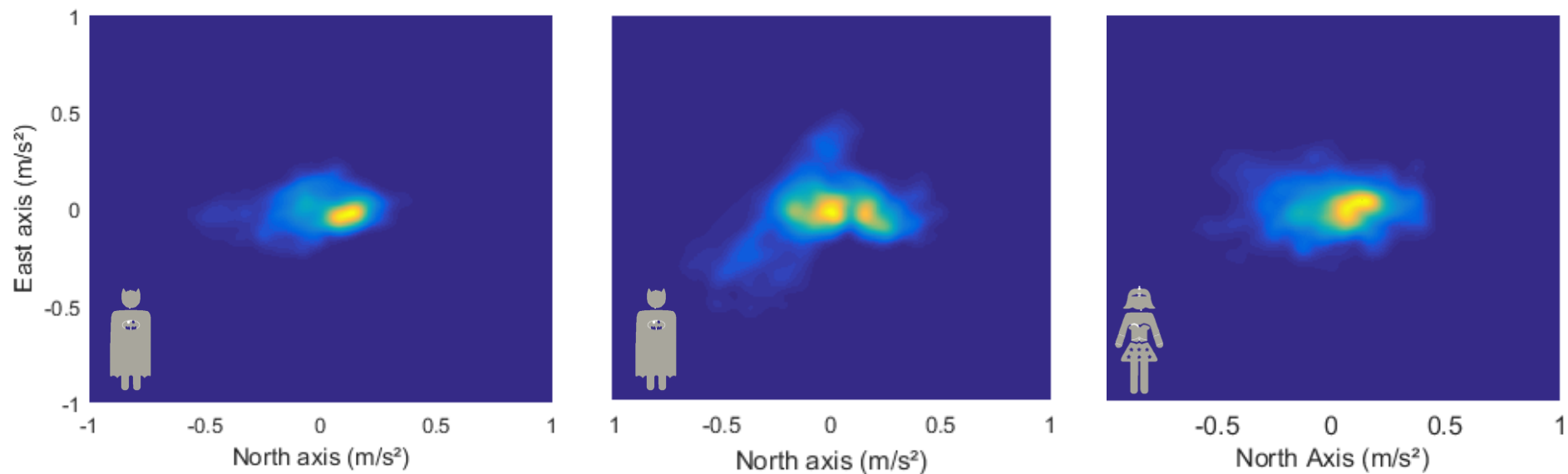
Test different types of carrying modes: texting / swinging
Create individual models appropriate to the person's walking style

Choosing the right GMM

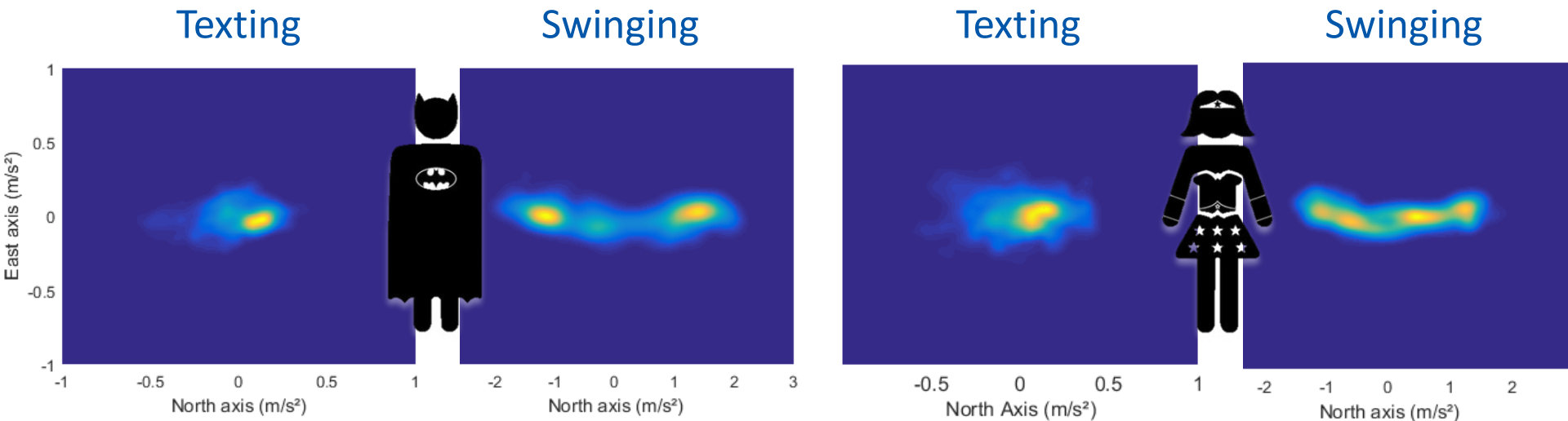
Different distributions for different persons

Need to adapt the number of GMM modes for each individual

Use of criterions



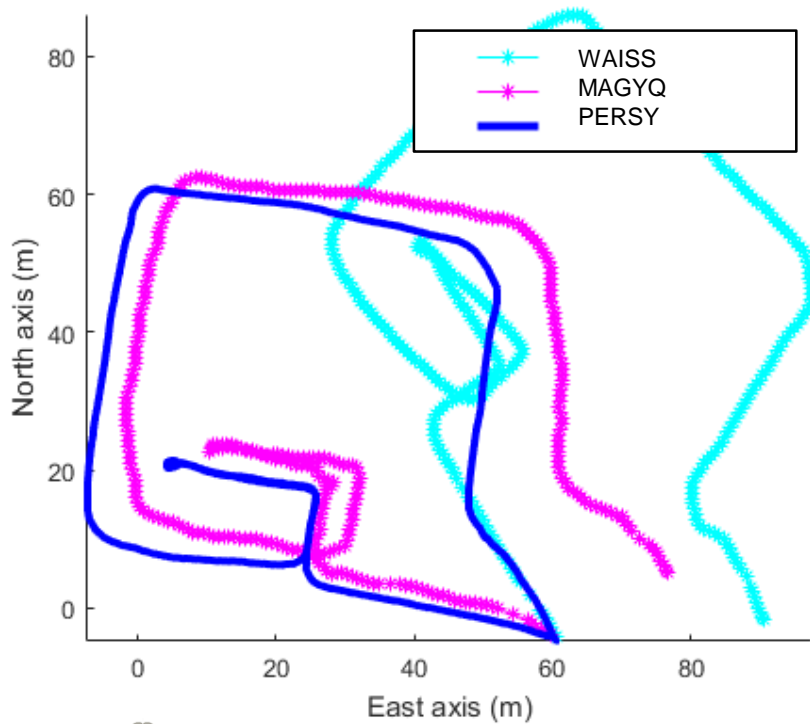
Impact of the Carrying Mode on Modeling



Different distributions for the same person

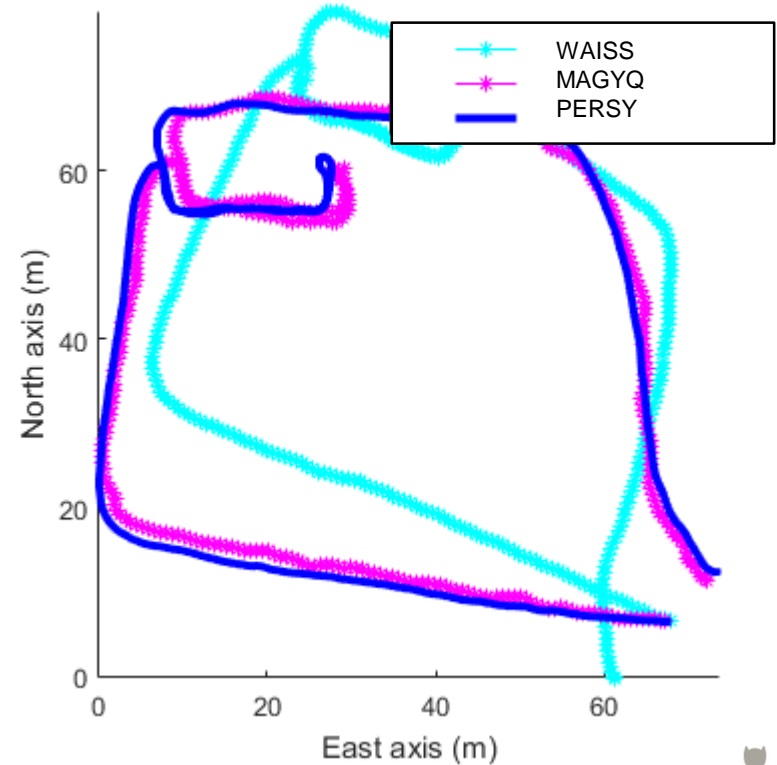
Need to adapt the number of modes for each individual and for each carrying mode

Assessment: Texting Mode with Misalignment



Woman – 291 m

| Error | MAGYQ | WAISS |
|----------|-------|-------|
| μ | 19.7° | 11.2° |
| σ | 11.1° | 12.4° |

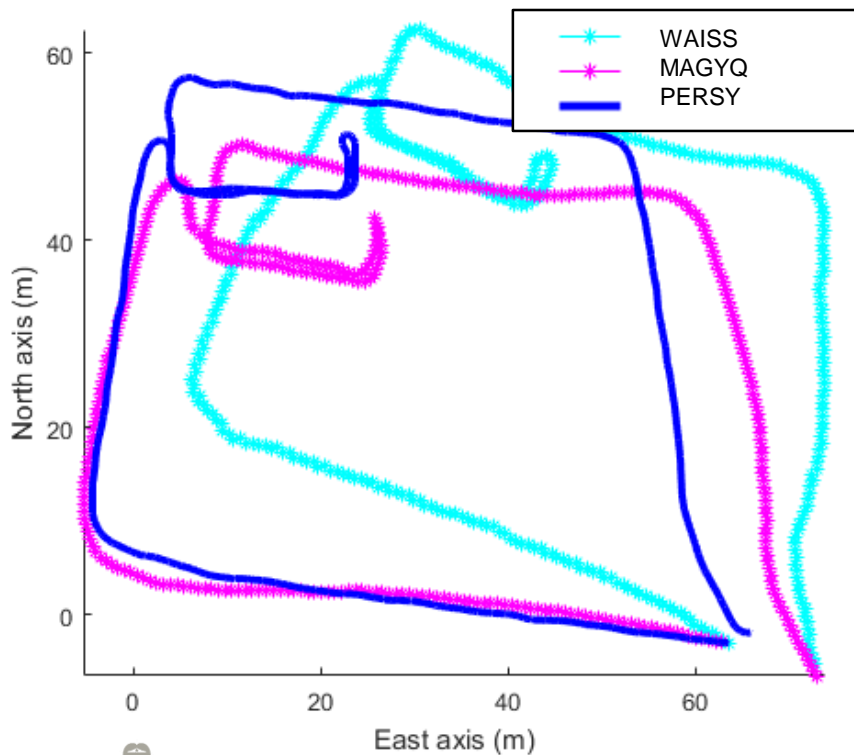


Man – 321 m

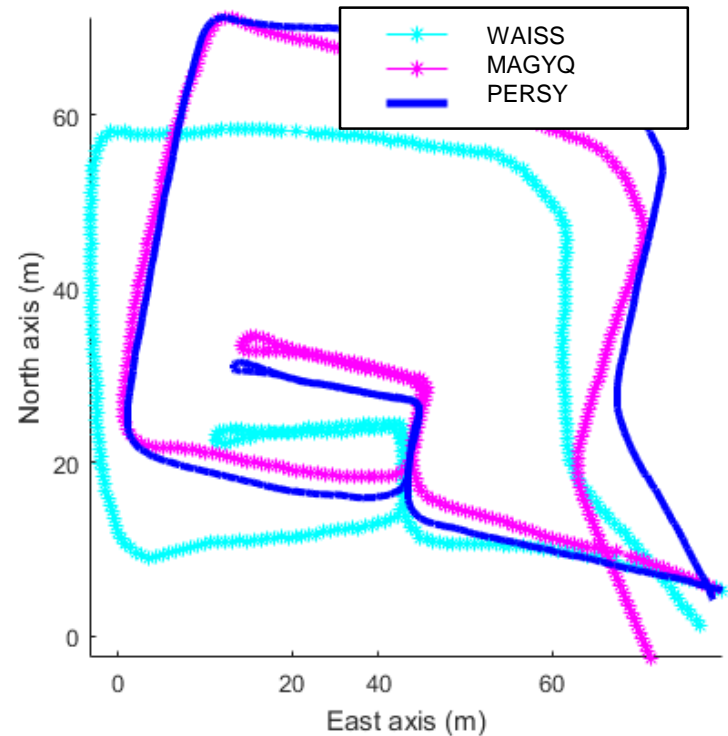
| Error | MAGYQ | WAISS |
|----------|-------|-------|
| μ | 34.1° | 13.7° |
| σ | 14.6° | 17.3° |



Assessment: Swinging Arm



Woman - 290 m



Man - 324 m

| Error | MAGYQ | WAISS |
|----------|-------|-------|
| μ | 20.9° | 8.6° |
| σ | 16.7° | 9.9° |

| Error | MAGYQ | WAISS |
|----------|-------|-------|
| μ | 16.1° | 8.8° |
| σ | 13.1° | 10.3° |



CONCLUSIONS



Human diversity challenges personal navigation technology



What scientific approach can solve it?
Modeling, artificial intelligence, ...?



Is the hypothesis of an average human being possible?

Inventing navigation for the new forms of mobility?



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