BITES | DEFENCE & AEROSPACE

"Cooperative Navigation in GNSS Degraded and Denied Environments" (SET-275)

A Novel Approach for Pedestrian Positioning Using Inertial Sensors

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FUTURE-ORIENTED TECHNOLOGIES

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AGENDA – PRESENTATION TOPICS

- Quick info -> ZUPT aided INS for pedestrians
  - Kalman filter framework

- Approach to develop ZUPT aided pedestrian navigation
  - Some requirements
  - Focus on subject invariant consistency

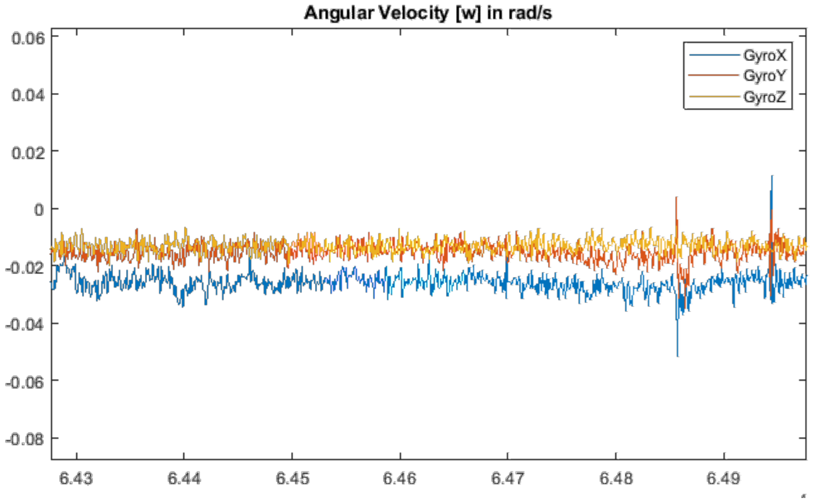
- Running and Walking motion compliant ZVD Design

- Validation approach for walking motion

- Validation approach for running motion

- Conclusion

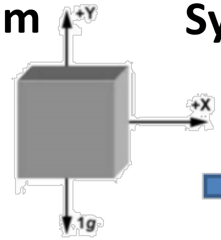
INS – GENERAL PROBLEM DEFINITION

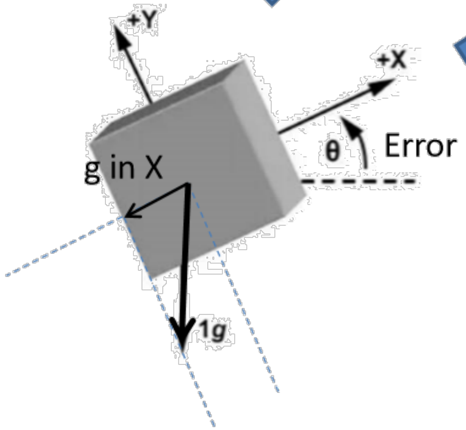


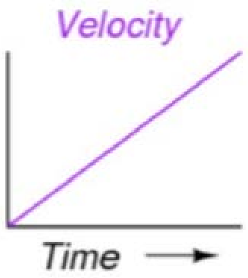
3-axis accelerations

$$\begin{bmatrix} -3.9443 \\ 1.6674 \\ 8.8358 \end{bmatrix} \rightarrow \begin{bmatrix} -0.0450 \\ 0.0037 \\ -9.8187 \end{bmatrix} \rightarrow \begin{bmatrix} -0.0450 \\ 0.0037 \\ -0.0087 \end{bmatrix}$$

IMU Coordinate System | **NED Coordinate System** | **NED Non-Gravitational**



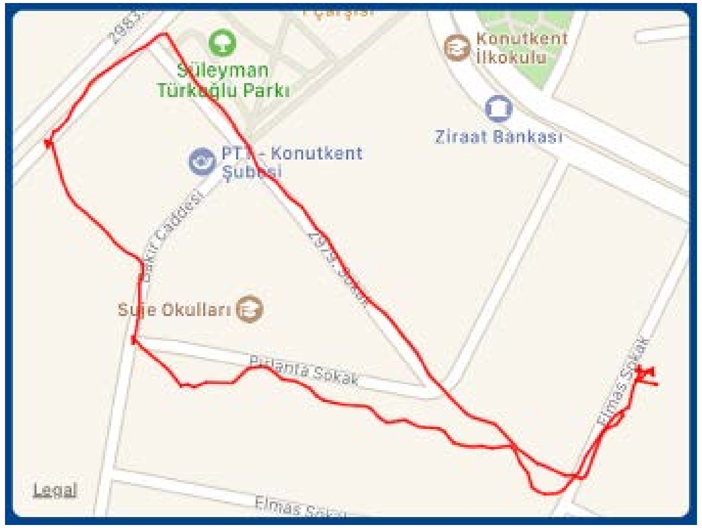


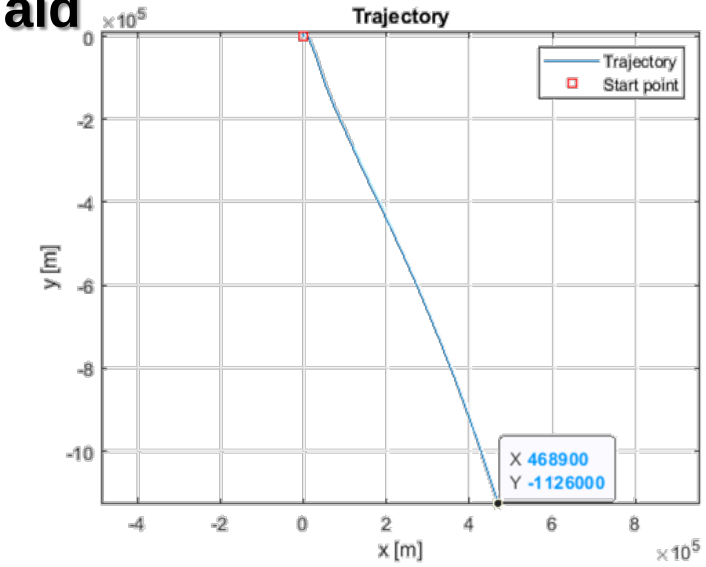


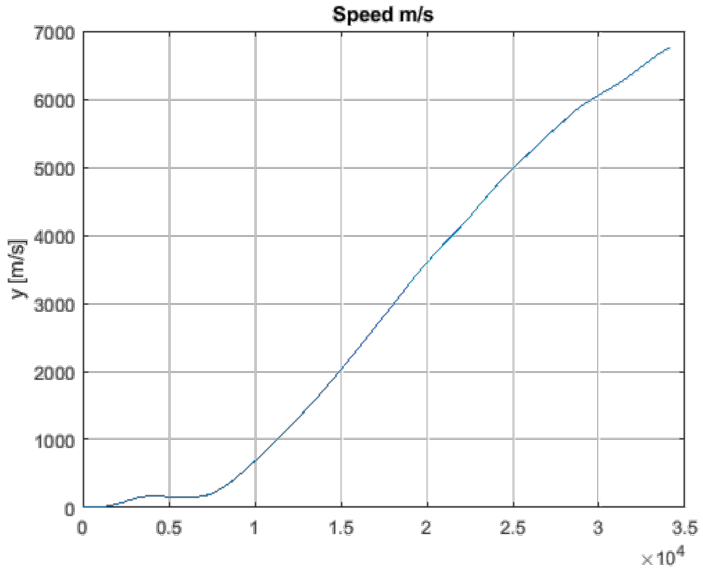
INS – GENERAL PROBLEM DEFINITION

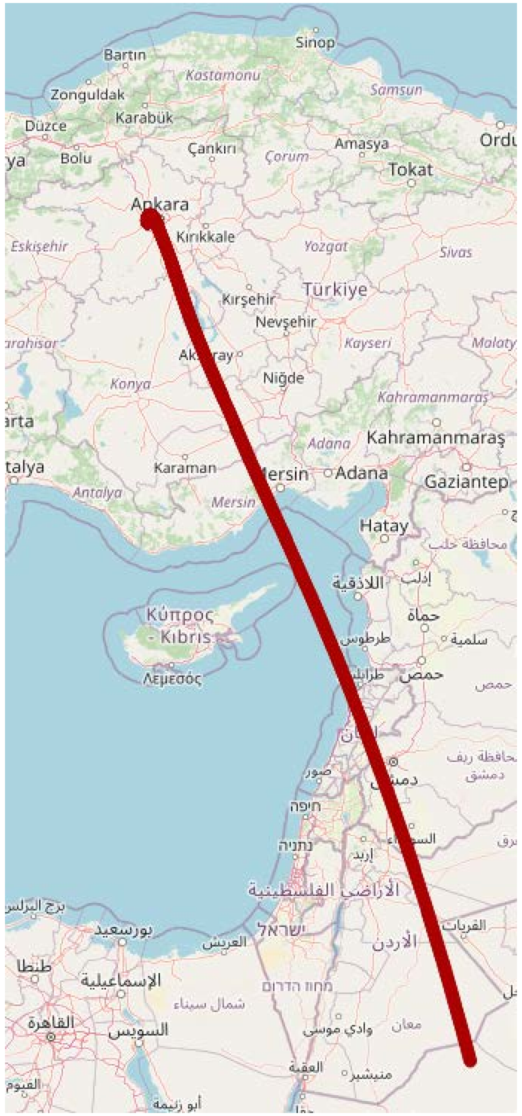
Free INS – Without any external source aid

Data Title:	pdr_TK_foot_walking_Konutkent1_20202705_1
Sampling Rate [Hz]:	51.2
Sensors Logged:	LN Acc, WR Acc, Gyroscope, Magnetometer, Timestamp, Pressure, Temp, Battery Level
Device:	Shimmer3 IMU
Test Duration and Estimated Distance:	666 sec 749 m
GPS Source and Map: pdr_TK_gps_walking_Konutkent1_20202705_1	

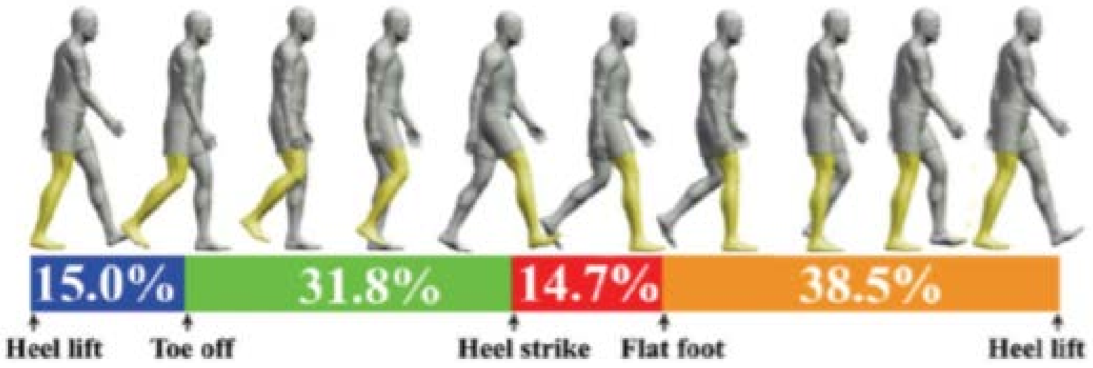


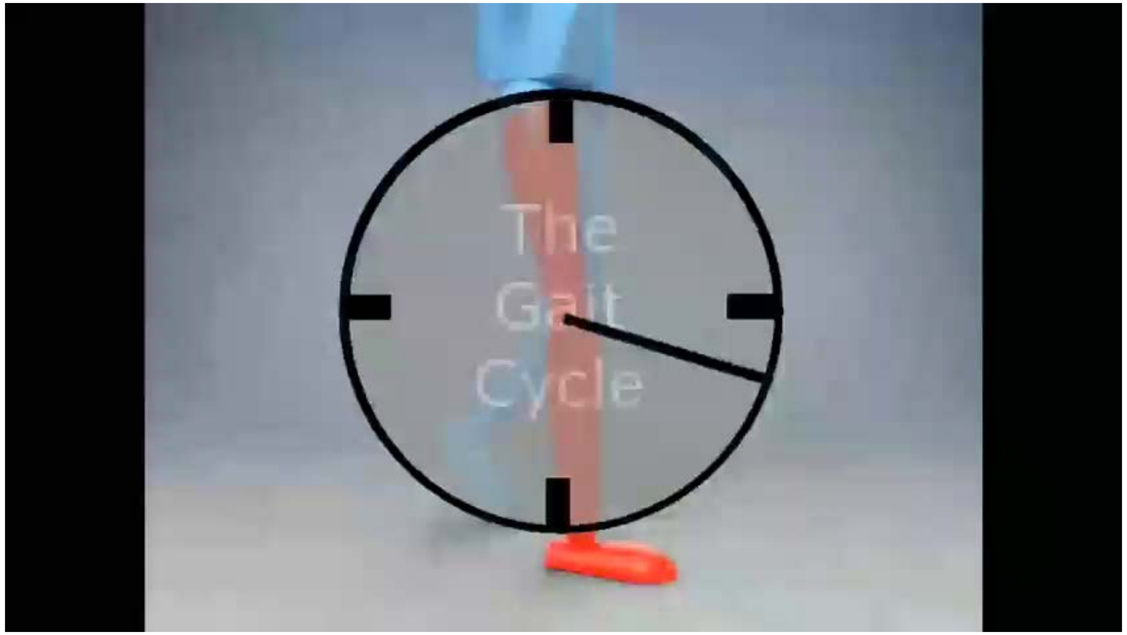


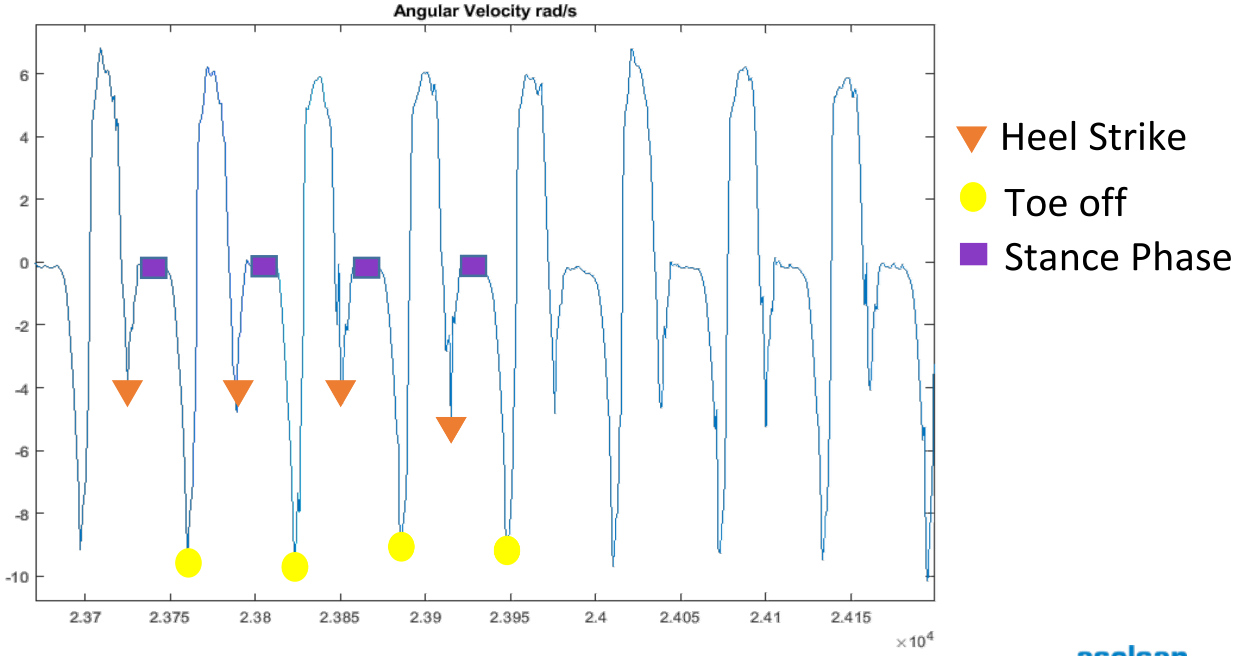




ZUPT AIDED INS CONCEPT







ZUPT AIDED INS CONCEPT

PDR – INS + ZUPT + MAG

Data Title:	pdr_TK_foot_walking_Konutkent1_20202705_1
Sampling Rate [Hz]:	51.2
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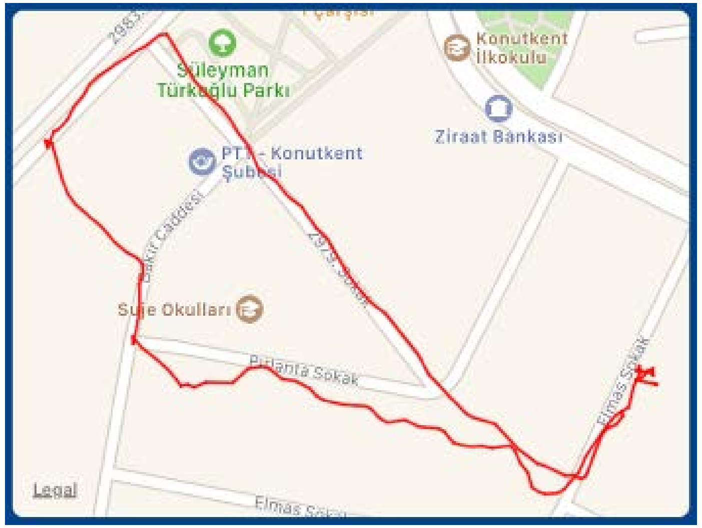
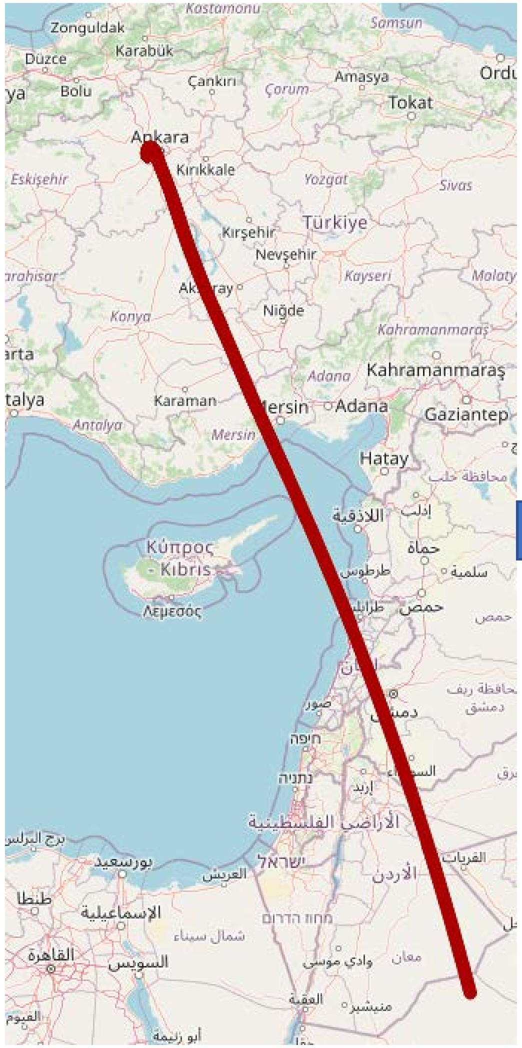
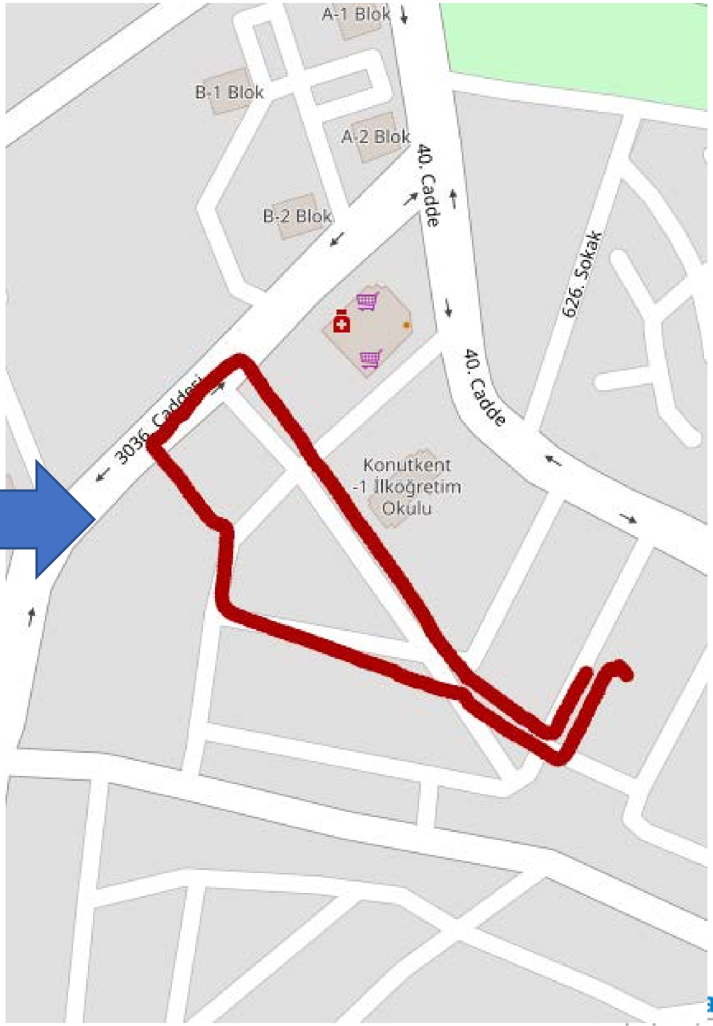
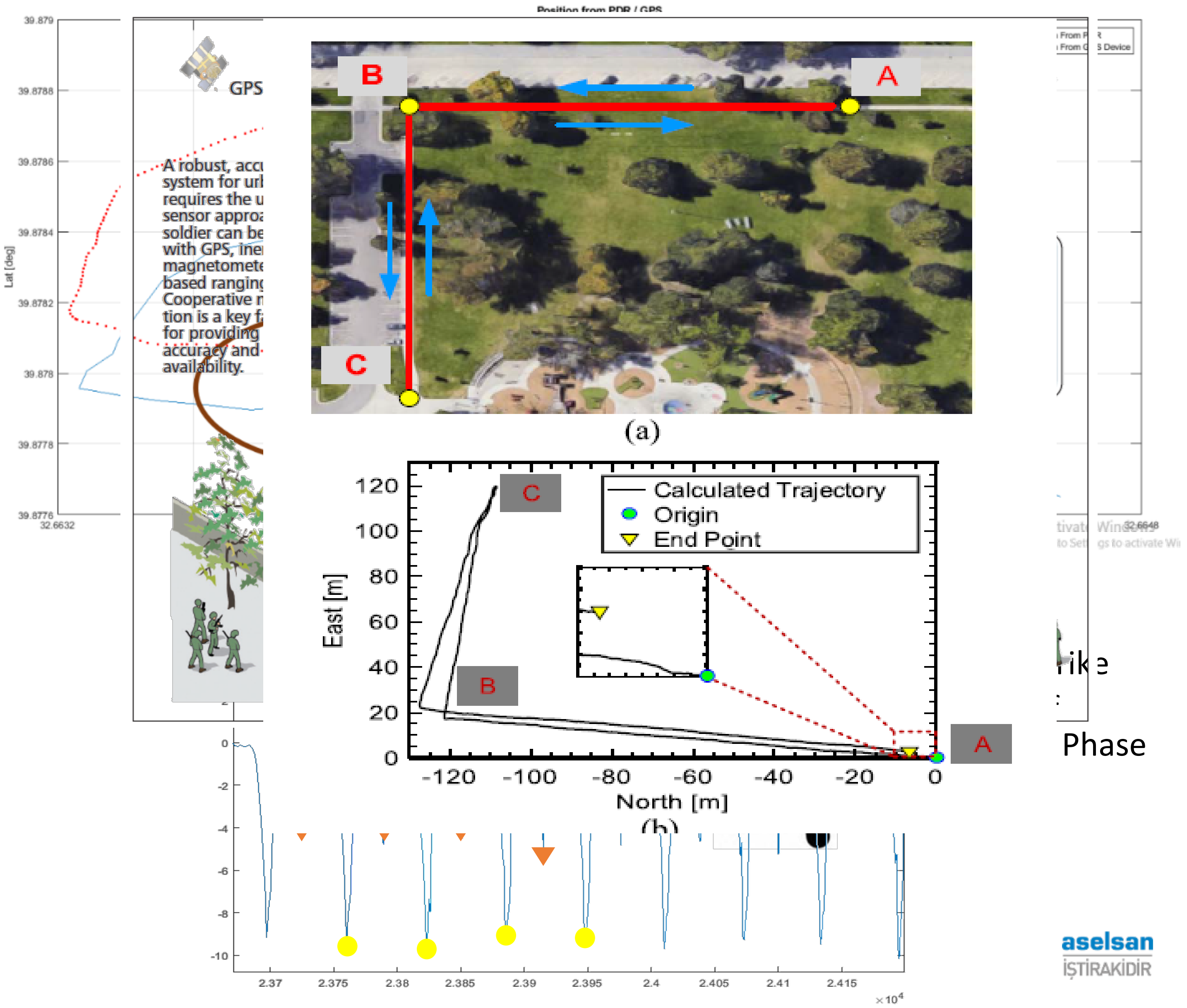






SOME REQUIREMENTS ON PEDESTRIAN NAVIGATION DEVELOPMENT

- Wearable technology
- Low cost:
- Environmental Factors:
- Data Loss:
- Indoor / Outdoor Usage
- Different Motion Types
- Major Prior Calibration
- ***Subject Invariant Consistency***

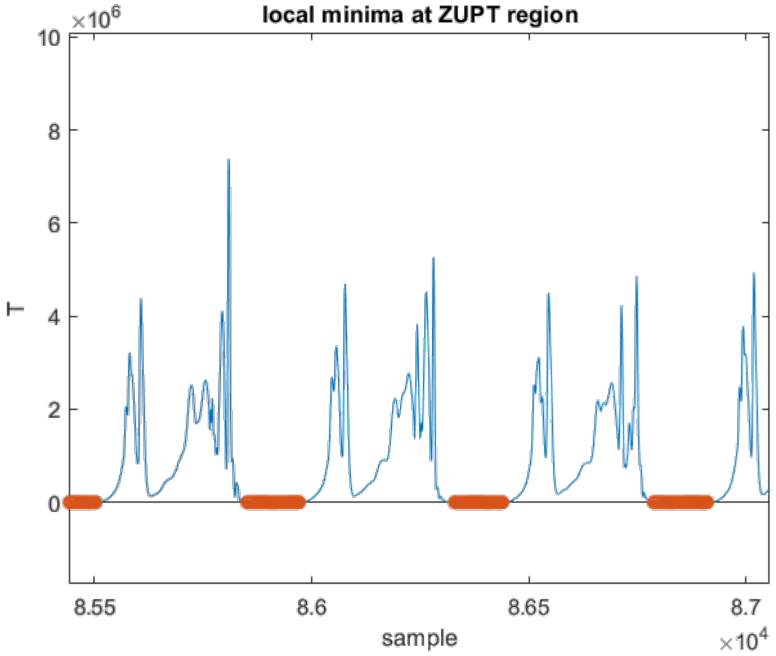


CONVENTIONAL ZERO-VELOCITY DETECTOR

- Generalized Likelihood Ration Test (GLRT) Based ZUPT Method

$$T(\mathbf{z}_n) = \frac{1}{N}\sum_{k\in\Omega_n}\left(\frac{1}{\sigma_a^2}\left\|\mathbf{y}_k^a - g\frac{\overline{\mathbf{y}}_n^a}{\|\overline{\mathbf{y}}_n^a\|}\right\|^2 + \frac{1}{\sigma_\omega^2}\|\mathbf{y}_k^\omega\|^2\right) < \gamma'$$

Changes regarding to motion different pace or dynamic level (running)



Again, especially for running we have this assumption that captured points are pure stationary (zero velocity), but in fact, they might not are!

Even for the same motion type, especially running, changes regarding to different subjects.

ZUPT performance plays crucial role, as they are independent from the quality of the sensor

Thus a robust ZUPT algorithm is required!!!

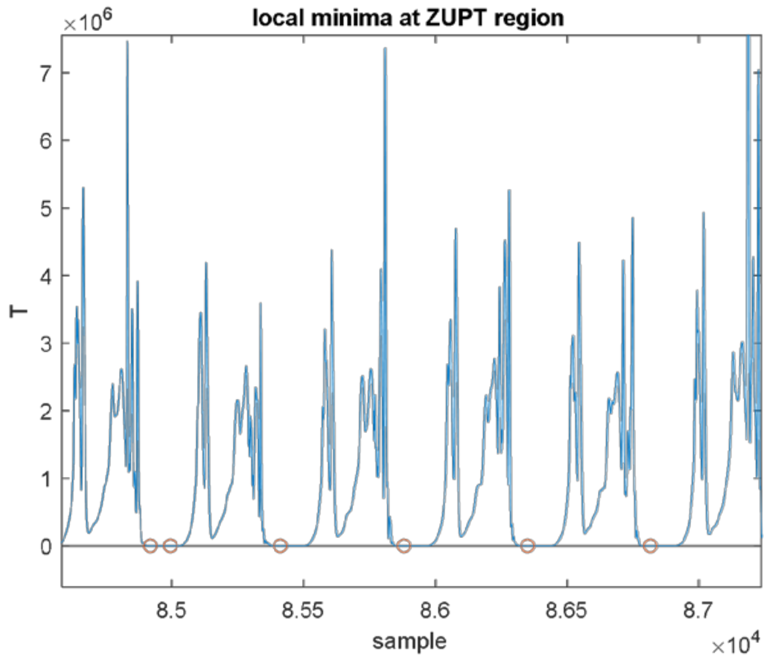
ROBUST ZERO-VELOCITY DETECTOR

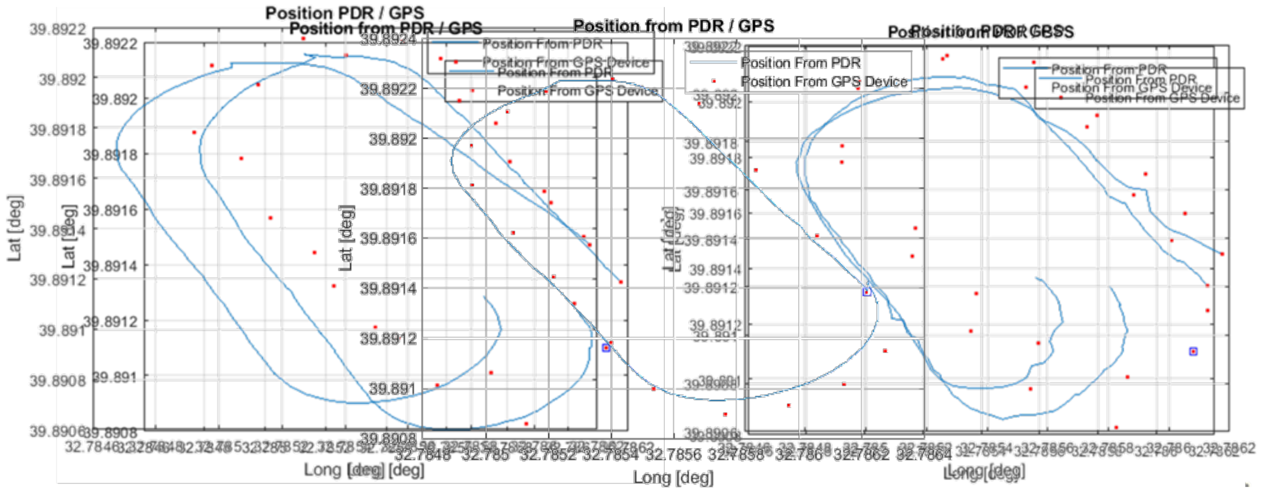
- Generalized Likelihood Ration Test (GLRT) Based ZUPT Method

$$T(\mathbf{z}_n) = \frac{1}{N} \sum_{k \in \Omega_n} \left(\frac{1}{\sigma_a^2} \left\| \mathbf{y}_k^a - g \frac{\overline{\mathbf{y}}_n^a}{\|\overline{\mathbf{y}}_n^a\|} \right\|^2 + \frac{1}{\sigma_\omega^2} \|\mathbf{y}_k^\omega\|^2 \right) < \gamma'$$

A threshold-less method is suggested

New approach is to select the points that closest to stationary in a threshold-less matter.

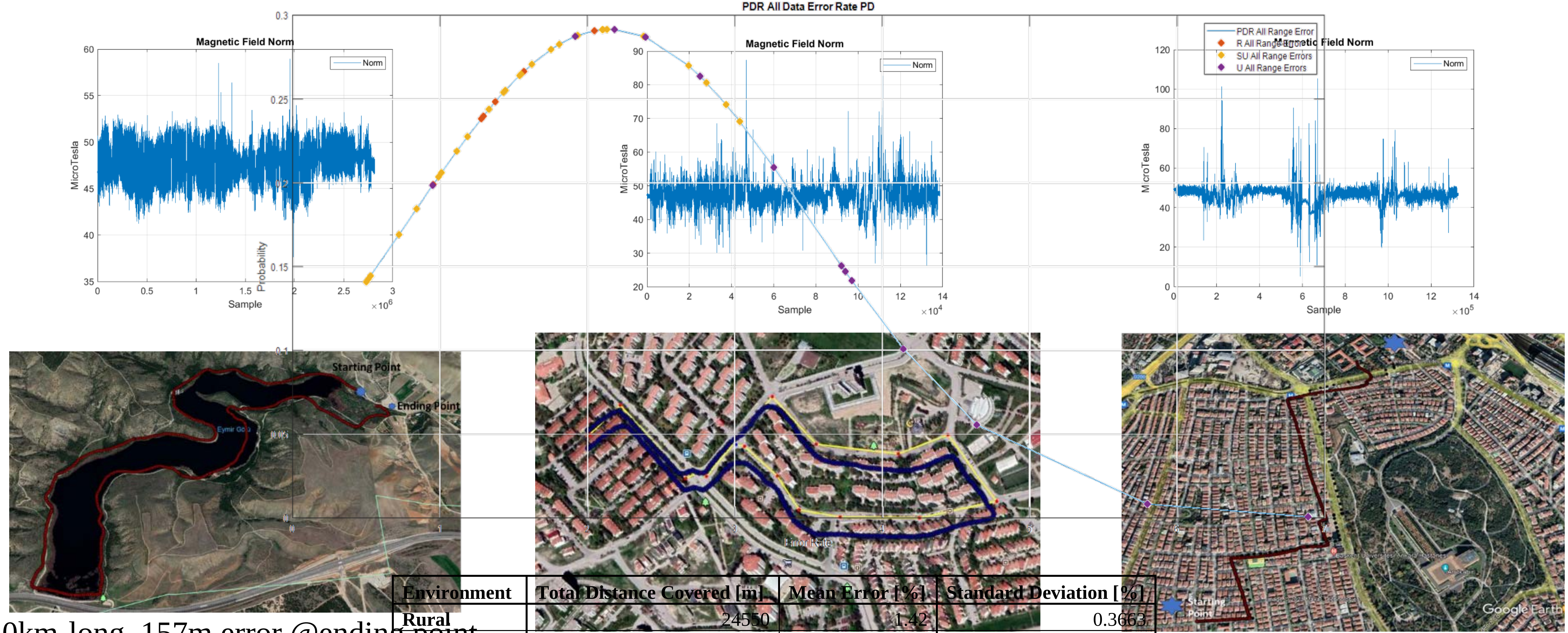




Position estimation with new method @12 kph (left) and @20 kph (right)

VALIDATION APPROACH FOR WALKING MOTION

Magnetic Field Dependency



Environment	Total Distance Covered [m]	Mean Error [%]	Standard Deviation [%]
Rural	24550	1.42	0.3663
Semi-Urban	45028	1.6157	0.7539
Urban	24667	3.5547	1.6124
All Data	94245	2.1497	1.3681

10km-long, 157m error @ending point

1.7km-long, 34m error @ending point

2.38km-long, 135m error @ending point

VALIDATION APPROACH FOR WALKING MOTION

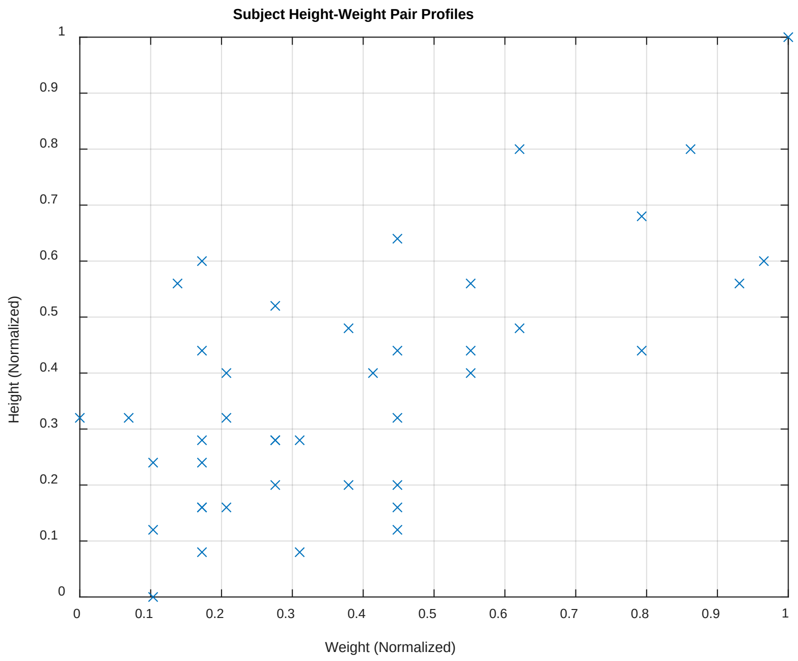
Subject Variation Dependency

Subject	Distance Covered [m]	Error [m]	Error [%]
Subject - 1	6995	78	1.115082
Subject - 2	6995	121	1.729807
Subject - 3	6995	80	1.143674
Subject - 4	6995	142	2.030021
Subject - 5	6995	122	1.744103
Subject - 6	6995	117	1.672623

VALIDATION APPROACH FOR RUNNING MOTION

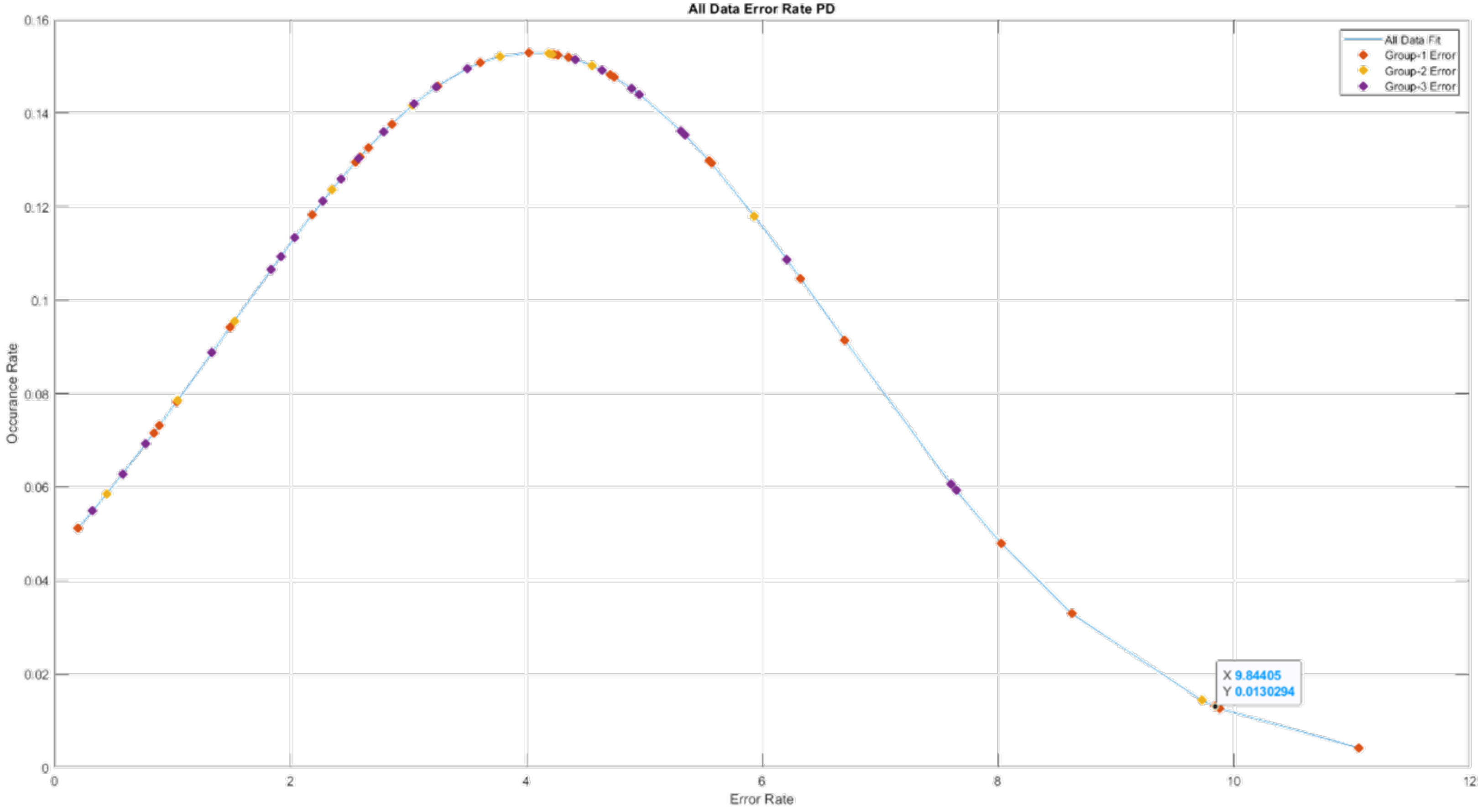
Subject Variation Dependency

- We asked 45 Subjects (3 groups, 15 subject per group) to run approx. 2 km.
- Testing over 45 subjects can cover different pace, running gait cycle, sensor mounting positions etc.



VALIDATION APPROACH FOR RUNNING MOTION

Subject Variation Dependency



	Total Distance [m]	Mean Error [%]	Standard Deviation [%]
Group – 1	34000	4.5213	2.963
Group – 2	23150	4.133503	2.626025
Group – 3	25800	3.464417	2.097108
Total	82950	4.055449	2.608127

CONCLUSION

- A consistent pedestrian navigation infrastructure is reached based on inertial sensors
- System can be used for long-term navigation purposes, thanks to its low energy requirements
- As we discuss standalone functioning, this system can be used as “core” element of an cooperative PNT architecture.
- Although we don’t focus on performance metrics, they are promising as there are several topics to improve them further
  - Non-zero velocity measurements during stance phase
  - Put more trust on gyroscope measurements for heading angle est.
    - Better sensor grade
    - Study on g-sensitivity
    - Dual foot implementation
    - …..